ASC

2002

Symposium on Seismology, Earthquake Hazard Assessment and Risk Management

held in conjunction with

the Fourth General Assembly of the Asian Seismological Commission,

24-26 November 2002, Kathmandu

PROCEEDINGS

Editor:
Amod Mani Dixit

October 2004, Kathmandu

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FOREWORD

Most parts of Asia lie in active seismic zones. In fact two of the three largest earthquakes in the world occurred in Asia during 2003, these earthquakes were also among the 10 deadliest disasters in the world that year. The high level of seismic vulnerability in Asia is largely due to the very high population density, and rapid pace of urbanization. Vulnerability is further exacerbated by unacceptably poor construction practices and processes used for the construction of non-engineered structures as well as poor quality of construction materials. Asia, therefore, needs special attention in terms of disaster risk reduction and emergency response planning and capacity enhancement. The scale of this risk in the Asia Pacific region demands that new and innovative approaches should be developed, internalized, and implemented to combat the problem of disaster risk in the region.

Both the Asian Disaster Preparedness Center (ADPC) and National Society for Earthquake Technology – Nepal (NSET) realize the challenge, and have developed a successful partnership during the last decade to work in this direction. A history of fruitful collaboration has been established, and efforts in earthquake risk management have occupied a prominent place in this close partnership. Both the institutions see the need to broaden this partnership and create a network in Asia and throughout the world.

The organization of the Asian Seismological Commission (ASC) 2002 by both NSET and ADPC in November 2002 in Kathmandu is one of the expressions of such innovative approaches taken by these institutions. While planning for ASC 2002 both institutions wanted to develop this event into an effort to treat earthquake hazard comprehensively:

a) The scope of the symposium during ASC 2002 was expanded to include earthquake engineering and earthquake risk management.

b) A training program on Earthquake Vulnerability Reduction for Cities (EVRC) was organized for about 30 participants.

We are thankful to the Asian Seismological Commission for the opportunity provided to organize the ASC 2002. We also extend our heartfelt thanks to His Majesty's Government of Nepal for sponsoring the project and the International Association of Seismology and Physics of the interior Earth (IASPE) and the B.P. Koirala India Nepal foundation for providing financial support. The International Institute for Geo-Information Science and Earth Observation (ITC), the Netherlands extended full cooperation in organizing the training program.

ADPC and NSET wish the forthcoming October meeting of the Asian Seismological Commission 2004 in Armenia every success.

Mr. Shiva Bahadur Pradhanang
President, NSET

Dr. Suvit Yodmani
Executive Director, ADPC

ASC 2002 : Symposium on Seismology, Earthquake Hazard Assessment and Risk Management

CONVENER

Amod Mani Dixit

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Balassanian, Serguei Yu., presently Professor of the Yerevan State University, and President of Armenian Association of Seismology and Physics of the Earth's Interior (AASPEI). Since 2000 he is the President of Asian Seismological Commission (IASPEI). In 2002 he is being rewarded as the Laureate 2002 of the UN-Sasakawa Award for his personal long-term commitment and dedication to the issue of disaster reduction, in particular in the field seismic hazards, as well as for mobilizing efforts in the scientific domain and political spheres towards a strong promotion and awareness-raising initiatives for the reduction of seismic disaster risk worldwide. He is author and designer of Armenian National Policy in the field of Seismic Risk Reduction; Founder and President (since foundation, 1991-2002) of the Armenian National Survey for Seismic Protection (NSSP); Initiator and the leading author of the two national programs on Armenia Seismic Risk Reduction in and Seismic Risk Reduction in Yerevan city adopted by the Government of Republic of Armenia in 1999; Author of the Armenian Seismic Protection Law adopted by the Armenian Parliament in 2002. He is also one of founders of World Agency for Planetary Monitoring and Earthquake Risk Reduction (WARMERR). A renowned authority in the field of natural hazards and risks, his main scientific research is devoted to: dynamics of geophysical and geochemical processes and non-linear phenomena, earthquake prediction research and early warning, seismic and environmental hazard and risk. He is author of more than 180 articles in reviewed journals and 3 edited monographs. The principal investigator in more than 30 projects funded by Armenian and USSR Governments, UN, EU, NATO, ISTC, CRDF, aims to strengthen the national capacity and informational cooperation in the field of hazard and risk evaluation, risk reduction through the knowledge exchange and dissemination as well as increase public awareness.

Pandey, Madhav Raj, born June 15, 1945. Presently the Senior Seismologist and Chief of the National Seismological Center, Department of Mines and Geology (DMG), Nepal. Graduated in 1969 with M. Sc. (Geophysics). Joined the DMG in 1969 as an exploration geophysicist. Carried out geophysical exploration for searching and exploration of mineral and hydrocarbon deposits in Nepal up to 1979. Initiated seismological observation under DMG in 1979 in technical collaboration with Laboratoire de Geophysique, France. Responsible for the creation of the National Seismological Network of 17 short period seismic stations covering the entire kingdom of Nepal in 1994. Developed velocity depth model of Nepal Himalaya to be used in routine location of epicenters. Organized and participated in cross Himalayan Experimental Seismological observation jointly with Institute of Physics of the Earth, Paris University. Carried out studies on intensity of the 1934 Bihar Nepal Great Earthquake, seismotectonic model of Central Nepal Himalaya, and characteristic of seismicity of Nepal and related segmentation of the Himalayan arc.

Rastogi, Bal Krishna, the Head of Seismology, NGRI, Hyderabad, India. Dr. Rastogi (i) developed seismic characteristics to differentiate reservoir-induced earthquakes from ordinary earthquakes, (ii) studied damaging earthquakes and aftershocks in India that occurred since 1967 and also studied inferred seismotectonics of several regions of India, and (iii) assessed earthquake hazard on regional basis and in specific areas.

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PROCEEDINGS

EARTHQUAKE HAZARD ASSESSMENT AND RISK MANAGEMENT IN ASIA

Serguei Yu. Balassanian

Abstract

With the increasing scale of disasters projected for the 21st century by the experts, the ASC should play an important role as a catalyst and coordinator for the Earthquake Hazard Assessment and Risk Management Strategy development and implementation in Asia-Pacific region for prevention of the earthquake hazards impact on population, vital infrastructure and property. The ASC activity for risk reduction in Asia and Pacific should take into account the above listed problems, additionally taking into consideration the big difference between developed and developing countries. The level of efforts focused on mitigation of strong earthquakes' effects in developing countries has remained rather low and constant, while the level of efforts focused on the same problems in developed nations has permanently increased. The full implementation of the Seismic Risk Reduction Strategy directly depends on economic resources of the country and policy in understanding of the existing problem. However, the key issues of the Strategy with very limited resources can be implemented in any country where the understanding of the problem on political level exists. The proposed approach has been successfully implemented in Armenia during the 1991-2002 after the devastating Spitak earthquake in 1988 (Balassanian, 2000, [1]). This unique experience in creation of comprehensive and advanced Seismic Protection System in the developing country with very limited economic recourses has been widely recognized and rewarded by the UN-Sasakawa Award in 2002 (Balassanian, 2002) and can be transferred to any developing country in Asia and Pacific. The ASC should promote the understanding that Earthquake Hazard Assessment and Risk Management in Asia and Pacific are immediately linked to the ability of the country to function appropriately for the guarantee of business continuity and hence economic growth and the potential of any Asian and Pacific country to prosper and develop. To promote this critical understanding for benefit and safety in particular for the most vulnerable developing countries the ASC should undertake practical steps by way of the ASC pilot projects.

Key words: Eearthquake hazard, seismic risk reduction, risk management, ASC pilot projects

INTRODUCTION

Asia is the most populated continent of the Earth, and has a high level of seismic hazard. Earthquakes are the major threat to the social and economic development of many developing nations in Asia. Death tolls from the recent earthquakes in urban areas have been the largest all over the world: the 1976 Tangshan earthquake in China reportedly killed 250,000 people; the 1990 earthquake in Tabhas, Iran with 40,000 victims; the 1991 earthquake in Spitak, Armenia with 25,000 victims; the 1995 Kobe earthquake, Japan 5000 victims; the 2000 Taiwan earthquake, China 6,000 victims; the 2001 Gujarat earthquake, India 17,000 victims. The rapid growth of the Asian population in earthquake prone urban areas will make such disasters more deadly and more frequent.

With the increasing scale of disasters projected for the 21st century by the experts, the ASC should play an important role as a catalyst and coordinator for the Earthquake Hazard Assessment and Risk Management Strategy development and implementation in Asia-Pacific region for prevention of the earthquake hazards impact on population, vital infrastructure and property.

Summarizing the experiences and achievements of different countries in the field of seismic risk reduction, the ASC should promote:

- understanding of the earthquake disaster reduction as the major priority in regional, national and international development;
- understanding of the central importance of disaster reduction as an essential element of the government policy;
- partnership establishment between scientific community, government and public, since effective disaster reduction depends upon a multi-sectoral and interdisciplinary collaboration among all the concerned actors;
- exchange and transfer of up-to-date scientific knowledge and technology and strengthening of the international and multidisciplinary cooperation in the field of seismic risk reduction;
- a move away from disaster recovery oriented approach towards disaster prevention and preparedness policy;
- development of a national strategy, program and legislation for earthquake risk reduction;
- establishment of an interagency governmental body on national level, which would act as a focal point for seismic risk reduction activities, concentrating efforts of all the sectors of the government and society relevant to seismic risk reduction;
- development of pilot projects for risk reduction in Asia and Pacific.

The ASC activity for risk reduction in Asia and Pacific should take into account the above listed problems, additionally taking into consideration of the big difference between developed and developing countries. The level of efforts focused on mitigation of strong earthquakes' effects in developing countries remains rather low and constant, while the level of efforts focused on the same problems in developed nations has permanently increased.

To fill this critical gap and increase the ability of each country to reduce its earthquake risk is the primary goal of ASC.

The Seismic Risk Reduction Strategy should include the following elements:

- seismic hazard assessment (SHA);
- seismic risk assessment (SRA);
- built environment vulnerability reduction through seismic codes and standards design, seismic strengthening and upgrading of existing buildings, seismoresistant construction and control;
- public awareness increase through education and training;
- current seismic hazard assessment, early warning and notification;
- rapid loss estimation and emergency response and rescue operations (disaster management);
- disaster relief and rehabilitation;
- insurance;
- national seismic protection law and regulations;
- responsible governmental institution establishment for the interagency multi-disciplinary seismic risk reduction management.

The full implementation of the Seismic Risk Reduction Strategy directly depends on economic resources of the country and policy of understanding of the existing problem. However, the key issues of the Strategy with very limited resources can be implemented in any country where the understanding of the problem on political level exists.

The key issues of the Seismic Risk Reduction Strategy are:

- establishment of the responsible institution for the Seismic Risk Reduction policy design and implementation;
- development of the Seismic Risk Reduction national program, including all the above listed elements with short, middle and long-term sub-programs adopted by Government;
- development of the National Seismic Protection Law, adopted by Parliament;
- internationalization of the national Seismic Risk Reduction program to involve for funding different international sources as well;

The proposed approach has been successfully implemented in Armenia during the last 11 years after the devastating Spitak earthquake in 1988 (Balassanian, 2000, [1]). This unique experience in creation of comprehensive and advanced Seismic Protection System in the developing country with very limited economic recourses has been widely recognized and rewarded by the UN-Sasakawa Award in 2002 (Balassanian, 2002) and can be transferred to any developing country in Asia and Pacific.

The ASC should promote the understanding that Earthquake Hazard Assessment and Risk Management in Asia and Pacific are immediately linked to the ability of the country to function appropriately for the guarantee of business continuity and hence economic growth and the potential of any Asian and Pacific country to prosper and develop.

To promote this critical understanding for benefit and safety in particular for the most vulnerable developing countries the ASC should undertake practical steps by way of the ASC pilot projects.

PRACTICAL STEPS FOR EARTHQUAKE HAZARD ASSESSMENT AND RISK MANAGEMENT IN THE ASIAN AND PACIFIC COUNTRIES: ASC PILOT PROJECT-PROPOSALS

Considering the existing background of earthquake hazard assessment and risk management in Asia and Pacific, the ASC pilot projects for the Asian and Pacific countries should be focused on the following issues:

Further improvement of the seismic hazard evaluation in developing countries.

Seismic risk assessment: regional and local contexts.

Seismic risk reduction in the selected most vulnerable urban areas.

Current Seismic Hazard Assessment for early warning and notification.

The implementation of the ASC pilot projects will promote the ASC further capacity building through networking and cooperation.

Further Improvement of the Seismic Hazard Evaluation in Developing Countries

Background

The further improvement of the seismic hazard evaluation in the Asian and Pacific countries is the initial step in the general strategy of risk reduction.

Earthquake hazard is usually expressed in probabilities of occurrence of certain earthquake (strong ground shaking) in a given time frame. Hazard assessment commonly specifies 90% of non-exceedance of certain ground motion parameter for an exposure time of 50 years, corresponding to a return period of 475 years.

We are considering that the further improvement of the seismic hazard evaluation in the Asian and Pacific countries should be based on the GSHAP approach, which was designed to provide a useful global seismic hazard framework and serve a resource for any national and regional agency for further detailed study applicable to their country needs.

The brief review of the current status of seismic hazard assessment on national level shows that there are considerable differences between countries, from Buhtan, Nepal, Vietnam and Laos, which do not have national seismic hazard maps to China, India and Russia with several generations of national hazard maps, and to Japan, which produces hundreds of seismic hazard maps throughout the seismological history in Japan. Thus, there are different objectives for further improvement of the seismic hazard evaluation in the Asian and Pacific countries, depending on the level of development of country.

For developing countries the main objective is to design national seismic hazard maps in accordance with international standards.

For developed countries the main objective is the further improvement of the national probabilistic SHA maps in three directions:

1. increase the quality and availability of the basic data needed for the seismic hazard assessment;
2. further development of the advanced methodology for probabilistic seismic hazard analysis, based on improved models of earthquake source, occurrence and ground motion, and seismic hazard calculation taken into account uncertainties in the input data;
3. minimize the level of uncertainties considering their aleatory and epistemic nature.

Necessity to increase the quality and availability of the basic data becomes obvious from comparison of existing instrumental earthquake's catalogues, covering only a few last decades with the recurrence of large earthquakes in active areas may need characteristic period of hundreds or thousands of years. Thus, the sufficient background, historical and prehistorical information based on geological, seismotectonic, paleo-seismological, geomorphological and other data is needed to complete the large earthquakes statistics, covering their recurrence period for the improvement of quality of seismic hazard assessment.

Further development of the advanced methodology is needed for improving earthquake source models, occurrence models, ground motion models and seismic hazard calculation approaches.

Besides the well known permanent (static) line source and areal source models, the earthquake source models improvement should be considered to discuss the temporary (dynamic) sources of the potential seismic hazard, which are defined as crust stress high gradient zones (Balassanian, et al. [2])

Different types of occurrence models such as Poissonian, time-predictable, slip-predictable and renewal have been used for the PSHA. But it must be recognized that the largest earthquakes in many cases occur at a rate per unit time that is different from the predicted by existing occurrence models (Mayer-Rosa 1999, [3])

The ground motion models are usually attenuation relationships that express ground motion as a function of magnitude and distance. Many of ground motion attenuation relationships have been determined using two different ways: empirical, based on previously recorded ground motions, or theoretical based on seismological models to generate synthetic ground motions that account for source, site and path effects.

The further development of ground motion models is needed in order to take into account:

1. different tectonic environments, because the shallow crustal earthquakes in active tectonic regions, shallow crustal earthquakes in stable continental regions and subduction zone earthquakes give rise to different ground motion attenuation relationships (Abrahamson and, 1997, [4]);
2. style of faulting, because reverse and trust earthquakes tend to generate larger Pik Ground Accelerations (PGA) and high-frequency Spectral Acceleration (SA) than strike slip and normal earthquakes (Abrahamson and, 1997, [5]);
3. rupture directivity(Somervill et al., 1997, [6]);

4. nonlinear effects in near source zone in case of large earthquakes (Campbell and,1994, [7]);
5. site classification ranging from qualitative descriptions of the near-surface material to very quantitative definitions based on shear-wave velocity (Dobry et al., 2000, [8]);
6. nonlinear dynamic properties of the soil at the local (receiver) sites (Stepp et al., 2001, [9]).

Further improvement of seismic hazard calculation should be based on consideration of uncertainty. The first step in this direction is already done by McGuire (McGuire, 1993, [10])

To minimize the level of uncertainties the nature of uncertainties should be taken into account. Because the aleatory uncertainty is naturally inherent in the earth and earthquake process, which in principle, cannot be reduced with additional data or information, the main focus should be placed on minimization of epistemic uncertainty.

Significant advances in the development of the methodology for quantifying epistemic uncertainty in seismic hazard, due to incomplete knowledge about earthquakes processes and ground motion attenuation and to incomplete data available for evaluating these processes, have been made during the last 20 years. These developments, based on weighting alternative interpretations of the seismotectonic environment city by multiple experts should be continued.

The objective of the proposal is to design the national seismic hazard maps for most vulnerable developing countries in the Asia-Pacific region.

In order to achieve the objective the following tasks should be solved:

- to select the most vulnerable 3-5 countries in Asia and Pacific;
- to establish a multinational research team, consisting of the best national multi-disciplinary experts from different organizations, representing national, governmental, NGOs and private sectors, and of the well-known leading experts from the Asian and Pacific countries for the advanced seismic hazard evaluation technology transfer into national seismological practices;
- to develop an initial realistic national standard for SHA, based on the quality and availability of the basic data needed to achieve the sufficient level of hazard mapping as close to international (GSHAP) standards as possible;
- to develop probabilistic seismic hazard map in accordance to the selected national standard.

The duration of the project should be 3 years.

The expected results are the following:

- developed SHA map, adopted by Government;
- improved national building codes and regulations;
- effective land use and planning;
- developed emergency preparedness and response plans;
- economic forecasts;
- insurance planning and development;
- housing and employment decisions;
- earthquake risk assessment and mitigation planning.

The end-users are national, state and local governments, decision-makers, engineers, planners, builders, emergency response organizations, universities and general public.

Seismic Risk Assessment in the Asian and Pacific countries

Background

The next important step after the earthquake hazard evaluation in the general strategy of seismic risk reduction is the seismic risk assessment.

The risk is expected losses of lives, persons injured, property damaged and economic activity disrupted due to earthquake. The seismic risk composed of seismic hazard, vulnerability and the elements at risk (population, structures, utilities, systems, socio-economic activities and many other) for which loss can be calculated.

The brief review of the current status in national seismic risk assessment shows that there is not even a global framework for seismic risk assessment to serve as a resource for any national and regional agency to develop further detailed study applicable to their country needs. And the difference between developing and developed countries is bigger than in case of seismic hazard assessment.

The noticeable risk analysis has been done mainly in frame of the UN-RADIUS (Okazaki, 2000, [11]), WSSI (Shah, 1999, [12]), Oyo Corporation and Geohazards International (Tucker et al., 1994, [13]), Earthquakes and Megacities (Green et al., 1993 [14]) and some other Initiatives. But it still remains a small drop in ocean of needs for seismic risk assessment in the Asian and Pacific countries.

Thus, there are different objectives for the further improvement of the seismic risk assessment in developing and developed countries.

For developing countries there are two objectives:

1. to design a regional seismic risk assessment map to provide a regional framework, and serve as a resource for any national and regional agency for further studies applicable to their needs;
2. seismic risk assessment for the most vulnerable urban areas in the Asian-Pacific countries.

For developed countries the main objective is the further improvement of the seismic risk assessment on the national level in the following directions:

1. increase the quality and availability of the basic data needed for the comprehensive seismic risk assessment;
2. further development of the advanced methodology for comprehensive seismic risk analysis and assessment;
3. minimize the level of uncertainties.

To increase the quality and availability of the basic data, additional studies should be done as the following:

- to complete the databases for ground shaking and collateral (maps of a topography, soil property, groundwater table, fault, liquefaction potential, landslide potential and rapture zone) analysis;
- to complete inventory of built environment and population, including databases of taxable buildings, non-taxable buildings, extended lifelines, modal lifelines; census and business/ economic data;

Further development of the advanced methodology should be based on the consideration and reduction of uncertainties in the various methodology components and in final risk assessment as well as on GIS-based modeling of the ground shaking and collateral hazards, complete inventory of built environment and population, damage and loss estimations. One of the main problems in future development of the advanced methodology is that the models are not easily adopted when large regions or megacities need to be evaluated. Often data are missing requiring that simplifying assumptions be made.

For minimizing the uncertainties the further research as the following is needed:

- structure response in case of multi-source earthquake (for example the Spitak earthquake, Armenia, 1988) (Balassanian et al.,1995, [15]);
- soil-structure nonlinear interaction;
- non-linear dynamic response of structure under ground shaking and collateral hazards.

In general, uncertainties reduction can be achieved through the development of more realistic damage and loss models that include calibration with empirical data.

The objectives of the proposal are:

1. To design a seismic risk assessment map for the Asian-Pacific region.
2. Seismic risk assessment for the selected most vulnerable urban areas in the Asian-Pacific region.

In order to achieve the objective 1 the following tasks should be solved:

- to establish a steering committee for project management;
- to select regions and test areas under the coordination of regional centers, based on GSHAP experience;
- to develop design principles for regional seismic risk assessment based on GSHAP approach ;
- to select a simplified methodology for seismic risk assessment (for example, Balassanian et al., 1994, [16]) taking into account equivalent availability for each country of the multidisciplinary basic data needed for seismic risk assessment: seismic hazard (based on GSHAP regional PSHA maps), vulnerability, and the main elements at risk (constructions and population);
- to develop and adopt a regional seismic risk assessment program, working plan and management principles.

For the achievement of the objective 2 the following tasks should be solved:

- to select the most vulnerable (3-5) urban areas in the Asian-Pacific region, taking into consideration the probability of the next strong earthquake, vulnerability of the given urban areas, scale of possible loss and preparedness to disaster;
- to establish a multinational working group, consisting of the best national multi-disciplinary experts from different organizations, representing governments, NGOs and private sectors from the Asian-Pacific countries for the advanced technology transfer into national practice;
- to develop multi-approaching standards aimed to achieve the international standards through several approaches (initial, middle, final) based on availability of basic data for comprehensive seismic risk assessment;

- to select as an initial standard the regional seismic risk assessment approach;
- seismic risk mapping for the selected urban areas in accordance to the adopted national standards.

The duration of the project should be 3 years, with parallel implementation of the objectives 1 and 2.

The expected results are the following:

- developed seismic risk assessment map for the Asian-Pacific region, (as an initial step) and then expand in the second step to cover continent by continent and finally the globe;
- developed SRA maps for the selected most vulnerable urban areas of the Asian-Pacific region, as an initial step and then expand in all the vulnerable urban areas of the region;
- developed bases for risk mitigation program and disaster management plans for the Asian and Pacific countries and the selected most vulnerable urban areas;
- developed framework for land use and planning;
- economic forecasts;
- insurance;
- framework for housing and employment decisions.

The end-users are national, state and local governments, decision-makers, engineers, planners, builders, emergency response organizations, universities and general public.

Seismic Risk Reduction in the selected most vulnerable urban areas

Background

The background for the project is RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) initiative launched by the IDNDR Secretariat, United Nations, Geneva in 1996, with financial and technological assistance from the Government of Japan. It aimed to promote worldwide activities for reduction of seismic disaster in urban areas, which was rapidly growing in developing countries.

The direct objectives of the RADIUS were:

- to develop earthquake damage scenarios and action plans in nine case-study cities three of which from Asia (Bandung, Tashkent, Zigong).
- to develop practical tools for risk management, which could be applicable to any earthquake-prone city in the world;
- to conduct a comparative study to understand urban seismic risk around the world;
- to promote information exchange for seismic risk mitigation at city level.

The direct objectives of the case studies were:

- to develop *an earthquake damage scenario*, which describes the consequence of a possible earthquakes;
- to prepare a risk management plan and propose an *action plan* for earthquake disaster mitigation.

The case studies aimed:

- to rise the awareness of the decision makers and the public to seismic risk;
- to transfer appropriate technologies to the cities;
- to set up a local infrastructure for a sustainable plan for earthquake disaster mitigation;
- to promote multidisciplinary collaboration within the local government as well as between the government offices and scientists;
- to promote worldwide interaction with other earthquake-prone cities.

All the case-study cities are well equipped with modern infrastructures, but they differ in l

Level of understanding of seismic disaster issues

In Bandung (Indonesia), there is a single coordinating office for emergency response. Because annual flooding is the most frequent disaster in the city, the focus is on flood disasters and seismic considerations were almost neglected. The general awareness of the citizens and the decision-makers of seismic risk were very low. In contrast Tashkent has experienced damaging earthquakes, and seismic risk issues are taken into consideration in urban planning. The level of public awareness is relatively high.

In Zigong, the administrative department for earthquake disaster prevention and mitigation is the Zigong Seismological Bureau. Programs about seismic safety and countermeasures are shown on TV, earthquake awareness pictures are shown on street billboards, and information is disseminated through radio and local newspapers. Consequently, the people of Zigong have a relatively high level of awareness regarding the possibility of earthquake damage.

In accordance with RADIUS initiative conclusions the case studies met their goals to complete the scenarios and the risk management and action plans. (Okazaki, 2000, [11])

However, the RADIUS initiative, as many other very good and useful actions, still remains a disposable undertaken effort unfortunately with short life time and cannot trigger the long-term efforts that are required for Seismic Risk Reduction program implementation.

The main objectives of the proposing project are:

1. To develop the Seismic Risk Reduction Program for the most vulnerable urban areas based on internationally recognized and tested standards for risk reduction;
2. To develop a mechanism for triggering the permanent process aimed to Seismic Risk Reduction Program implementation through planning, management, research and permanent education.

In order to achieve the objective1 the following tasks should be solved;

- to select the most vulnerable urban areas, where the risk assessment is already made based on RADIUS or any other initiatives;
- to establish a multinational working group consisting of the best national multidisciplinary experts from different organizations (representing the government, NGOs and private sectors) and the well-known leading experts from the Asian and Pacific countries for the advanced seismic risk reduction knowledge transfer into national practice;
- to develop an advanced Seismic Risk Reduction program taking into account the national peculiarities of the urban area based on the experience of RADIUS or other effective initiative.

For achievement of the objective 2 the following tasks should be solved:

- to develop sub-programs and master plans for each element of Seismic Risk Reduction where the sub-programs and planning do not exist;
- to establish an interagency and multidisciplinary management body on the level of government (national, regional, local depending on the status of the selected urban area)for Seismic Risk Reduction program implementation;
- to develop research programs for each element of seismic risk reduction, to begin permanent research process in universities and other research institutions.
- to develop educational and training programs for public awareness increase;
- to establish a permanent educational process in the selected schools, universities and municipalities.

The duration of the project should be 3 years.

The expected results are the following:

- Developed seismic risk reduction programs for the most vulnerable urban areas, based on internationally recognized and tested strategy for risk reduction;
- Developed mechanism for promoting the permanent process of risk reduction program implementation through planning management, research and permanent education;
- Promoted scientific research in all the elements of Seismic Risk Reduction, aimed to prepare scientific ground for their potential funding from potential donors such as local industries, financial and insurance sectors, and international aid organizations;
- Promoted permanent educational process on the levels of school, university and municipality, aimed to public awareness increase;
- Developed sub-programs and master plans for each element of seismic risk reduction;
- Established interagency and multidisciplinary management body on the level of government (national, regional or local, depending on the status of the selected urban area) for seismic risk reduction;
- Strengthened the corporation among the seismic risk reduction all the concerned actors, focusing on local participation to build capacity among the local community.

The end-users are national, state and local governments, decision-makers, scientists, emergency response organizations, citizens, schools and universities, general public.

Current Seismic Hazard Assessment for Early Warning and Notification

Background

Current seismic hazard assessment based on intermediate results of earthquake prediction research is one of the promising elements in Seismic Risk Reduction Strategy for early warning and notification.

Earthquake prediction is the most complicated problem in seismology. It has two important aspects: scientific and social. The scientific aspect is intimately linked to the basic definition of earthquake prediction: type of prediction (long-term, intermediate-term, short-term, and imminent); general geodynamic conditions and local geology at the place of earthquake source location; size of an earthquake, etc. The social aspect is linked to prevention and protection of society from strong earthquakes, in order to save lives and protect economic and social assets. Three various points of view summarizing the scientific achievements in the field of earthquake prediction research in the XX century should be noted: pessimistic (about 90% of scientists), optimistic (about 9% of scientists) and realistic (about 1% of scientists). The pessimistic point of view has been formulated and shared in decreasing order mainly from the USA to Europe and to Asia. The optimistic point of view has opposite direction – from Asia to Europe and to the USA in decreasing order. The realistic point of view has pretty homogenous and diffusive character worldwide. It is shown that the above listed patterns in evaluation of the earthquake prediction achievements depend on: earthquake prediction definition and requirements, degree of country development; the current scientific policy based on general state policy, priority of the earthquake prediction need for country; personal understanding, the research and experience of the expert in that field; experience of majority of experts, general opinion and scientific atmosphere and emotions.

In last decade approximately 100 authors published articles about scientific aspect of the earthquake prediction in reviewed scientific journals, in which they claimed that they had found various types of precursors before the earthquakes. On the other hand, several reputed scientists doubt that these or any other precursory phenomena exist. These doubts and lack of spectacular progress in earthquake prediction research, as well as exaggerated claims of individual researchers with low quality standards, have led to a worldwide lull in earthquake prediction research. Some renowned and respected scientists no longer dare broach the subject, lest they be attacked by opponents, more or less regardless of the improvements they may have included in their analysis. This situation is counterproductive. It stops the possible development of this and other methods of earthquake prediction and thus may deprive humanity of a tool to cope better with earthquake disasters. At the same time, in regard to social aspect of the earthquake prediction research, there is a number of very promising publications in reviewed scientific journals where authors demonstrate efficiency of using intermediate scientific results in earthquake prediction research for early warning and notification. The definite progress in this approach has been made in China (Zhang Guomin et al.,1997, [17]), Armenia (Balassanian et al., 2000, [18]) and Island (Thorkelsson 1996, [19]) on the level of the sate countermeasures undertaken by the governments on the basis of the current seismic hazard assessment made by the responsible government seismological agencies.

Taking into consideration:

- the importance of the current seismic hazard assessment, in particular for developing countries, which do not have economic resources for seismic risk reduction in its full scale, as well as power to stop earthquakes for several decades to undertake traditional full-scale countermeasures;
- the critical need to protect population from strong earthquakes in particular in the most vulnerable developing countries;
- the necessity of evaluation of the scientific results for the current seismic hazard assessment based on high quality data and objective expertise;

The ASC could take the lead in current seismic hazard assessment for early warning and notification.

The objectives of the proposal are:

1. To unite the state-of-the art tools and intellectual capacities of different countries into virtual network for fast, high and professional level of assessment of the current seismic hazard in any country of the region requesting the ASC independent expertise;
2. To develop a sophisticated formation system for the current seismic hazard assessment based on the existing and developing real-time, multidisciplinary well organized national networks for earthquake prediction researches;
3. To maintain high scientific standards and strong expertise of the scientific outputs.
4. To develop an expert system for the current seismic hazard assessment, early warning and notification based on multidisciplinary retrospective analysis of all the seismic events occurred and occurring in the region.

For the successful current seismic hazard assessment the following key requirements are needed:

- a multi-parameter unified real-time monitoring network;
- a specific site selection, including highly-sensitive energy-active points (Balassanian, 2000, [18]) for setting of the multi-parameter observation stations;
- well studied region from geological, geophysical, seismological and seismotectonic point of view with complete data bank;
- state-of-the-art equipment, hardware and software for data processing and analysis;
- highly professional staff and research team.

In order to achieve the objectives, the following tasks should be solved:

- to select several test sites in accordance with the above stated requirements for various seismotectonic conditions representing collision, subduction and transform fault zones in different parts of the Asian-Pacific region;
- to unite the selected test sites into transnational, real-time multidisciplinary monitoring network, based on the state-of-the-art and reliable communication links among selected test sites for on-line data transmission and receiving;
- to establish data acquisition processing and analysis centers at each of the selected test site;
- to develop an expert system for the current seismic hazard assessment;
- to develop a protocol for real-time data exchange and fast expertise for the current seismic hazard assessment;
- to develop an early warning and notification expert system based on the current seismic hazard assessment.

The project will consist of three phases (I-III).

Phase I is the pilot project, where the main participants are countries, where the well-organized monitoring networks already exist (Armenia, Australia, China, Japan and others) and where relatively small amount of funds will be needed for some improvement of the existing network up to above stated requirements and for solving the main objectives of the project. The duration of phase I is 3 years.

Phase II is the core project where the main participants are the same as in the pilot project plus other countries that have monitoring networks, which should be significantly improved in accordance with the above stated requirements. The duration of the phase II is 3 years.

Phase III is the full project where the participants are all the countries located in the seismically active zones of the Asian-Pacific region and which would like to join this initiative.

The duration of the phase III is 4 years. The duration of the whole project (I-III) is 10 years.

The research team

Taking into consideration the context of the proposal, the research team should be composed of proponents of the earthquake prediction research, of critics skeptical that any precursors exist and neutral scientists. This make up is essential for the working process. The moderating presence of the neutral parties can be very beneficial, because the two sides in a debate about the current procedure run the risk of getting entrenched in a way that hinders progress.

The expected results are the following:

- developed virtual network of high level experts for the current seismic hazard assessment in any country requiring the ASC independent expertise;
- established united multidisciplinary real-time transnational monitoring network producing high quality data for the current seismic hazard assessment;
- developed expert systems for the current seismic hazard assessment, early warning and notification, based on intermediate scientific results of earthquake prediction research and multidisciplinary analysis of all the seismic events occurred and occurring in the studied region.

The end-users are national, regional and local governments, decision-makers, emergency response organizations, scientific community, universities and general public.

The potential funding of all the presented project-proposals is supposed from potential donors such as local industries, financial and insurance sectors, developed countries of the Asian-Pacific region and international aid organizations.

CONCLUSION

1. With the increasing scale of disasters projected for the 21st century by the experts, the ASC should play an important role as a catalyst and coordinator for the Earthquake Hazard Assessment and Risk Management Strategy development and implementation in Asia-Pacific region for prevention of the earthquake hazards impact on population, vital infrastructure and property.
2. The ASC activity for risk reduction in Asia and Pacific should take into account the above listed problems, additionally taking into consideration the big difference between developed and developing countries. The level of efforts focused on mitigation of strong earthquakes' effects in developing countries has remained rather low and constant, while the level of efforts focused on the same problems in developed nations has permanently increased.
3. The full implementation of the Seismic Risk Reduction Strategy directly depends on economic resources of the country and policy in understanding of the existing problem. However,

the key issues of the Strategy with very limited resources can be implemented in any country where the understanding of the problem on political level exists.

The key issues of the Seismic Risk Reduction Strategy are:

- establishment of the responsible institution for the Seismic Risk Reduction policy design and implementation;
- development of the Seismic Risk Reduction national program, including all the above listed elements with short, middle and long-term sub-programs adopted by Government;
- development of the National Seismic Protection Law, adopted by Parliament;
- internationalization of the national Seismic Risk Reduction program to involve for funding different international sources as well;

The proposed approach was successfully implemented in Armenia during the 1991-2002 after the devastating Spitak earthquake in 1988 (Balassanian, 2000). This unique experience in creation of comprehensive and advanced Seismic Protection System in a developing country with very limited economic recourses has been widely recognized and rewarded by the UN-Sasakawa Award in 2002 (Balassanian, 2002) and can be transferred to any developing country in Asia and Pacific.

4. To promote this critical understanding for benefit and safety in particular for the most vulnerable developing countries the ASC should undertake practical steps by way of the ASC pilot projects.

- Further improvement of the seismic hazard evaluation in developing countries.
- Seismic risk assessment: regional and local contexts.
- Seismic risk reduction in the selected most vulnerable urban areas.
- Current Seismic Hazard Assessment for early warning and notification.

The implementation of the ASC pilot projects will promote the ASC further capacity building through networking and cooperation.

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EARTHQUAKE VULNERABILITY REDUCTION - FUTURE CHALLENGES

Suvit Yodmani

Abstract

As major earthquakes in the Asian region over the last decade have demonstrated (Kobe, Chamoli, Taiwan, Bengkulu and Gujarat), they remain a devastating risk the region faces and the key strategy for management of seismic hazards is through mitigating earthquake vulnerability of communities, structures and their economy. The improvement of the capacity of the stakeholder organizations to respond to future events quickly and efficiently remains short-term preparedness measures and mitigation initiatives. To reduce the devastating efforts of earthquakes in the future long term measures also are needed. ADPC through its ongoing programs try to demonstrate the effectiveness of short and long term mitigation initiatives and also building the capacity of local emergency response groups, city officials, professionals to handle their assigned roles effectively.

Using lessons learnt and building on experiences from these successful initiatives, ADPC is planning to initiate Earthquake Vulnerability Reduction (EVR) programs in future in selected high-risk cities/districts in Asian countries.

EVR program will use an integrated approach for earthquake risk mitigation through vulnerability reduction, preparedness and response planning and is proposed to be implemented through close co-operation between the stakeholders i.e. the local community, local authorities, public emergency response services and locally available technical experts in Universities, NGOs as well as supporting national institutions.

IMPACTS IN ASIA

Asia is believed by many to be the most disaster-prone region in the world. Earthquakes are one among the most frequent events, which bring huge losses of life and property annually. It results in severe setbacks to the economic and physical development process of less developed and developing countries within the region. Asia accounts for only 30% of the world's landmass, but receives disproportionately higher disaster impacts.

The annual average number of events, people killed, affected, and damages reported by earthquake disaster events are presented in Table 1. It indicates that earthquake disaster impacts in the region are significantly higher compared to other regions of the world. Table 2 below, shows Number of people killed, affected, and damages due to Earthquakes by period (1992 to 2001).

The period has witnessed a rapid increase in the number of people killed and injured by earthquake disasters. This can be attributed to more frequent earthquakes in the Asian region with relatively high injury-to-death ratio. This may be an indication that the earthquake risk mitigation and preparedness programs implemented in the region have not been adequate.

Factors that increase vulnerability of human habitats such as fast population growth, un-regulated development initiatives, increasing concentrations of people in urban areas and most importantly the vulnerability of infrastructure facilities and dwellings to ground acceleration created by earthquake events have not been remedied.

Table 1

Annual average number of events, people killed, affected, and damages due to earthquakes by region (1992 to 2001

	Africa	Americas	Asia	Europe	Oceania	Total
Number of events % of Total.	10 *4,6%*	48 *22.3%*	112 *52.1%*	37 *17.2%*	8 *3.7%*	215
Killed % of Total	784 *1.0%*	3,463 *4.5%*	52,440 *67.4%*	20,998 *27.0%*	71 *0.1%*	77,756
Affected (in thousands) % of Total	145 *0.4%*	3,518 *10.1%*	28,799 *82.4%*	2,436 *6.9%*	45 *0.1%*	34,943
Damaged (Mill.USD) % of Total	339 *0.17%*	39,611 *16.6%*	170,119 *71.7%*	27,233 *11.4%*	314 *0.13%*	237,616

Source: World Disasters Report 2002

Table 2

Number of people killed, affected, and damages due to Earthquakes by period (1992 to 2001)

	1992 to 1993	1994 to 1995	1996 to 1997	1998 to 1999	2000 to 2001
Killed	14,049	9,208	3,658	28,282	21,559
Affected	1,057,000	3,759,000	2,589,000	5,771,000	21,765,000
Damage (Mill. USD)	1,942	186,318	5,952	33,792	9,612

Source: World Disasters Report 2002

EARTHQUAKE DISASTER RISK SCENARIO IN THE FUTURE

Countries in Asia are affected by almost every conceivable hazard - geological hazards such as earthquakes, landslides and volcanoes; hydro-meteorological hazards such as floods, cyclones, hot and cold waves, forest fires and droughts. Among the hazards of man made nature are epidemics, insect infestations, forest fires, various types of accidents, conflicts and events of civic disorder etc.

There appears to be a trend for increase of risk from natural as well as man-made disasters in cities in the future. A noticeable feature in many cities in Asia is the scarcity of inhabitable land, value appreciation of available land, and the concentration of population in and around growth centers. Due to the un-affordability of quality construction, lack of appropriate technical guidance and non-compliance of building code requirements the vulnerability of infrastructure facilities and residential and commercial buildings is getting increased. This is reflected in high losses and damages due to earthquakes during the past decade and increase in such trend can be observed even in the future.

Today we are witnessing an unprecedented migration of rural population to urban and suburban areas due to economic reasons. The concentration of industries and factories, commercial centers, welfare and recreational centers within urban areas are seen as positive factors of Urbanization. That is negated by unprecedented migration as it increases the physical vulnerability. People assemble in large numbers in such areas for employment, recreation and the like, thus increasing the risk of exposure to future disaster events. On the other hand concentration of population unavoidably leads to a high demand for better services. The city authorities are burdened with problems connected to supply of water, energy, telecommunication, gas, and garbage disposal. Destruction of these lifelines (such as waterworks, sewerage, city gas piping and electric lines) due to a disaster, especially in an earthquake event, will therefore create great impact to population living in urban areas in future.

Such population densities will also get exposed to associated secondary hazards like fire, waterborne diseases, epidemics and technological accidents. All of these possibilities contribute to higher vulnerability and risk of these communities living in earthquake prone areas.

Urban sprawl and unplanned growth with little heed to sensible construction practices may add to this vulnerability. Since collapsing buildings kill most victims of earthquakes, risk is more concentrated in urban areas. In larger cities, high-rise buildings, large underground shopping centers, basement structures, and expressways are increasing in number. Therefore in future special attention must be given to earthquake and fire proofing aspect of buildings by the authorities. As a result, an increase in cost of building and construction may result. This will pose a challenge to authorities who wish to get away with practices of non-conformity to building codes. On the other hand it is a challenge for the architects and structural engineers to provide necessary cost reduction alternatives without compromising the quality and appearance of buildings in terms of compliance with building code requirements.

The buildings in urban areas are designed to have partitioned areas to accommodate facilities; such as markets, shops, parking lots etc in the ground floor and in some cases there are more than one basement to accommodate such service facilities. This type of designs tends to increase the vulnerability of the structure to earthquakes. With the spread of urbanization, the development of low wetland and land lots having higher slope gradients would also be promoted. Such newly developed areas are often susceptible to storm floods, landslides, debris flows, and liquefaction, so that special approval procedures have to be adopted by city authorities.

The recent past has also witnessed rapid progress in motorization. As a consequence, problems of urban traffic are emerging and special provisions are being made by the city authorities to have elevated toll ways, multi-storied car parks in commercial buildings etc. On one hand an increasing trend in traffic accidents may be anticipated in the future while the overhead bridges, elevated roads may increase the vulnerability of populations to earthquakes.

Many developing countries in Asia face increasing levels of pollution and disasters such as earthquakes may increase the vulnerability further. They face a difficult choice between the need for development and industrialization in urban areas. Pollution control under general conditions is invariably conceived as a disadvantage due to increased cost of production. On the other hand location of industries, factories that deals with toxic material, pesticides, chemicals, toxic substance etc within urban areas prone to earthquake hazard increase the vulnerability of population to secondary effects. These areas are subjected not only to earthquake events, but also due to secondary hazards such as urban fire, contamination of air and water with poisonous material. But regulations to limit location of such facilities within urban residential areas have yet to be enforced by many developing countries.

Economic incentives for pollution prevention facilities by such enterprises under general conditions as well as when located in hazard prone areas especially within earthquake prone areas do not appear to be viable within developing country scenarios. Unless foolproof preventive measures are not adopted to regulate the consequences, with greater industrialization, the greater risk of technological hazard triggered by the incidents of serious earthquakes, as secondary hazard is eminent in future. Therefore city authorities should take in to account the seriousness of future scenarios due to such incidents and appropriate regulatory mechanisms should be considered, in urban planning process,

INITIATIVES REQUIRED FOR EARTHQUAKE DISASTER RISK MANAGEMENT GOALS IN THE FUTURE

The recipe for mitigation of the impact of earthquakes and any other type of hazard event consists of range of options. The assessment of vulnerability and risk, building up scenarios, generation of information on different associated attributes, enforcement of building codes, land use regulations, effective warning, evacuation and establishment of efficient response systems, etc. are some of them. In order to manage the futuristic events effectively, the national, provincial and local government institutions should take a lead role in implementation of such short and long term measures in partnership with affected communities and other stakeholder institutions. Politician's role and responsibility to ensure establishment of administrative instruments to carry out effective programs, and also provision of adequate funds are also needed, to complement the scientific research on the subject.

The measures taken to reduce the impacts due to potential future earthquake disaster events demand for the transformation of the earthquake disaster risk management discipline in to a multi disciplinary science capable of finding cost effective and speedy solutions. The accurate prediction of the exact time and location of impact of an earthquake is still beyond the capacity of scientists. What is possible today is the defining the boundaries of potential areas of impact. That can be done with high accuracy and mathematical models may help to give probabilistic predictions of even time scales. What is discouraging is the inability of the scientific community to change the perception of the potential victim community to take proactive measures even with availability of such research findings.

The zoning and data pertaining to physical vulnerability provided by the scientists are enough to generate warning signals but the victims should know what they could do to reduce the losses at their level. Present day sciences possess the capacity to predict an earthquake which will provide sufficient time to disable gas and electricity distributions. But most of city authorities within high-risk zones are still not convinced that they should have such installations for their facilities.

It's a fact that substandard construction costs lives. Most of the International agencies used to underline the significant role; the appropriate construction can play in terms of reduction of earthquake losses. Many thinks application of seismic regulations and building codes will be enough to avoid such low quality construction in the future. But this has to be viewed in a broader context and answers have to find to all associated problems. The factors on physical vulnerability have to be weighted against the economic vulnerability to find ways to remedy the situation.

One another area, which should receive attention, is the information on ground conditions and providing correct guidance to construction sector on the same. In most part of the world very generalized zonation maps or vulnerability maps are available but not detail enough to get an idea about the subsurface conditions. Sometimes the urban areas are located on active faults or in the surrounding areas. Sometimes on soils susceptible to liquefaction or on unstable slopes. So more investigations by individuals will cost more money and will add in to construction cost. Therefore the central government or local bodies need to consider provision of such information as one of their obligations for making the communities disaster free. If they can make necessary funds available to scientific community they will be able to generate such information for the benefit of others.

In most countries codes are the requirement by statute but the building regulations in most countries do not recognize the enforcement needs. In order to comply with the building code practices it needs to be practiced by professionals and also a proper inspection and quality audits have to be in place from the local government side. Both aspects are not in place in the context of local government institutions of many countries in most countries in Asia capacity building programs have to recognize the need for building the capacity of professionals, construction workers and supervisory staff for local bodies in order to have proper compliance of building codes.

In disaster mitigation programs we place high emphasis on the physical vulnerability. Most experts think in future if all new construction in earthquake prone areas can be constructed with adequate earthquake resistant elements, in the years to come the impact from earthquake events will be minimum. In the same way if the present buildings can be retrofitted to absorb the impact created by ground acceleration due to earthquakes the future scenario of earthquake victims can be drastically changed. But what one cannot realize is the fact that the level of affordability of potential victims is the key to success in such programs. In order to create that enabling environment financial instruments also should be created for those who are in need of such assistance. Therefore government lending institutions and private sector should place emphasis on micro-credit schemes for construction of earthquake resistant buildings. Other financial instruments such as tax benefits, insurance coverage for risk transfer, and subsidies have to be introduced in an appropriate way, if the desired success to be achieved in mitigation programs on housing reinforcement and new constructions.

Professionals have to dedicate themselves to a continuing process of systematic observations, analysis, synthesis and dissemination of disaster related knowledge on cost effective affordable construction that allows for earthquake resistant structures. This should not be limited to infrastructure facilities and engineered construction but more importantly they should pay more attention on non-engineered construction especially on private dwellings.

The other aspect is the need for strengthening the local emergency response mechanisms. Whenever there is an earthquake or any other serious disaster international humanitarian organizations have to bring in rescue teams. This not only creates logistical, cultural and other type of problems but also found to be useless exercise as survivors are found only in exceptional cases by such rescue teams. As at present local emergency response often depend on volunteerism and their services are not duly recognized by government institutions. Therefore government in earthquake prone countries should plan for creation of skilled emergency response teams within the available government machinery. Also steps are necessary to recognize the efforts of volunteers and to encourage them. Most practical way is to have trained and skilled teams within the army or police or internal security units.

Many feel that earthquake education should be a part of school curricular in areas prone to earthquakes but still school authorities are reluctant to make changes in education systems to integrate such important aspects. Education provided to our next generation on risk reduction measures can lead to a culture of safety. Through school children the parents can be forced to take measures at household level such as fixing hanging objects tightly or avoid fixing of objects on the ceiling etc. Basic preparedness measures one should be taken when living in earthquake prone areas such as maintenance of survival kit in possession by family members and keeping duplicates of important documents elsewhere can be reminded through school children. The conduct of regular earthquake drills in schools is one such thing that teaches can initiate to increase the preparedness.

It is difficult to detach people's perception from the way in which they reach them as they take them from their historical context. Today happenings will become a history until they see the next event. We do not try to convert the lessons from one disaster in to opportunities to build the future. Negative lessons learned should not affect the approach of the disaster management community. Lack of programs to create public awareness is seen as a key factor. Inability of the disaster management community to influence the vulnerable communities for a behavioral change is seen as a set back but it should be regarded as challenge. Therefore public awareness creation should be done using different approaches and we should learn to market the ideas and to monitor the effectiveness in our approach.

ROLE OF ADPC AS A REGIONAL ORGANIZATION

ADPC, as a regional resource center dedicated to safer communities and sustainable development through disaster reduction in Asia and the Pacific, has taken up number of initiatives with the view of reducing the earthquake vulnerability in countries of Asia. It supports the initiatives for building the capacity of local authorities, national government, non-government organizations, businesses and others responsible for implementation of effective earthquake risk reduction programs ADPC also facilitates knowledge sharing and dialogue between key stakeholders to enhance the effectiveness.

One such initiative is the Asian Urban Disaster Mitigation Program implemented by ADPC through the funding support from USAID/OFDA. The goal of the AUDMP is to reduce disaster vulnerability of urban populations, infrastructure, lifeline facilities and shelter in Asia. In an environment where good governance and decentralization are high in most countries' political agenda, AUDMP aims to demonstrate the importance of and strategic approaches to urban disaster mitigation as part of the urban development planning process in targeted cities of Asia.

ADPC under the Asian Urban Disaster Mitigation Program (AUDMP) with core funding from Office of Foreign Disaster Assistance of USAID, with its national partners especially Nepal Society for Earthquake Technology (NSET) and Institute of Technology, Bandung, Indonesia, have implemented several innovative initiatives, such as the Kathmandu Valley Earthquake Risk Mitigation Program (KVERMP) in Nepal, Indonesia Urban Earthquake Disaster Mitigation Project (IUDMP). KVERMP has been assisting three municipalities of Kathmandu Valley to understand the risk of earthquakes and the vulnerabilities of communities to earthquake hazards and the implementation of the Mitigation Action Plan.

IUDMP focuses on reducing the vulnerability of Bandung, West Java, to natural disasters, particularly to earthquake hazards. Special attention has been paid to identifying critical facilities such as schools and hospitals, and to implementing a school earthquake safety program. Highly successful public awareness programs are also an integral part of these projects.

The course on Earthquake Vulnerability Reduction in Cities (EVRC), developed with the inputs from NSET (Nepal), WSSI, EMI has become a regular feature in the training calendar of ADPC. In addition to the AUDMP, ADPC has initiated an earthquake risk management component in Uttaranchal under the Asian Development Bank funded Technical Assistance project in India.

The improvement of the capacity of the stakeholder organizations to respond to future events quickly and efficiently remains short-term preparedness measures and mitigation initiatives. To reduce the devastating efforts of earthquakes in the future long term measures are needed.

It is recognised that the death toll can be reduced significantly by medical first response and search and rescue operations carried out immediately after a disaster by well-trained citizens from within the affected community.

In the light of this, ADPC, in collaboration with the Office of U.S. Foreign Disaster Assistance (OFDA) and Miami-Dade Fire Rescue Department (MDFRD), is implementing a Program for Enhancement of Emergency Response (PEER) capacity of four Asian countries: India, Nepal, Indonesia and the Philippines. The principal vehicle for achieving the program objectives and outcomes is through training that utilizes a "train the trainer" approach, designed to generate a large pool of trained instructors from emergency response agencies who will in turn train others from their organization.

PEER has conducted various trainings in Medical First Responder (MFR) courses, Collapsed Structure Search and Rescue (CSSR) and Training of Instructors (TFI) courses and has developed a cadre of trained personnel from the First Responder agencies including the fire services, police, army and Red Cross from each of the four countries. A new course, Hospital Preparedness for Emergency (HOPE) is being developed, which focuses on hospital preparedness for disasters.

Using lessons learnt and building on experiences from these successful initiatives, ADPC is planning to initiate Earthquake Vulnerability Reduction (EVR) programs in selected high-risk cities/districts in Asian countries in the future.

EVR program will use an integrated approach for earthquake risk mitigation through vulnerability reduction, preparedness and response planning and is proposed to be implemented through close co-operation between the stakeholders i.e. the local community, local authorities, public emergency response services and locally available technical experts in Universities, NGOs as well as supporting national institutions.

CONCLUSIONS

A community's resilience to disasters can be achieved through long-term mitigation initiatives and preparedness measures capable of reducing its consequences and impacts economically, physically, and psychologically. The emphasis also should be placed on addressing the root causes of disasters within a long-term perspective. Thus, all disaster mitigation and preparedness endeavors should be viewed as components of developmental planning.

Therefore, roles and responsibilities of different stakeholders have to be redefined accordingly. Awareness raising at community level and also at all national, regional, and local levels should be seen as a priority need. The ad-hoc approach to disaster management seen in the past is undergoing rapid change. In the past it was an operation to meet needs during and immediately after a disaster. Recently there has been a shift of the mantle of responsibility from the shoulders of emergency agencies to everyone in the community. The present day priority should be building of resilient communities. Community accountability, empowerment and transfer of ownership are some of the important aspects that disaster management community has not considered in the past.

Therefore in the future, it is very essential to take into consideration the voice of victims or potential victims when providing assistance to rebuild destroyed facilities, or building new settlements or undertaking initiatives to strengthen the current facilities.

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EARTHQUAKE CATALOGUES IN THE ERA OF DIGITAL SEISMOLOGY: THE STATE-OF-THE-ART AND FUTURE PROSPECTIVE

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Abstract

Earthquake catalogue is one of the representations of the evolution of seismological observation and interpretation. In the study of earthquake hazard and risk as well as earthquake prediction, earthquake catalogue is one of the most important set of input information. Since recent years, with the development of digital broadband seismology, it has been possible for seismologists to obtain more earthquake parameters by inverting digital broadband seismic waveforms. Measurement of 'modern' earthquake parameters has become one of the most important missions of some seismological agencies on routine basis. Introducing the concept of 'modern earthquake catalogue' has a significant impact on both seismological observation and interpretation and the study of seismic hazard and earthquake prediction, calling for further international cooperation and exchange of data and knowledge.

INTRODUCTION: EARTHQUAKE CATALOGUES IN THE ERA OF DIGITAL SEISMOLOGY

The history of earthquake catalogues can be traced back to the time prior to instrumental seismology. Collection of earthquake information and seismic disasters in the countries/regions with long history such as China, Iran, and Italy formed the primitive forms of earthquake catalogues. Early generations of earthquake catalogues have only place, time and rough descriptions of the damages of earthquakes. Introducing of the concept of intensity quantified the descriptions of damages, and provided an indirect description of the size of an earthquake. In the history of earthquake catalogues, one of the most important advancements is the introducing of earthquake magnitude in the 1930s, the first step to assign an earthquake an empirical/physical description. Another important development is the determination of hypocentral depth. The observation and study of deep and intermediate-depth earthquakes led to the discovery of the Wadati-Benioff zone, which was regarded as one of the most important observational basis for global plate tectonics. Since the 1940s earthquake catalogue which contains origin time, location, depth and magnitude of earthquakes had become the 'standard' form of earthquake catalogues. Earthquake catalogue has been one of the main outputs of seismological observation and interpretation on routine basis. International data exchange and cooperation, such as those under the umbrella of the International Seismological Center (ISC), played an essential role in the production and improvement of earthquake catalogues. Global distribution of earthquakes observed by worldwide and/or regional seismograph networks provides another direct evidence for global plate tectonics. Since the 1960s seismology has become a well-developed quantitative science in the perspective of the understanding of the propagation of seismic waves and the structure of the Earth's interior. On the other hand, however, some of the earthquake phenomenologies are still not well understood within the present framework of seismology. One of 'the last frontiers' of modern seismology is the regularity and physics of seismic activity. Physical significance of the Gutenberg-Richter's law and Omori's law is still one of the outstanding questions in the physics of earthquakes, which leads to the controversy on the predictability of earthquakes. For physicists and seismologists, to understand and model an earthquake catalogue is still a challenging problem.

The last three decades witnessed the emerging and accelerated development of broadband digital seismology. Deployment of high sensitivity, high dynamic range, and broadband seismometers lowered the detection threshold of seismological network. Digital seismic recording makes the acquisition, archive and pre-processing of seismograms very convenient. The processing and analysis of seismograms, such as waveform zooming, filtering, phase picking, stacking, Hilbert transform, and so on, can be conducted interactively and/or automatically on routine basis. Developments in algorithms and structure models improved the quality of earthquake location. Some of the data processing techniques, such as correlation analysis of seismograms for relative locations, are possible only using digital seismic recordings. Signal detection, arrival picking, phase-event association, event identification and parameter determination on routine basis can also be carried out automatically by intelligent computational systems using various algorithms such as artificial neural network, pattern recognition, and wavelet transformation, among others. Using of three-dimensional heterogeneous structure models based on the result of seismic tomography improved earthquake location results to much extent. Catalogues of small earthquakes are used to figure out active faults and other seismogenic tectonic structures.

Most importantly, development of digital seismology and quantitative seismology has made it possible to measure more and more parameters of an earthquake, such as centroid moment tensor (CMT), broadband radiated energy, source time function (STF) or source spectra, rupture propagation velocity and fault length, and even the 'snapshots' of rupture process. This advancement has led to the opportunity to produce 'modern earthquake catalogues' which include not only location parameters and magnitudes as in the conventional catalogues but also new parameters of earthquakes as mentioned above. With time elapses such 'modern earthquake catalogues' have accumulated and shown their potentials in the study of seismotectonics, geodynamics, physics of earthquakes, seismic hazard, and earthquake prediction, no matter whether or not these catalogues have been widely used.

In this article we discuss some of the potential applications of 'modern earthquake catalogues'. We focus on the problem of seismic hazard and earthquake prediction, an unsolved and controversial problem in seismology. More specifically, we focus on one of the technique problems in seismic hazard estimation and earthquake prediction, that is, the analysis of seismic activity based on earthquake catalogue.

'MODERN EARTHQUAKE CATALOGUES': TWO EXAMPLES

At present there have been several 'modern earthquake catalogues' available. Examples of global catalogues include the Harvard CMT catalogue; the USGS National Earthquake Information Center (NEIC) moment tensor catalogue; the NEIC radiated energy catalogue; the Earthquake Research Institute (ERI), Tokyo University, CMT catalogue; among others. Examples of regional catalogues include the Chinese moment tensor catalogues, produced by the China Digital Seismograph Network (CDSN) and the China National Seismograph Network, respectively; and the moment tensor catalogue for earthquakes in Japan. Examples of local catalogues include the moment tensor catalogues for earthquakes in southern California, among others.

One of the examples of the widely used 'modern earthquake catalogues' is the Harvard CMT (Dziewonski *et al*., 1981) catalogue. Although still having some regional bias (e.g., Patton, 1998), this 'modern earthquake catalogue' has been widely used in many researches such as the frequency-moment relation (Frohlich and Davis, 1993 ; Sornette et al., 1996; Kagan, 1997), clustering properties of earthquakes (Kagan and Jackson, 1994), 'seismic gap' (Kagan and Jackson, 1995), rate of foreshocks (Reasenberg, 1999), global distribution of non-double-couple sources (Kawakatsu, 1991), change of 'crustal potential energy' (Tanimoto and Okamoto, 2000; Tanimoto *et al.*, 2002), 'earthquake doublets' (Kagan and Jackson, 1999), temporal correlation of earthquake focal mechanisms (Kagan, 2000), and relation between entropy and mean energy fluctuation of global seismicity (Main and Al-Kindy, 2002), not mentioning the study of stress state and seismotectonics in which focal mechanism plays an important role. The Harvard CMT catalogues are regularly published in *Phys. Earth Planet. Interi*. as research letters, and are available on the web.

An example of the 'modern earthquake catalogues' which is still not widely used is the NEIC broadband radiated energy (Boatwright and Choy, 1986) catalogue. Comparing to the Harvard CMT catalogue, the NEIC broadband radiated energy catalogue caused less attention among seismologists, although there are a few works related to apparent stress (Choy and Boatwright, 1995; Wu, 2001; Wu et al., 2002). One of the reasons for this situation is that generally it is thought that broadband radiated energy is not necessarily a better measure of an earthquake than scalar seismic moment. But this idea is wrong: Broadband radiated energy, being derived from the velocity power spectra, is a measure of seismic potential for damage; while seismic moment, derived from the low-frequency approximation of displacement spectra, is more physically related to the final displacement of an earthquake (Choy and Boatwright, 1995). Or in another word, broadband radiated energy is not a better measure of an earthquake than seismic moment, it is rather an alternative measure other than seismic moment. In fact, the relation between energy and seismic moment is quite scattering (Choy and Boatwright, 1995), and some of the properties, such as the global frequency-size distribution of earthquakes, as represented by energy and moment, respectively, have different characteristics (Wu, 2000). Another reason for that the NEIC energy catalogue is not widely used is that the acquisition of this catalogue is not so convenient. The NEIC energy catalogue was firstly published in *Bull. Seism. Soc. Amer*. in the earthquake notes of NEIC. Since recent years the earthquake notes have changed to be published in *Seism. Res. Lett*. of the Seismological Society of America. Measurement of energy and energy magnitude can also be obtained electronically from the earthquake catalogues of NEIC. But there is not an independent energy catalogue available on the web.

INTRODUCING MORE DEGREES-OF-FREEDOM OF EARTHQUAKE CATALOGUES INTO THE STUDY OF SEISMIC HAZARD AND EARTHQUAKE PREDICTION

In the study of seismic hazard and earthquake prediction, one of the conventional approaches is to identify patterns of seismic activity from an earthquake catalogue, which leads to a variety of prediction methods such as seismic quiescence, foreshocks, burst of aftershocks, clustering, time-to-failure analysis, changing of *b*-value, and so on (Ma *et al*., 1982). These methods, dealing with different time scales, have limited but statistically significant efficiency in predicting the likelihood of a future earthquake. What is more often used is an expert system which gives the time of increased probability for strong earthquakes (the TIPs) by combining different factors together (e.g., Keilis-Borok, 1990).

But these analyses have an intrinsic limitation: With a limited degrees-of-freedom of the earthquake catalogues used, different precursors may be correlated to each other. In physics, if the degrees-of-freedom of observational data is less than the degrees-of-freedom of a dynamic system, then the prediction of the behavior of the dynamic system based on the observational data will be difficult. This is just the present status quo of seismology: At present for seismic hazard estimation and earthquake prediction, several seismicity parameters have been defined based on the statistical properties of an earthquake catalogue. The change of these parameters, or their combination, is expected to reflect the increase of the probability of earthquakes. The problem is, a 'classical' earthquake catalogue have only four to five independent parameters (i.e., origin time, place, and magnitude). In this case, even if one defines tens of parameters describing the changes of seismicity, these parameters will be dependent on each other. Statistical analysis shows that most of the 'seismological indexes', that is, changes of statistical parameters of seismicity as potential earthquake precursors, are correlated with each other (Han *et al*., 2001). That is to say that no matter how many 'new' parameters are defined, the prediction capability cannot be improved, unless the degrees-of-freedom of the observational data is enhanced.

Seen in the perspective of the analysis of dynamic systems, effectively many of the previous approaches are aiming to overcome this limitation by increasing the degrees-of-freedom of earthquake catalogues. One examples of such a method is the 'ambient stress' (Chen and Duda, 1996) or 'Creepex' (Kaverina *et al*., 1996) analysis which makes use of the difference between body wave magnitude and surface wave magnitude. In this analysis the difference between body wave magnitude and surface wave magnitude becomes a 'new' parameter, forming an extra degrees-of-freedom of an earthquake catalogue. Another example is the 'burst of aftershocks' (Keilis-Borok *et al*., 1980). In this case the number of aftershocks becomes an extra parameter describing the property of the main shock. Still another example is the 'load-unload response ratio' (Yin *et al*., 2002) which assigns a load- or unload- phase to an individual earthquake. Extremely speaking, experience of experts also plays the role of an alternative degrees-of-freedom.

With the development of digital broadband seismology, description of an earthquake is no longer merely four to five parameters. Introducing of more earthquake parameters into the analysis of seismicity provides a new look at the problem of seismic hazard and earthquake prediction. We take an example to demonstrate that 'modern earthquake catalogues' can provide some heuristic clues for the estimation of seismic hazard. These clues are impossible to obtain using traditional earthquake catalogues.

With the occurrence of the November 14, 2001, Tibet-Qinghai border, China, M_w7.8 earthquake which is one of the largest shock striking the Tibetan plateau since the 1950s, once again seismologists encountered the old question whether or not there will be another shock following, with comparable magnitude, approximately in the same place. This question is reasonable to much extent, because after the main shock the aftershocks were small in magnitude (with the maximum magnitude only 6.0) and small in number (there were only about ten aftershocks with magnitude larger 5.0 within one year after the main shock). Moreover, there do have been many examples that earthquakes tend to occur in 'pairs' or 'groups'. At present, earthquake prediction is still one of the outstanding problems in seismology. On the other hand, however, with the development of modern seismology, seismologists can at least 'say something' about this question.

Shortly after the earthquake, seismological agencies such as Harvard University, the NEIC of USGS, the ERI of Tokyo University, and the China Seismological Bureau (CSB) issued their results of seismic moment tensors and other earthquake parameters (see, *http://neic.usgs.gov/neis/FM/*; *http://wwweic.eri.u-tokyo.ac.jp/*; also see, *http://www.eq-igp.ac.cn/, in* Chinese). Inversion of the rupture process of the seismic source, aftershock distribution, and field investigation show that the seismic faulting plane orients in the EW direction, and the focal mechanism of the earthquake is left-lateral strike-slip (van der Woerd *et al*., 2002; Lin *et* *al*., 2002). This information provides useful clues for estimating the likelihood of strong aftershocks. Using the Harvard CMT catalogue, we conducted a statistics showing that for earthquakes with seismic moment larger than 10^{19} Nm, there are 84% thrust events occurred in 'pairs' or 'groups', while the 'paired' or 'grouped' strike-slip events are only 14% of all of the strike-slip events. Here the term 'paired' and/or 'grouped' means that successive earthquakes occurred during 3 years with the spatial distance between the centroids less than 200km. Classification of earthquakes into thrust, strike-slip, and normal type uses the method of Frohlich (1992). Using the NEIC broadband radiated energy catalogue with earthquakes larger than magnitude 5.5, we also got that there are 71% of thrust events occurred in 'pairs' or 'groups', while the 'paired' or 'grouped' strike-slip events are 24% of all of the strike-slip ones. Here we change the criteria for the 'paired' or 'grouped' earthquakes a little bit to see whether or not the conclusion is robust against the arbitrariness of the definition. In the later case because moderate events are also included, the spatial-temporal range is changed into 100km and 2 years, with another criteria added that the difference between magnitudes of different events within a 'pair' or 'group' is less than 1.0. Although the values are different for different cases, the tendency always holds that strike-slip earthquakes tend to have fewer 'succeeding' shocks. This result implies that, because of the strike-slip focal mechanism of the Kunlunshan mountain pass earthquake, the probability for another big quake following the M_w7.8 main shock is relatively small, being roughly less than 1/4.

This earthquake has more special characteristics. Comparison of reduced energy (Kanamori and Heaton, 2000), that is, radiated energy divided by seismic moment, of different earthquakes, shows that this event has an extremely low apparent stress, in which apparent stress can be calculated by multiplying the shear modulus of the source medium and the reduced energy (Wyss and Brune, 1968). We conducted a statistics showing that if a strike-slip earthquake has an extremely low reduced energy or apparent stress, the earthquake is more likely to be 'single'. But due to the limited number of samples (there are only tens of earthquakes to be studied) the statistical significance is limited. In the statistics we use the NEIC broadband radiated energy catalogue and the Harvard CMT catalogue to calculate the reduced energy. This result, together with the result mentioned above, implies that the probability for another earthquake with comparable magnitude to happen near to the M_w7.8 earthquake is even lower.

This kind of statement is by no means an earthquake prediction. On the other hand, however, modern seismology has provided seismologists with the ability to make some independent judgments about the future tendency of seismic activity, which is also useful in the study of seismic hazard and earthquake prediction. Some of the judgments are impossible to make in the past, because at that time the information in the traditional earthquake catalogues is limited. In contrast, using 'modern earthquake catalogues', even simple statistics can lead to some useful clues. We made the estimation shortly after the earthquake (Wu, 2002), but this estimation still needs to be tested by the real situations of seismic activity.

CLASSIFICATION OF EARTHQUAKES AND HYPOTHESIS TESTING IN EARTHQUAKE PREDICTION

One of the most important information contained in 'modern earthquake catalogues' is that different types of earthquakes have different properties. Taking focal mechanism as an example, it has been found that quite a few earthquake phenomenologies are focal mechanism dependent, such as the frequency-magnitude relation (Frohlich and Davis, 1993), tidal triggering of earthquakes (Tsuruoka et al., 1995), level of apparent stress (Choy and Boatwright, 1995; Perez-Campos and Beroza, 2001), scaling of reduced energy or apparent stress versus seismic moment (Wu, 2001; 2002), scaling of earthquake parameters (Stock and Smith, 2000), and rate of foreshocks (Reasenberg, 1999), reflecting the physics of earthquake preparation and occurrence. One of the conclusions deduced from this phenomenon is that in the testing of hypothesis related to earthquake prediction, classification of earthquakes needs to be considered. That is to say that a certain precursor will be valid only for a certain class of earthquakes.

It is well-known that there are three general cases associated with an earthquake prediction: successful prediction, false-alarm, and failure-to-predict. A 'game rule' for hypothesis testing is mainly a comparison of the performance of a prediction approach with that of random prediction, according to the normal rate of seismicity. If earthquakes can be classified into different categories, then false-alarm and failure-to-predict have different physical significances. In principle, for any specific precursor, for some earthquakes, failure-to-predict is inevitable because the precursor under consideration is valid only for some specific classes of earthquakes. In the study of potential precursors, therefore, an appropriate research strategy is to depress the false-alarms and to tolerate the failures-to-predict. Such a research strategy does not conflict with the ethics of seismological study. To tolerate the failures-to-predict does not mean that seismologists are irresponsible. Comparing the study of earthquake prediction to the study of medicine, it is unreasonable to require a technique or instrument to be able to diagnose all diseases. Similarly, it is not rational to require that an earthquake precursor is valid for all kinds of earthquakes. Decreases in failures-to-predict can be achieved by searching new precursors which are valid for other kinds of earthquakes.

Hypothesis testing is an essential problem in the study of earthquake prediction. The 'game rule' associated with this test is especially important because it leads to the criteria for accepting or rejecting a statistical hypothesis related to earthquake prediction. In recent years the problem of hypothesis testing in earthquake prediction study has caused an increasing attention among seismologists (Stark, 1996, 1997). Up to now, however, the 'game rules' of earthquake prediction have almost completely overlooked an important problem: The classification of earthquakes. In the statistical test, it often happens that all the earthquakes within a magnitude-space-time range are treated as the same, which has no sound geophysical basis. An extreme example is the claim of Geller (1997) that time and effort need not be wasted on evaluating prediction schemes that cannot outperform the 'automatic alarm' strategy of Kagan (1996). If earthquakes were all the same, then this claim would be absolutely reasonable. However, from the perspective of the classification of earthquakes, such a stance might lead to the loss of some useful information. Geller *et al*. (1997) proposed that the question of precursor test can be addressed using a Bayesian approach where each failed attempt at prediction lowers the *a priori* probability for the next attempt. In this case, if all earthquakes are treated as the same and no difference is made between failures-to-predict and false-alarms, the 'game rule' will be extremely harsh, and many potential precursors will be rejected by this 'razor'. It is well-known that one of the pioneer works in seismology is the classification of earthquakes by R. Hoernes in 1878. Ironically, however, 120 years after, seismologists have almost forgotten this 'classical' problem and treat all earthquakes alike in their statistical tests. From the discussion above, it is too early to accept the conclusions that the search for earthquake precursors has proved fruitless and earthquakes cannot be predicted (Geller *et al*., 1997). In another word, the evaluation of the performance of earthquake precursors should be reconsidered using 'modern earthquake catalogues' which provide appropriate classifications of earthquakes.

BEYOND THE SCOPE OF PRESENT EARTHQUAKE CATALOGUES: SILENT EARTHQUAKE AND ITS IMPLICATIONS FOR EARTHQUAKE PREDICTION

We prospected that 'modern earthquake catalogues' may contribute much to the study of seismic hazard and earthquake prediction. On the other hand, however, the 'modern earthquake catalogues' at present are still not enough to solve the problem of seismic hazard and earthquake prediction. Beyond the scope of the present earthquake catalogues there should be another invisible but important earthquake catalogue, that is, catalogue of silent earthquakes. A silent earthquake is a transient tectonic slip event which has a nonzero seismic moment but has almost no seismic wave radiation (Beroza and Jordan, 1990). In the past, silent earthquake is also called as 'slow earthquake', but this is easy to confuse with another kind of 'slow earthquake' in seismology (Kanamori and Kikuchi, 1993) which has a relatively longer duration of source time function. Record of silent earthquakes can be traced back to as early as the 16th century in the Chinese literatures (see, Zhang *et al*., 2001). Systematic observation and study on silent earthquakes started from the 1970s when record of silent earthquakes on strainmeters were reported (Sacks *et al*., 1978). In recent years, observation and research on silent earthquakes attracted much attention among seismologists (e.g., Crescentini *et al*., 1999). This advancement has an important impact on the study of earthquake prediction and seismic hazard.

Silent earthquake has significant importance for the study of earthquake prediction. For example, using the CN algorithm to evaluate the future seismic risk, retrospective long-term earthquake prediction experiment was conducted for northern Italy (Peresan *et al*., 1999). Within the identified periods of the 'Time-of-Increased-Probability (TIP)' for earthquake occurrence, there were earthquakes occurred accordingly. But in the TIP period from 1972 to 1976, there was no earthquake occurred. Traditionally this is regarded as a false alarm. However, a tiltmeter near to Trieste, northern Italy, recorded a series of silent earthquakes from 1973. This shows that the prediction is still 'successful', but the difference is that what happened is not a regular earthquake but silent earthquakes. In another word, the precursors observed do reflect the accumulation of tectonic strain, but the strain release is through silent earthquakes.

Stress triggering, which describes the change of the probability for a future earthquake through changing the Coulomb failure stress (CFS) by either the past earthquakes or tectonic loading, has become one of the hot topics in seismology since the 1990s (Harris, 1998; Stein, 1999). In the calculation of the static CFS change, both regular earthquakes and silent earthquakes play the same role, while dynamic CFS change has no relation with silent earthquakes. This will be important in solving the controversy between static and dynamic stress triggering.

Recently, GPS and/or INSAR measurements show that silent earthquakes can be observed in the aftershock process of an earthquake (Takai *et al*., 1999; Reilinger *et al*., 2000). In earthquake prediction study, 'burst of aftershocks' (Keilis-Borok *et al*., 1980) is an important index to the likelihood of a future earthquake. How this method could accommodate silent earthquakes is still a problem which needs to be investigated. But it seems that in this consideration, silent earthquake is by no means negligible.

We can even have a 'devil's proof' for the reason why the ratio-of-success for most of the earthquake prediction methods cannot outperform 30%. We take foreshock as an example. It is well known that foreshock ranks the best among different precursors. Suppose that foreshock as a precursor has 100% ratio-of-success. The only difference is that both regular earthquakes and silent earthquakes must be accounted for. In this case, we have four situations: (A) foreshock/s before a main shock; (B) silent foreshock/s before a main shock; (C) foreshock/s before a silent main shock; and (D) silent foreshock/s before a silent main shock, among which we are not interested in (D). Traditionally, situation (B) is considered as a failure-to-predict; and situation (C) is considered as a false alarm. Having no *a priori* knowledge about their relative importance, let us assume that the probability for situations (A), (B) and (C) equals to each other. In this case, the ratio-of-success, that is, the probability for situation (A) to appear, is 1/3, that is, near to 30%. If foreshock does not exist for all the cases, then the situation will be more complex, and the probability for (A) will be less than 30%. The above 'deduction' is absolutely not a proof. On the other hand, however, it is worth pointing out that in recent years, study on the 'nucleation' of earthquake rupture through foreshocks is an important topic under discussion. Silent earthquakes, although still out of the view of seismologists, is sure to be important in such kind of studies. In fact, observations show that 'nucleation' process, deduced using the information of regular earthquakes, does not accompany all the earthquakes.

At present, the activity of silent earthquakes is not known for most of the seismic active regions. What is not clear is also the frequency-moment distribution of silent earthquakes. Based on the relation between the fractal dimension of seismic fault system and Gutenberg-Richter's *b* value (Aki, 1981), it can be postulated that the frequency-moment distribution of silent earthquakes is similar to that of regular earthquakes, with the *b*-value for silent earthquakes being approximately 1.0. This means that in the study of earthquake prediction using earthquake catalogues, there should be two parallel catalogues: regular earthquake catalogue, and silent earthquake catalogue.

CONCLUSIONS AND DISCUSSION: FROM RESEARCH TO ROUTINE ANALYSIS

Earthquake catalogue is one of the most important representations of seismological observation and interpretation. Since the 1970s with the development of broadband digital seismology, analysis of seismic waveforms and retrieve of earthquake source parameters have gradually changed from frontier researches in seismological laboratories to routine works in seismological data centers and/or stations. As a result, production, comparison/calibration, and application of 'modern earthquake catalogues' became possible, which will have a significant impact on the study of tectonics, geodynamics, physics of earthquakes, seismic hazard and earthquake prediction.

For a long time the analysis of earthquake catalogues is one of the most widely used techniques in the approach to seismic hazard estimation and earthquake prediction. Using the information provided by 'modern earthquake catalogues', it is possible for seismologists to obtain more informative and more reliable conclusions about the future tendency of seismic activity. But at present the potentials of 'modern earthquake catalogues' for the study of seismic hazard and earthquake prediction have not been fully explored.

'Modern earthquake catalogue' can provide appropriate classification of earthquakes based on their physical properties and tectonic settings. This classification has significant importance in the testing of hypothesis and the determination of the 'game rules' of earthquake prediction. Overlooking of this problem has caused several controversies and misleadings in the study of earthquake prediction.

Study of the interaction between seismic and aseismic slip is not a new topic in the physics of earthquakes. Observation of silent earthquakes can be traced back to the 1970s. What is different today is that with the development of very-broadband seismological observations, the 'boundary' separating geodesy and seismology is being diminished. Digital recordings of ground motion, or ground deformation, or ground strain, make the analysis of the signal of silent earthquakes easy to conduct. But because there is no radiation associated with silent earthquakes, the systematic observation of silent earthquakes is still a challenging goal in observational seismology.

The value of an earthquake catalogue lies in two aspects. Firstly, an earthquake catalogue is important because it is self-consistent and systematic. As long as one has the parameters of many earthquakes, some important information can be drawn when combine all these parameters together, even if the parameters are only overall and approximate measurements of earthquakes and have significant uncertainties and/or bias. One of the examples is the scaling relation which is widely used in the physics of earthquakes. In the study of earthquakes, scaling relation between earthquake parameters is shown to be useful for understanding the nature of earthquakes. Secondly, an earthquake catalogue acts both as an output result of seismological observation and interpretation and as an input information set for the study of tectonics, geodynamics, physics of earthquakes, seismic hazard, and earthquake prediction. In another word, earthquake catalogue acts as the 'interface' between seismological observation and interpretation and other disciplines related to earthquake seismology. The enhancement of the level of the 'interface' will in turn enhance the level of the interdisciplinary study. What is worth pointing out is that in some research fields, the importance of 'modern earthquake catalogues' has not been fully recognized.

Production of 'modern earthquake catalogues' is basically based on the analysis and inversion of digital broadband seismic waveforms. The transition from research results to the procedures of routine analysis is one of the important missions of seismological observation and interpretation at present. The difficulty of the inversion of earthquake parameters lies in neither the inversion itself nor the data processing. One of the tricky part is the synthesis of 'Green's functions' or the 'coefficient matrix' for the inversion, which is based on the knowledge of Earth structure and seismic wave propagation. Accommodating this part of knowledge into the procedures of routine analysis is one of the key elements in the transition from research results into routine works.

At present, most of the regional/local data centers have not yet started to provide 'modern earthquake parameters' such as moment tensor, radiated energy, and others. Earthquake parameters given by different agencies still have significant discrepancies. Due to the complexity of Earth structure and seismic wave propagation, the algorithms and models used to produce the 'modern earthquake catalogues' need to be compared, 'calibrated' and upgraded. The threshold magnitude of earthquakes above which 'modern earthquake parameters' can be provided systematically is still high. For example, the Chinese CMT catalogue is only for earthquakes above magnitude 5.0. The completeness of 'modern earthquake catalogues' is still poor and inhomogeneous for different regions. While some of the 'modern earthquake catalogues', such as the Harvard CMT catalogue, have been widely used in the study of seismology, geodynamics and tectonics, the importance of some of the other 'modern earthquake catalogues', such as the NEIC catalogue of broadband radiated energy, have not been widely recognized. It is clear that much work needs to be done in promoting the production, comparison/calibration, standardization, and application of 'modern earthquake catalogues', which calls for international cooperation, and inter-disciplinary cooperation as well.

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SEISMICITY PATTERNS AND GROWING EARTHQUAKE RISK IN INDIA

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Abstract

The paper describes growing earthquake risk in India. Earthquake risk is growing in India as more and more elements are at risk as well as more and more areas are being put under high hazard. The elements under risk are enumerated and the reasons for considering more and more areas under high hazard are stated. The danger of a great earthquake is looming large in Himalayas and until that occurs the moderate to major earthquakes in the Indian Peninsula are likely to recur more frequently. The statistics of great and moderate earthquakes is examined to establish these ideas. The levels and variations of stresses and the resulting strains in different region are examined. Reanalysis of intensity data for several earthquakes indicates slow decay of intensity (acceleration) posing greater hazard than hitherto considered. Onset of digital seismology in India during the last five years has brought a revolution in this field. Exciting new results obtained regarding structure, source and medium properties that have provided better assessment of earthquake hazard are summarized. The future directions required to be pursued are stated.

GROWING RISK

Earthquake risk is the hazard multiplied by vulnerability. The hazard level has been realised to be more in the Peninsular Region in terms of the frequency of earthquakes and areas affected by them. In Himalayas, I recommend that a larger area may be considered under zone V. The elements under risk are also growing more and more in India. The increase in both the factors causes growing risk.

EARTHQUAKE HAZARD

In the revised seismic zoning map of India (BIS, 2002), the Earthquake hazard is now recognized as a matter of serious concern for more than 60% area of India, where MM intensity VII or more is possible (Fig. 1). The 5% area of India has been additionally put under zone III. The increased areas cover some parts of Maharashtra including Killari as well as the border area of Andhra Pradesh and Tamilnadu including Chennai and Chittoor. Now all the four mega cities of India are in zone III where Ahmedabad type damage as that caused by Bhuj earthquake or Latur earthquake type damage can be expected. About 25% area that was in Zone I has been upgraded to zone II. This has been necessitated by occurrence of six moderate to major earthquakes during the thirteen-year period of 1988-2001 i.e. one every two years. These earthquakes were: Mw 6.7 Bihar-Nepal earthquake in 1988, Mw 6.8 Uttarkashi earthquake of 1991, Mw 6.2 Latur earthquake of 1993, Mw 5.8 Jabalpur earthquake of 1997, Mw 6.6 Chamoli earthquake of 1999 and Mw 7.7 Bhuj earthquake of 26 January 2001. If these earthquakes could cause devastation, one shudders with fear imagining the deaths and destruction due to a really big earthquake in Himalayas.

The entire Indian continent has a high stress due to its convergence with the Eurasian plate (Rastogi, 1992). However, the details of the stress field and the resulting slow deformations (strains) vary from region to region. Measurements of annual strain rates using GPS indicate the rates of movement of 2 mm/yr or strains at 10^{-9} or so giving a recurrence interval of thousands of years in a particular region (Bilham and Gaur, 2000). However, occurrence of three damaging earthquakes in a span of 9 years indicates that some factors in addition to crustal contraction are causing higher strains

One such factor is accumulation of higher strains due to density contrast in some pockets due to compositional changes in the regions of pre-existing faults (Fig. 2). Many faults may be hidden beneath the Deccan volcanics. High-density intrusive bodies have been detected along the rifts in Kutch and Koyna and along a ridge in Chamoli area that may act as stress concentrators (Mandal et al., 2002).

Along the Himalayan arc earthquakes occur more frequently along a series of long thrusts. The three major ones that run for 2400 km from Kashmir to Assam are the Main Central Thrust that demarcates High Himalayas in the north and the Main Boundary Thrust that delimits the metamorphic rocks and Lesser Himalayas to the south and the Main Frontal Thrust, which is the contact between the Himalayas and the Gangetic plains. GPS measurements in Kumaon, Nepal and Laddakh indicate about 20 mm/yr of convergence (Bilham et al. 2001). This means that 2 m strain can accumulate every 100 years or 4 m every 200 years that are capable of causing great earthquakes. Hence, these thrusts can create every 200 years or so a series of Great earthquakes that would sequentially cover the entire 2400 km long arc by 200-300 km long ruptures. Hence about 10 or so great earthquakes can occur every 200 years.

Presently the areas of past great earthquakes have been put under Zone V. According to the seismic gap theory, the probability of future earthquakes is greater in the gap areas. Rupture in a great earthquake may cover area from MCT to MFT. Hence, the entire Himalayan belt between these two thrusts needs to be put under Zone V. Presently, the seismic activity is taking place along the detachment surface between MCT and MBT. The portion of the detachment surface between MBT and MFT is locked as indicated by absence of earthquakes and low convergence of 2-8 mm/yr indicated by GPS. The start of activity in the MFT region may herald the onset of a great earthquake. Detailed seismic, GPS, hydro-geodynamic, helium and some other measurements could be diagnostic to that.

The seismicity has varied considerably in different places and periods. During the 53-year period of 1897 through 1950, four great earthquakes of magnitude 8+ occurred (Assam 1897 and 1950, Kangra, 1905 and Nepal 1934), but none such has occurred in the last 50 years. Hence, one great earthquake is now due in Himalayas. It is observed that during the lull periods in Himalayas, the Stable Continental Region (SCR) of India experiences heightened seismicity. This may be the reason for many damaging earthquakes occurring from 1960s.

The SCR India earthquakes exhibit all the three patterns of Mogi. The damaging earthquakes are of Type I and could be in upper or lower crust.. The Type II and III earthquakes are sub-crustal. The Type I, II and III mainshocks release about 70-90%, 50% and 30% energy, respectively. So far in no case aftershocks have caused severe additional damage. Type I earthquakes gave aftershocks of 1-2 units lower magnitude. The felt aftershocks can continue for ~6 months for a M6 earthquake and for ~ 18 months for M8 earthquake.

ELEMENTS UNDER RISK

The pressure of increasing population and the non-engineered fragile structures greatly enhance the earthquake risk. The population has increased up to 10 times as compared to the times of past great earthquakes. The deaths and damage is also feared to go up to 10 times. Added to this is the newly imposed vulnerability of the high-rise buildings up to a distance of a few hundred kilometers from the epicenter. About 50 million people living in the Ganges plains are at risk. It is estimated that depending upon the time of occurrence of the earthquake, 200,000 – 300,000 people may perish in a great earthquake (Arya, 1992). The multistory buildings are often very poorly designed and many of them may be destroyed or damaged. Pressure of the increasing urbanization forces people to inhabit unsafe areas. Moreover the moving population is unaware of the traditional (local) and safe construction practices. For example the laborers who moved from Bihar to Assam constructed mud cake houses with which they were familiar and not the Assam type houses. As a result 30 Bihari labourers died in a M5.4 Cachar earthquake of 1984. In Uttarkashi and Chamoli I observed that due to ignorance the people are following the suicidal construction practices. They are constructing single or even double story rubble masonry houses that collapse even in an M6 earthquake. These types of constructions were in Latur, Uttarkashi, Chamoli, Old Bhuj town, Anjar and Morbi and are existing in many other parts of the country. Until 1950 people were mostly living in thatched houses and now living in rubble masonry or adobe houses, which are highly vulnerable. Hence, earthquakes of M6 can cause devastation in a 50-km radius and M8 in a 300-400km radius anywhere in the country.

In SCR India it has been observed that the intensity could be higher by 1-3 units than say expected for hard rock region of Eastern US, hence, posing a greater hazard. Several earthquakes like Bhuj, Bhadrachalam, Coimbatore and Bellary show slower decay of intensity (and acceleration) in India than for the Eastern U.S. Some earthquakes like Koyna and Latur were assigned lower intensities by some agencies giving a faster decay. Reassignment of intensities for these earthquakes has given slow decay for these earthquakes also. This fact also gives higher hazard than so far considered.

The earthquakes in western and eastern Himalayas could be as deep as 100 km but within central region not more than 20 km. It is difficult to explain deeper than 50km depth earthquakes by the shallow-dipping detachment surface in the MBT region and earthquake modeling of the rrregion needs serious rethinking. In SCR India the earthquakes are of magnitude < 6.5 except in Kutch where these could be of M8. The depths can be as shallow as 2.8 km (as that for the Latur earthquake) or as deep as 35 km for Jabalpur. The cause of the earthquakes in the lower crust is to be understood, as there are several instances of earthquakes in the lower crust. The damage for the shallow earthquakes in the upper crust is confined to a smaller area but the damage (though at somewhat smaller level) spreads out to larger distances for lower crust earthquakes.

RECENT DEVELOPMENTS IN SEISMOLOGY

The period of 1997-2002 has been of revolutionary change in Seismology in India with the deployment of about 50 digital seismographs (Fig. 3) under various schemes of DST and tremendous data processing capability. This along with other collateral studies has enabled fundamental knowledge of source, structure and medium properties. It has been possible to study on one hand 3D rupture and 3D tomography and on the other hand precise hypocentral locations and mechanism by waveform inversion and local earthquake moment-tensor analysis as well as coulomb stress in small earthquakes. This in turn has led to characterization of faults and earthquake processes in different areas. The important findings are in the following aspects:

Source studies: Cause of earthquakes, Nucleation, Causative faults.

Structure: 3D tomography, shear wave modeling.

Hazard Studies: Q, Attenuation of intensity and acceleration, microzonation, site response, probabilistic and deterministic risk maps.

Source Studies

Through painstaking fieldwork, aftershocks monitoring and thorough analysis of worldwide seismograph data, mechanism of large damaging earthquakes like Koyna, Bihar-Nepal, Uttarkashi, Latur, Jabalpur, Chamoli and Bhuj and moderate earthquakes like Idukki, Dhamni and Bhatsa have been well understood. Some of the path-breaking findings are as follows:

Helium Measurements along the active faults of damaging Latur and Koyna indicate depth and extent of the active faults that is confirmed by drilling of deep boreholes (Gupta et al., 1998, Gupta et al. 1999).

The Mesozoic and older rifts like Narmada and Kutch are now having thrusting in a compressive stress regime due to reversal of tectonics from a tensional regime which gave rise to those features. The thrust type earthquakes cause greater damage as compared to strike-slip or normal earthquakes. The vertical movement is more hazardous to buildings as experienced during Latur, Jabalpur and Bhuj earthquakes. Vertical movement from even $M < 4$ earthquakes in Bhavnagar has caused severe damage to 500 houses.

An important finding that has tremendous potential for meaningful hazard estimation in Himalayas is that the rupture of strong earthquakes takes place along the detachment plane as inferred for the Uttarkashi earthquake (Cotton et al., 1998) and Chamoli earthquake. The gigantic thrusts may be only the secondary features.

The Detection of a nucleation process for Koyna earthquake 100 hr prior to mainshocks has tremendous potential for earthquake prediction.

Studies on Structure of the Indian region

An important recent finding is presence of anomalous low velocity zones by 3D tomography that may be susceptible to earthquake generation in Koyna, Chamoli and Kutch regions. The high-velocity zones nearby may be acting as stress/strain concentrators.

Hazard Studies

Microzonation of Jabalpur is nearly complete. First order microzonation for Delhi is expected in 2 years.

Several seismic studies of Kutch have been started towards working out earthquake hazard assessment. There studies include site response, attenuation of seismic waves and probabilistic as well as deterministic hazard maps.

CONCLUSIONS

The hazard level is realized to be more in the Peninsular Region in terms of the frequency of earthquakes and areas affected by them. In Himalayas, I recommend that a larger area may be considered under zone V. The elements under risk are also growing more and more in India. Hence, an increase in both the factors causes growing risk in India. The risk mitigation plan should include the following:

i. Earthquake hazard is to be estimated in seismically active areas. Accurate hypocentral locations are essential to look for precursory changes. Hence the digital seismographs in selected areas need to be deployed with a station spacing of 50km. Helium and groundwater studies, quantitative geomorphologic studies, GPS measurements, studies on active faults including paleoseismology, mapping of active faults will help in better estimates of earthquake hazard and possibly forewarning in some cases.
ii. Preparation of risk maps to the scale of district level in all the areas covered by zones III to V in a phased manner. The first order map for the entire country coming under zones III to V can be prepared with the existing maps of soil/rock cover.
iii. Legislation and enforcement of earthquake resistant building byelaws.
iv. Programs for public awareness and motivation of societies.
v. Large-scale implementation of retrofitting program for important structures.

vi. Installation of early warning systems for critical facilities. The multistory buildings can be designed in such a way that people can come out to safer places in tens of seconds as is done in Japan and western countries. Early warning systems could be life saving devices in multistory buildings say in Ganges plains for earthquakes in Himalayas.

vii. Emplacement of disaster management plans in each state through institutional mechanism like the National Committee for disaster Management.

viii. International Cooperation is desired as the earthquakes in Pakistan, Nepal, China and Bangladesh may cause severe damage in the Indian region as well.

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PREDICTION STATISTICS OF STRONG EARTHQUAKES USING COMPLEX METHODS IN UZBEKISTAN

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Abstract

The main results of complex regime observations on the territory of Uzbekistan give an account for the period 1968- 2002 that conducted with the purpose of prediction of strong earthquakes. Observations were ordered by seismic, electromagnetic, geochemical, deformormetrical methods. The information from the Network of 12 complex forecasting stations and permanent observations was daily collected in the Center of Analysis and Processing. Data of regime observations was weekly the case of study of the Sessions of Forecasting Commission and short-term and mid-term forecasts were carried out. The results of evaluation of informative of each method separately and statistics of forecasting of strong earthquakes by a complex of methods are indicated.

Key words: Electromagnetic phenomena in the Earth's crust; prediction of the earthquakes; seismic zoning; estimate of seismic hazard etc.

THE MAIN TEXT

The scientists from many countries attend to forecast earthquakes for more than hundred years. However the problem of forecasting of place, strength and time of earthquake is not solved completely till now. In spite of in the multitude of the articles approving successful forecasting of that or other earthquake we frequently become witnesses of not predicted seismic events. Only during the last century the number of human victims on the globe, from the partial data, makes more than 2 million people. Especially after the next catastrophic earthquakes with numerous victims we come back to this problem again and again with new aspiration. So was after destructive Tashkent earthquake on April 26, 1966. The Institute of Seismology of Academy of Sciences of Uzbekistan was organized in the autumn 1966. The Institute was entrusted to manage fundamental and applied researches on the problem "Out work scientific bases and methods of seismic zoning and forecasting of earthquakes".

In consideration of geo-tectonic and seismotectonic environment, hydro-geological conditions on the territory of Uzbekistan the network of forecasting stations was created, which fulfil regimens observations over a complex of seismological, geophysical, hydrogeochemical, geodetic, deformometric, and other parameters with the purpose of search and research of forerunners of earthquakes (Fig.1) [3-5,7,8].

Till 1990 in Uzbekistan were 35 seismic, 18 magnetometric, 9 deformometric, 6 electrotelluric, 12 complex forecasting stations, and also 5 stations for study of natural impulse electromagnetic radiation were functioning. Now the number of seismic stations was reduced up to 23, and complex forecasting stations up to 9.

The results of regimen observations are daily transmitted to the Center of Processing in Tashkent and are weekly reported on the sessions of Forecasting Commission. Forecasting Commission of the Institute of Seismology implements the joint analysis of the whole complex of the received data for more than 25 years and on its basis concludes weekly about the probability of strong earthquake with $M \geq 5$ and its parameters. The decision is accepted for a week, month and longer terms.

In the present article it is supposed to fulfil two purposes. The first is evaluation of informative of each method separately. The second is determination of percentage of real forecasting of a place, strength and time took place of strong earthquakes. For this purpose only the strongest earthquakes with $M \geq 5$ and above are used.

For evaluation of informative of methods the diagrams of time series of continuous or discrete measurements-seismic, geophysical, hydrogeoseismological, deformetrical observations were designed and compared with the moments of strong earthquakes with $M \geq 5$, which were occurred on the territory of Uzbekistan and adjacent areas. Only those earthquakes are included in the list, which epicenter lays inside the radius with $R = e^M$ km [2] or on distances up to 30 of multiple sizes of the epicenter [6].

The results of researches are shown on the table. Columns 2-5 - parameters of strong earthquakes, which forerunners according to I.P. Dobrovolsky and etc. [2] and V.I. Ulomov [6] should be, displayed on items of regimens observations.

In columns 6-9 the results of availability or absence of anomalous changes in seismic, electro-magnetic, hydrogeoseismological and deformometrical fields connected with indicated earthquakes are shown.

The percentage of availability of anomalous changes or informative for seismic forerunners has made 35 percents, electromagnetic - 71, hydrogeoseismological - 64 and deformometrical - 50. Informative of the complex of forerunners (column 10) has made 71 percents. In column 11 the cases of specific forecasting of earthquakes are indicated. As it is visible, the percent of self-warranty of forecasts has made 50 percents.

№	Data	Coordinates		M Mag-nitude	Forerunners				Exist of prognoztic anomalous	Have been prognozed	Note
		Latitude Φ	Longitude		Seis-mi-cals	Electro-magne-ticals	Hydrogeo-seismolo-gicals	Deformometricals			
1	2	3	4	5	6	7	8	9	10	11	12
1	08.04.1976	40.14	63.74	7.0	-	-	-	-	-	-	Gazly
2	17.05.1976	40.28	63.38	7.3	+	+	+	-	+	+	Gazly
3	31.01.1977	40.11	70.79	6.3	-	+	+	-	+	-	Isfara-Batkent
4	03.06.1977	39.96	71.81	5.2	-	-	-	-	-	-	Shakhimardan
5	06.12.1977	41.58	69.68	5.1	-	+	-	-	+	-	Tavakcay
6	01.11.1978	39.20	72.36	6.8	+	+	+	+	+	+	Alay
7	11.12.1980	41.33	69.05	5.2	+	+	+	+	+	-	Nazarbek
8	06.05.1982	40.22	71.50	5.8	+	+	+	+	+	+	Chimion
9	17.02.1984	40.85	71.06	5.5	+	+	+	+	+	+	Pap
10	19.03.1984	40.38	63.36	7.2	-	-	-	-	-	-	Gazly
11	26.10.1984	39.20	71.03	6.3	-	+	+	+	+	+	Djirgatal
12	13.10.1985	40.28	69.08	6.0	-	+	+	+	+	+	Kayrakkum
13	15.05.1992	41.04	72.38	5.6	-	-	-	-	-	-	Izbaskent
14	17.08.1992	42.08	73.71	7.0	-	+	+	+	+	+	Suusamir
Quantity of anomalous displays:					+5	+10	+9	+7	+10	+7	
Quantity absence of anomalous displays:					-9	-4	-5	-7	-4	-7	
Percentage of realization:					35%	71%	64%	50%	71%	50%	

The absence of anomalous changes connected with earthquakes is explained by the absence of regimens observations in the zone of expected distribution of forerunners (Gazli on April 8 1976, Shakhimardan 1977 and etc.). Cases of absence of the prognosis at the availability of anomalous changes are explained on any other business. For Isfara-Batkent and Tavaksay earthquakes the measurement were conducted very seldom 1-2 times per year and thereby short-term forerunners practically could not be detected.

In the case of Nazarbek earthquake anomalies were revealed over 3-5 months. Even forecasting conclusion were given. However literally one day prior to earthquake the forecast was removed. This fact is explained, apparently, by lack of experience in a 1980^{th}.

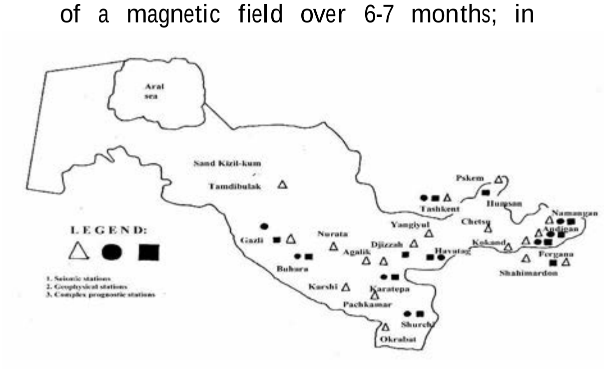
Now briefly we shall stay about cases of successful forecasting of earthquakes: [4].

1. Gazli earthquake on 17 May 1976. After first Gazli earthquake on 8 April 1976 in the area of epicenter complex observation seismic, hydrogeoseismological, geophysical observations were urgently organized. For 1-2 day there were sharp short-term anomalous changes in hydrogeoseismological and electromagnetic fields. Forecasting conclusion was given over one day.
2. Alay earthquake on 1 November 1978. The intermediate term abnormal changes were displayed in variations: the relation of speeds of seismic waves (V_p/V_s) for 2 years; inclinations of an earthly surface on stations of Tashkent, Yangibazar, Namangan, Fergana over 11-12 months; a magnetic field on a structure Madaniyat-Karasu over 3 years; hydrogeoseismological parameters (radon, carbon dioxide, helium, fluorine etc.) over 3-4 months. The short-term anomalous changes were displayed: in variations of a magnetic field on station Andijan (Bagishamal) over 7 days; pulse electromagnetic radiation of Earth crust over 2-3 days; a lot of hydrogeoseismological and hydrodynamical parameters over 3-10 day (Fig.2).

   By results of complex mid-term and short-term seismological, hydrogeoseismological, electromagnetic, deformometrical forerunners of the data on 1 November 1978 at 20^{00} the forecast of strong earthquake to the southeast from Andijan was given. The earthquake has taken place on 2 November on local time in 130 kilometers to the south from Andijan in Alay valley.

3. A complex of mid-term and short-term forerunners (Fig.3) also accompanied Chimion earthquake on 6 May 1982.

Tashkent, Chimion, Namangan; in changes of a magnetic field over 6-7 months; in



changes of hydrogeoseismological and hydrodynamical parameters from 3-5 months to one year.

The short-term anomalous changes were displayed: in variations of a magnetic field of the Earth over 30-40 days on the stations of Andijan and Chimion; in variations of hydrodynamical and hydrogeoseismological parameters from 1 month to 2-3 days (change of water level in chinks, change of contents of fluorine, boron, silicon). Forecasting conclusions were given over 2-3 weeks.

The mid-term anomalous variations were observed: in changes of relation of seismic waves (V_p/V_s) over 4 months; in changes of inclinations of Earth surface over 4-6,5 months on the stations of Tashkent, Chimion, Namangan; in changes of a magnetic field over 6-7 month; in changes of hydrogeoseismological and hydrodynamical parameters from 3-5 month to one year.

The short-term anomalous changes were displayed: in variations of magnetic field of the Earth over 30-40 days on the stations of Andijan and Chimion; in variations of hydrodynamical and hydrogeoseis-mological parameters from 1 month to2-3 days (change of water level in chinks, change of contents of fluorin, boron, silicon). Forecasting conclusions were given over 2-3 weeks.

The similar mid-term and short-term anomalous changes were displayed before Pap, Jirgital and Kaiyrakkum strong earthquakes and they were also successfully predicted [4]. On the Fig. 4 are given anomalous changes of a complex of electromagnetical, seismical and hydrogeochemical fields before Pap earthquake on 17 February 1984, M = 5,5.

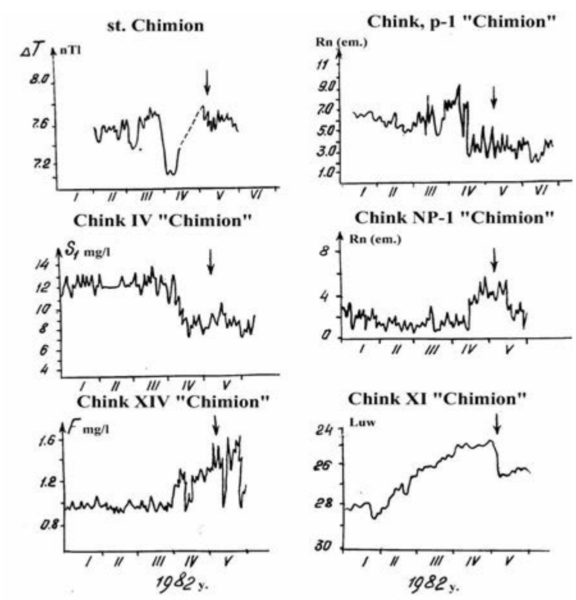


Fig.2. Anomalous changes of a complex of parameters connected with Alay earthquake 1 November 1978 .

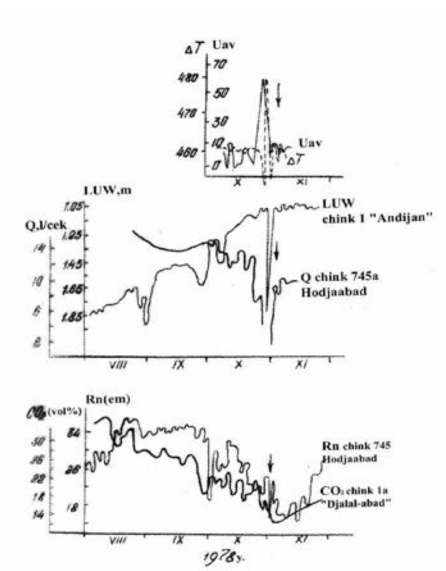


Fig. 3. Anomalous changes of a complex of parameters connected with Chimion earthquake 6 May 1982.

If to take into account all earthquakes, including weak and appreciable, the amount of forecasting conclusions will increase to 1-2 order. For example, only with the help of magnetometric method in 1982-1992 were given 91 forecasts of expected earthquakes with the indication of a place, time and strength were submitted to Forecasting Commission [9]. In 35 cases (38 %) all three justified the forecast para-meters, in 34 (37 %) - one of parameters was not predicted but under satisfactory determination of two

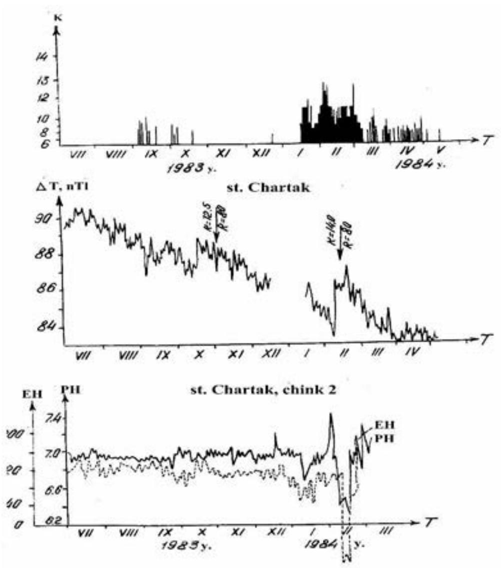


Fig. 4. Anomalous changes of a complex of parameters connected with Pap earthquake 6 May 1982. others, in 22 (24 %) - two or all three parameters were not justified.

From 22 unpredictable earthquakes, in 5 cases the earthquakes occurred without anomalous changes, and in 7 cases, on the contrary, the anomaly was displayed without earthquake. As a whole, the percentage of satisfactory forecasts has made about 75%.

Thus, on the basis of analysis of long-term forerunners of earthquakes on the polygons of Uzbekistan and other regions it is possible to assert, that the level of fundamental and applied scientific researches allows to predict them with certain degree of reliability (1). The main task in the decision of the problem for today is development of a service of earthquakes forecasting. The service can be organized by insignificant improvement of an existing network of complex forecasting stations.

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STUDY ON POTENTIAL RISK OF LARGE EARTHQUAKE ALONG THE ANNINGHE-ZEMUHE FAULT ZONE, WESTERN SICHUAN, CHINA

Yi Guixi, Wen Xueze, Fan Jun, and Wang Siwei

Abstract

Taking the Anninghe-Zemuhe fault zone, western Sichuan, China, as an example, we study spatial heterogeneity of modern seismicity and its relation to potential seismic risk. The main work includes mapping probable asperities on the fault from *b*-value distribution, and identifying current faulting behavior from parameters of modern seismic activity. The main results show: The studied fault zone is of 5 segments with different behaviors of current faulting. Of which, the Mianning-Xichang segment of the Anninghe fault has been locking under high stress. The locking fault plane is at depth between 5 and 17 kilometers, and its center part is an about 65-long asperity. For this segment, the average recurrence interval to the next characteristic event is estimated to be about 67 year, and the magnitude of the coming event is estimated between 7.0 and 7.5. These mean that it is soon to the potential large earthquake for this fault segment. In this study, we develop a method, the method of *multiple seismicity parameter value combination*, to analyze current fault behavior. A preliminary application proves this method is useful to identify current behaviors of faulting for individual segments of fault. We also find that not all fault segments ruptured historically during large quakes are asperities now. It seems that for a certain fault segment, faulting behavior should evolve with time dynamically.

INTRODUCTION

Scientific and practice issues: From seismicity of small earthquakes of the latest 20 to 30 years, can we identify current faulting behaviors for various segments of a fault zone, and then point out fault-segments that future strong or large earthquake probably occur on and estimate the probable strength of the coming earthquake?

Historically, several strong and large earthquakes have occurred along the Anninghe-Zemuhe fault zone, western Sichuan, China. Can we evaluate the potential seismic risk of this fault zone based on the modern seismicity only?

About this study: Example from the Anninghe-Zemuhe fault zone, western Sichuan, China, we investigate spatial heterogeneity of modern seismicity, make a preliminary effort to map probable asperities (Aki, 1984) on the fault zone from spatial distribution of b-value. We try to develop a method to identify current faulting behavior from parameters of modern seismic activity. Based on this method and combined with data of historical earthquakes and relocated hypocenters, we identify individual segments with various current faulting behaviors for the fault zone, and estimate the average recurrence intervals for characteristic earthquakes on the asperity-segment, as well as the possible magnitude of the coming earthquake there.

ACTIVE FAULTS AND EARTHQUAKE ACTIVITY BACKGROUND

As a portion of the E-boundary of the Sichuan-Yunnan faulted block, the about 300km-long Anninghe-Zemuhe fault zone in western Sichuan, China, is a large-scale strike-slip fault zone with high seismic activity (Figure 1). Reportedly this fault zone has a mean left-lateral slip-rate of 6 ~ 7mm/a (Wen, 2000).

As shown in Figure 1, a gap for background earthquakes has been developing since the February of 1977, centered roughly at the joining point of the Anninghe and Zemuhe faults. The gap belongs to a typeIIseismic gap defined by Mogi (1968) and has an area of about 30000km^2 at most. There has been no any $M_L \geq 3.8$ earthquakes within the gap since the February, 1977.

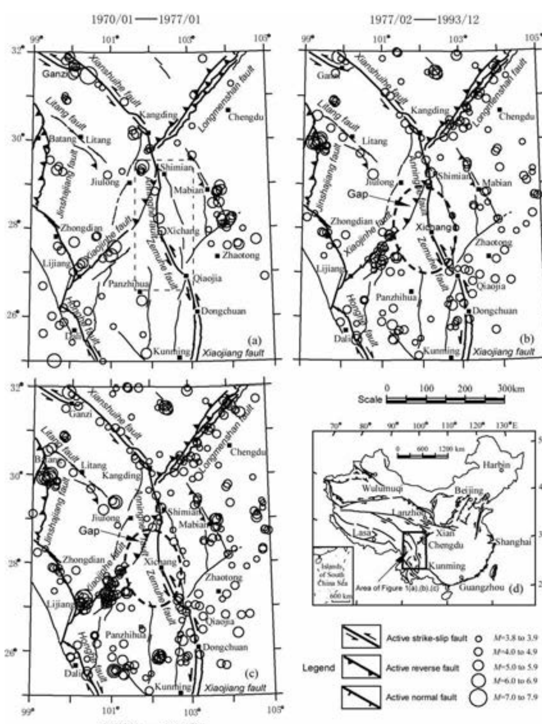

Figure 1. Maps showing main active faults and epicenters of modern earthquakes ($M_L \geq 3.8$) of the region centered at the studied area. (a) Epicenters for the period from 01/1970 to 01/1977, dashed rectangle indicates the studied area, i.e. the

area of Figures 2 to 4. (b) Epicenters for the period from 02/1977 to 12/1993, suggesting that a typeIIgap exists in the area that the Anninghe-Zemuhe fault zone extends through. (c) Epicenters for the period from 02/1977 to 06/2001, showing that the secondary-type gap is still there, but its area has contracted. (d) Index map showing the position of Figure 1 (a), (b), (c), in the main active fault system of the Chinese mainland.

Figure 2 suggests that the N-S-trending Anninghe fault hasn't been ruptured by any $M \geq 7$ earthquake for over 460 years. Relative to the 1786 $M7.7$ rupture on the southern segment of the Xianshuihe fault and the 1850 $M7.5$ rupture on the Zemuhe fault, a gap for large earthquake rupture has formed along the Anninghe fault, which belongs to a typeIseismic gap defined by Mogi (1968).

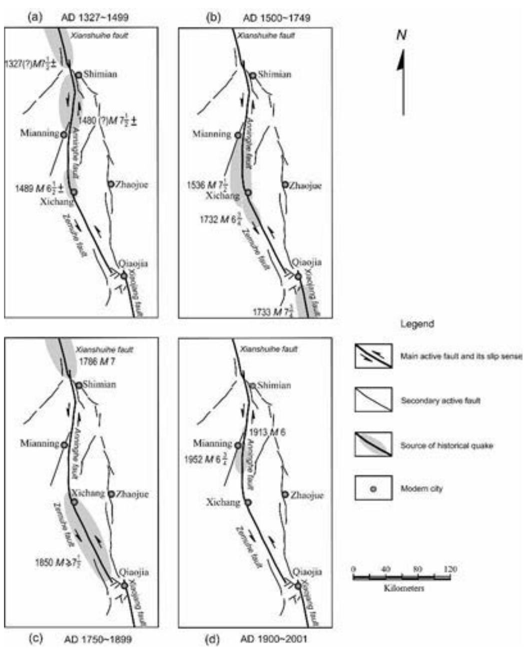

Figure 2. Maps showing sources of strong and large historical earthquakes along the Anninghe-Zemuhe fault zone for 4 various periods of the past over 600 years. Each source is an area suffered relatively-severe damage during a quake. Empirically, a source's extent along the fault is roughly comparable with the rupture length of the corresponding quake. Information for determining these areas with relatively-severe damage is from the documented record of historical earthquakes (Department of Earthquake Disaster Prevention, SSB or CSB, 1995, 1999; Geophysical Institute, SSB, and Historical Geographical Institute of Fudan University, 1990a, b, c), and from relevant geologic investigations (Wen, 1995, 2000; Wen and others, 2000).

MAPPING LOW-B-VALUE ANOMALIES AND ASPERITIES ON FAULT ZONE

Data and method

A regional network catalog of $M_L \geq 2.0$ earthquakes of the studied area (Latitude 26.5°to 29.6°N , longitude 101.5°to 103.17°E) for the recent 25 years from 07/1976 to 06/2001 is used. The epicenters are shown in Figure 3.

To map likely asperities along the fault zone, we use a method developed by Wiemer and Wyss(1997) , and Wyss et al (2000) to calculate b values. It is that for the area studied, we use a catlog for the recent 25 years to construct *b*-value maps in grid of 10 ×10 , using the earthquakes within a - circular area of radius r (= 20 or 30 km) centered at every node. In each sample, the minimum complete

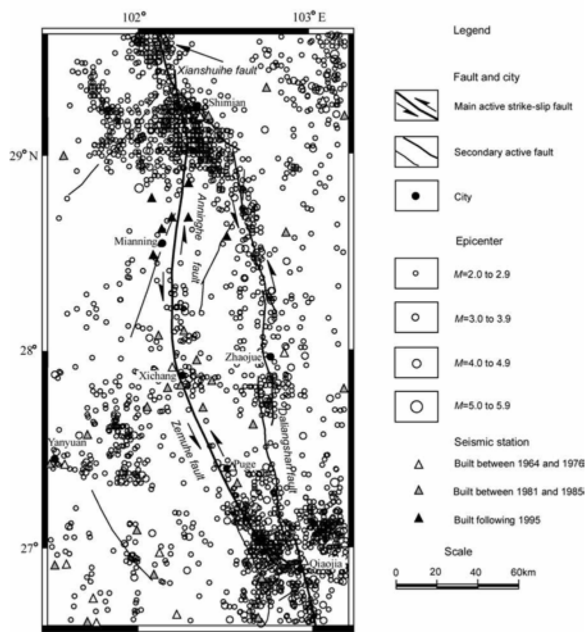

Figure 3. Map showing epicenters of $M_L \geq 2.0$ earthquakes (07/1976—06/2001) and distribution of seismic stations in the studied area. Stations were built gradually with time and spatially not well-distributed, so the monitoring ability varied with time and space. For the whole area and over the period we study, however, the minimum complete magnitude, M_c, is equal to $M_L 2.0$

.magnitude, M_c, is estimated, and the *b*-value in the magnitude-frequence relationship

$$\log N = a - bM \quad (1)$$

is calculated, for events with $M_L \geq M_c$ only, from the least-square method. Then we draw maps of *b*-value contours over the area, and finally determine areas of having anomalously low *b*-value (≤0.6) along the fault zone as possible asperities.

Preliminary result

Figure 4 are Maps of *b*-value contours of the studied area. The difference between Figure 4(a) and Figure 4(b) is that information of the $M_L = 5.3$ quake (28°16N, 102°12E) on January 1977 is contained or not in the calculation.

Figure 4 shows that a lowest b-value (≤0.6) area appears at the middle-southern portion of the Anninghe fault, suggesting that the fault portion has been being under high-stress background for the recent 25 years. According to the principle to map asperities from Wiemer and Wyss(1997) , and Wyss and others (2000), the anomalously low b-value area and its surroundings with b-values lower than 0.8 are considered as a probable asperity, and it has a lentgh of about 65 km along the Anninghe fault.

Also, Figure 4 shows that, spatially, *b*-values vary significantly with portions of the Anninghe-Zemuhe fault zone, suggesting that there are different stress level having cumulated and thus different faulting behaviors on various portions of the studied fault zone.

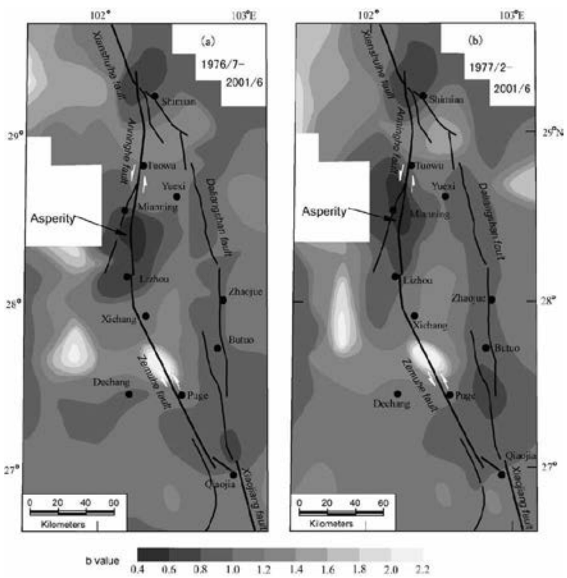

Figure 4. Maps of b-value contours of the studied area. (a) and (b) are results for periods from 07/1996 to 06/2001 and from 02/1977 to 06/2001, respectively. White areas are places having too few earthquakes to calculate b value or places without making calculation. An area with anomalously low b-value (≤0.6) exists at the middle-southern portion of the Anninghe fault, indicating the center of a probable asperity.

IDENTIFYING CURRENT FAULTING BEHAVIORS OF INDIVIDUAL FAULT SEGMENTS

Method

We divide the Anninghe-Zemuhe fault zone into 5 segments as shown in the map in right side of Figure 5. The segmentation is made on the following factors: (1) Density of the modern small earthquake distribution along the faults (Figure 3), (2) *b*-values (Figure 4), (3) Fault geometry (Figure 2), (4) Locations of historical ruptures (Figure 2).

For each fault segment, seismic data for the period from 07/1976 to 06/2001 are used to calculated 4 parameters of seismicity, average *b*-value, $\bar{b}$, annual rate of strain energy for unit fault length, $\sqrt{E}$, annual frequency of earthquake for unit fault length, *n*, and $\bar{a}/\bar{b}$ value. It is considered that various combinations of the parameter values have different physical implications and could reflect different behaviors of current faulting. For example:

One of the combinations of the 4 parameters could be of low $\bar{b}$ -value, low *n* and $\sqrt{E}$ values, and relatively high $\bar{a}/\bar{b}$ value. Such a combination could suggest the faulting behavior that the fault plane has been locking under high stress, or an asperity exists there.

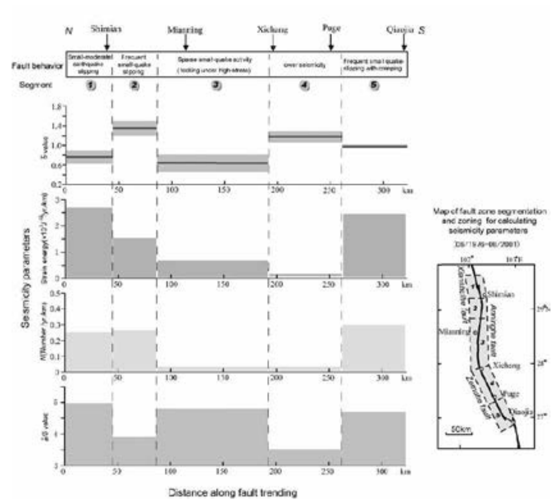

Figure 5. Diagram showing the combinations of the 4 parameter values of seismicity and current faulting behaviors for 5 segments of the Anninghe-Zemuhe fault zone. 2-time standard errors of average $\bar{b}$ value are illustrated. The map on right side shows the fault segmentation.

Another of the combinations of the parameters could be of high $\bar{b}$ and *n* values, middle or relatively high $\sqrt{E}$ and $\bar{a}/\bar{b}$ values. This combination could suggest the faulting behavior of small earthquake slipping under relatively low stress.

Table 1. Combinations of the parameter values of seismicity and identification of current faulting behavior for individual segments of the Anninghe-Zemuhe fault zone

Parameters \ Segments	Shimian	Tuowu	Mianning to Xichang	Xichang to Puge	Ningnan
$\bar{b}$	0.76	1.34	0.63	1.17	0.97
n(number/yr./km)	0.256	0.271	0.035	0.033	0.309
$\sqrt{E}$ ($10^3J^{1/2}$/yr./km)	2.68	1.55	0.70	0.18	2.45
$\bar{a}/\bar{b}$	4.96	3.92	4.79	3.52	4.72
Relative stress levels	Relatively high	Low	High	Low	Medium
Faulting behaviors	Small to moderate quake slipping	Frequent small quake slipping	Locking (Asperity)	Low seismicity	Small quake slipping with creeping

Preliminary result

The result for calculation of the 4 seismicity parameters and the identification of current faulting behaviors for the 5 fault segments are shown in Table 1 and Figure 5.

We have relocated all $M_L \geq 2.5$ earthquakes within the 25km-wide belt-like area along the fault zone for the recent 21 years (from 1981 to 2001). A cross-section of the hypocenters along the fault zone is obtained and shown as Figure 6. From Figure 6, we known that at the segment ③, a gap for hypocenters exists at the depth from about 5km to 17km. This gap should suggests both the area and the depth range of the locking fault plane of the segment ③, and thus indicates the possible depth range of the asperity identified above (Figure 4 and 5). For the segment ④, a gap also exists at the depth from 0 to about 19km (Figure 6), which should be the indication of the Zemuhe fault plane ruptured during the large 1850 earthquake (see Figure 2). Our field investigation shows that along the segment ④ the coseismic left-lateral slip of the 1850 rupture is between 2 and 5 meters. All these support the inference in Table 1 and Figure 6 that the segment ④ behaves very low activity of small earthquakes under low stress.

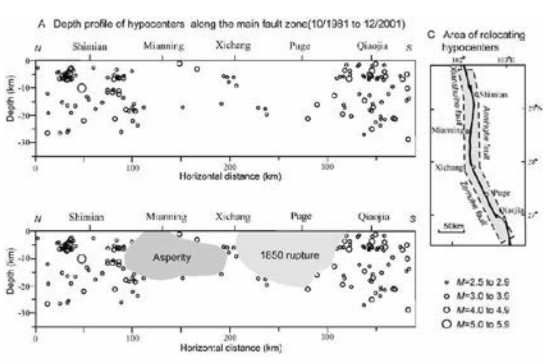

Figure 6. Cross-section view of hypocenters of $M_L \geq 2.5$ earthquakes for the period from 1981 to 2001 along the Anninghe-Zemuhe fault zone (A) and explanation of fault plane states (B). Map C shows the zone in which earthquakes are relocated. A non-linear numerical method developed by Prugger and Gendzwill (1988) is employed in the relocation of hypocenters. Errors of hypocenters from the relocating are generally 2 to 3 kilometers.

It is clear from above that for various segments of the Anninghe-Zemuhe fault zone, current behaviors of faulting are quite different, and such difference can be identified on the basis of analyzing quantitatively modern seismicity.

Discussion

Making a comparison analysis among Figures 2, 4, 5 and 6, we find that not all fault segments ruptured historically during large quakes have asperities now. This phenomenon can be explained as that following a large earthquake rupture the fault plane needs time to re-couple. So, we believe that asperities on active faults are not always there. For a certain fault segment, faulting behavior should evolve with time dynamically. Therefore, identifying current behaviors of faulting from analyzing quantitatively modern seismicity should be a promising technique to make out risky portions of potential earthquakes.

POTENTIAL EARTHQUAKE RISK OF MIANNING-XICHANG SEGMENT

In order to assess potential earthquake risk of the studied fault zone, it is necessary to estimate average recurrence interval and magnitude of the characteristic earthquakes on the Mianning-Xichang segment (i. e. the asperity segment) of the Anninghe fault.

Estimating average recurrence intervals

We employ two methods associated with parameters of modern seismicity to estimate average recurrence intervals of characteristic earthquakes, and then use historical earthquake intervals to test the estimated ones.

Method 1—A method from *b*-value model of asperity (Wiemer and Wyss, 1997) : Establishing a magnitude *M*—frequency N_t relationship for the fault segment ③ using data of the recent *t* (=25) years

$$\log N_t(M) = a_t - bM \quad 2$$

Then, estimating average recurrence intervals, $T(M)$, for earthquake with magnitude M by using the estimated parameters a_t and b in equation (2) :

$$T(M) = \frac{t}{10^{(a_t - bM)}} \quad 3$$

Method 2—A method from characteristic seismic moment (Molnar, 1979; Papazachos, 1992): From

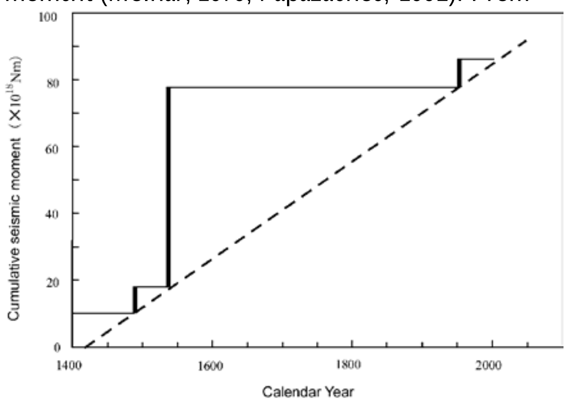

Figure 7. Diagram showing cumulative seismic moment—time pattern of the Mianning-Xichang segment of the Anninghe fault. Note the pattern showing a time-predictable recurrence process.

Figure 7 we know that the historical earthquake recurrence of the Mianning-Xichang segment (the asperity segment) behaves a time-predictable process. So, we may use the time-predictable recurrence model (Shimazaki and Nakata, 1980) to estimate the average recurrence intervals, T, of characteristic earthquakes of the segment,

$$T = M_0 / S \times m_0 \quad 4$$

Where, M_0 is the moment of the latest characteristic event, m_0 is the moment rate on unit surface area of the segment, S is the surface area of the segment (i. e. the area of the polygon 3 in Figure 5). Seismic moment M_0 is in Nm and estimated from the empirical relationship

$$\log M_0 = c\ M\ d \quad 5$$

Where, empirical constants $c=1.09$, $d=11.6$ (Chen and Chen,1989). Moment rate m_0 is calculated from a formula derived by Molnar (1979)

$$m_0 = \frac{10^{(a+bd/c)}}{1-b/c} \times M_{0,\max}^{(1-b/c)} \quad 6$$

Where, $M_{0,\max}$ is the moment of the largest earthquake of the studied segment (for the segment ③, the magnitude of the largest historical event, $M_{\max}$, is 7.5). Constant b is from equation (2), and the relation between a and a_t in equation (2) is

$$a = a_t - \log(St) \quad (7)$$

(Papazachos, 1992) .

A preliminary result for the average recurrence intervals estimated from the 2 methods above is listed in Table 2.

Table 2. A comparison between historical and estimated recurence intervals of characteristic earthquakes of the Mianning-Xichang segment of the Anninghe fault

Historical events yr. m. d. M	Historical recurrence interval (yr.)	Estimated average recurrence intervals (yr.)					
		Method 1 (a=3.03, b=0.63)			Method 2 (a=3.03, b=0.63)		
		M6.7	M7	M7.5	M6.7	M7	M7.5
1489 01 04 6.7 1536 03 19 7.5 1952 09 30 6.7	47 416	388	560	1239	67	141	487

It can be seen from Table 2 that the estimated recurrence intervals from *method 1* are quite different from the historical intervals. A main reason could be that the method 1 assumes characteristic events (main sized events on a fault segment) obey the magnitude-frequency relation built from data of small and moderate events there. But the characteristic events do not.

While, the estimated recurrence intervals from *method 2* are close to the historical recurrence intervals, telling us that combining the magnitude-frequency relation of modern earthquakes and the characteristic moment method should be a promising technique to estimate average recurrence interval of characteristic earthquakes on a locking or asperity segment of fault.

For the Mianning-Xichang segment of the Anninghe fault, the latest event is the 1952 earthquake of magnitude 6.7, and the estimated average recurrence interval to the next event following a M6.7 earthquake is about 67 year (Table

2). So, it is soon to next characteristic event for this fault segment.

Estimating earthquake size

The asperity on the Mianing-Xichang segment has a length of about 65km (Figure 4). This length is assume to be a mean length of the coming rupture along this segment of the Anninghe fault, and the corresponding magnitude of the coming earthquake is estimated from several empirical relationships between magnitude and rupture length for strike-slip earthquake. The result shows that estimated magnitude is between 7 and 7.5 (Table 3).

Table 3. Selected magnitude-rupture length relationships and estimated magnitudes for the coming earthquake of the Mianning-Xichang segment of the Anninghe fault zone.

Relationships	Error	Region suitable to the relationship used	Author	Estimated Mag.
Ms 6.24 0.619lg*l*	0.29	Worldwide	Bonilla et. al.(1984)	7.36 ± 0.29
Ms 4.94 1.296lg*l*	0.19	USA and China	Bonilla et. al.(1984)	7.29 ± 0.19
Ms 5.117 0.579ln*l*	0.21	Western China	Wen (1995)	7.53 ± 0.21
M 5.16 1.12lg*l*	0.28	Worldwide (surface)	Wells et. al. (1994)	7.19 ± 0.28
M 4.33 1.49lg*l*	0.24	Worldwide (subsurface)	Wells et. al. (1994)	7.03 ± 0.24

Note: *Ms* and *M* are surface-wave magnitude and moment magnitude, respectively.

CONCLUSIONS

The Anninghe-Zemuhe fault zone, western Sichuan, China, is of 5 segments with different behaviors of current faulting. Of which, the Mianning-Xichang segment has been locking for at least 25 years under high stress. The locking fault plane is at depth between 5 and 17 kilometers, and its center part is an asperity with a length of about 65 kilometers.

For the Mianning-Xichang segment of the Anninghe fault, the average recurrence interval to the next characteristic event is estimated to be about 67 year, conditional on the size of the latest event (the 1952 M=6.7 earthquake). And the magnitude of the coming event is estimated to be between 7.0 and 7.5. These mean that it soon to the potential large earthquake for this fault segment.

The method of *multiple seismicity parameter value combination* developed in this study is a promising technique to identify current behaviors of faulting for individual segments of fault.

Not all fault segments ruptured during historical large quakes are asperities now. For a certain fault segment, faulting behavior should evolve with time dynamically.

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EARTHQUAKE AND VOLCANO TSUNAMIGENIC DATA BASE AND ZONING AND THEIR APPLICATION FOR TSUNAMI EARLY WARNING SYSTEM IN INDONESIA

Latief Hamzah and Triyoso Wahyu

Abstract

The historical tsunami data base in Indonesia (HTDBI) and their GIS was developed according to Gusiakov's concept. The concept is based on the integration of numerical models with observation, historical and geological data, and processing and analysis tools. These components are integrated with the visualization and mapping software providing fast and efficient manipulation of maps, models, and data. The HTDBI is intended to be a comprehensive source of observational data on historical tsunamis and seismicity in a particular region, along with some basic additional and reference information related to the tsunami problem.

In its current form, the HTDBI contains data of earthquake, volcano and landslide tsunamigenics, based on the compilation data during the period of 1600-2002. Based on the data compiled, 106 tsunamis could be listed up in Indonesia. Ninety six events (90 %) of them were caused by earthquakes in a shallow region at subduction and plate boundaries, and 9 (9 %) by volcanic eruption, and one (1 %) by landslides.

In order to clarify regional characteristics of tsunamis, we divide into 6 regions; west and east Sunda, Banda, Makassar, Molucca and Irian Jaya, and make the histograms of earthquakes and tsunamis in each region and every decade from 1600 to 2002. The seismic activities at east Sunda, Banda and Makassar are high and those for tsunamis at west Sunda, Banda, and Molucca are significant. Around 100 years interval for earthquakes and tsunamis from 1800-2002 could be found. Percentages of earthquakes accompanied by tsunamis to all one at Banda and Molucca exceeds 50 %. In terms of human loss due to tsunamis, west Sunda is the worst because of the devastating damage due to the 1883 Karakatau volcano. However, tsunamis potentials at Banda and Molucca as for frequency as well as damage are very high. Remarkably, the recent activity of tsunamis at Banda after 1960 is significant.

In understanding the characteristics of tsunamigenic for each particular region, and developing several scenarios of numerical tsunami simulations, then stored into the database, so we can retrieve the simulation results by rapid tsunami numerical model for tsunami early warning, which appropriate to the seismity of the source region.

Key words: Indonesia, Earthquake Tsunamigenic, Zoning, and Early Warning System

INTRODUCTION

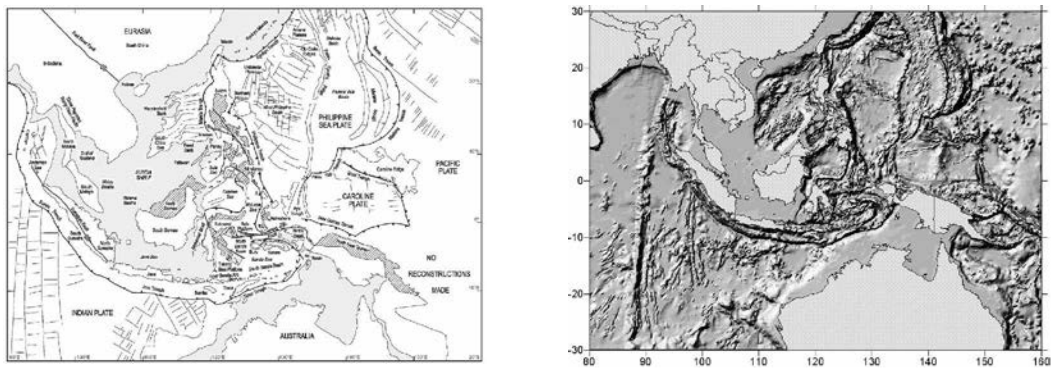
The Indonesian region and its surrounding area have very complicated plates-convergence consisting of subduction, collision, back-arc thrusting and back-arc. As a result of its complexity, the region is considered to be one of the most active areas in the world. At least about 460 earthquakes of the magnitude M > 4.0 have occurred every year (Ibrahim et al., 1989). Most of large earthquakes in Indonesia have caused huge damages and fatalities in historical time as given by Utsu (1992) and Fauzi (1999). In addition to the high seismic activities in the subducting zone, the Indonesian is characterized by high volcanic activities. There are 76 volcanoes that have erupted until the present time (Kusumadinata, 1979).

Many major earthquakes in a shallow region under the sea have generated large tsunamis, killing thousands people, and eruptions of submarine volcanoes also have caused tsunami generations. Typical example among them is that generated by the 1883 Krakatau eruption in Sunda strait, as the most catastrophic disaster due to tsunami in recent centuries, killing about 36,000 people.

Although several tsunamis have frequently attacked the Indonesian region, the nature of tsunamis, their mechanism and regional characteristics are still less known. Furthermore, the frequency and regularity of tsunamigenic earthquakes/volcanoes, tsunami modeling and concept of the early warning sytem for mitigation are still needed to be further investigated. In this study, the historical tsunami data base in Indonesia (HTDBI) and rapid numerical tsunami model are made to discuss for early warning system.

TECTONICS SETTING AND ITS SEISMICITY

The complexity of tectonics and plate boundaries and motions in south East Asia (include Indonesia and its surrounding area) are shown in Fig. 1, which are placed on complex convergence of the Eurasia, India-Australia, Caroline, and Philippine sea plates and several minor ones. The plates have been relatively moving to each other in a rather complicated manner. A typical plate motion and their activity have been studied by several researchers (i.e. Hamilton, 1979; Puspito, 1993; Puspito & Shimazaki, 1995, and Hall, 1997) and summarized by Latief, et. al (2000).



(a) (b)

Fig.1.a Tectonics and plate boundaries in the South East Asia (after Hall, 1997)

b. Seabed feature of Indonesia and Its surrounding

The Indonesia consists of five active island arcs such as: Sunda, Banda, Sangihe, Halmahera and North Sulawesi arcs. The Sunda arc resulted from the convergence of the Indian Ocean and Eurasia plates, extends westward from Sumba passing to Java, Sumatra and Andaman Islands. In east Sunda arc, Banda arc extends eastward from Sumba passing to Tanimbar Islands, and then curves sharply counterclockwise to a westward trend in the north Ceram and Buru islands. The Banda arc is resulted from collision between the southeastern part of Eurasia and Australia plates. In the northern part of Banda arc, Sangihe and Halmahera arcs in the Molluca sea region are caused by activities of the two opposing subductions of Molucca sea plate. The plate is simultaneously subducting eastward beneath the Sangihe and westward below the Halmahera.

As a result of such complicated plate-convergences, the Indonesia has very high seismic activities. Figure 2 shows seismicity map of the region based on the USGS data and its 3D plots. The seismicity map shows that most of shallow earthquakes are located along the plate boundaries, while a maximum depth of seismicity is changed. Along Sunda arc the deepest seismicity abruptly changes near Sunda strait (a strait that separates Sumatra from Java). Earthquakes in northwest Sunda strait do not exceed a depth of 250 km, while in east Sunda strait the maximum depth reaches 650 km with a gap of seismicity between depths of 300 to 500 km. In Banda Sea, the Benioff-Wadati seismic zone defines a basin-shaped zone that plunges gently westward to a depth of about 650 km. In the Molucca sea region the Benioff-Wadati seismic zone dips westward to a depth of 650 km beneath Sangihe, while another zone dips eastward to a depth of 250 km below Halmahera. By taking account of the above tectonics in Indonesia into consideration, Latief, et al (2000) divided within 6 zones as shown in Fig. 3 as follows:

- Zone-A: West Sunda arc, including the region in northwest Sunda strait, i.e. Sumatra and Andaman Islands.
- Zone-B: East Sunda arc, including the region in east Sunda strait to Sumba, i.e. Java, Bali, Lombok, Sumbawa, and Sumba
- Zone-C: Banda arc, covering the region of Banda Sea, i.e. Flores, Timor, Banda Islands, Tanimbar Islands, Ceram and Buru.
- Zone-D: Makassar strait.
- Zona-E: Molucca sea, Sangihe and Halmahera
- Zone-F: North Irian Jaya

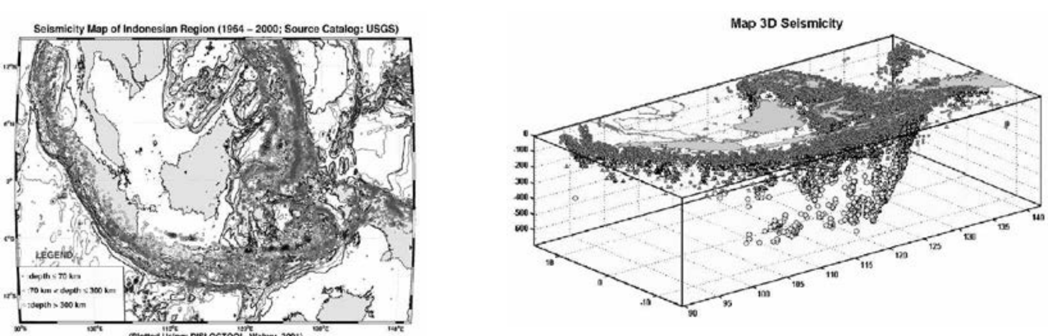


Fig.2 Seismicity map of the Indonesian region and 3D plot. Source Catalog: USGS

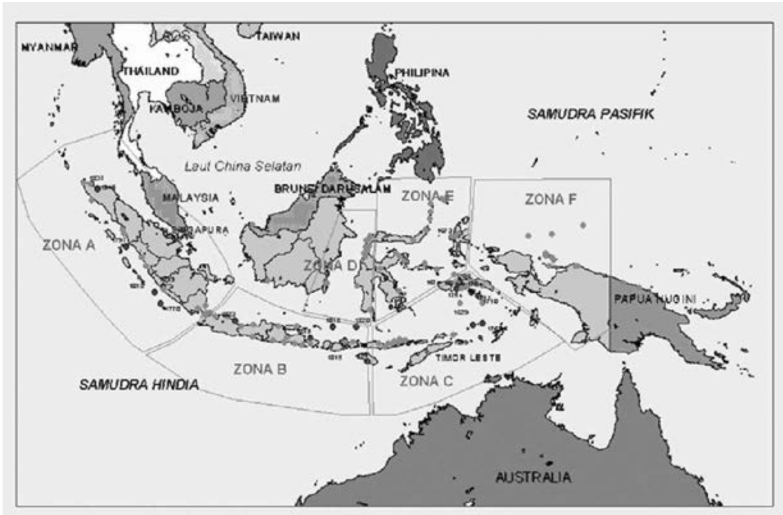


Fig.3 Seismotectonics of the Indonesia, which divided into 6 zones (Zone-A, B, C, D, E, and F).Red lines denote the boundaries of each zone.

Historical Tsunami Data Base in Indonesia (HTDBI)

This historical tsunami database in Indonesia (HTDBI) and their GIS was developed acoording to Gusiakov's concept (Gusiakov and Osipova, 2000). The concept is based on the integration of numerical models with observation, historical and geological data, and processing and analysis tools. These components are integrated with the visualization and mapping software providing fast and efficient manipulation of maps, models, and data. The HTDBI is intended to be a comprehensive source of observational data on historical tsunamis and seismicity in a particular region, along with some basic additional and reference information related to the tsunami problem. The tsunami data which using in this database base on the data from a catalog tsunami Indonesia which have been compiled by Latief, et al (2000). The HTDBI and their GIS are shown in Appendiks A.

The tsunami catalogs are related with earthquakes and volcanoes. Discription of the catalog data consist of earthquakes, tsunamis, and volcanoes data, as follows:

a. Earthquakes

In the Indonesia, about 460 earthquakes, which magnitude is greater than 4.0 have occurred every year. Percentages of the earthquakes in shallow, intermediate, and depth are 61%, 34% and 5% respectively Most of the earthquakes are located beneath the sea along seismic zones as shown in Fig. 2. Many of the large shallow earthquakes in the Indonesian, both of inter-plate and intra-plate types, have caused great damages and killed thousands people. Destructive earthquakes that occurred in the region during the period from 1800 to 1999 have been listed by Latief, et al, (2000). During the period of tabulation, at least 183 destructive earthquakes have occurred in the region, that has killed at least 11,000 people. Table 1 shows the number of destructive earthquake and their fatalities.

Table 1 Activity of destructive earthquakes around Indonesia

Zone	Region	Number of disaster earthquakes occurrences	Percentage of occurrences	Number of fatalities	Percentage of fatalities
A	Western Sunda arc	35	19.1 %	716	6.7 %
B	Eastern Sunda arc	82	44.8 %	2502	24.9 %
C	Banda arc	20	10.9 %	285	2.7 %
D	Makassar strait	10	5.5 %	2	0.0 %
E	Molucca sea	23	12.6 %	340	3.2 %
F	Northern Irian Jaya	13	7.1 %	6,738	63.2 %
Total		183	100 %	10,663	100 %

b. Tsunamis

The historical tsunami data in the Indonesia during the period from 1600 to 2002 are compiled from catalog of destructive earthquake in the world given by Utsu (1992). Then cross checking of these data has been done with the collection data of Berninghausen (1966,1969), Cox (1970), Arnold (1985) and Ismail (1989) and found that those data are mostly conform. Furthermore, the compiled data are updated by adding recent tsunami data (Latief, et al, 2000). The old data before 1970 was not well reported. However, for recent tsunamis such as *the 1992 Flores, the1994 East Java, the1995 East Timor, the1996 Sulawesi*, and *the 1996 Irian Jaya tsunamis*, have been investigated by International Tsunami Survey Team and have been reported (Yeh et al., 1993; Synolakis et al., 1995; Tsuji et al., 1995; Efim et al., 1996; Imamura et al., 1997). Based on the data, 105 tsunamis have occurred in the Indonesian region. Among them 96 tsunamis have been generated by earthquakes, 9 tsunamis caused by volcanic eruptions, and one tsunami due to a landslide. The tsunamis have caused casualties and killed about 54,100 people in Indonesia. Table 2 summarizes the number of tsunamis and their fatalities for each zone.

Table 2 Tsunamis activity around Indonesia

Zone	Region	Number of tsunami occurrence	Percentage of occurrence	Number of fatalities	Percentage of fatalities
A	Western Sunda arc	16	15.3 %	36,360	67.7 %
B	Eastern Sunda arc	10	9.5 %	3,261	6.0 %
C	Banda arc	35	32.3 %	5,570	10.3 %
D	Makassar strait	9	8.6 %	1,023	1.9 %
E	Molucca sea	33	30.8 %	7,576	13.9 %
F	Northern Irian Jaya	3	2.9 %	357	0.7 %
Total		106	100 %	54,147	100 %

c. Volcanoes

As a result of the subducting/tectonic processes, the Indonesia has very high volcanic activities. Most of the volcanoes in the Indonesia took place in the Sunda-Banda arc, a 3,000-km-long line of volcanoes, extending from northern Sumatra to the Banda Sea. These volcanoes are resulted from subduction of the India-Australia plate beneath the Eurasia plate. About one-fourth of the volcanoes are located in north Sunda-Banda arc with complex tectonics. The volcanoes at Sulawesi, Halmahera, and Sangihe in the Molucca Sea are resulted from the Molucca sea plate-boundary which is simultaneously subducting to the west beneath the Sangihe and to the east beneath the Halmahera (Hamilton, 1979; Puspito, 1993). The Indonesia has 76 volcanoes that have erupted in historical time, which is the largest number among other volcanic regions (Kusumadinata, 1979). At least 9 tsunamis generated by volcanic eruption in the period from 1600 to 2002, (see Table 3), occurred in the Indonesia. The volcanic tsunamis have caused about 43,200 people killed, among them the largest tsunami in terms of magnitude and damage is the 1883 Krakatau eruption in Sunda strait which claimed about 36,000 people victims. This is considered to be the most catastrophic disaster caused by a tsunami in recent centuries (Simskin and Fiske, 1983).

Table 3 Volcanoes generating tsunamis

Volcano Name	Location	Coordinates	Zone	Eruption (year)	Fatalities (people)
G. Krakatau	Sunda Strait	5.8S 106.3E	A	1883 1928	36,000 -
G. Tambora	Sumbawa	-	B	1815	-
G. Rokatinda	Flores	8.6S 121.7E 8.4S 121.7E	C C	1927 1928	226 -
G. Ruang	Sangir Island	2.2U 125.4E	E	1889	-
G. Awu,	Sangir Island	3.5U 125.5E	E	1856 1892	3,000 -
G. Gamalama	North Mollucas	0.0 128.0E	E	1871	4,000
Total				9 events	43.226

Numerical Model of tsunami

The 1992 Flores Tsunami, which killed more then 1900 people, gave a warning and trigger to Indonesian scientists to study tsunamis. This event also called attention to the International Tsunami Survey Team (ITST) for survey and share experience for tsunami mitigation, analysis and numerical simulation of the tsunamis in Indonesia. Therefore, after that several tsunami studies carried out the moment release by Imamura and Kikuchi (1994), the numerical simulation by Imamura *et al*.. (1994), Imamura *et al.* (1995), and Imamura and Gica (1996); and modeling of seismic source and tsunami generation by Hidayat *et al.* (1995) for *the 1992 Flores Tsunami*. As for *the 1994 East Java Tsunami*, Horiuchi (1995), and Takahashi *et al.* (1995) have simulated the tsunami sources and tsunami heights along the coast, however both used very course mesh size. They suggest that the computed tsunami heights would be much smaller than those observed along the coast. Not only source mechanism of "tsunami earthquake" but also resolution problems in the simulation would cause less computed heights than observed. Latief and Imamura (1998) resimulated the 1994 East java Tsunami with smaller mesh size and more complex tsunami source model. As for *the 1996 Irian Jaya Tsunami,* Koshimura *et al.* (1999), and Tanioka and Okada (1997) have simulated trans-pacific tsunamis, which propagated to Japan.

In this study, the 1994 East Java Tsunamigenic earthquake and the 1883 Krakatau Tsunamigenic Volcanoes were simulated with several scenarious and stored into the database. Moreover, by using the rapid interpolation numerical tsunami model the simulation result can be retrieve immediately. The numerical models of tsunami are using the TUNAMI model (Goto, C. and Y. Ogawa, 1992). Numerical simulation results are shown in Appendiks B.

TSUNAMI WARNING SYSTEM

The Japan Meteorological Agency (JMA) developed the new tsunami forecast methods using database for the varies kinds of results calculated by the new numerical method. This method is using to build the tsunami early warning system in Indonesia. Fig 4 shows the concept of interpolation theory for 2 dimension coordinates of location hypotetic eartquakes. The wave height and arrival times of any tsunamis generated in the four hypocenters can be estimated with next approximation formula (Tatehate, 1996):

$$f(x,y) = (1-l)\{(1-k)f(x_0,y_0) + k \quad f(x_1,y_0)\} + l\{(1-k)f(x_0,y_1) + k \quad f(x_1,y_1)\}$$

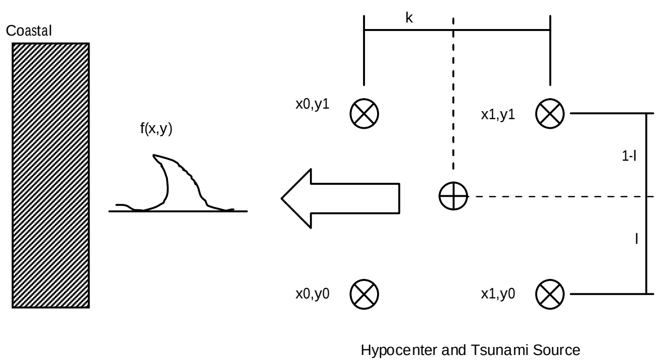


Fig. 4 Concept of interpolation theory on 2 dimensional coordinates (after Tatehata, 1996)

Figure 5 shows many simulation output files which small whitecircle means data file related to tsunami heights the entire to the coast.

The early warning systems are designed in 2 parts such as: (i) database of tsunami heights and arrival times of tsunami for each earthquake, and (ii) the actual tsunami forecast. Flow chart of each part is shown in Figure 6 and 7 respectively.

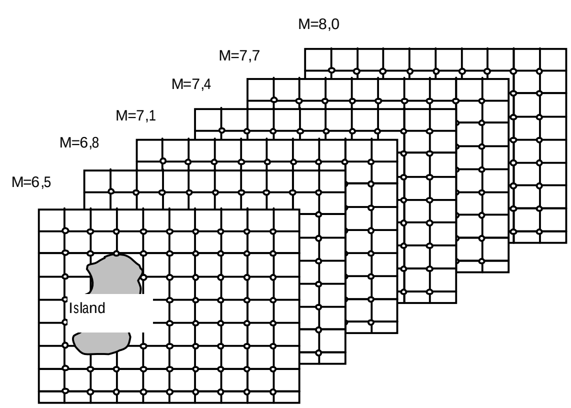


Fig. 5 The Structure of the database for tsunami forecast that are composed of many results of numerical simulations about various source parameters (after Tatehata, 1996)

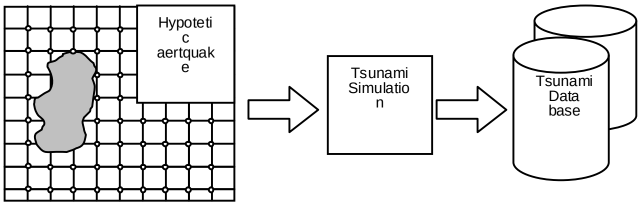


Fig. 6 Database of tsunami height, arrivel time etc. for each earthquake

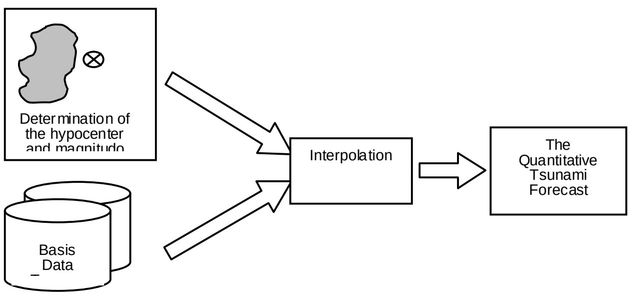


Fig. 7 Actual tsunami forecast

CONCLUSIONS

The historical tsunami data from 1600 to 2002, and the destructive earthquake data from 1800 to 2002 have been compiled and stored in the HTDBI. Due to lack of historical data before 19th centuries, the limited number and time distribution of the compiled data give some limitations in the analysis. However, some remarks can be concluded as the followings;.

- At least 106 tsunamis and 183 destructive earthquakes occurred in the Indonesian from 1600 to 2002 and 1800 to 2002 respectively. The tsunamis consist of 96 (90%) tsunamis generated by earthquakes, 9 (9%) tsunamis caused by volcanic eruptions, and 1 (1%) tsunami generated by landslide.
- It seems that tsunami activities have correlation with seismotectonic characteristics in each region. The Banda arc region and Molluca sea region, which are considered to be the most tectonically active region, were found to be the most active region for tsunami generation. At least 34 tsunamis occurred in the Banda arc, followed by Molluca sea with 32 tsunamis, the western Sunda arc with 16 tsunamis, east Sunda arc with 10 tsunamis, and the Makassar strait with 9 tsunamis. North Irian Jaya region is found to be the most tsunami inactive region with only 3 tsunamis occurred during the period.
- The numerical simulations have been simulated for several recent tsunamis and their results were stored into the database. The rapid numerical tsunami model have successes to retrieve and interpolate the results, however, the model still need some improvement to performing good results.

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APPENDIKS A

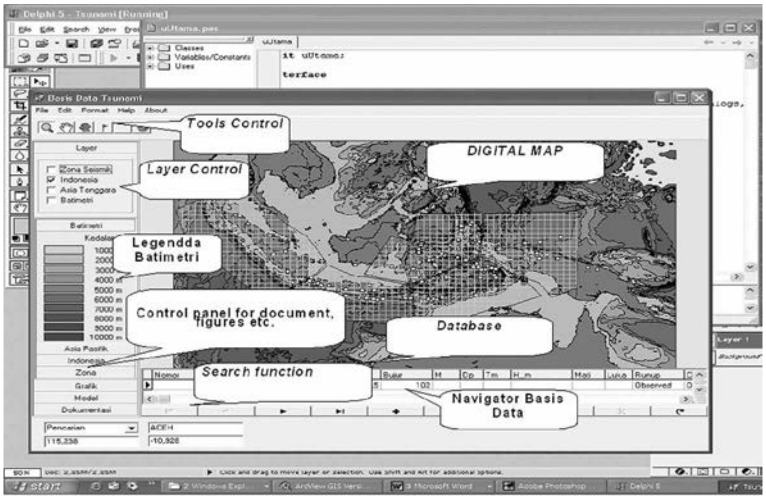


Fig. 8. Software interface of tsunami database and information system of Indonesia

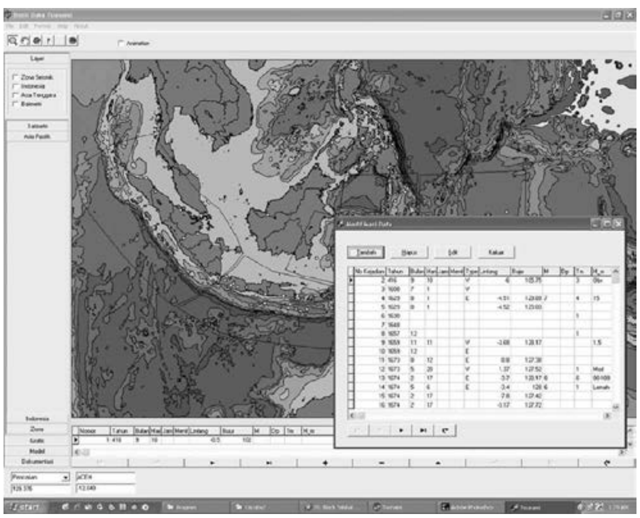


Fig. 9. Map layer window and database editing window

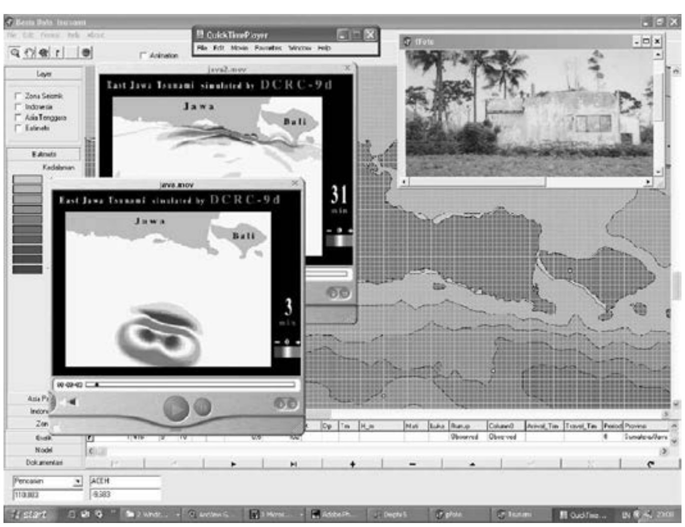


Fig. 10. Animation windows and photos as atribute of the 1994 East Java tsunami

(tsunami animation were provided by DCRC-Tohoku Univ, Japan)

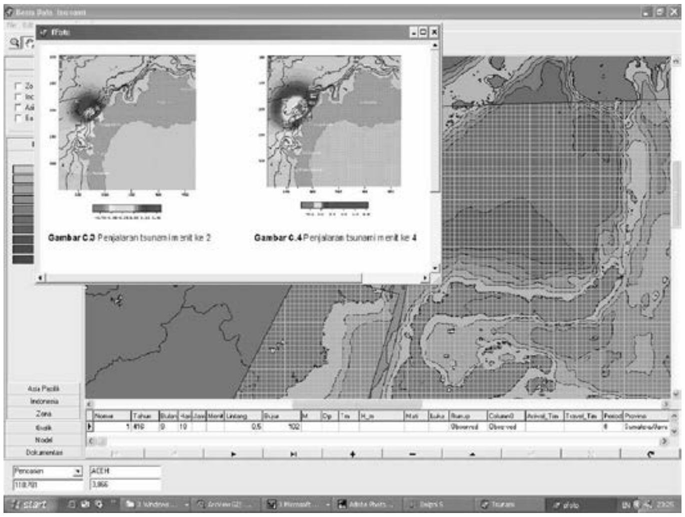


Fig. 10. Window of simulation results of the 1996 Palu tsunami

APPENDIKS B

The 1994 East Java Tsunami generated by earthquake (Propagation tsunami)

Tsunami propagation = after 6 minutes

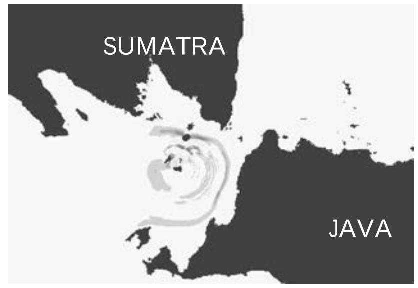
Tsunami propagation = after 12 minutes

Tsunami propagation = after 34 minutes

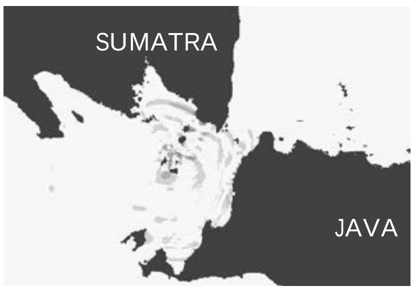
Tsunami Simulation = after 84 minutes

The 1883 Krakatau Tsunami generated by volcano (Propagation Tsunami)

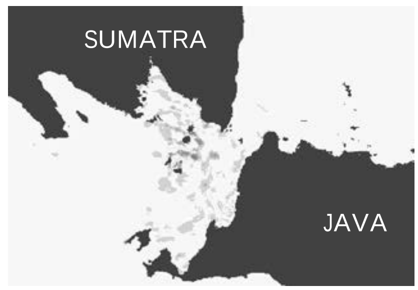
Tsunami propagation = after 1 minute



Tsunami propagation = after 20 minutes



Tsunami propagation = after 40 minutes



Tsunami propagation = after 70 minutes

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SEISMIC MICROZONATION OF GREATER BANGKOK USING MICROTREMOR OBSERVATIONS

Rabin Tuladhar1, Fumio Yamazaki, and Pennung Warnitchai

Abstract

Bangkok, the capital city of Thailand, is located at a remote distance from seismic sources. However, it has a substantial risk from distant earthquakes due to the ability of underlying soft clay to amplify ground motions. It is therefore imperative to conduct a detailed seismic hazard assessment of the area. Seismic microzonation of big cities, like Bangkok, provides a basis for site-specific risk analysis, which can assist in systematic earthquake mitigation programs. In this study, a seismic microzonation map for the greater Bangkok is constructed using microtremor observations. Microtremor observations were carried out at more than 150 sites in the greater Bangkok. The predominant periods of the ground were determined from the horizontal to vertical (H/V) spectral ratio technique. A microzonation map was then developed for the greater Bangkok based on the observations. Moreover, the transfer functions were calculated for soil profiles at eight sites using computer program SHAKE91, to validate results from the microtremor analysis. Areas near the gulf of Thailand, underlain by a thick soft clay layer, were found to have long natural periods ranging from 0.8s to 1.2s. However, areas outside the lower central plain have shorter predominant periods, less than 0.4s. It shows that there is a great possibility of long-period ground vibration in Bangkok, especially in the areas near the Gulf of Thailand. This may have severe effects on long-period structures, e.g. high-rise buildings and long-span bridges.

Key words: Microzonation, Bangkok, Microtremors, Predominant Period, H/V spectral ratio.

INTRODUCTION

Local ground conditions substantially affect the characteristics of incoming seismic waves during earthquakes. Flat areas along the coast and rivers generally consist of thick layers of soft clay and sand. The soft deposits amplify certain frequencies of ground motion thereby increasing earthquake damage. A well-known example is Mexico City in 1985 Michoacan earthquake. Mexico City sustained catastrophic damage from the distant earthquake with a fault rupture around 350 km away [1, 2]. The devastation caused in Mexico City due to enormous amplification of the ground motion by superficial deposits signifies the potential risk of distant earthquakes in modern cities built over soft deposits.

Although Bangkok, the capital city of Thailand, is located in a low seismic hazard area, there is a potential risk from distant earthquakes, due to the ability of underlying soft clay, to amplify ground motions [3]. The variation in the ground motion, according to the geological site conditions, makes it necessary for big cities like Bangkok to conduct seismic microzonation. Seismic microzonation is defined as the process of subdividing an area into zones with respect to geological characteristics of the sites,

so that seismic hazards at different locations within a city can correctly be identified [4]. Microzonation provides the basis for a site-specific risk analysis, which can assist in the mitigation of earthquake damage. No studies have been done for the microzonation of Bangkok so far.

This study is focused on the microzonation of the greater Bangkok using microtremor observations at different sites. The microtremor method measures ambient vibrations in the order of microns present on the ground surface. The main sources of these vibrations are traffic, industrial and human activities [5]. Observation of these microtremors can be used to determine the predominant period of vibration of a site [6-8]. Nakamura [6] proposed H/V spectral ratio method, in which the predominant period of the ground vibration is determined by the ratio of horizontal and vertical Fourier spectra of microtremors recorded at a site. A number of experimental investigations have validated the reliability of the H/V method in determining the predominant period of the ground [9-10].

The conventional means for determining the soil profile is the borehole method. However, this method is costly and time consuming, and hence it is generally not suitable for microzonation. Methods based on the analysis of strong motion records are more straightforward for determining site effects. However, the availability of ground motion records is limited to very few countries only. The strong motion records for Thailand are very limited, and hence, are not adequate for estimating the site effects. In this context, microtremor observation becomes the most appealing approach for the site effect studies.

The area of study (Figure 1) is located within latitudes N $13°30'$ and N $14°30'$ and longitudes E $99°45'$ and E $101°30'$, including Bangkok Metropolitan Area and the areas in the vicinity. Microtremor measurements were performed at more than 150 sites in Bangkok and the H/V spectrum ratio technique was applied to estimate the predominant periods of the ground vibration at different stations. A microzonation map for the city was then developed based on the results of the microtremor analysis.

Figure 1 Area of Study

SEISMICITY OF BANGKOK

Thailand lies in the east of the Andaman-Sumatra belt. The major active faults are rather far from Bangkok between 400 km and 1000 km. Some active faults are found in the western parts of Thailand at around 120 km to 300 km from Bangkok; however, their seismic activities are low. Nutalaya et al. [11] identified twelve seismic source zones in this region after a comprehensive study on the seismo-tectonic features of the Burma-Thailand-Indochina region.

Study carried out by Warnitchai et al. [3] identified that the soil profile underlying Bangkok has the ability to amplify earthquake ground motions about 3 to 6 times for low intensity input motions and about 3 to 4 times for relatively stronger input motions. The mean peak ground acceleration (PGA) values for input peak rock acceleration (PRA) values of 0.015, 0.019, 0.043, 0.056, 0.075, 0.088 and 0.10 g are 0.056, 0.072, 0.14, 0.18, 0.22, 0.24, and 0.26 g, respectively. These are the best estimated PGA values for Bangkok that have, respectively, 70%, 50%, 10%, 5%, 2%, 1% and 0.5% probabilities of being exceeded in a 50 year exposure period. They identified three factors as the main cause of the risk. First, several regional seismic sources that may contribute significantly to the seismic hazard of Bangkok are capable of generating large earthquakes. Second, the attenuation rate of ground motions in this region appears to be rather low and third the surficial deposits in Bangkok have the ability to amplify earthquake ground motions about 3 to 4 times. This study showed that although the possibility of a large earthquake near Bangkok is very low, there is still a risk of damaging earthquake ground motions in Bangkok. It was inferred that the maximum credible ground motion, if it occurred, would most likely cause severe damage to structures with fundamental periods ranging from about 0.5 s to 1.5 s and the short period structures that do not have sufficient lateral strength may also sustain severe damage [3].

GEOLOGY OF BANGKOK

Bangkok is situated on a large flat plain underlain by thick alluvial and deltaic sediments of the Chaophraya basin. This plain, generally called as the lower central plain, is about 13,800 km^2 in area [12]. The plain was under shallow sea 5000 to 3000 years ago, and the regression of sea took place around 2700 years ago leaving the soft clay deposits, which now forms the lower central plain (Figure 2). This plain consists of thick clay known as Bangkok clay on its top layer, and its thickness is about 15 m to 20 m in the Bangkok metropolitan area. The soft clay has very low shear strength, and is highly compressible, as it has never been subjected to mechanical consolidation. The soft clay rests on first stiff clay layer, which has comparatively high shear strength and less compressibility than that of the soft clay. At deeper strata the alternate layers of sand and stiff clay with relatively high shear strength exits [12].

The in-situ shear wave velocity (V_S) measurement by Ashford et al. [13] shows a notably low V_S profile in soft Bangkok clay (about 60 to 100 m/s). The shear wave velocity was found to increase sharply to about 200 m/s in the first stiff clay layer, and at a slower rate in the deeper strata. The extremely low V_S for Bangkok clay is comparable to that of Mexico City clay. Moreover, the drastic change of V_S in the top soft layer and the underlying layer can aggravate the amplification of ground motion.

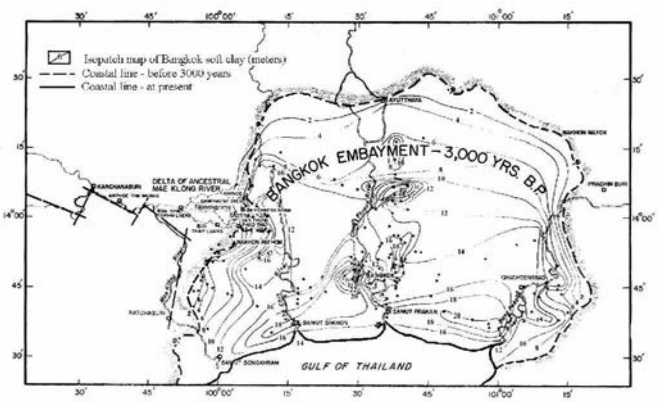

Figure 2 Isopach map showing the thickness of soft clay in Bangkok [15]

MICROTREMOR MEASUREMENT AND DATA ANALYSIS

Instrument Setup

Microtremor observations were performed using portable microtremor equipment. GEODAS (Geophysical Data Acquisition System) made by Butan Service Co. Japan was used for the data acquisition. The sigma delta type 24-bit analog-to-digital (A/D) converter converts the analog electrical signals to digital signals and stores the data in its memory. The sampling frequency for all the measurements was set at 100 Hz. The low pass filter of 50 Hz was set in the data acquisition unit. The velocity sensor used can measure three components of vibration, two horizontal and one vertical. Natural period of the sensor is 2 s, and its sensitivity is 1 V/cm/s. The available frequency response range for the sensor is 0.5-20 Hz. A global positioning system (GPS) was used for recording the geographical coordinates of observation sites.

Data Acquisition and Processing

Microtremor observations were carried out at more than 150 sites in the greater Bangkok. The measurements were carried out along the highways that run in the radial directions from the central Bangkok, at a distance interval of approximately 10 km. The observations were done along small streets at least hundred meters away from busy highways. However, inside the Bangkok metropolitan area most of the measurements were carried out in open-public spaces, e.g. parks, schools, universities, temples and government offices.

Data was recorded for 327.68 seconds (i.e. 32768 data points at the sampling rate of 100 Hz). The recorded time series data were divided into 16 segments each of 20.48s duration. Ten sets of the records were used in the calculations. The Fourier spectra were calculated for the discrete samples of the selected segments using the Fast Fourier Transform (FFT) algorithm. The resulting spectra were smoothed using the Parzen window of bandwidth 0.4 Hz. The Fourier amplitude ratio of the two horizontal Fourier spectra and one vertical Fourier spectrum were obtained using Equation 1.

$$r(f) = \frac{\sqrt{F_{NS}(f) \times F_{EW}(f)}}{F_{UD}(f)} \qquad (1)$$

where *r*(*f*) is the horizontal to vertical (H/V) spectrum ratio, F_{NS}, F_{EW} and F_{UD} are the Fourier amplitude spectra in the NS, EW and UD directions, respectively.

After obtaining the H/V spectra for ten segments, average of the spectra were obtained as the H/V spectrum for a particular site. The peak period of the H/V spectrum plot shows the predominant period of the site.

The H/V spectrums were obtained for all the observation sites and the predominant periods of ground motion at different sites were identified. Observation points were then overlaid on a digital map of the greater Bangkok and the inverse distance weighing (IDW) method was used for spatial interpolation from the data measured at discrete locations.

RESULTS OF THE MICROTREMOR MEASUREMENT

The microtremor measurements show that the predominant period vary from notably high values in the lower-central plain to very low values at the boundary of the plain. The sites located near the gulf of Thailand have considerably long predominant period, around 0.8 s to 1.2 s. This matches quite well with the variation of the soft soil thickness as shown in Figure 2, which suggests that the thickness of soft clay in these areas ranges from 16 m to 20 m. The Bangkok metropolitan area also has considerably long predominant period, longer than 0.8 s. The predominant period decreases towards the north and the period reduces below 0.4 s near Ayutthaya, which is located about 80 km from the central Bangkok. The period also decreases towards the east and west directions.

According to the variation of the predominant period of the ground, the greater Bangkok is classified into four zones as follows :

Zone I - period less than 0.4 s

Zone II - period ranging from 0.4 to 0.6 s

Zone III - period ranging from 0.6 to 0.8 s

Zone IV - period longer than 0.8 s

The H/V spectral ratios for the sites in the different zones classified on the basis of the predominant period are shown in Figure 3. The variation of the predominant period of ground in the greater Bangkok is shown Figure 4. The proposed four period ranges were taken from the highway bridge code of Japan [14] because these ranges are suitable to classify the predominant period of ground in the greater Bangkok.

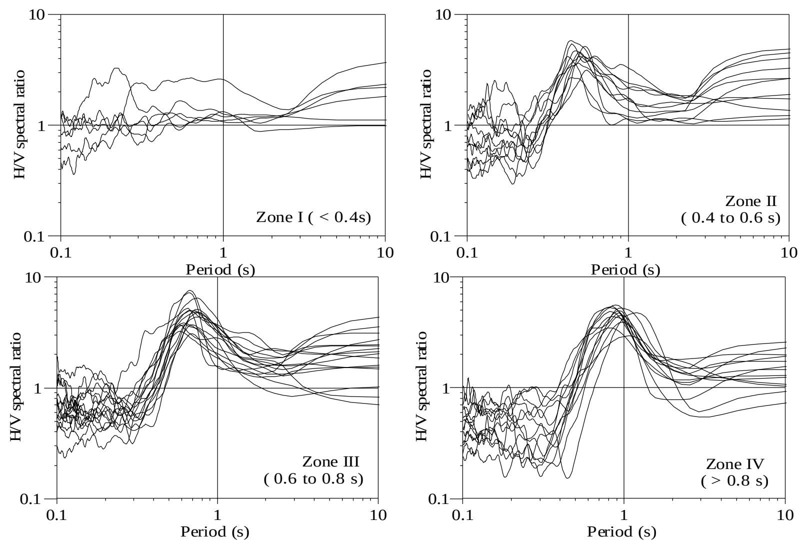

Figure 3 H/V spectral ratio of microtremor for sites in the four zones, based on the predominant period

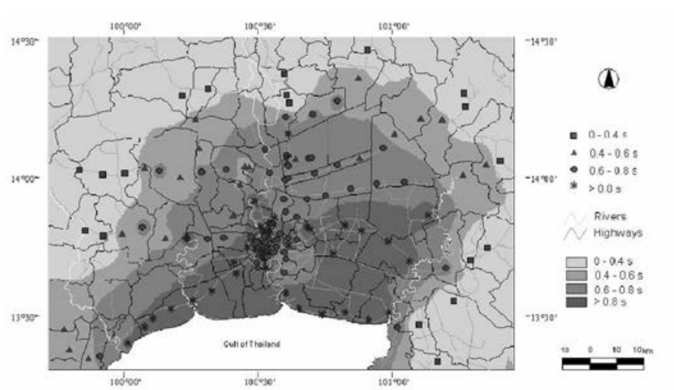

Figure 4 Microzonation of the greater Bangkok on the basis of variation of the predominant period

Variation of the predominant period with the thickness of soft clay layer

In this study, soil profiles at eight different sites in the greater Bangkok were analyzed. These eight sites were chosen because soil profile and geological investigation data (PS logging and/or SPT *N*-value) and microtremor observation data were available. The plot between predominant period obtained from microtremor observations and the thickness of soft clay layer is shown in Figure 5. It can be observed that there is a good correlation between thickness of the soft clay layer and the predominant period from the microtremor observations. The predominant period is longer for the sites with a thicker soft clay layer. The period decreases with the decrease in the depth of the soft clay layer.

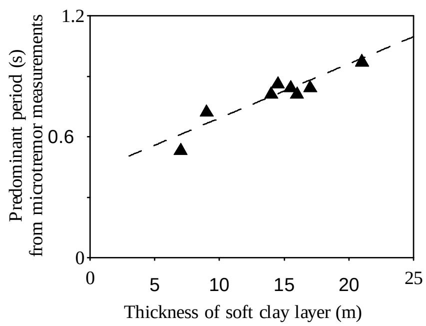

Figure 5 Variation of the predominant period with soft clay thickness

Soil and Shear wave velocity profile for Bangkok subsoil

In the context of Bangkok, the number of sites with S-wave velocity (Vs) profile is very limited. Among the eight sites chosen, detailed Vs profiles were available at four sites viz. Asian Institute of Technology (up to 60m depth), Thamasart University Rangsit (up to 50m depth), Chulalongkorn University (up to 60m depth) and Ladkrabang (up to 15m depth) from the in-situ downhole measurement performed by Ashford et al. [13]. Based on these observations they proposed a generalized Vs profile for Bangkok subsoil. However, due to lack of observation data after 60m, they estimated V_s profile up to the depth of 80 m based on available data viz. SPT *N*-values and shear strength (S_u). Moreover, after the depth of 80m there were no data available for them to make a reasonable estimate. The generalized S-wave velocity profile proposed by them assumes that a rock like material exists below the depth of 80m with a S-wave velocity of 900 m/s.

In this study V_s profiles for these four sites are taken from PS-logging [13] up to the depth where PS-logging data were available. After these depths V_s profile is estimated from SPT-N values, shear strength (S_u) and from the generalized soil profile proposed by Ashford et al. [13]. Below the depth of 120 m, only data available was compressive strength up to 600m depth at the site Samut Sakhon, near the gulf of Thailand. V_s was estimated for this site from compressive strength of soil using empirical formulae. It showed that there is no sudden increase in V_s at greater depths and V_s is of the range 500-600 m/s. Hence, in this study, V_s was taken as 550 m/s after the depth of 120 m.

Soil profile data were also available for other four sites (viz. Nakhon Pathom, Chatuchak, Samut Sakhon, and Ban Tamru), where microtremor observations were also conducted. These sites were also used for the comparison between the results from the microtremor observations and the transfer functions obtained by SHAKE91. For these four sites, the S-wave velocity were estimated from the SPT *N*-values using the set of equations proposed for the Bangkok subsoil by Ashford et al. [13].

Transfer function of Bangkok sites using SHAKE91

The transfer functions were calculated using the computer program SHAKE91, for the eight sites where microtremor data were also available (Figure 6). Here, transfer function is defined as the ratio of surface Fourier spectra to the rock outcrop Fourier spectra.

As stated earlier, the microtremor observation measures the vibration in the range of microns. At this level of vibration, soil essentially has a very low strain. At such a low strain, soil basically behaves like a linear material having a constant damping ratio and a shear modulus. The transfer functions were computed for the sties, assuming the damping ratio as two percent.

The H/V spectral ratios from microtremor observations for the eight sites are shown in Figure 7. The predominant periods obtained from the transfer functions of the subsoil at the eight sites are analogues to the predominant periods obtained from the microtremor observation at the respective sites (Figure 8).

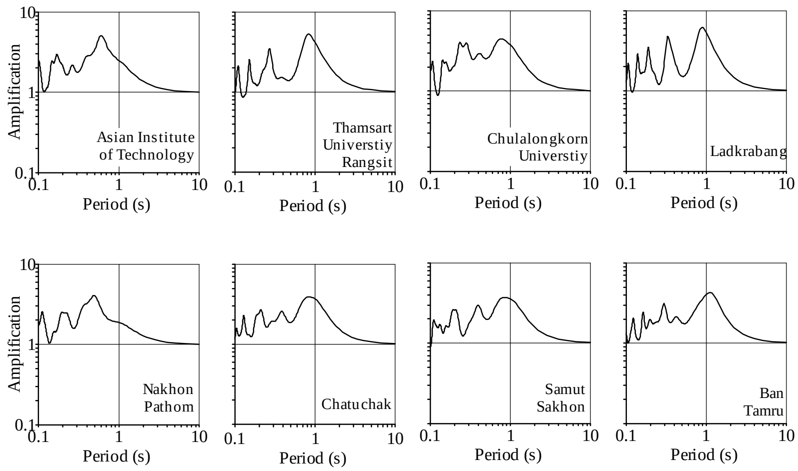

Figure 6 Transfer function calculated for eight sites in the greater Bangkok using SHAKE91

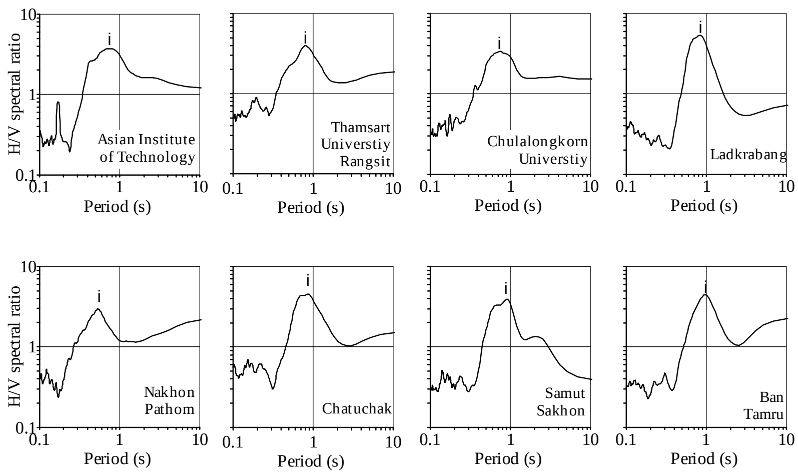

Figure 7 H/V spectral ratio for the eight sites from microtremor measurements

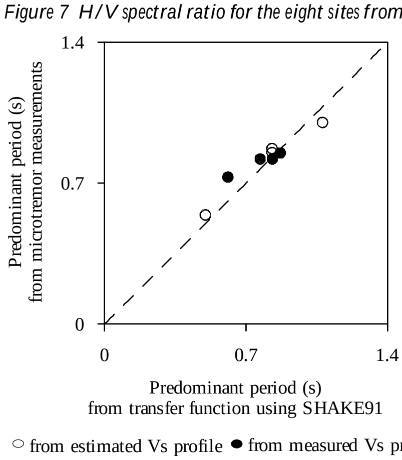

Figure 8 Predominant period from the microtremor observation and SHAKE91

CONCLUSION

In an attempt to construct a seismic microzonation map for the greater Bangkok, microtremor measurements were carried out at more than 150 sites. The predominant periods of the sites were obtained using the horizontal to vertical spectra ratio (H/V) method. The study showed that the predominant period varied from considerably high values, ranging from 0.8 s to 1.2 s, near the Gulf of Thailand, to very low values, less than 0.4 s at the boundary of the plain. On the basis of variation of the predominant period, the greater Bangkok was classified into four zones. Moreover, the transfer functions were calculated for the eight sites using SHAKE91. The good correlation between the results from the microtremor analysis and the results from SHAKE91 validated the reliability of the H/V method. The study also showed that the predominant period is dependent on the thickness of the soft clay layer; the thicker the layer of soft clay, the longer the predominant period of the ground.

This study shows that there is a possibility of long-period ground vibration in Bangkok, especially in the areas near the Gulf of Thailand. This can bring severe damage to the long-period structures e.g. high-rise buildings and long-span bridges. Hence, special attention should be given towards a seismic resistant design of such structures.

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SEISMIC HAZARD ESTIMATION ON THE BASIS OF COMPARATIVE ANALYSIS OF SEISMIC STRAIN RELEASE AND GEOLOGICAL DEFORMATIONS

S. Yunga

Abstract

A quantitative approach is proposed for estimating magnitude Mmax of large size earthquakes. Suggested seismo-geological approach is based on comparative analysis of geological and seismological evidences of seismotectonic deformation process. The seismic moment release rate depends on the parameters of G-R law and the maximum magnitude Mmax. On the other hand tectonic strain release rates for the seismogenic part of the lithosphere may be estimated from a flexural-plate model, constrained by vertical deformation rates from neotectonic data. Thus, in the East-European region geological deformations are estimated based on data of vertical neotectonic movements. Data processing include normalization, averageing, renormalization of the results, taking into account space distribution of deformation indicators. Method of Mmax estimation is based on comparative analysis of the release rates of the tectonic strain and seismic moment. The latter is dependent on the seismicity parameters and Mmax. As a result, an expression for evaluating Mmax, which depends on one constant, is obtained. On this basis, the equalizing seismotectonic and tectonic deformations in the seismotectonic province is revealed. Evaluation of accuracy is performed by the Monte-Carlo method.

Key words: Earthquake, stress, strain, deformation, magnitude, neotectonic vertical movement.

INTRODUCTION

The world's seismicity are located mostly along the lithospheric plates boundaries where rates of deformation typically high. Nevertheless, the interiors of plates, i.e. intraplate regions, are not totally rigid and have been the sites of known historic and pre-historic earthquakes. The first extensive review of intraplate earthquakes and intraplate magmatism for North and South America, Africa, Australia and western Europe was published by Sykes (1978). A major examination of earthquakes in so-called Stable Continental Regions in the last decade was presented in 1994 report the Electric Power Research Institute. Its main results with some minor revisions and additions are summarized by Johnston (1996a-c).

Taken as a whole, intraplate activity in the East European Platfrom (EEP) or Russian Plate lower than that in most other large continental intraplate areas of the world. Both local and distant earthquakes influence the seismicity of the region. The typical values of earthquake intensities are below 5. Main elements generating seismicity are active rupture zones of the Baltic Sea, junction zone between the Baltic Shield and Russian Plate, the suture zones of the Precambrian East European Platform.

The geology of that platform has many similarities to that of other intraplate areas. Hence, experience gained in understanding seismic risk in one area can be transferred to sites in other intraplate regions. Intraplate earthquakes and the stresses that generate them are of importance in understanding processes in plate interiors, seismic monitoring and accurate ascertaining seismic hazards and risks.

Our study of intraplate geodynamics, neotectonics and seismicity in EEP were concentrated mainly on the origin of stress state and intraplate earthquakes. The intensity of the stress state and therefore seismic activity of platforms were shown to be controlled by both their distance to divergent and convergent plate boundaries and curvature of plate (Grachev, Mukhamediev, 1996; Grachev, Mukhamediev, Yunga, 1996). Tensor components of curvature and torsion, invariant under rigid motions of the lithosphere, were analyzed and mapped for the East European platform (Grachev, Magnitsky, Mukhamediev, Yunga, 1996). These components are characteristics of the stress state, as is shown within the framework of mechanics of deformation solid continuum. Based on the inferred results, a new approach to the determination of maximum possible earthquake magnitudes was developed and implemented with reference to specific conditions of the East European platform. In its essence, this approach consists in the comparison between observed values of neotectonic bending deformations and intensity of seismotectonic deformations analytically determined from the information about certain parameters of the seismic regime. An essential point of the study in question is the estimation of a limiting possible level of maximum possible earthquake magnitudes in the East European platform. This upper bound was estimated from the geodynamic and analysis of the stress state and seismicity of the East European platform.

STATEMENT OF THE PROBLEM AND METHOD OF SOLUTION

A proposed approach to the evaluation of earthquakes maximum magnitudes through consideration of various geological and geophysical factors in terms of tectonic deformations is briefly formulated as follows. Study of neotectonic vertical crustal movements allows to estimate numerically characteristics of neotectonic strain rates, associated with lithosphere bending deformations. On the next step, the tectonophysical representation of displacement discontinuities in terms of long-term seismic strain rates is obtained analytically through the value of maximum magnitude of earthquakes. The comparison of intensities of above-mentioned macrodeformations makes possible to evaluate the space distribution of maximum magnitudes of earthquakes in region under investigation.

The analysis of seismic history and instrumental seismicity let one estimate the seismic regime parameters and the rate of seismotectonic deformation release. The consideration of analyzed factors in the tectonic deformation term supports a unique tectonophysical base to research the problem as a whole. At the same time, direct methods of Mmax evaluation, based on the estimation of the seismogenerating fault length, remain an important controlling factor.

The essence of the method of maximum magnitude quantitative determination in the seismotectonic provinces is based on the equalization of the estimated rate (accounting Mmax) of the release for seismic moment for earthquakes of the region investigated from one hand and of the rate of recent deformation process fixed by geological methods, from the other hand. Under the equalization there is considered the fact experimental data about durable seismicity providing the similarity of displacement character in sources give direct analytical expression of deformation rate for earth's crust, depending on the level of the earthquake maximum magnitudes. Used in the calculation parameters are the plot slope of the recurrence for earthquake number on magnitude, the seismic activity level, and parameters of correlation between seismic moment and earthquake magnitude (Grachev, Magnitsky, Mukhamediev, Yunga, 1996).

As for theoretical aspect such an approach can be formally justified when macrodeformation being shown through displacement jump (Kostrov, 1975; Nikitin, Yunga, 1978). It is evident, such macroscopic approach requires representative volume of the data used. So, the most efficiency is received when similar evaluation being spread on the geological time range and separate provinces. Their cumulative seismotectonic deformation depends first of all on seismic conditions , describing the rate of release of earthquake seismic moments. The other side of the problem is that the calculation of seismotectonic deformations gives no value of entire tectonic deformation, yet. Comparing them quite real contribution into the tectonic deformation of creep movements along faults, mechanism of rock creeping, and phenomena like these should be taken into account. These and similar effects must be considered by an assumption of similarity of tectonic and seismotectonic deformation processes being expressed in linear dependence , where coefficient can be put into calculation a priori and determined under recurring building up. Thus, primary ambiguity in the problem in the relationship of tectonic and seismotectonic deformations may be eliminated further by analysis of deformation pattern in separate subregions, whose seismic and geological history is known rather well.

Let us discuss more thoroughly the method of seismic potential evaluation. General schedule for seismic potential evaluation is as follows.

Carrying out of combined geological investigation of deformations and neotectonic vertical movements of the earth's crust discovers the possibility to evaluate the rates of geological deformations for neotectonic stage, informing a lot, providing the first component in problem formulation. The other component can be received, when using the earthquake recurrence law and correlation seismic moment dependence of magnitude. It gives independently analytical expression to estimate seismotectonic deformation, depending on the maximum magnitude of earthquake Mmax and seismic regime parameters. The equalization of the mentioned macrodeformation evaluation remains free the only constant. The constant can be fixed, considering materials of teaching and known values of deformations under certain conditions of separate subregion, where Mmax values are determined rather well. In combination there appears the possibility of evaluation and subsequent mapping Mmax within the EEP territory.

Theoretic, techniques, and calculating aspects of rate evaluation for seismotectonic deformations according to sesmic observations are as follows. Seismotectonic deformation as irreversible process, caused by numerous motions along seimogenic fault planes can be considered phenomenologically and formally by means of displaying the deformation through displacement jumps. So it is evident seismotectonic deformation rate is at first determined by the sesmic moment release rate.

Analytical expression, connecting the rate of release with earthquake recurrence parameters and earthquake maximum magnitude, is received in a number of papers of past two decades, including for example, in the papers (Anderson, Luco, 1983; Anderson, 1986).

The description of seismic regime usind the recurrence law for earthquakes of different magnitude level is expressed by means of coefficients A and b of linear correlating dependence of logarithm of earthquake number per time unit, on square unit in the given range of magnitude value, where b is a recurrence plot slope and A is seismic activity under the given magnitude level M.

The important relationship is positive correlation of seismic moment logarithm Mo and magnitude M with coefficients D and d, where the latter gives plot slope Johnston [1996a-c].

Taking into consideration recurrence in the investigated region at geological time scale earthquakes of all different magnitudes up to maximum possible, let compare evaluation of geological and seismotectonic deformation, and thus receive by its help the expression for maximum magnitude, where constant C is the measure of uncertainty :

= C/(d-b) exp((d-b)Mmax).

It is worth noting the mentioned above circumstance, i. e. the dependence of the rate of seismic moment release of magnitude given a certain independently received estimation of the deformation rate by geological methods, provides the possibility of estimation for earthquake maximum magnitude. The similar ideas on comparative estimation of the seismic rate deformation and tectonic deformation rate, controlled by geological methods are considered also in the paper by Anderson (Anderson, 1986).

On the basis, from the results about longterm seismicity - (recurrence of earthquakes of diferent magnitudes and seismic activity level- indicators b and A), correlation of seismic moment and magnitude (parameters d and D), it is possible to evaluate accurate to one overall constant C relative level of maximum possible earthquake magnitude, absolute relation of which should make on the basis of materials of teaching in the subregions with well known structural tectonic peculiarities and deduced limited values of earthquake magnitude.

Another important component of Mmax evaluation is corresponding interpretation in deformation terms of data concerning geological evidences of the earth's crust movement. This approach realization contains the estimation of basement deformation and neotectonic deformations by analysis of already figured material on the neotectonic vertical movements.

The analysis is carried out by estimation of component tensor of curvature--torsion deviator, which method was comprehensively discussed in the papers by Grachev (Grachev et al., 1994)

Used characteristics of deformation of the earth's crust must be invariant relatively the movement of lithosphere block investigated as a whole and are associated in framework of correct geodynamic models with tectonic stresses. The requirement are primarily met the characteristics of bending for curved under vertical movements of the earth's crust (VMEC).

To connect VMEC kinematics with stress-strain state (SSS) of lithosphere there is used a model of lithosphere plate bend, considered as a thin homogeneous and isotropic plate being H thick (thus an error due to neglect of lithosphere bending is small). Let x - radius-vector of a point of middle lithosphere surface. VMEC amplitudes w(x), averaged on space at specific scale of averaging of the order in lithosphere, are considered as plate bends.

At small compared with h amplutudes VMEC two-dimensional stress tensor T in the lithosphere is shown as superposition of permanent in lithosphere thickness stress tensor P and linearly changing in thickness tensor, proportinal to tensor of bending moment M. The first of the tensors (P) can be interpreted as tensor of global tectonic stress, given from lithosphere plate borders, and the second - as regional parts of global SSS owing to VMEC. For elastic and visco-elastic lithosphere tensor of bending moment is linearly connected with two-dimensional kinematic tensor of curvature--torsion W of bent (curved) surface, which components are the second space derivatives of VMEC amplitude. At small gradients VMEC tensor eigen values W are main curving K1(x), K2(x) of the bent surface (K1 > K2). Positive values of curving correspond to concave surface, and negatives ones - to convex.

It is advisable to discuss following invariant of tensor W:

K = (K1+ K2)/2; k = (K1- K2)/2, (k > 0),

where: K - average curving, k - bend intensity.

The space distribution of tensor for neotectonic curvature--torsion W and its invariants is calculated for the region investigated. Initial data are represented as figure massive in specific sites of given with certain increments step square grid. Tensor characteristics of bending as a result of figure differentiation and finding of tensor eigen values and vectors are determined in the specific sites of the same square grid. The neotectonic map of North Eurasia was constructed in the United Institute of Physics of the Earth, Russian Academy of Sciences (Grachev, 1996) . The map incorporated data provided by numerous Russian geological and geophysical institutions.

Scheme of earthquake magnitudes of the East European platform based on data on neotectonic bending deformations and seismicity parameters is presented on Fig. 1. We take in this case maximum magnitude in teaching province as 6.0.

The determination of seismogenerating zones on the basis of known site estimation and information of seismotectonic region structure seems rather evident and is of objectivity. Mmax evaluation are related to concrete geological structures, developed in a certain seismotectonic province (large faults, earth's crust block boundaries, etc), and seismogenerating zones are traced according to these active structures.

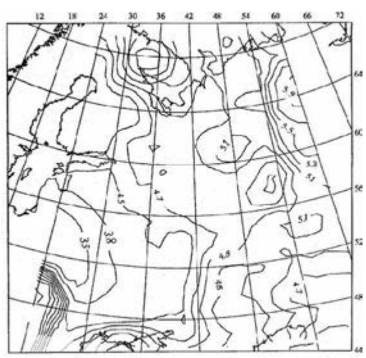

Fig. 1. Scheme of estimated maximum earthquake magnitudes of the East European platform.

CONCLUSION

The higher values of bending deformation intensity are characteristic of the whole periphery of East European platform being with good correspondence with historical earthquakes. Comparison of computed results shows that, in spite of a certain understandable difference in Mmax estimates, the total pattern of isolines in the space remains virtually unchanged. The present investigation of the problem of Mmax evaluation for platform regions revealed the necessity of studying and analyzing many additional geological and geophysical factors determining the thermodynamic and rheological features of deformation of the potentially seismoactive layers of the lithosphere. In modern geodynamics, these problems have already been elucidated to a certain extent, and this largely ensures the prospects for constructive use of the obtained results in the evaluation of Mmax, which is supported by modern knowledge of the geodynamics of platform regions.

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EPEIROGENIC UPLIFTS AND THEIR SEISMOGENIC IMPLICATIONS IN CENTRAL INDIA

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Abstract

In Indian shield, each intracontinental region of epeirogenic uplifts is a composite of several smaller wavelength features of uplift separated in several areas by sharp low-lying tectonic lineaments. Despite the large dimension, considerable upliftment and high seismicity associated with the Satpura orogenic belt, our understanding of its seismogenic character is not well understood. A close look at the spatial distribution of moderate earthquake in peninsular India, hitherto considered "Stable Continental Region", reveals a relatively higher level of seismicity associated with the Narmada Son Lineament (NSL). The seismicity pattern of the elevated Pachmarhi plateau (a part of Satpura range) shows the concentration of the seismicity at the boundary of the Satpura Gondwana basin, which is, uplifted more than 500 m along boundary faults. They are predominantly associated with strike slip or thrust mechanism; consistent with the compressive tectonic regime imposed on the Indian shield by its plate boundary forces. Besides, the influence of uplifting process that possibly originates through lithosphere-mantle interaction could be a significant contributor though may not be uniform in magnitude and in direction of the operating forces. The plateau forming processes and the 3-D character of a distensional tectonics that epeirogenic uplift imposes on an otherwise compression domain are proposed as the twin cause mechanism for the present day seismicity of the region.

Key words: Epeirogenic, Deccan Traps, intracontinental, and Narmada-Son-Lineament.

INTRODUCTION

Several intracontinental regions of epeirogenic uplifts that endeavor to establish a mass balance arising from both mantle and crustal buoyancy characterize the Indian shield. The major uplifted plateaus in the shield are (i) The NW trending Western Ghats, (ii) The NE trending Eastern Ghats, (iii) The easterly trending Satpura-Chotanagpur belt, (iv) The NE trending Aravalli Mountain range and (v) The Shillong plateau that shares the Himalayan tectonic regime. The Narmada-Son lineament, straddling the Indian shield, is the most conspicuous feature among them. Despite its large dimension and considerable upliftment, lithotectonic evolution of the Satpura orogenic belt and its seismogenic character is the matter of debate.

Narmada Son Lineament (NSL) is a mid-continental rift system that divides the Indian shield into two halves. A thick pile of Deccan lava flows covers the western part of the NSL. Other litho associations forming an integral part of the lineament zone include the Late Archaean to Early Proterozoic Mahakoshal group with occasional patches of relict basement gneisses, Madanmahal granite, Vinddhyan Supergroup, Gondwana Supergroup, Lameta Group and the Quaternary/Recent alluvium and laterite (Fig. 1). The volcano-sedimentary Mahakoshal fold belt presents a lithological sequence evolved in an intracratonic rift, bounded by two major faults, termed as the Narmada North Fault (NNF) and Narmada South Fault (NSF) trending ENE-WSW (Roy and Bandopadhyay, 1990; Nair et al., 1995). In contrast to the dormant tectonic history of the NNF, the SSF has witnessed protracted reactivation from Precambrian to Phanerozoic. Subsidence along the NSF resulted in uphorsting of the Mahakoshal belt, thus restricting the northward extension of the Gondwana basin into the Vindhyan province. This condition continued during the Permo-Triassic Gondwana sedimentation of the Satpura and South Rewa basins resulting in the pre-Upper Gondwana depocentres to the immediate south of the Narmada South Fault. Geomorphologically, the Satpura Gondwana basin around Pachmarhi is at an elevated level compared to adjacent Archaean rocks. This is one of the indications that Gondwana rocks of Satpura region have been uplifted after the Gondwana period. The Satpura range in central India characterizes a consistent ENE-WSW trending structural feature delimited by faults on either side giving rise to graben and horst structure in the region (Qureshy, 1964). There are geological evidences that the NSF has again partially reactivated during Deccan volcanism in the area. The main eruptive activity in the Satpura area is along the present day Satpura axis from south of Khandwa to north of Mandla through Lakhandon (Acharyya et al., 1998). Faulting activity continued in post trappean times offsetting Quaternary sediment cover. One such example exhibited by block faulting could be noticed southeast of Jabalpur (Srivastava et al., 1999). This fault could be traced and is sub-vertical having N60-70 E strike. The controversy, therefore, still exists as to whether it is an ancient rift zone, a zone of persistent weakness and tectonism or it is the consequence of a strong plume head mushrooming beneath the region. In this study the deep seismic sounding, historical seismicity and gravity data have been analyzed and the results are considered in the light of available geological information of the area to come out with a model which could satisfy main tectonic features observed in the area.

SEISMICITY

Seismicity is the manifestation of tectonically weak zones/faults, which might be still active. In order to study the seismicity of the region (18° N to 25° N and 74° E to 83° E), historical earthquake data since 1060 has been considered (Fig. 2). The seismicity map has been prepared from combination of PDE data and historical earthquake data from Tandon and Srivastava (1974); Chandra (1977); Srivastava and Ramchandran (1983) and Rao and Rao (1984). Because of the poor distribution of recording stations in the adjoining region the catalogue is short of full details especially of lower magnitude earthquakes. However, considering a long duration of seismicity one can draw certain inferences. The trend of spatial distribution of earthquakes in the central India shows three interesting correlations:

1) Most of the historical earthquakes are confined to geological contacts (Fig. 1). However, the area between longitudes 75^0 to 78^0 E, completely covered with Deccan traps, is conspicuously devoid of seismicity.
2) A simple seismicity pattern of this region shows a distinct correlation with the Satpura Gondwana basin margin (Fig. 2) Suggesting their reactivation nature.
3) Several thermal springs along the Narmada Son Lineament occur mostly at the contact of Vindhyan-Deccan traps or Gondwana-Deccan traps out crops. We find a distinct pattern that is related to tectonic setting and earthquake occurrence in the Narmada-Sone lineament zone (Fig. 3).

EVIDENCES OF BLIND FAULTS DERIVED FROM DEEP SEISMIC SOUNDING DATA

Among all, the most devastating earthquake was the 1997 Jabalpur earthquake. The earthquake was found associated with a fault well indicated by clear shifts in refraction travel times on the Hirapur-Mandla Deep Seismic Sounding records of SP150 and SP160 (Kaila et al 1989). Because of the recording gap between SP150 and SP160 due to cultural noise in Jabalpur city it was not possible to fix the place of the fault on the surface (Fig. 4). The Jabalpur earthquake (1997) provided additional data to fix the position of that fault on the surface. The hypocentral cross section of the main shock and after shocks of Jabalpur (1997) earthquake along NW-SE line (Fig. 5) cutting across meizoseismal zone and after shock zone (Acharyya et al., 1998) show that the seismogenic fault FF' dips steeply towards SE. Its fault plane cuts the surface in meizoseismal zone. It is interesting to note that Srivastava et al. (1999) and Srivastava and Pattanayak (2002) on the basis of correlation of various Deccan trap flows in the eastern Deccan volcanic province have reported a major shift (~ 150 m) in the stratigraphic height of a lava flow at the western flank of the Nagapahar range. They have interpreted it due to a NE-SW trending, post trappean normal fault in this region. In the light of hypocentral cross section, presence of shift in traps flows and geological evidences of well developed fault gauges (Nair et al., 1995), the place of basement fault may be reviewed and could be correlated with the seismogenic fault delineated by hypocentral cross section. Similar post Deccan trap faults have also been reported along the Satpura range (Crookshank, 1936). He opined that emplacement of intrusive complex may have resulted in faulting in lava flow. Cox (1988), however, has attributed it to post eruptive isostatic adjustments.

TECTONIC IMPLICATIONS

From the observation of the spatial distribution of historical earthquakes in SONATA zone (Fig. 2), it can be seen that the NSL has experienced a diffused occasional earthquakes whereas the Pachmarhi plateau is surrounded by at least eight historical earthquakes. The earthquakes around the Pachmarhi are aligned with the Satpura Gondwana basin margin faults (Fig. 6). These faults controlled the depositional history of Satpura Gondwana sediments as they are located at geological contacts between Gondwana rocks and Archaean basement on the south margin and Gondwana /Mahakoshal on the northern margin. A sudden change in elevation of about 400 m of Pachmarhi Gondwana basin above the granitic basement shows that there has been post Gondwana epeirogenic uplift in this area. There could be various causes for such uplift. A possible mechanism of the epeirogenic uplift was discussed by McKenzie (1984) and it was summarized that the intrusion of large thickness of basic magma into the lower part of the continental crust could cause epeirogenic upliftment under favorable conditions and could result in pushing the crust upward along the faults. Geochemical and Petrological evidences indicate that majority of lower Deccan tholeiites lava evolved in local and multiple magma chambers close to the surface up to a depth of 7 km (Bhattacharji et al., 1996). The emplacement of such a thick magmatic body could cause an up warp above this body and also could cause down warp below it to stay at depth. The eruption activity in the Satpura area is considered to be along Satpura axis from south of Khandwa to north of Mandla through Lakhandon (Bhattacharya et al., 1996). Hence axis of eruption most probably would be along the boundary of this uplift and/ or adjoining graben/rift structure. Dykes with ENE-WSW trends intrude the Deccan trap flow profusely along Narmada Tapti rift and over Gondwana near Betul. Field and geochemical relations and age similarities (67–64 Ma) of many mafic dykes and basal flows indicate their comagmatic nature and establish many rift oriented mafic dykes as primary feeder.

Although, there are numerous lineaments in the SONATA zone, only few of them are being activated to cause earthquake activities. Particularly, in the NSL zone east of the extension of Godavary graben is characterized by moderate seismicity, the zone west of which is conspicuously devoid of it. Correlation of Bouguer anomaly, shallow and deep seismic velocity structure and heat flow anomalies show presence of mafic bodies as shallow as 5 – 6 km along the Satpura (Verma and Banerjee, 1992; Mishra, 1992; Mall et al., 1991). The low-velocity (Kaila et al., 1989) lower crustal serpentinized layer in the given rheological boundary conditions acted as local stress concentrator for the deeper earthquakes of the region (Rajendran and Rajendran, 1998; Manglik and Singh, 2002; Rao et al., 2002). Contrary to which, the elliptical shaped NE-SW trending gravity-high in the western part of the NSL was interpreted to be due to the high velocity/high-density intrusive body in the lower crust (Singh and Meissner, 1995; Singh, 1998). This implies that the magmatic underplating which, was inferred from bouguer gravity high axis by Singh and Meissner (1995), is not seismogenic.

Much intra-continental deformation within the crust is accommodated by reactivation of preexisting structures (Coward, 1994). Reactivation of pre-existing faults (Sykes, 1978) and local stress concentration (Campbell, 1978) are generally considered as cause for intraplate seismicity. However, localized zone of high strain rate (Zoback et al., 1985) can also explain some of the upper crustal earthquakes. The zone of weakness model proposes that contemporary earthquake activity be caused by the reactivation of ancient faults and other weak boundaries within the crystalline crust, which are presently subjected to apparently ambient regional stress field. Earthquake occurs where local deviatoric stress exceeds the threshold for brittle failures. In fact structural reactivation, a common feature of deformation in continental crust, is mostly accounted for by the reactivation of existing planes of weakness rather than by creation of new faults. As a result, intraplate seismicity on the continent is commonly concentrated along the ancient fault zones (Seeber, 1998). Local stress perturbations may also be caused by lateral variations in crustal structure, density, lithological boundary and stress concentration along the edges of structures. The stress concentration theory works on the lithospheric mass variations and perturb the ambient stress regime to the extent of triggering earthquakes. Stress localization model proposes that sites of large intraplate earthquakes be controlled by the zone of localized strain in the lower crust, which concentrates stresses in the upper crust.

Though the significant earthquakes in Central India are Son valley/Rewa (1927, M=6.5), Satpura (1938, M=6.3), Balaghat (1957, M=5.5), Broach (1971, M=5.4) and Jabalpur (1997, M=6.0), focal mechanism solution is available only for the Broach and Jabalpur earthquakes having fault planes orientation in NE to ENE and NW to EW (Rajendran and Rajendran, 1998; (Kayal, 2000). These are indication that faulting could occur along this plane. Field evidences are also in support of the involvement of ENE oriented fault in the Broach and Jabalpur earthquakes. Fissures that opened during the Broach earthquake were generally oriented in ENE-WSW direction (Chandra, 1977). Ground cracks associated with Jabalpur earthquake were also oriented in ENE-WSW direction (Gupta et al., 1997). Thus, the geological and seismological data shows a good correlation of spatial distribution of historical earthquakes and known linear tectonic features of Son-Narmada-Tapti (SONATA) zone in central India. Further, recurring seismicity point to the reactivation of original faults that are associated and parallel to the Narmada rift.

It may also be noted that the models mentioned above has been based mainly on the earthquake processes in the brittle upper crust and they may not adequately explain the deeper events. As mentioned earlier at least two major earthquakes in Narmada zone are deep focus earthquakes, namely the 1938 Satpura earthquake at a depth of 40 km (M 6.3) and of 1997 May 21 Jabalpur earthquake (Mw 5.7) at a depth of about 35 km (Rao et al., 2002). The occurrence of deep focus earthquake at lower crustal depths is quite unusual for Indian shield and mid continental zones and indicates causative mechanism related to crust-mantle interaction. Rao et al. (2002) support the idea of weak intrusive in the lower crust that are capable of stress concentration. Rezanov (1991) inferred that the most probable composition of weak inclusion in the lower crust is serpentinized ultramafic rocks formed by dehydration of rocks that were formerly part of the mantle. Disposition of these earthquakes along NSL, magmatic intrusion in the middle and the lower crust could be a probable cause of stress accumulation in the lower crust.

In the Satpura Gondwana basin near Pachmarhi the heat flow data is so disturbed that a large variation in surface heat flow (48-96 mWm-2) is observed in a small area of 50km x 50km (Gupta, 1993). He inferred that the surface waters percolate through dyke contacts and show a disturbed surface heat flow. Some of the lineaments of the region are also associated with geothermal springs (Gupta, 1993). Baren et al. (1978), Gastil and Bertine (1986) and Chadha (1992) have also reported regional association of thermal springs and seismicity. Presence of thermal springs scattered along well-defined tectonic structures generating earthquake along Satpura, suggest that the faults associated with such structure are seismically active. Since most of the described faults where springs emerge are seismically active they must be considered excellent site for monitoring seismic activity.

CONCLUSIONS

The main conclusions that arise from the re-evaluation of the seismic data can be summarized as follows:

1) The Narmada-Sone-Tapti zone is found to be a composite tectonic domain in which different tectonic zones were active during different geologic time.
2) Pachmarhi area of Satpura Gondwana basin has been up warped over and above normal Satpura orogeny. The Deccan trap activity is interpreted to be one of the influencing factors for elevated Gondwana sediments.
3) The occurrence of historical earthquakes shows a striking correlation with major faults and contacts between different geological units.
4) It has been found that the area has undergone post Gondwana uplifting. The epicentral distribution pattern suggests reactivation of the fault systems, flanking the uplifted Gondwana block. In other words neo-tectonic activity is still on.

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FIGURE CAPTIONS

Figure 1. Geological map of central India showing the distribution of historical earthquakes. Source of magnitude of historical earthquakes are Rao and Rao (1984).

Figure 2. Seismicity and elevation map of central India. Increased seismicity can be seen around the elevated Pachmarhi plateau between longitude 77°E and 80°E and latitude 21°N and 23°N due to epeirogenic upliftments of Satpura Gondwana basin. The increased seismicity in 73° E to 74.5° E longitude range is associated with Western Ghat epeirogenic tectonic zone. Location of historical earthquakes is marked with red solid circles.

Figure 3. Seismicity map of central India showing the correlation with the major linear features of the region. Location of thermal springs and earthquakes are marked with + signs and solid circles respectively.

Figure 4. (a) Stratigraphic correlation of the fifth lava flow in measured section adjacent to Nagapahar fault F1-F1' (after Srivastava et al., 1999) along Hirapur-Mandla DSS profile. Reduced travel times of shot points SP150 and SP160 showing the shift in refraction travel time indicating faults (modified after Kaila et al., 1989). Shift in refraction travel times can be seen at NSF and NNF. The NSF is correlated with the Nagapahar Fault.

Figure 5. a) Epicentral map of the main shock and aftershocks of 21st May 1997 Jabalpur earthquake. The meizoseismal zone, isoseismal VIII is shown with dashed line. The fault plane solution (lower hemisphere) of the main shock and aftershocks are illustrated with usual notation (after Acharyya et al., 1998). b) Hypocenter section of the main shock (hatched circle) and aftershocks (solid circle) of Jabalpur earthquake, 1997 along A-B in the dip direction of Narmada south fault. The fault F-F' extends to mantle depth (after Acharyya et al., 1998).

Figure 6. Seismicity, elevation and geological boundary of the Satpura Gondwana basin. The outline of the Satpura Gondwana basin is shown with thick line and the locus of basin margin faults is shown by thin line.

FIGURES

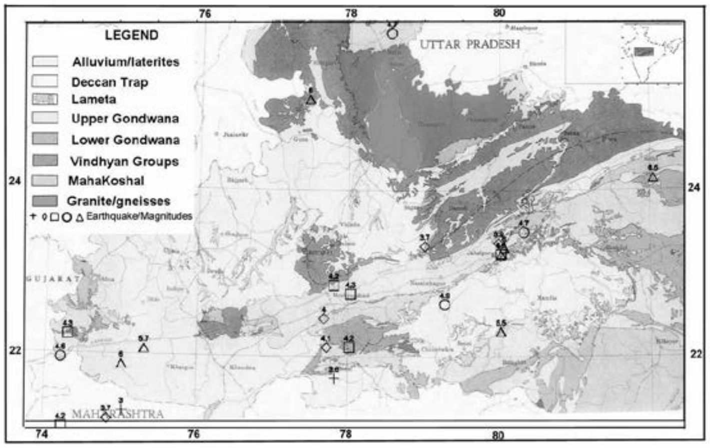
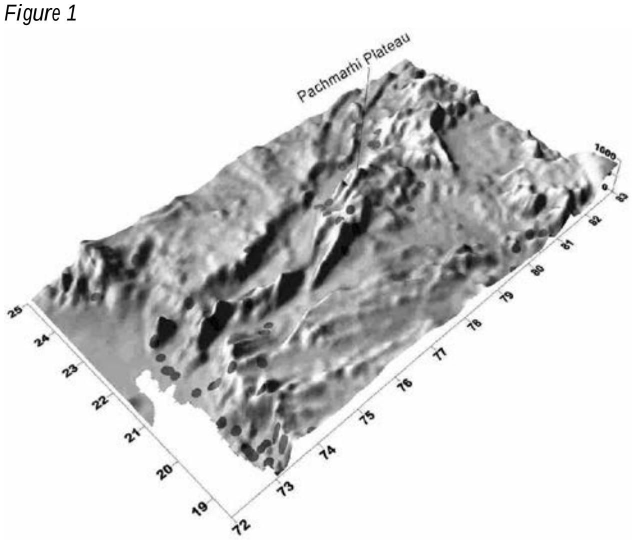


Figure 1



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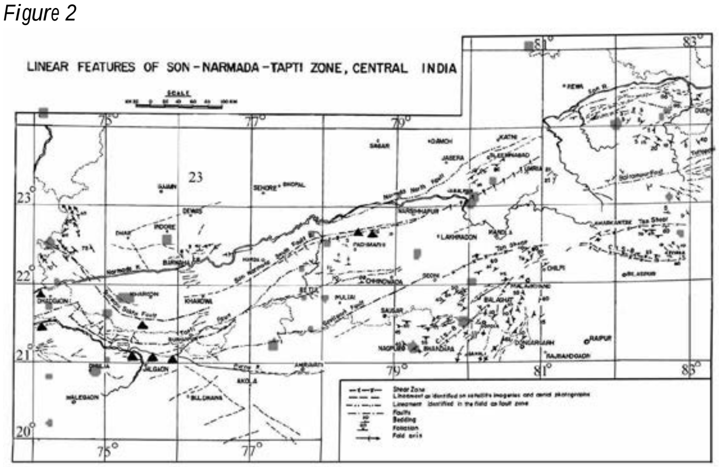

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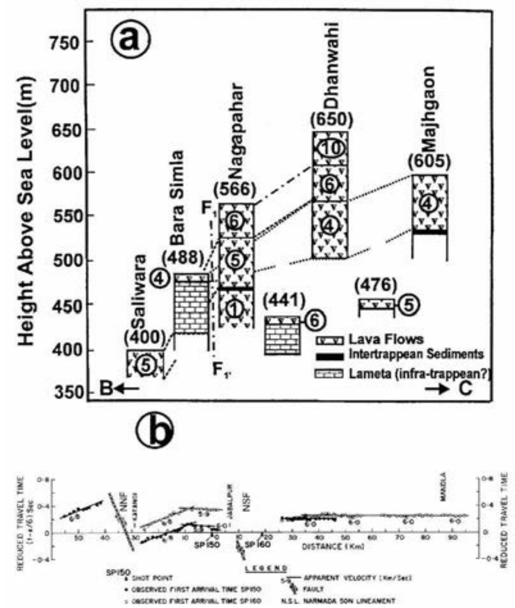

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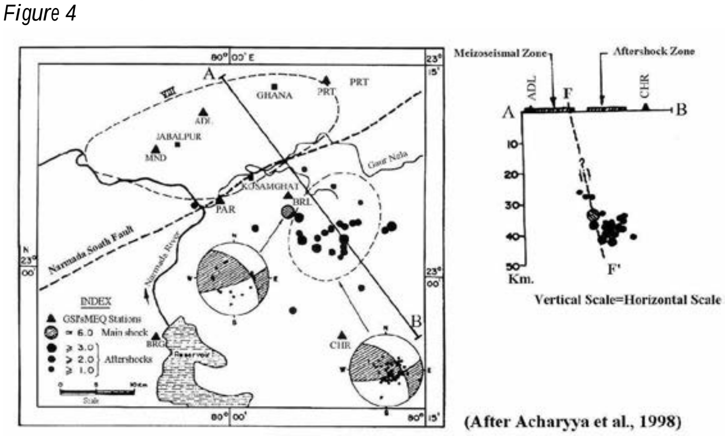

(After Acharyya et al., 1998)

Figure 5

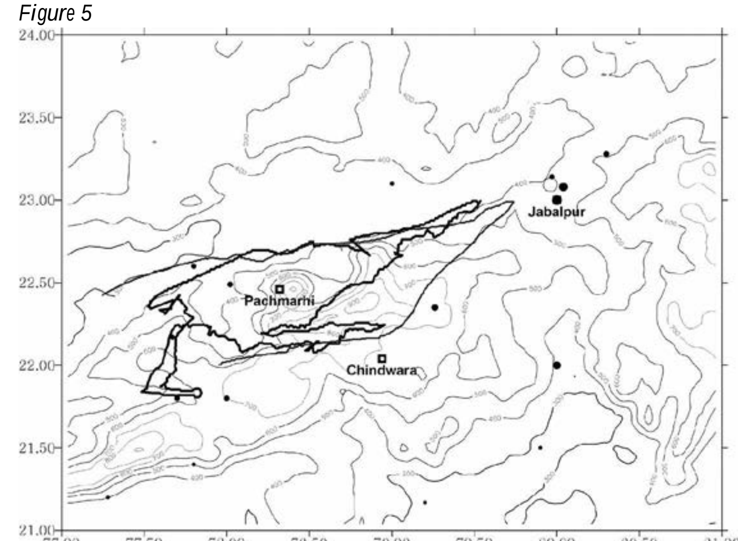

Figure 6

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THE ATTENUATION LAWS OF RESPONSE SPECTRA WITH MULTI-DAMPING RATIOS OF SMALL-MODERATE EARTHQUAKES

Zhao Fengxin and Wang Haijiang

Abstract

The consideration of the effect of the diffuse seismicity is an important work in the seismic hazard analysis for nuclear power plants. Usually, those earthquakes whose magnitudes are about 5 and near the source play an important role in the diffuse seismicity. To estimate the influences of the diffuse seismicity, the attenuation laws, which are based on the ground motion records of small-moderate earthquakes near the source, are needed. In this paper, the attenuation laws of response spectra with damping ratios of 0.005, 0.02, 0.05, 0.1 and 0.2 of small-moderate earthquakes near the source are presented. Based on the theoretical analysis and observed data, a model which is simple in the form and clear in the physical meanings is adopted, since the effects of magnitude saturation and distance saturation of high-frequency ground motion near the source can be neglected in this study, i.e.

$lgSA(T,\xi)=C_1+C_2M+C_3lgR+\varepsilon$

where M is the local magnitude, R is the hypocentral distance. The records used in this study are from the following three parts: strong ground motion data of the California of USA before 1992's; data of South California Earthquake Catalog; National Strong Motion Project of USA. The records on rock site with magnitude between 4.0 to 6.5 and hypocentral distance less than 70 km are selected for developing the attenuation laws.

The attenuation laws developed in this study can be used in seismic hazard analysis of nuclear power plants.

Key words: Response spectra, Small-moderate earthquake, Attenuation laws.

INTRODUCTION

The consideration of the effect of the diffuse seismicity is an important work in the seismic hazard analysis for nuclear power plants. Usually, those earthquakes whose magnitudes are about 5 and near the source play an important role in the diffuse seismicity. It has been reported that some small magnitude earthquakes have produced peak accelerations that have exceeded the Safe Shutdown Earthquake (SSE) of several nuclear power plants in Eastern North America (ENA) since 1978. These accelerations have stimulated an interest in ground motions from small-moderate magnitude earthquakes, especially among earthquake engineers, engineering seismologists and regulators of different countries responsible for the design and safety of nuclear power plants. The dependence of peak horizontal acceleration on magnitude, distance, and site effects for small magnitude earthquakes in California and Eastern North America was Studied (Kenneth W. Campbell, 1989). In his study, one-hundred and ninety free-field accelerograms recorded on deep soil (>10m deep) were used to study the near-source scaling characteristics of peak horizontal acceleration for 91 earthquakes ($2.5 \leqq M_L \leqq 5.0$) located primarily in California. Of the six attenuation relationships developed in that study, the one considered most reliable is given by the expression:

$$\ln PHA = -2.501 + 0.623M_L - 1.0 \ln[R + 7.28] + \varepsilon$$

where PHA is the mean of the two horizontal components of peak acceleration in g, M_L is local magnitude, R is epicentral distance in kilometers, and ε is a random error term with and standard deviation of 0.506.

To estimate the influences of the diffuse seismicity, the attenuation laws of response spectra, which are based on the ground motion records of small-moderate earthquakes near the source, are needed. Many attenuation laws of response spectra have been developed (Joyner-Boore, 1982; Kawashima-Aizawa-Takahashi, 1984; Ambraseys, 1996; Boore-Joyner-Fumal 1997), but almost all of them did not focus on the characteristics of small-moderate earthquakes near the sources. The present study is on the dependence of response spectra with different damping ratios, on magnitude, hypocentral distance for small-moderate earthquakes and the acceleration records used are in horizontal directions on rock.

THE ACCELERATION RECORDS USED IN THIS STUDY

The acceleration records used in this study are from three parts: strong ground motion data before 1992's, data from SCEC (South California Earthquake Catalog) and NSMP (National Strong Motion Project), all of the records observed in California. The majority of the acceleration data used was scaled directly from accelerograms recorded on SMA-1, RFT-250, S-M and FBA-23 accelerographs. The effective high-frequency recording limits are 25 Hz for SMA-1 and S-M, 20 Hz for RFT-250, and 40Hz for FBA-23.

One-hundred free-field horizontal accelerograms are used for 35 earthquakes ($4.0 \leqq M_L \leqq 6.5$). The information about the earthquakes is shown in Table 1.

Table 1 Earthquake Data

Date (yyyy-mm-dd)	Earthquake	Focal depth	Magnitude (M_L)
1957-03-22	San Fernando earthquake	0.0	5.3
1971-02-09	San Fernando earthquake	8.0	6.5
1975-01-12	Cape Mendocino Earthquake	15.0	4.5
1975-06-07	Humboldt county earthquake	6.0	5.3
1980-05-25	Mammoth Lakes earthquake	9.0	6.1
1980-05-25	Mammoth Lakes aftershock	14.0	6.0
1980-05-25	Mammoth Lakes aftershock	16.0	6.1
1980-05-25	Mammoth Lakes aftershock	2.0	5.7
1980-05-26	Mammoth Lakes aftershock	5.0	5.7
1980-05-27	Mammoth Lakes aftershock	14.0	6.2
1981-04-26	Westmorland earthquake	6.0	5.6
1987-10-01	Whittier Narrows earthquake	9.0	5.9
2001-09-09	West Hollywood, California Earthquake	3.9	4.2
2001-01-14	Pacoima, California Earthquake	5.7	4.3
2001-02-10	Big Bear Lake, California Earthquake	6.0	5.1
2000-12-02	Big Bear City, California Earthquake	2.2	4.1
1998-08-12	San Juan Bautista, California Earthquake	8.0	5.4
2001-02-25	Calaveras Fault, California Earthquake	8.2	4.4
2000-09-03	Yountville, California Earthquake	9.0	5.0
1991-06-28	2021449	9.1	5.8
1994-03-20	3159411	13.1	5.2
1992-09-15	3062563	8.3	5.1
1994-01-19	3142595	14.4	5.1
1994-01-29	3147406	1.1	5.1
1994-03-20	3159411	13.1	5.2
1994-01-21	3143546	7.6	4.3
1994-01-21	3143547	7.7	4.3
1994-01-24	3145168	12.1	4.3
1994-01-29	3147259	2.7	4.3
1994-02-06	3150210	9.3	4.1
1995-06-26	3217586	13.3	5.0
1996-05-01	3263467	14.4	4.1
1997-06-28	9014489	10.0	4.2
1997-04-26	9008753	16.5	5.1
1994-03-20	3159411	13.1	5.2

**: 0.0 of focal depth means this parameter is unknown and the earthquakes from SCEC only have the numbers of events.*

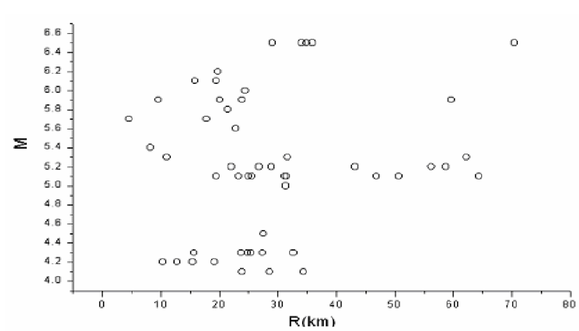

Fig. 1. The distribution of ground motion recordings with respect to magnitude and hypocentral distance for this study.

About the site effects, the accelerograms obtained on hard rock and soft rock are chosen in this study according to site geology.

Table 2 Site Condition Data

Station	Site condition
Pasadena	Early cretaceous massive to gneissoid quartz diorite
Calabasas	Shallow stream-channel alluvium (gravel, sand and clay) on top of soft, marine sedimentary rock
Rancho Palos Verdes	Quaternary sedimentary rock of sand and rubble
Pinyon Flat Observatory	Mesozoic granite, Quartz monzonite, granodiorite, and quartz diorite
Strawberry Peak	Mesozoic granite, Quartz monzonite, granodiorite, and quartzdiorite
Agoura	Tertiary volcanics flow rocks; minor pyroclastic deposites
Redlands; Seven Oaks Dam	Complex of Precambrian igneous and metamorphic rocks. Mostly gneiss and schist intruded by igneous rocks; may be Mesozoic in part
Pleasant Hill; Fire Station No. 2	Sandstone, shale, and conglomerate; mostly well consolidated
Woodside; Filoli Visitor Center	Franciscan complex: Cretaceous and Jurassic sandstone with smaller amounts of shale, chert, limestone, and conglomerate
Wrightwood; Post Office	Complex of Precambrian igneous and metamorphic rocks. Mostly gneiss and schist intruded by igneous rocks; may be Mesozoic in part
Los Angeles; Acosta Residence	Sandstone, shale, siltstone, conglomerate, and breccia; moderately to well consolidated
Lytle Creek; Fire Station	Mesozoic granite, Quartz monzonite, Granodiorite, and quartz diorite
Hollister; SAGO Vault	Mesozoic granite, Quartz monzonite, Granodiorite, and quartz diorite
Redlands; Seven Oaks Dam	Complex of Precambrian igneous and metamorphic rocks. Mostly gneiss and schist intruded by igneous rocks; may be Mesozoic in part
Forest Falls; Post Office	Mesozoic granite, Quartz monzonite, Granodiorite, and Quartz diorite
Poplar Bluff; Fire Station	Tertiary volcanic flow rocks
Los Angeles; Sepulveda Canyon	Shale, sandstone, minor conglomerate, chert, limestone; minor pyroclastic rocks
Benicia; Fire Station No. 1	Upper cretaceous sandstone, shale and conglomerate
Los Angeles; Mullholland Fire Station No. 109	Shale, sandstone, minor conglomerate, chert, limestone; minor pyroclastic rocks
Caltech seismic station, mount Wilson	quartz diorite
Cape Mendocino, Petrolia	cretaceous rock
Garvey reservoir, control bldg	rock
Golden gate park, San Francisco	chert
Griffith park observatory, Los Angeles	granite
Long valley dam upper l abut	rhyolite (layered, blocky)
Long valley dam, up left abut	rhyolite (layered, blocky)
Santa Ana bridge, north abutment	igneous rock - diorite
Shelter cove, sta. 1	cretaceous rock
Superstition mountain	granite
Fairmont reservoir	granite (earth dam)
Fort Tejon	granite
Griffith park observatory, Los Angeles	granite
Lake Hughes, array 4	weathered granite
Lake Hughes, array 9	gneiss
Long valley dam (CR) l. abut	rhyolite (layered, blocky)
Long valley dam (CR) outlet	rhyolite (layered, blocky)
Long valley dam upper l abut	rhyolite (layered, blocky)
Long valley dam(CR) downstream	rhyolite (layered, blocky)
Long valley dam, Dwnstm outlet	rhyolite (layered, blocky)
Long valley dam, left abutment	rhyolite (layered, blocky)
Long valley dam, left crest	rhyolite (layered, blocky)
Long valley dam, up left abut	rhyolite (layered, blocky)
Seismologicallab,Caltech, Pasadena	granite

ATTENUATION RELATIONSHIPS OF RESPONSE SPECTRA

Since the effects of magnitude saturation and distance saturation of high-frequency ground motion near the source can be neglected in this study, attenuation relationships of response spectra with different damping ratios are developed using a least-squares regression analysis based on an expression of the form:

$$\log SA(T,\xi) = C_1 + C_2 M + C_3 \log R + \varepsilon \qquad (1)$$

where $SA(T,\xi)$ is the response spectrum in cm/s^2 with the damping ratio of ξ, M is local magnitude, R is hypocentral distance, and ε is a random error term with zero mean and standard deviation σ.

The results of the regression analyses are summarized in Table 3 to Table 5. The attenuation relationships of response spectra with damping ratio ξ= 0.05 are plotted in Fig. 2 .

Table 3 Results of Regression of the Response Spectra with ξ= 0.005 and ξ= 0.02

	ξ= 0.005				ξ= 0.02			
Period (sec)	C_1	C_2	C_3	σ	C_1	C_2	C_3	σ
0.040	.892	0.437	-1.051	0.275	.828	0.450	-1.081	0.275
0.044	.960	0.444	-1.091	0.307	.862	0.446	-1.071	0.293
0.050	1.056	0.445	-1.120	0.304	.923	0.448	-1.087	0.292
0.060	1.417	0.405	-1.151	0.304	1.233	0.409	-1.098	0.301
0.070	1.330	0.410	-1.062	0.308	1.199	0.408	-1.040	0.299
0.080	1.362	0.396	-0.989	0.305	1.222	0.392	-0.964	0.299
0.090	1.590	0.384	-1.052	0.323	1.485	0.386	-1.087	0.311
0.100	1.349	0.414	-0.987	0.312	1.249	0.412	-0.996	0.304
0.120	1.389	0.411	-0.999	0.310	1.250	0.421	-1.025	0.304
0.150	1.097	0.468	-0.968	0.309	1.041	0.459	-0.978	0.304
0.200	.454	0.550	-0.883	0.350	.455	0.538	-0.916	0.342
0.240	.261	0.593	-0.948	0.396	.279	0.578	-0.983	0.376
0.300	-.186	0.618	-0.787	0.343	-.217	0.616	-0.831	0.337
0.340	-.217	0.641	-0.865	0.350	-.223	0.634	-0.915	0.343
0.400	-.034	0.620	-0.958	0.382	-.218	0.636	-0.958	0.374
0.440	-.329	0.671	-0.972	0.408	-.351	0.667	-1.014	0.391
0.500	-.190	0.657	-1.063	0.398	-.275	0.656	-1.078	0.394
0.600	-.323	0.653	-1.059	0.420	-.421	0.663	-1.095	0.405
0.700	-.462	0.723	-1.283	0.414	-.519	0.719	-1.298	0.401
0.800	-.472	0.729	-1.397	0.418	-.642	0.738	-1.368	0.406
0.900	-1.145	0.794	-1.253	0.406	-1.117	0.789	-1.305	0.403
1.000	-1.258	0.808	-1.261	0.408	-1.356	0.815	-1.278	0.395
1.500	-2.232	0.872	-1.074	0.409	-2.155	0.863	-1.143	0.396
2.000	-2.700	0.912	-1.084	0.406	-2.662	0.898	-1.093	0.393
3.000	-3.296	0.963	-1.137	0.420	-3.183	0.939	-1.146	0.409
4.000	-3.925	1.025	-1.094	0.434	-3.763	0.991	-1.091	0.419

Table 4 Results of Regression of the Response Spectra with ξ= 0.05 and ξ= 0.1

	ξ= 0.05				ξ= 0.1			
Period (sec)	C_1	C_2	C_3	σ	C_1	C_2	C_3	σ
0.040	.828	0.450	-1.081	0.275	.738	0.459	-1.065	0.284
0.044	.862	0.446	-1.071	0.293	.762	0.456	-1.058	0.289
0.050	.923	0.448	-1.087	0.292	.839	0.449	-1.064	0.288
0.060	1.233	0.409	-1.098	0.301	1.028	0.424	-1.059	0.297
0.070	1.199	0.408	-1.040	0.299	1.065	0.416	-1.025	0.297
0.080	1.222	0.392	-0.964	0.299	1.120	0.401	-0.985	0.296
0.090	1.485	0.386	-1.087	0.311	1.282	0.401	-1.070	0.300

0.100	1.249	0.412	-0.996	0.304	1.155	0.417	-1.019	0.304
0.120	1.250	0.421	-1.025	0.304	1.134	0.423	-1.027	0.302
0.150	1.041	0.459	-0.978	0.304	.926	0.457	-0.979	0.309
0.200	.455	0.538	-0.916	0.342	.392	0.534	-0.929	0.330
0.240	.279	0.578	-0.983	0.376	.203	0.571	-0.976	0.355
0.300	-.217	0.616	-0.831	0.337	-.166	0.606	-0.903	0.336
0.340	-.223	0.634	-0.915	0.343	-.250	0.628	-0.950	0.342
0.400	-.218	0.636	-0.958	0.374	-.359	0.642	-0.957	0.364
0.440	-.351	0.667	-1.014	0.391	-.368	0.649	-1.012	0.377
0.500	-.275	0.656	-1.078	0.394	-.356	0.653	-1.080	0.385
0.600	-.421	0.663	-1.095	0.405	-.451	0.659	-1.127	0.388
0.700	-.519	0.719	-1.298	0.401	-.568	0.703	-1.274	0.388
0.800	-.642	0.738	-1.368	0.406	-.748	0.734	-1.339	0.391
0.900	-1.117	0.789	-1.305	0.403	-1.128	0.781	-1.317	0.394
1.000	-1.356	0.815	-1.278	0.395	-1.373	0.807	-1.296	0.382
1.500	-2.155	0.863	-1.143	0.396	-2.055	0.844	-1.185	0.376
2.000	-2.662	0.898	-1.093	0.393	-2.540	0.868	-1.096	0.372
3.000	-3.183	0.939	-1.146	0.409	-2.929	0.889	-1.138	0.382
4.000	-3.763	0.991	-1.091	0.419	-3.358	0.920	-1.100	0.394

ξ= 0.2				
period (sec)	C_1	C_2	C_3	Σ
0.040	.624	0.469	-1.042	0.290
0.044	.641	0.467	-1.039	0.290
0.050	.688	0.463	-1.046	0.290
0.060	.767	0.455	-1.050	0.292
0.070	.825	0.443	-1.030	0.292
0.080	.871	0.434	-1.018	0.294
0.090	.884	0.434	-1.016	0.295
0.100	.877	0.434	-1.007	0.297
0.120	.823	0.443	-0.999	0.302
0.150	.578	0.478	-0.959	0.308
0.200	.247	0.526	-0.939	0.316
0.240	.085	0.548	-0.945	0.333
0.300	-.081	0.578	-0.985	0.334
0.340	-.207	0.597	-0.996	0.334
0.400	-.332	0.614	-1.011	0.339
0.440	-.374	0.619	-1.027	0.343
0.500	-.409	0.625	-1.067	0.351
0.600	-.478	0.638	-1.133	0.354
0.700	-.613	0.661	-1.187	0.357
0.800	-.756	0.681	-1.214	0.356
0.900	-.964	0.705	-1.210	0.353
1.000	-1.138	0.722	-1.199	0.348
1.500	-1.528	0.733	-1.145	0.333
2.000	-1.802	0.738	-1.096	0.322
3.000	-1.992	0.736	-1.116	0.327
4.000	-2.118	0.727	-1.109	0.329

Table 5 Result of Regression of the Response Spectrum withξ= 0.2.

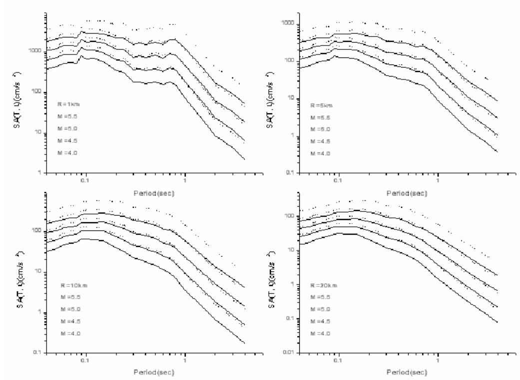

Fig. 2. Attenuation relationships of response spectra with damping ratio of ξ=0.05.

(The solid lines are mean values and the dotted lines are results of mean value+σ)

CONCLUSION

To meet the need of estimation of response spectra produced by small-moderate earthq-uakes for nuclear power plants, the attenuation laws, which are based on the ground motion records of small-moderate earthquakes near the source, are developed. The records used in this study are from the three parts: strong ground motion data of the California of USA before 1992's; data of South California Earthquake Catalog; National Strong Motion Project of USA. The records on rock site with magnitude between 4.0 to 6.5 and hypocentral distance less than 70 km are selected for developing the attenuation laws.

Response spectra with damping ratios of 0.005, 0.02, 0.05, 0.1 and 0.2 of small-moderate earthquakes near the source can be estimated by these attenuation laws in seismic hazard analysis of nuclear power plants.

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SEISMIC EARLY WARNING SYSTEMS FOR OIL AND GAS PIPELINES

Oktay Babazade, Lothar Griesser, and Martin Wieland

Abstract

Similar to other structures, pipelines may be damaged by earthquakes. Moreover, oil and gas pipelines as well as other petrochemical installations might be destroyed by a subsequent fire. This happened to the oil refinery in Izmit, Turkey, following the magnitude 7.4 Kocaeli earthquake on August 17, 1999.

At an earthquake, the first effect are vibrations of the ground. Buildings are mainly affected by them. With regard to pipelines, damage is more likely caused by landslides, rock falls, ground movements and similar effects. These are referred to as secondary effects of earthquakes. Therefore, any strategy of pipeline protection against earthquakes should emphasize on these secondary effects.

With regard to the environmental impact, the oil spill caused by a leaking pipeline, especially offshore, results in considerable ecological consequences. With gas pipelines there is a major fire hazard. At offshore gas production, the highest risk is a pipeline rupture near the platform. The consequences of fires at offshore platforms were tragically demonstrated by the Piper Alpha accident in the North Sea in 1988.

In economic terms a large oil pipeline may transport 5'000 tons of oil per hour. Expressed in energy figures this corresponds to roughly 50'000 MW or 50 large nuclear power plants. Considering the huge economic assets involved there are two main requirements:

a. Maintaining the integrity of the pipeline because a pipeline rupture would result in the unavailability of the pipeline for an extended period of time.
b. Uninterrupted oil flow. If at an earthquake it appears too risky to continue normal operation, it is preferred to maintain at least a reduced flow.

The Earthquake Pre-warning System (EPS) was developed by Electrowatt Engineering, Zurich, for nuclear power plants. Suitable modified it can be applied for the protection of oil and gas pipelines against earthquakes. The EPS for pipelines includes seismic and displacement sensors. It will be integrated in the SCADA system. In this case it provides the following advantages:

- The risk of oil spills and, for gas pipelines, the fire hazard are reduced.
- The risk of pipeline integrity failure is reduced by the "Pressure Relief Before Break" principle implemented in the EPS.
- Depending on the size of the earthquake, a reduced flow can be maintained.

In the present paper mainly oil pipelines are addressed while corresponding considerations can be made for gas pipelines, offshore platforms and other petrochemical installations.

EARTHQUAKES, EFFECTS ON PIPELINES

Earthquakes generate seismic waves, which propagate in the earth and on the surface. The primary compressive or P-waves usually do not cause structural damage because they have small amplitudes and high frequencies. More destructive power in the epicentral region is produced by the shear or S-waves due to the high amplitude of the ground motion and the relatively low frequencies, which are in the order of the eigenfrequencies of typical structures. The seismologists and earthquake engineers are able to estimate the characteristics of seismic waves at a given site for specific types of earthquakes, wave attenuation, dynamic soil structure interaction, peak values of the ground motion and floor response spectra for the seismic design of the equipment. According to the present state-of-the-art, methods are available for designing structures against seismic waves and, presumably, these rules are observed. With regard to pipelines, the stresses induced by seismic waves are usually of minor importance for the following reasons:

1) In transverse direction, pipelines have a considerable flexibility. At underground pipelines, any transverse oscillation is attenuated by the surrounding medium.
2) In longitudinal direction, the stress caused by internal pressure is generally much lower compared to the circumferential direction. Any additional stress caused by seismic waves in longitudinal direction is easily absorbed by the piping material.

Pipelines are more seriously affected by another aspect of earthquakes, the secondary seismic effects:

- earthquake-triggered landslides, rock falls and ground movements at faults or due to soil liquefaction;
- flood waves due to the failure of dams in the vicinity of the pipeline;
- offshore pipelines are susceptible to subsea earthquakes which can cause tsunamis and turbidity currents at submarine slopes.

Investigations have been carried out for potential landslides, which are traversed by a pipeline

(Bruschi et al., 1995), but not for mass movements, which can be activated during an earthquake in mountainous regions. For example in the epicentral region of the 1990 Manjil earthquake (magnitude 7.5) in the Alborz mountain region located in the south of the Caspian Sea, several hundred rockfalls occurred and a small diameter fuel pipeline was punctured by a rockfall. It should be noted that the site selection of pipelines is dictated by the required transport route. In most cases the pipeline routing cannot be modified under seismic aspects, whereas nuclear power plants for instance can be sited to avoid damage by earthquakes. This aspect is specifically important with regard to existing pipelines where seismic effects have been underestimated at the design stage.

The secondary seismic effects, which are fairly unpredictable, are usually not covered by design regulations and, therefore, have often not been taken into account in the design of pipelines.

In most countries, the earthquake activity is monitored continuously by national institutions. These do not provide indications as to structural damage and the earthquake parameters are available after several hours only. Early warning systems have been installed or are being implemented (Erdik, 2000). These systems are extremely useful for saving lives. However, for immediate actions on pipelines and other installations of the oil industry, dedicated systems are needed.

EARTHQUAKE PRE-WARNING SYSTEM FOR NUCLEAR POWER PLANTS

For nuclear power plants (NPPs) there is a long history of design against earthquakes. Two levels, Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE), are taken in consideration. After the OBE the NPP shall be able to continue normal operation. At an SSE the systems required for shutting down the plant shall remain intact. In Central Europe typical peak ground acceleration (PGA) values are 1 m/s² for OBE and 2 m/s² for SSE. In the Caucasus region, Turkey and the Far East, PGA values of 5 m/s² or more may have to be considered for the SSE. The construction of buildings and components for the high SSE accelerations can be extremely costly. This is specifically valid for existing NPPs if they are found to be seismically underdesigned. However, the determination of the SSE acceleration at a specific site is ambiguous because such strong earthquakes are extremely rare.

A method of eliminating this ambiguity is the Earthquake Pre-Warning System (EPS). Such a system was installed at the NPP of Ignalina in Lithuania (Wieland et al., 1997).

The EPS for NPPs consists of seismic stations, which are placed at a distance of 50 km from the NPP. Each station includes seismic sensors and digitisers as shown in Figure 1. The digital signal is fed to the differentiation software processor. The software is able to distinguish between seismic and non-seismic events. The required processing time is 2 seconds. This is by far less than the time which would be required for the calculation of the complete set of earthquake parameters. The signal is transmitted to the NPP by radio waves, which requires practically no time.

The seismic sensors are housed in a small cubicle with a length of 2.5 m (Figure 2).

Considering the wave propagation velocity of the seismic shear waves of roughly 5 km per second and a distance of 50 km between the seismic sensors and the NPP, the earthquake is detected 10 seconds before the arrival at the site. With the software processing time of 2 seconds, 8 seconds remain for pre-warning before the arrival of the damaging seismic waves. In NPPs the reaction can be stopped rapidly by insertion of the control rods into the reactor and 8 seconds are sufficient for this.

EARTHQUAKE PRE-WARNING SYSTEM FOR PIPELINES, PRESSURE-RELIEF-BEFORE-BREAK PRINCIPLE

Similar to nuclear power plants the benefits of earthquake pre-warning can also be utilized for pipelines. The EPS for pipelines consists of seismic sensors installed along the pipeline (see Figure 3). In hazardous seismic zones, additionally, deformation sensors are installed on the pipeline. A proprietary fibre optic cable system is applied for this. The sensor signals are transmitted to a central processing unit (CPU). The existing SCADA system of the pipeline is used for signal transmission. A proprietary EPS software installed on the CPU controls the following pipeline components:

- Pipeline pumps, partial or full stop
- Pump discharge and suction valves
- Block valves if they are motorized [1])
- Other pipeline safety installations.

Let us now consider the behaviour of pipelines in case of earthquakes. Figure 4 shows the scenario if no EPS is installed. The normal operation stress in the pipeline by the internal pressure and by other loads is taken as 100%. In case of an earthquake first the seismic waves hit the pipeline.

[1]) Any pipeline control action has to take into account the water hammering phenomena.

As outlined in Section 1, no damage is expected from that. Landslides and other secondary seismic effects, which are more important for pipelines, require some time to develop. It is anticipated that a landslide might hit the pipeline 40 seconds after the earthquake. At that time, the stress in the pipeline starts to increase due to the deformations caused by the landslide. Shortly afterwards the fracture stress, which is assumed to be 150% of the normal operation stress, might be reached and the pipeline breaks.

Figure 5 shows the scenario if an EPS is installed on pipeline sections in hazardous seismic zones. The pipe stresses are at the maximum immediately after the pumps and this is considerate the most vulnerable location from the view of pipe stresses. The pipeline elevations have a considerable influence on the pipeline pressure and there for on the pipe stresses. Hence, the assessment of the critical pipeline location has to be done based on the layoud of the pipeline, the distance from pumping stations and the seismicity along the pipeline. A typical oil pipeline section consists of pump stations every 100 km and block valves every 10 km. The following considerations are made for a reference point arbitrarily selected at a distance of 30 km downstream of a pump station. When an earthquake is detected by the sensors of the EPS, certain control actions are issued. For example at moderate earthquakes the pipeline pumps will be stopped partially. This reduces the flow in the pipeline and the oil velocity to 50% for instance. Due to the fact that the pressure loss is proportional to the square of the velocity, the pressure would be reduced to 25% of the previous value. However, the stresses in the pipeline do not depend on the fluid pressure only but on other loads too. Therefore, it is assumed that the stress in the pipeline is reduced to 50% in this case.

According to the Joukowski formula [2]) the propagation velocity of pressure surges is 1 km/s. Therefore, as demonstrated in Figure 5, the pressure reduction caused by the pump stop at the reference point, 30 km downstream of a pumping station, will commence 30 seconds after the pump stop. When the landslide or other secondary seismic effects hit the pipeline, the pressure is already reduced. This procedure is designated as Pressure-Relief-Before-Break principle. From Figure 5 it is evident that pipeline breaks can be avoided by the Earthquake Pre-Warning System combined with the Pressure-Relief-Before-Break principle.

The EPS action are configured in two steps. The first step outlined above and consisting of partial pump stop shall be activated in the case of moderate earthquakes. In this case a partial production flow can be maintained. In the case of very strong earthquakes, a total pump stop shell be activated resulting in a total interruption of the oil flow. A total pump stop shell also be activated if the displacement sensors of the EPS in the case undue displacement of the pipeline. In the case it is recommended to close the block valves adjacent to the displaced section of the pipeline. This has to be done slowly in order to avoid undue water hammering. The bloc valves shell also be closed if the flow and pressure indicators of the pipeline SCADA system indicated a pipeline break.

If hazardous seismic zone is located far down stream of a pumping station, the pressure reduction by pump stop requires too much time to travel to the endangered pipeline location. In this case the pipeline is to be equipped with pressure relief valves this collecting basin.

Ground movements at faults have a small delay time compared to other secondary seismic effects. Therefore, fast acting relief valves controlled by the EPS may be required at pipeline fault crossings. Additionally, flexible pipeline sections might be installed.

Considering the huge environmental impact of an offshore oil spill, special pipeline safety systems are recommended here in addition to the EPS. Such safety systems consisting of check and ball valves have been installed, for example, in the North Sea (Masheder, 1995). Pipelines are usually equipped with a SCADA system. The sensor signals, control system and commands of the EPS will be integrated in the SCADA system.

Pipelines are usually equipped with a SCADA system. The sensor signals, control system and commands of the EPS will be integrated in the SCADA system.

ECONOMIC CONSIDERATIONS, RELIABILITY OF THE EPS

A large oil pipeline may transport 5'000 tons of oil per hour. Expressed in energy figures this corresponds to roughly 50'000 MW or 50 large nuclear power plants. With gas pipelines, the corresponding figures are somewhat lower but still quite important. Considering the huge economic assets of pipelines there are two main

[2]) Pressure surge propagation velocity: $a = [Ef/\rho/(1+Ef/Ep \times D/s \times (1-\mu^2)]^{0.5}$ Modulus of elasticity: fluid Ef 1.2×10^9 Pa, pipe material steel Ep 2.1×10^{11} Pa, Poisson's ratio μ 0.3, fluid density ρ 800 kg/m^3, pipe diameter D 1m, wall thickness s 10mm (reference values). Therefrom a = 1'000 m/s

requirements concerning the behaviour of pipelines in case of an earthquake:

1) The integrity of the pipeline is to be maintained also at strong earthquakes because a pipeline rupture would result in the unavailability of the pipeline for an extended period of time.
2) The oil flow shall not be interrupted. If at an earthquake it appears too risky to continue normal operation, it is preferred to maintain at least a reduced flow.

The EPS combined with the Pressure-Relief-Before-Break principle fulfils these requirements by the configuration in two steps, partial/full pump stop.

In order to minimize the economic losses, the reliability of the EPS is of major concern. An investigation using the fault tree method has shown that the number of spurious signals of the EPS is extremely low so that the economic losses by unreliability of the EPS can be disregarded.

In order to keep the high reliability, the EPS must be fully maintained and checked at regular intervals.

ENVIRONMENTAL ASPECTS

Considering the huge number of oil and gas pipelines in the world, the number of accidents with environmental damage is surprisingly low. A failure report of the pipelines in the English Channel indicates that the majority of the failures is attributed to crossing vessels, especially to anchoring operations (Thygesen et al., 1990). However, this depends strongly on the local conditions and in areas of high seismicity the earthquake risk might be the most important aspect. In 1998, a pipeline failure caused by an earthquake happened at the Santa Clara River in California with an oil spill of 900 tons (Los Angeles Times, 1998).

We are not a position to asses the environmental impact of an oil spill in the Caspian Sea and the neighbouring countries.

Generally, the following aspects should be taken in consideration in that respect:

- Seismicity of the region
- Subsea earthquakes, tsunamis and subsea landslides can endanger offshore pipelines. Offshore oil production can induce subsea landslides.
- Failure of dams near pipelines.

Some conclusions can be drawn from these remarks. In order to protect the environment from large oil spills and in order to protect the offshore platforms from accidents, the following measures should be taken:

- Due to the high seismicity, special precautions should be taken at the existing onshore pipelines because of questionable Soviet design.
- Concerning the new onshore pipelines, measures are highly recommended to be taken due to the vicinity to Ganja and to Mingechaur dam, and Georgia-Turkish section of oil and gas pipelines from Baku to Geyhan passing through high-risk seismic areas (Babazade, 1998).
- At the offshore pipeliones and platforms, measure are recommended due to the major environmental impact of oil spills in the Caspian Sea.

On the national level, some measures should be taken:

- The national seismic networks in the area should be upgraded in order to improve the assessment of the seismic risks.
- Considering the transnationality of the pipeline installations – and of the earthquakes, the cooperation of the countries in the world should be intensified. Initiatives in that respect have been taken (Babazade, 2000), but are not completely realised yet. The installation of well-developed national seismic networks consisting of seismometers with digitisers and wireless data transmission to a central receiving station could be combined with the earthquake pre-warning system.

CONCLUSIONS

In order to protect the environment from large oil spills, the following measures should be taken:

- Concerning new onshore pipelines, the installation of an EPS is highly recommended in areas of high seismicity, near faults and in the vicinity of dams.
- At offshore pipelines, the installation of an EPS is recommended in areas of moderate seismicity due to the major environmental impact of offshore oil spills. Additionally, special pipeline safety systems shall be installed in areas of high seismicity (Masheder, 1995).
- At existing onshore pipelines, an EPS should be installed in areas of moderate to high seismicity because of sometimes questionable design
- With oil and gas production in seismic active regions, the seismicity should be thoroughly

investigated on an international level (Babazade, 1998, 2000)

In view of the huge economic assets of pipelines, an EPS with Pressure-Relief-Before-Break should be implemented on all new pipelines in hazardous seismic zones.

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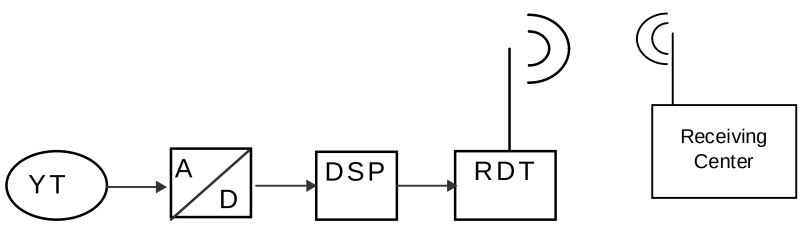
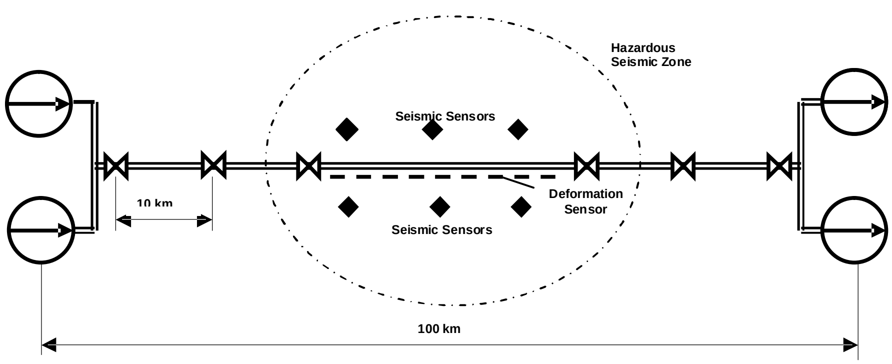


YT = seismic sensor DSP = differentiation software processor

A/D = digitiser RDT = radio data transmitter



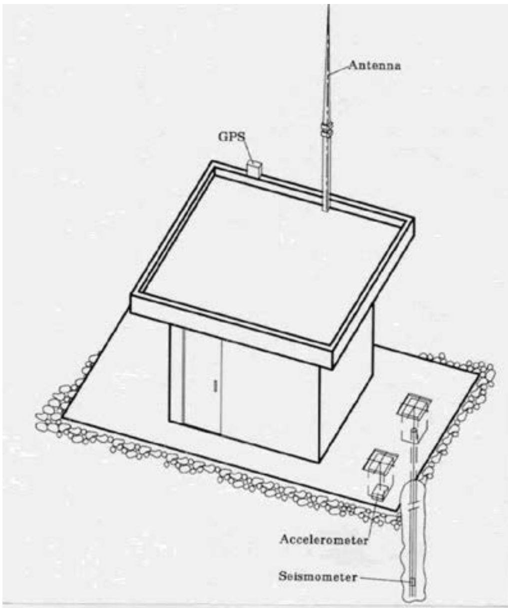


Fig. 1 Block diagram of earthquake pre-warning system

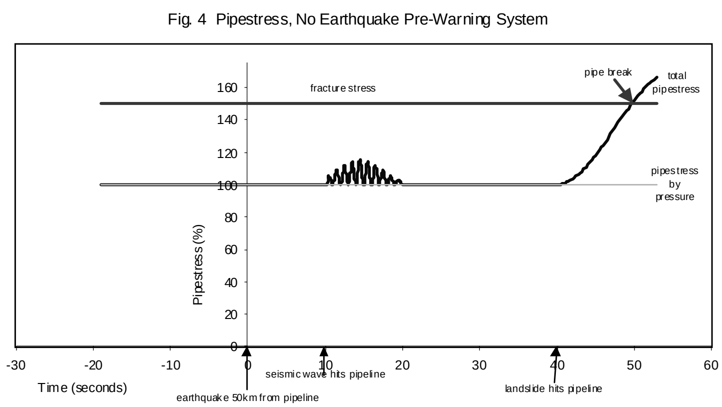


Fig. 2 Architectural view of earthquake pre-warning seismic sensor station

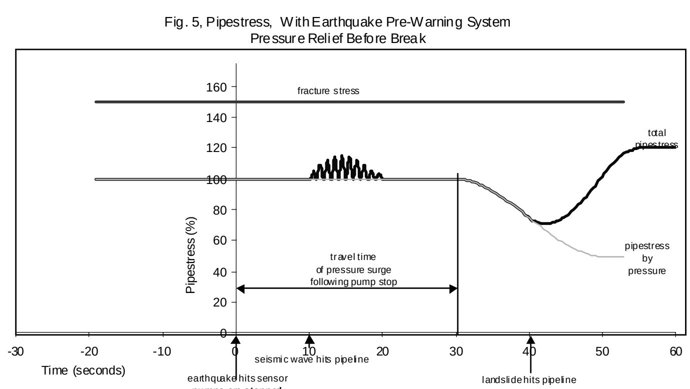


Fig. 3 Earthquake Pre-warning System for Oil Pipelines

STRONG MOTION OBSERVATIONS IN INDIA - SYNTHESIS OF RESULTS

B. K. Bansal[1], G. D. Gupta, and H. N. Srivastava [2]

Abstract

During the last two decades strong motion arrays have been installed in various parts of Himalaya including NE India through the Department of Science & Technology. Several moderate earthquakes have been recorded by these networks, which have brought out interesting results about the pattern of attenuation of ground acceleration in these regions. The networks are being strengthened further covering the entire Indian region. Significant improvement in the strong motion data have been made possible with the installation of digital accelerographs with GPS timing systems.

The paper presents the strong motion results of Bhuj (2001) and other earthquakes recorded at Delhi, Ahmedabad, Koyna region, besides Himalaya and NE India. The most interesting results pertain to the distinct difference in the attenuation characteristics in the Himalayan region vis-à-vis NE India. Closer examination of results in western Himalaya brings out differences in the attenuation pattern between Himachal Pradesh and Uttaranchal regions.

The paper also summarizes the methods used to synthesize expected ground motions by random summation of the Empirical Green's Function and the stochastic methods for different site conditions in Delhi due to a possible great earthquake (M=8.0) in the central Himalaya. It is concluded that for reliable assessment of strong ground acceleration, the network of stations needs further improvement.

INTRODUCTION

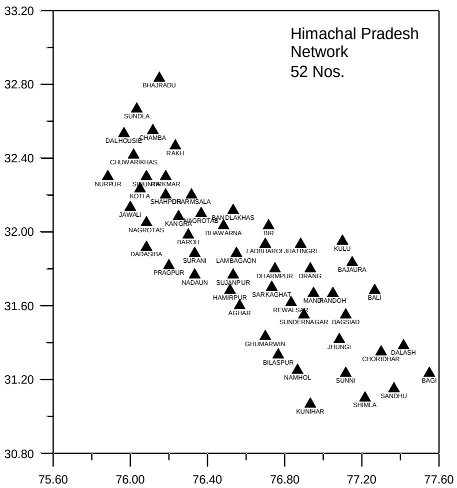
Strong motion observations are concerned with earthquake ground motion in the amplitude range that poses the threat of human injury and/or property damage. Due to the engineering need for estimates of future ground motion, the scope of the field of strong motion seismology encompasses seismic source theory and other aspects of seismology which are helpful in making the best possible estimates with the limited data.

Strong ground motion is generally described in terms of the peak horizontal acceleration and some times by peak horizontal velocity, or in terms of the Fourier amplitude spectrum. Another description, widely used for engineering purposes, is the response spectrum, which is defined as the peak responses, to the given motion, of a set of single degree of freedom oscillators of different natural periods and damping. The oscillators are intended to represent simple models of structures, and the responses spectrum is thereby a compact description of the potential effect of the motion on structures. The factors affecting strong motion are source, propagation path, and site response followed by methods for simulating and estimating strong motion. In this connection, Srivastava (1988) compared the ground motion characteristics of the great Mexican earthquake vis-à-vis great Indian earthquakes and brought out the generation of a secondary meizoseismal area about 250 to 300 km away from the epicenter of the main earthquake. In such regions, the vulnerability of tall structures assumes great importance. However, earthquakes of damaging intensity (M= 7.6) may also occur locally and cause significant damage to shorter structures as well. This would suggest the need to cover different regions with a closer network of acelerographs.

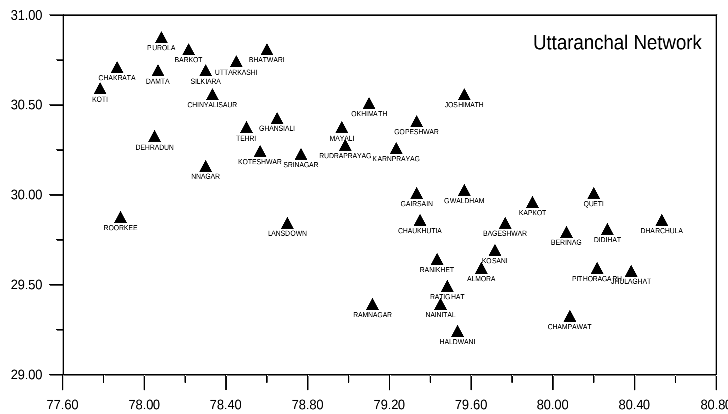
STRONG MOTION ARRAYS AND ACCELEROGRAPHS IN INDIA

Fig. 1 (a), (b) and (c) show the strong motion arrays in the Himalayan region funded by the Department of Science & Technology and operated by the Indian Institute of Technology (IIT), Roorkee. A network of accelerographs has also been installed in the Koyna region. The total number of accelerographs in India is more than 250 which are being maintained and operated by various agencies including, Indian Institute of Technology, Roorkee, India Meteorological Department, National Geophysical Research Institute, River valley projects and other institutions. The networks are being strengthened further. IIT Roorkee also operates a few indigenously designed accelerographs and structural response recorders. The response characteristics of Indian national strong motion instrumentation network (INSMIN) accelerographs broadly compared with that of similar imported analogue systems. The triggering of INSMIN network due to Uttarkashi (1991) earthquake also gave comparative accelerations as obtained with the imported systems (Chandra et al, 1995).

The first strong motion record in India was obtained by the analog type accelerograph due to Manipur-Burma earthquake of 1954 (M= 7.0) which had similar depth (about 100 Km) as the earthquake of August, 1988, occurred near Indo-Burma border. The later earthquake was recorded by several accelerographs in northeast India. Prior to this, the Kangra array was triggered by the Dharamshala earthquake of 1986, followed by the Uttarkashi earthquake, 1991 (Uttaranchal array), Chamoli earthquake, 1999, Koyna 1967 and Bhuj earthquakes, 2001 and a few others in northeast India. Several earthquakes of slight to moderate intensity have generated acceleration data in the Koyna, Bhuj and Delhi regions, which show distinct regional variations. Tables 1 & 2 give the peak ground acceleration recorded due to Dharamsala, Uttarkashi and Bhuj earthquakes.



Department of Earthquake Engineering, Indian Institute of Technology, Roorkee has been prepared along with the locations of the recording stations. Each record has been analysed and various strong motion parameters for all the records have been tabulated along with other relevant information about the earthquake. The archive has been prepared in the HTML format. In future, the data of future earthquakes will also be included in this archive.



The data have been used to prepare an Atlas of strong motion data for the Indian region. An index of all the Indian earthquakes recorded by strong motion instruments network operated by

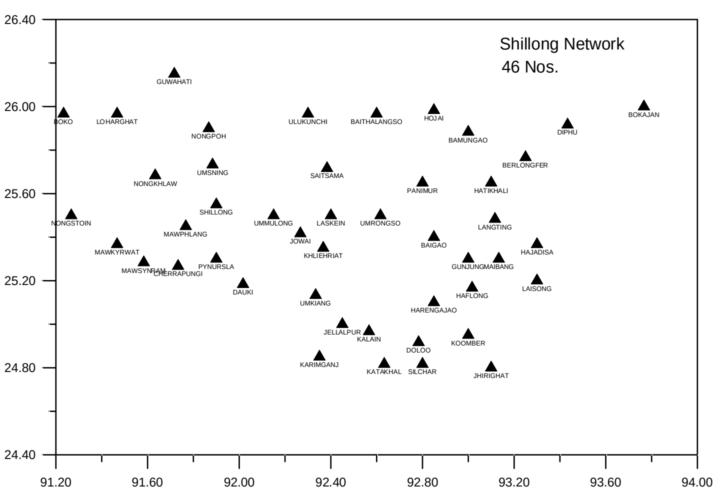


Table-1

Peak accelerations of the horizontal components recorded in 1986 Dharamsala earthquake (Chandrasekharan and Das, 1992 a).

Station	Epicentral Distance km)	Hypocentral Distance (km)	a_{max} – L a_{max} – T(cm/s^2)	Mean (cm/s2)	Resultant (cm/s2)
Bandlakhas	24.40	25.38	142.49 122.36	132.4	144.0
Baroh	19.55	20.77	57.56 56.17	56.9	60.4
Bhawarna	24.40	25.38	36.49 34.72	35.6	38.0
Dharamsala	5.39	8.83	172.21 182.89	177.6	237.6
Jawali	26.40	27.31	14.87 16.55	15.7	18.7
Kangra	8.80	11.24	144.97 109.43	127.2	157.4
Nagrota-Bagwan	11.43	13.40	145.54 78.59	112.1	145.6
Shahpur	10.08	12.27	200.17 243.20	221.7	263.9
Sihunta	23.28	24.31	50.41 35.32	42.9	57.0

Table-2

Peak accelerations of the horizontal components recorded in 1991 Uttarkashi earthquake (Chandrasekharan and Das, 1992 b).

Station	Epicentral Distance (km)	Hypocentral Distance (km)	a_{max} – L a_{max} – T (cm/s^2)	Mean (cm/s2)	Resultant (cm/s2)
Uttarkashi	159.46	159.77	17.41 21.02	19.22	22.27
Barkot	53.07	54.00	93.18 80.47	86.83	103.88
Bhatwari	16.75	19.51	248.37 241.89	245.13	271.63
Ghansiali	41.68	42.86	115.59 114.89	115.24	141.98
Karnprayag	73.26	73.94	60.99 77.35	69.17	84.74
Kosani	149.22	149.56	28.34 31.50	29.92	31.58
Koteshwar	64.06	64.84	98.85 65.23	82.04	99.08
Koti	97.79	98.30	20.64 40.95	30.80	41.09
Purola	72.83	73.51	73.95 91.68	82.82	96.13
Rudraprayag	59.88	60.71	52.29 50.76	51.53	65.27
Srinagar	62.06	62.86	65.44 49.45	57.45	65.77
Tehri	52.47	53.51	71.41 61.13	66.27	73.63
Uttarkashi	33.36	34.83	237.27 303.99	270.63	313.09

Table-3

Pgak of bhuj earthquake recorded at some of the gsn stations of imd and Cbri network

(Bhuj earthquake DST/IMD Report 2002)

Station	Distance (Km)	PGA (Vertical) (cm/sec**2)	PGA (Radial) (cm/sec**2)	PGA (Transverse) (cm/sec**2)
Pune (IMD)	654	4.40	5.23	4.94
Bhopal (IMD)	731	3.61	3.02	3.86
Karad (IMD)	788	1.85	1.84	3.26
Chennai (IMD)	1553	0.78	0.99	1.50
Bokaro (IMD)	1593	0.62	1.47	1.40
Thiruvananthapuram(IMD)	1794	0.11	0.13	0.17
Panipat (CBRI)	944	4.66	8.73	9.01
Roorkee (CBRI)	1041	1.60	4.11	4.00

ATTENUATION CHARACTERISTICS OF STRONG GROUND MOTION

It was found that the vertical component recorded strongest acceleration in Himalayas – Uttarkashi earthquake, 1991. The pattern of attenuation and normalized shape of response spectra were similar to that observed in Kangra region. However, different attenuation properties were inferred from these two earthquakes (Kumar et al, 1997). Also, attenuation characteristics were different for North West India as compared to the two regions i.e. northeast and central Himalaya. It was noted that the attenuation is much faster in NW Himalaya as compared to NE India, which is an important result from the point of view of earthquake resistant designs.

The shape of spectra as recommended by USNRC shows that in the short period ranges from 0.04 to 0.25, the values are larger than USNRC and at long periods, the values are lower. The vertical component shows the same trend as horizontal component, but beyond 0.45 sec period, it is larger than horizontal component in northeast India. A comparison of McGuire's attenuation relationship in northeast India showed that McGuire's relationship does not fit with the recorded data for all the events. (Chandrasekharan and Das, 1992 c).

Attenuation studies were also carried out for Delhi region using strong motion data. A frequency dependent Qc value ($Qc=252f^{0.82}$) was found. A regression model, which takes care of depth as well as local ground condition along with other parameters, is given by

$$\log(Y) = a_0 + a_1M + a_2r + a_3\log(r) + a_4H + c_1$$

where 'H' is the depth in kilometers of the point in fault plane that is closest to the recording site, 'c' is a co-efficient representing the local site effect at the recording site, r is the epicentral distance and a0, a1, a2, a3 and a4 are regression coefficients.

Pandey et al (2001) found that the pattern of decay in peak ground acceleration for Uttarkashi (1991) and Chamoli earthquakes was similar for increasing epicentral distance.

A few attempts have been made to utilize the strong motion data generated in the Indian region and the attenuation relationships have been worked out.

MODELLING OF ACCELEROGRAMS

There are several techniques for simulation and estimation of strong ground motion namely:

(i) Auto regressive moving average (ARMA) methods (stochastic simulation of ground motion)
(ii) Composite source model
(iii) Empirical green's function approach to synthesize the strong ground motions from sub-events or small earthquakes.

Several methods are available for calculating green's functions for earth models in which the material properties vary only with depth. Toki et al (1985) suggested a method to synthesize strong ground motion from the records of microearthquakes.

Based on the analysis of strong motion data due to Uttarkashi earthquake, Khattri et al (1994) estimated the hazard due to the great earthquake in the seismic gap of central Himalayan. Kumar et al (1999) extended this result using a semi empirical method.

Singh et al (2003) used two finite source stochastic models. In this method, the strength factor is physically related to the maximum slip rate on the fault. Their conclusions were as follows:

i. The stress $\Delta\sigma$ that explains AMAX data for shield events may be a function of depth, increasing from ~50 bars at 10 km to ~400 bars at 36 km. The corresponding strength factor values range from 1.0 to 2.0. The $\Delta\sigma$ values for the two Himalayan events are 75 and 150 bars

ii. The $\Delta\sigma$ required to explain VMAX data is, roughly, half the corresponding value for AMAX, while the same strength factor explains both sets of data

iii. The available far-field AMAX and VMAX data for the Bhuj mainshock are well explained by $\Delta\sigma$ =200 and 100 bars, respectively, or, equivalently, by strength factor = 1.4. The predicted AMAX and VMAX in the epicentral region of this earthquake are 0.80 – 0.95 g and 40-55 cm/s, respectively.

Strong motion data generated for Chamoli earthquake (1999) was also used for estimation of ground motion in Delhi from possible future large/great earthquakes in the Central seismic gap in the Himalaya. The results showed that the maximum acceleration value at the "hard" sites are 3 to 4 times less than the "soft" sites while maximum velocity are roughly 2 to 3 times at "soft" sites as compared to the "hard" site. Singh et al (2002) compared their results with that of Kumar et al (1999) and brought out significant differences.

It may be of interest to note that Shrikhande et al (2001) found that the predominant site period and the spectral amplification was quite different during main shock and aftershocks. They inferred that the use of weak motion/aftershock records may lead to erroneous conclusions regarding the expected ground motion during a strong earthquake.

LIMITATIONS OF RESULTS IN THE INDIAN REGION

The results have limitations due to:

i. Availability of strong motion data only in a few specified region

ii. No data is available for earthquakes of magnitude greater than 6.8

iii. Ground motion simulation results are preliminary due to sparse data

Also, limited utilisation of available data has been made so far particularly for many seismological applications like improvement of epicentral parameters (Srivastava, 1989), local magnitude and source parameters. It is interesting to note that Wood Anderson magnitude of 7.6 was obtained from strong motion data for the Bhuj earthquake of 2001 (I.D. Gupta, personal communication). This magnitude remarkably agreed with the moment magnitude. However, from weak motion broad band digital instruments from Gujarat seismological stations (where Wood Anderson instruments are operating within 600 Kms), the magnitudes ranged from 6.9 to 7.1 only. Srivastava et al (1994, 1996) have shown that earthquakes in the Indian region are generally chaotic but their simulations for strong ground motion uses stochastic methods. Hence dynamical methods need to be developed for the prediction of strong ground motion.

ACKNOWLEDGEMENT

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A REVIEW ON THE THREE EARTHQUAKES DURING JUNE-OCTOBER 2002 IN IRAN: CHANGUREH (22/06/2002, MW6.3), ANDEKA (25/09/2002 MW5.5), AND RAVAR (16/10/2002, MB4.6)

Mehdi Zaré

Abstract

Three recent (June to October 2002) earthquakes in Iran caused some life losses amd damages. This paper summarizes the seismological aspects of these events. The first event was the Changureh (Avaj) earthquake of 22 June 2002, Mw6.3, I_0 =VIII+ (7:28:00 a.m. local time, 2:58:27.2 GMT) has shocked a great area in NW Iran (about 250km west of Tehran). The official report on life losses says about 233 fatalities and about 1500 injured and more than 50000 homeless. The second important event was the Andeka Earthquake of 25/09/2002 occurred in 22:28:15 UTC (01:58:15 of 26/09/2002 local time) in the north-west of Masjed-Soleyman in Zagros fold belt. The event caused no life losses but 4 people are reported to be injured in 11 main villages which are partially damaged. The third one earthquake was a moderate event shocked the Ravar city in the north of Kerman in 09:20:53 of 16/10/2002 UTC. The region is known by the high Seismicity along the NW-SE fault of Kuhbanan and the North-South oriented faults (Nayband, Ravar, Golbaf).

INTRODUCTION

The Changureh (Avaj) earthquake of 22 June 2002, Mw6.3 has shocked the a great area in NW Iran (about 250km west of Tehran). The region is located in the west of Takestan-Hamedan road along an east-west oriented valley in the west of the Abegarm village. The Andeka Earthquake of 25/09/2002 occurred in the north-west of Masjed-Soleyman in Zagros fold belt. A moderate earthquake has shocked the Ravar city in the north of Kerman in 16/10/2002. This earthquake seems to be related to the reactivation of the Ravar or Lakar-Kuh faults.

In this paper it is tried to summarize a seismotectonic and seismological conditions of each of each these three events. The result of the studies on these events are discussed based on the time of their occurrence and finally a conclusion is sited.

CHANGUREH (AVAJ) EARTHQUAKE OF 22 JUNE 2002, MW6.3

The Changureh (Avaj) earthquake of 22 June 2002, Mw6.3 (7:28:00 a.m. local time, 2:58:27.2 GMT) has shocked a great area in NW Iran (about 250km west of Tehran; Figure-1). The region is located in the west of Takestan-Hamedan road along an east-west oriented valley in the west of the Abegarm village (Figure-2). The localities of the greatest damages were the villages of Abdarreh and Changureh (Figures 2 and 3). The official report on life losses says about 233 fatalities and about 1500 injured and more than 50000 homeless. The earthquake impressed generally about 50 villages (most of them partially damaged. Based on the moment magnitude estimation (according to the 55 strong motion records obtained during the mainshock) and the extension of the surface fissures and an estimated focal depth of 6 km for the mainshock, a magnitude of Mw6.3 is estimated for the event. The preliminary process of source parameters indicates a high stress drop and fast attenuation of ground motion.

The Changureh earthquake prone area is distinguished by the domination of the NW-SE and WNW-ESE directed fault systems (Figure-1). The area is representative for the major NW-SE and east-west structural trends in southwestern Alborz and north central-Iran. There are, hence, the major active tectonic intersection structural zones in which the great earthquakes have happened (1177 and 1962 Buin-Zahra great earthquakes with the estimated magnitudes of greater than 7.0). The recent 22 June 2002 earthquake seemed to be a major event in the western continuation of the Divandarreh-Buin lineament (Figure-1).

The focal mechanism of the event, that is representative for a mostly compressional displacement (Figure-1), which is justified based on the field observations in the prone area. The surface fissures had the general strike of N70-80W. The extension of the area, in which the surface fissures are reported and could be related to the earthquake fault, was about 20km. The principal axes of the moment tensors were in (N20-23E) direction. According to the direction of the planes and the principal axis of moment tensors, the fault plane with a slop towards the north and a compressional slip with a slight left-lateral strike-slip displacement can be introduced as the causative earthquake fault plane.

The stress drop was found to be very fast in the preliminary estimations and the rate of the attenuation of the strong motions (based on the observed intensities) was fast (it looks like the attenuation of the strong motions in Zagros area). The duration of the mainshock was short, and it coincides with the other interpreted source parameters.

The Changureh earthquake prone area was the location of major earthquakes during the history. The epicenters of the historical (pre-20th century) earthquakes (Figure-4) are more concentrated towards the southern Alborz and southern Tehran area (Ambarseys and Melville 1982). The earthquakes during the 20th century occurred along the southern Ghazvin plain and western Tehran (Figure-4). The major earthquakes along the east-west trend of Divandarreh-Buin lineament indicate the activity of this trend and according to the background seismicity of the region, it seems that the Changureh area was the location of a probable seismic gap along this active structure, which is activated in 22 June 2002.

The Changureh earthquake caused the devastation of Changureh and Abdarreh villages in its prone area and induced major casualties towards Avaj. A maximum intensity of VIII-IX is assigned to the macroseismic epicentral region and general trend of the damage extension is WNW-ESE (Figure-5). The village of Changureh was the location of greatest fatalities and damages, such that more than 150 people, of total 233 reported life losses, are killed just in this village.

ANDEKA (NE MASJED-SOLEYMAN) EARTHQUAKE OF 25 SEPTEMBER 2002, MW5.5

The Andeka Earthquake of 25/09/2002 occurred in 22:28:15 UTC (01:58:15 of 26/09/2002 local time, Mw = 5.6, mb = 5.5, Ms = 5.5) in the northeast of Masjed-Soleyman in Zagros folded belt (Figure-6). The event caused no life loss but 4 people are reported to be injured in 11 villages (mainly in Boneh-Amiralmomenin village; Figure-7). The quake occurred in the southern parts of the Zagros belt in an oil-rich area, where is as well the locality of some important hydroelectric infrastructures (Masjed-Soleyman Dam – Figure-8 - and Power Plant and Shahid-Abbaspour Dam and Power Plant).

The region is known with the moderate to great earthquake seismicity (Figure-9). The greatest event in the 20th century is known to be the event of 14 December 1978 (mb5.9, Ms6.1), in which the landslide (rock-block falls) of Andeka is triggered (actually in the northern parts of the Masjed-Soleyman dam reservoir). The prone area of the Andeka earthquake is located nearby the Zagros mountain Front Flexure (is known as a hidden but active fault), which is traced along the outcrop of the Asmari Cretaceous formation, with a seismicity of moderate to great earthquakes during the 1970's (24 April 1976 mb5.0, and 12 December 1978, mb5.9). The macroseismic epicentral region is located along the Andeka fault (Figure-6).

The focal mechanism (reported by Harvard seismology web site, 2002) indicates a pure compressional movement (Figure-6). The P axis in this focal mechanism report shows a N50E direction for the principal moment tensor solution. The fault plane had a NW-SE direction, which is parallel to the major trend of the Zagros structures. Such trend coincides well with the trend of the Andeka fault towards the north-northeast of Godar-Landar.

The macroseismic intensity is estimated to be VI-VII (EMS-98; European macroseismic intensity scale) in Boneh-é-Amiralmomenin village, where some damages are observed in the village buildings (Figure-7). The rescue efforts were started with a delay of 5 to 6 hours by the Red-Crescent of Iran. The damages to the Masjed-Soleyman dam (Figure-8) were limited to some longitudinal superficial cracks and some rock falls in the downstream of the dam. The intensity of VI (EMS-98) could be assigned to these evidences in the dam site. The intensity in the great city of Masjed-Soleyman is estimated to be "V" (EMS-98), according to the reported panic of the people who have been waken up at 01:58 a.m. (local time of the mainshock), but no damage was reported from the city of Masjed-Soleyman. The iso-intensity map of the macroseismic epicentral region is shown in Figure-10.

FEYZABAD (RAVAR, NW KERMAN) EARTHQUAKE OF 16 OCTOBER 2002, ML5.0

A moderate earthquake has shocked the region around Ravar city (Figure-11) in the northwest of Kerman in 09:20:53 of 16/10/2002 UTC. The region is known by the high Seismicity along the NW-SE fault of Kuhbanan and the North-South oriented faults (Nayband, Ravar, and Golbaf). The recent earthquake seems to be related to the reactivation of the Ravar or Lakar-Kuh faults (Figure-11). The problem should be verified after the field visits. A preliminary estimation of macroseismic intensity is indicative for a V-VI EMS-98 around Ravar (Figure-12). This estimation agrees well with the reports of the damage in the Feyzabad and Tarz villages.

CONCLUSION

The events in northwest, southwest and southeast of Iran has shock the Iranian plateau during the June to October 2002 with the magnitudes of 5.0 to 6.3. The events having the magnitudes greater than

5.5 caused property damages, but unfortunately the Mw6.3 Changureh earthquake caused more than 200 victims. The two events with the reported focal mechanisms has showed mostly compressional movements.

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FIGURES

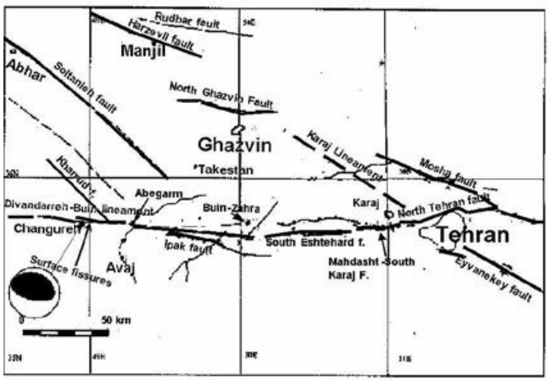

Figure-1: The tectonic map of the region, the focal mechanism is from Harvard Seismology Web site (June 2002).

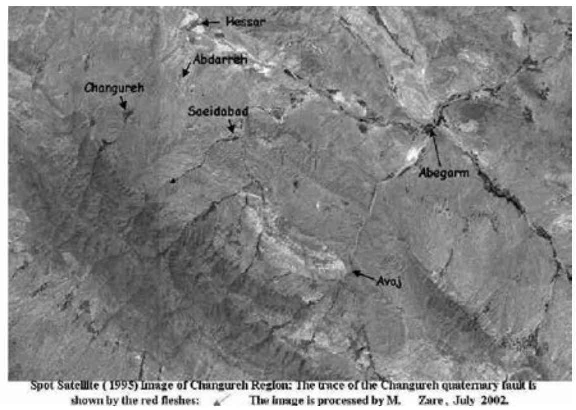

Figure-2: The trend of reactivated Changureh quaternary fault, which is reactivated during the 22/06/2002 earthquake. The trend is shown on a spot image (1995).

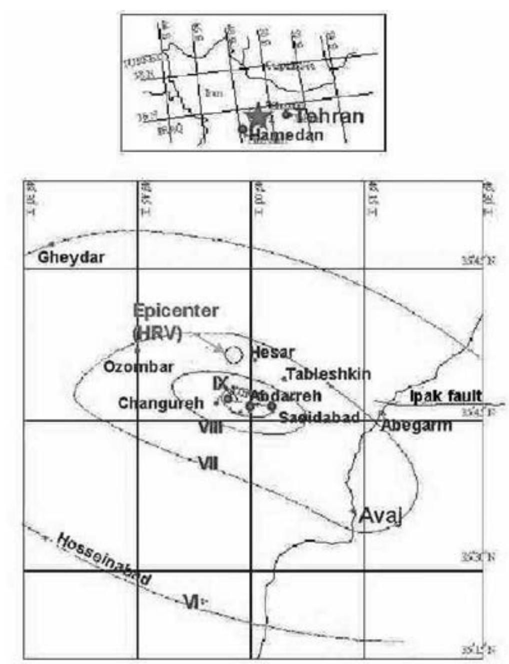

Figure-3: Damages in Changureh (macroseismic epicenter.

Figure-4: The seismicity of the prone area of the Changureh earthquake (before the event of 22/06/2002).

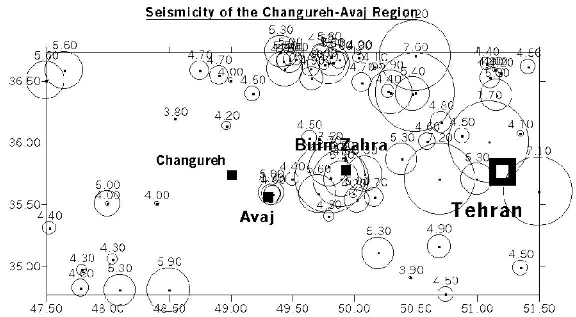

Figure-5: The iso-intensity map of the Changureh earthquake.

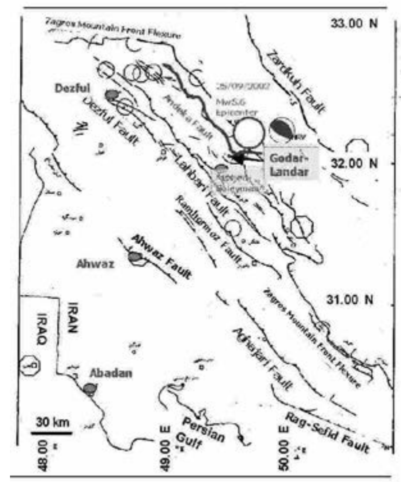

Figure-6: The tectonic map of the 25/09/2002 earthquake, the focal mechanism is reported by Harvard (web site, 2002).

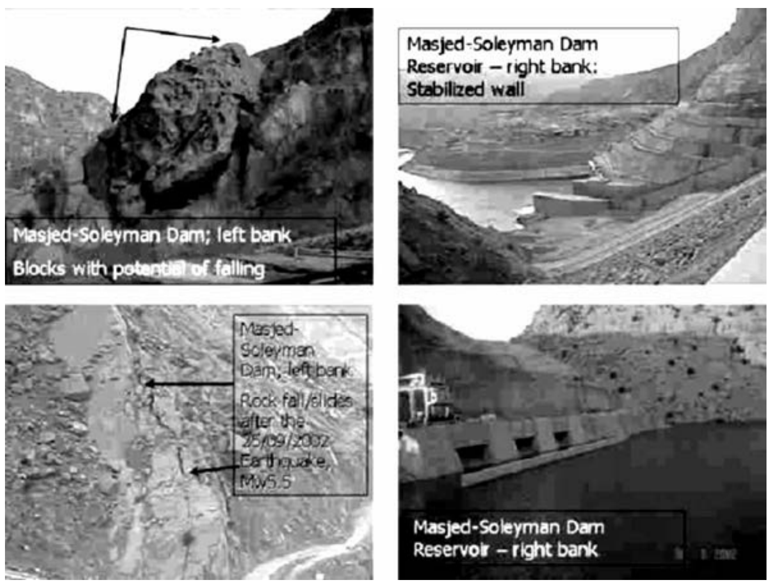

Figure-7: The damages in the Boneh-Amiralmomenin village.

Figure-8: The Masjed-Soleyman dam reservoir and rock falls induced by the 25/09/2002 earthquake.

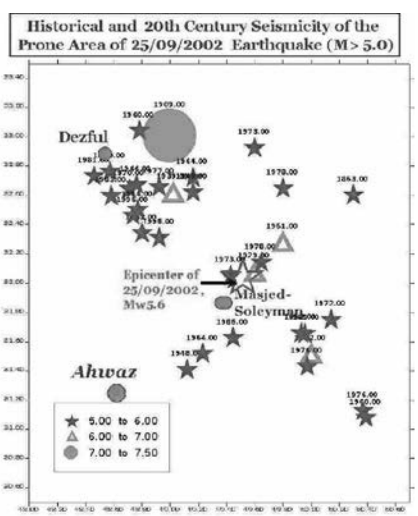

Figure-9: The seismicity of the Masjed-Soleyman earthquake region (for M > 5.0).

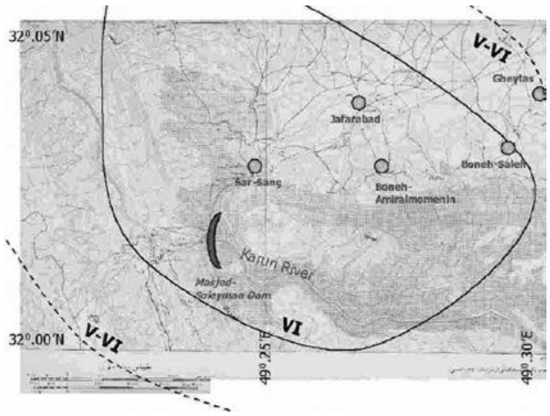

Figure-10: The iso-intensity map of the epicentral region of the 25/09/2002 earthquake.

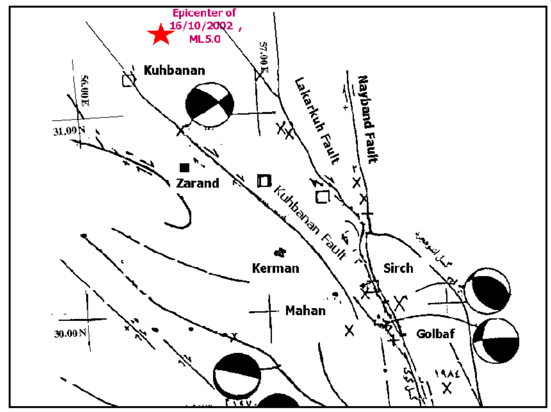

Figure-11: The fault map of the Kerman region and the epicenter of the 16/10/2002 earthquake.

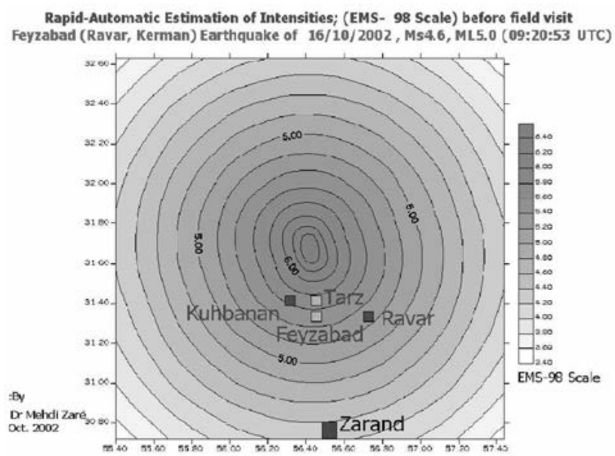

Figure-12: The automatic estimation of macroseismic intensity for the epicentral region of 16/10/2002 Feyzabad earthquake.

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PRELIMINARY ESTIMATIONS OF MISLOCATION VECTORS OF TWO IMS ARRAYS IN CHINA

Zhong Zheng

Abstract

According to the annex of CTBT, there are two primary seismic array stations in the mainland China. One is located in Hailar, northeast of China (PS12), and another is in Lanzhou, northwest of China (PS13).

The site survey activities started at early 1999. After we fixed the candidate sites for two arrays, Institute of Geophysics, China Seismological Bureau and CTBTO/IMS jointly carried out the site survey observations during August 1999 for PS13 and September 1999 for PS12 respectively. The array site of PS13 is located at where 18km southwest away of Lanzhou city(Fig.1), and the one for PS12 is 34km northeast of the city Hailar(Fig.2). Each site survey is divided into four deployments, and 2 Guralp CMG-3T and 5 CMG-3ESPV were used to do the observations (Fig.5, 6, 17, 18).

Figure 1. View of PS13 array site

Figure 2. View of PS12 array site

The PS13 array site area is located south of Lanzhou at the Wusu mountain range, which is a complex geosyncline consisted of competent and stable base rocks. The Quaternary deposits are about one meter in thickness. No large active faults are found nearby. However, small fissures in the weathered top layer of the Wusu mountain range are apparent. The Wushu complex geosyncline extends NNW, the core of which consists of volcanic tuffs of Wusushan group of the upper and middle Ordovician system. This stratigraphic unit has been in a state of corrosion after the fold and rise of the region during the Caledonian movement.

Most of the Wusu mountain range consists of the Hekou group of Cretaceous system. This strata consists of two parts, the lower part is gravels of thick layer and sands of thin layer; the upper part is sands and mudstone of fluviolacustrine replacement. A short syncline dipping 15 to 20 degrees was formed during the fold and rise of the Yanshan movement.

A geologic map of the area is given in Figure 3; the geologic labels descriptions follow:

Unit label   Description

k_1hk	Sands and gravels of the Hekou group of Cretaceous system
$O_{2\text{-}3wx}$	Volcaneous tuffs of the Wushushan group of middle and upper Ordovician system
Q	Quaternary alluvium

Figure 3. Geologic map of Dajian Mountain. The city of Lanzhou is located in the top right corner of the map, the location of the array is indicated with the PS13 code (LZDM). The grid spacing is 10 km both in latitude and longitude.

The array site of PS12 is located in Chenbaerhuqi, Hulunbeir Region, 38km from Hailar city and 30 km directly from the existing Hailar seismic station. The terrain of this area includes rolling plains with brush, grasses and scattered woodlands, as is shown in Figure 2. The flat mountains rise to an elevation of 787.4 m. The Moleger river is 2km southeast of the array site, which runs northeast and empties into Hailar river. Groundwater is scarce beneath the array site, but shallow groundwater 3 m down exists along the Moleger River banks.

The array site area consists of volcanic tuffs overlaying the basement rock, which is competent and stable. To the north is the Derbukan fault extending northeastwards and to the south is the Hailar river fault which is oriented in an EW direction. Closest to the array site is the Moleger fault. Seismicity on all these faults is low. A geologic map of the Hailar region is shown in Figure 3 where the location of the HSS is shown with a filled in circle near the banks of the Hailar river in the lower right quadrant of the map. The region where the site survey was conducted is colored blue in the map (C_4) and contains the following stratigraphic units:

J_{3zh} Coal formation of Zhalainoer group of Jurassic Pliocene epoch

J_{3xn} Volcanic rock of The Xinganling group of Jurassic Pliocene epoch

Pz_2 Light metamorphic rock of upper Palaeozoic era

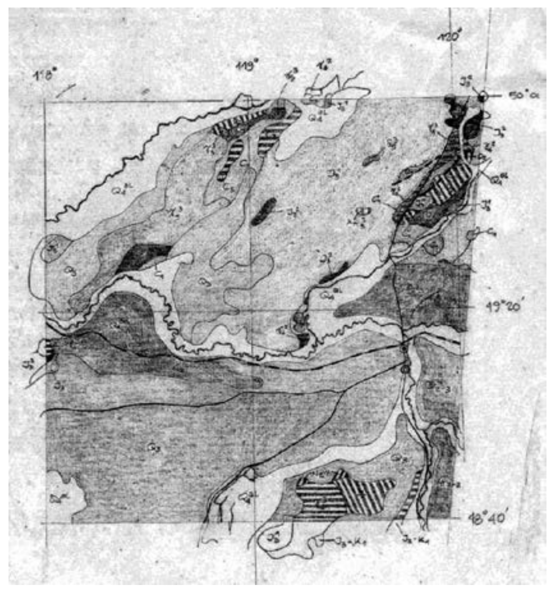


Figure 4. Geologic map of the Hailar region. Note that the grid spacing is 20 minutes in latitude and is 1 degree in longitude.

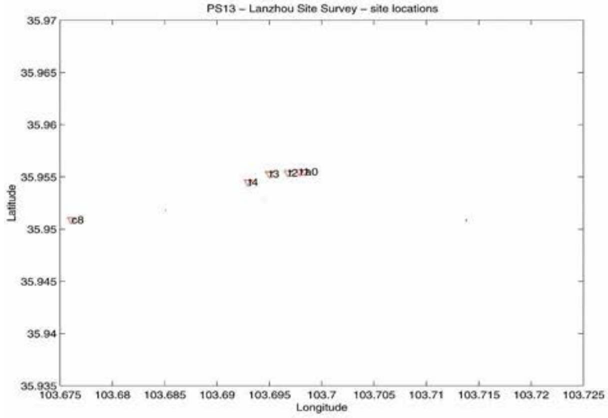
52 events listed in REB are recorded during the site surveys(Fig. 7, 16, Table 1 and 2). And 30 of them have been compiled mislocation vectors from compa-ring event location based on f-k-analysis with the result from IASP91 model in a slowness representat-on.

1. Results of PS13 site survey

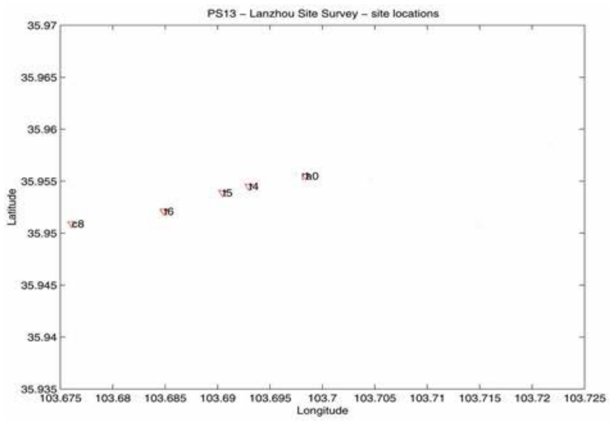
Table 1. REB events recorded during PS13 site survey

Date Time	Lat Lon	Nph	Depth	Mag	Region
1999/08/08 02:43:51.0	5.94N 127.09E	38	63.8	mb 4.8	Philippine Islands Region
1999/08/09 22:59:55.8	6.29S 103.99E	18		mb 4.7	Southwest Of Sumatera, Indonesia
1999/08/10 10:47:41.9	7.35N 126.53E	41	85.6	mb 4.5	Mindanao, Philippine Islands
1999/08/10 12:21:15.6	22.13S 170.24E	17		mb 4.7	Loyalty Islands Region
1999/08/10 13:56:51.6	12.76N 143.89E	11	114.5	mb 3.8	South Of Mariana Islands
1999/08/10 18:38:11.9	43.42N 147.86E	30	47.2	mb 4.5	Kuril Islands
1999/08/11 04:27:31.2	34.77N 32.99E	17		mb 4.3	Cyprus Region
1999/08/12 05:44:56.1	1.59S 122.67E	32		mb 5.6	Sulawesi, Indonesia
1999/08/12 16:43:46.5	0.58S 127.46E	45	65.1	mb 4.8	Halmahera, Indonesia
1999/08/12 20:50:27.7	43.80N 147.63E	26	62.3	mb 4.4	Kuril Islands
1999/08/13 00:30:29.5	52.19N 169.56W	37	32.4	mb 4.9	Fox Islands, Aleutian Islands
1999/08/13 03:00:25.6	52.18N 169.56W	39		mb 5.2	Fox Islands, Aleutian Islands
1999/08/13 10:12:17.4	1.58S 122.78E	19		mb 5.1	Sulawesi, Indonesia
1999/08/13 13:05:57.1	44.07N 149.09E	38	44.5	mb 4.7	Kuril Islands
1999/08/14 00:04:33.7	48.14N 128.48E	7		mb 3.7	Northeastern China
1999/08/14 00:16:54.0	5.84S 104.67E	55	102.4	mb 5.9	Southern Sumatera, Indonesia
1999/08/14 21:06:16.2	2.74N 128.71E	19	233.8	mb 4.3	Halmahera, Indonesia
1999/08/15 02:17:03.4	18.72N 145.48E	19	605.7	mb 3.4	Mariana Islands
1999/08/15 16:18:38.0	18.46N 96.31E	28	20.2	mb 4.5	Myanmar
1999/08/15 16:23:47.9	18.29N 96.33E	23	16.7	mb 4.1	Myanmar
1999/08/15 19:50:09.0	5.36S 152.53E	33		mb 4.9	New Britain Region, P.N.G.
1999/08/17 00:01:37.7	40.77N 30.09E	29		mb 5.6	Turkey
1999/08/17 04:20:17.7	40.76N 30.33E	22		mb 4.5	Turkey
1999/08/17 04:24:28.4	29.03N 129.91E	29	65.0	mb 4.4	Ryukyu Islands
1999/08/17 10:41:12.4	29.39N 105.61E	28	48.2	mb 4.3	Sichuan, China
1999/08/17 15:06:31.0	34.89N 32.84E	28	49.3	mb 4.6	Cyprus Region
1999/08/17 15:06:39.1	18.94N 145.69E	30	215.4	mb 4.0	Mariana Islands
1999/08/17 19:56:10.7	15.97N 119.35E	20		mb 4.3	Luzon, Philippine Islands
1999/08/18 21:15:39.8	10.75S 113.08E	13		mb 4.8	South Of Jawa, Indonesia
1999/08/18 21:15:47.6	40.30N 31.40E	6		mb 4.0	Turkey
1999/08/19 17:14:56.2	24.02N 114.62E	24	14.3	mb 4.1	Near Southeastern Coast Of China
1999/08/20 10:02:18.1	9.26N 84.17W	20		mb 5.5	Costa Rica
1999/08/20 20:33:12.3	34.10N 135.57E	42	65.5	mb 4.7	Near S. Coast Of Western Honshu
1999/08/21 02:58:01.8	20.39S 173.62W	20		mb 5.1	Tonga Islands

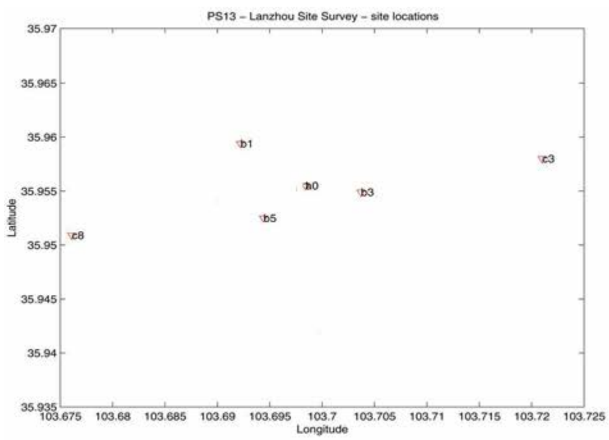
(a)


PS13 – Lanzhou Site Survey – site locations
Latitude
Longitude
t4
t3
c8

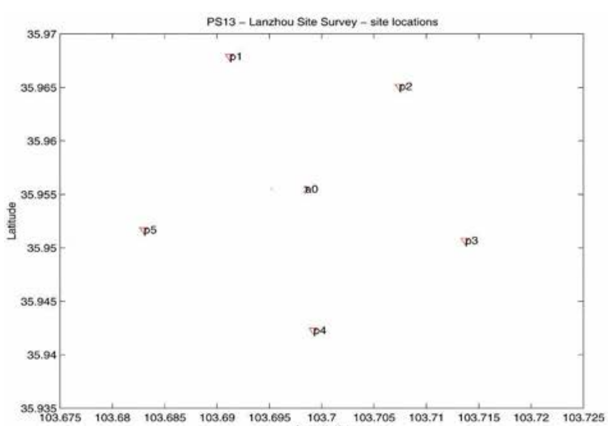
(b)


PS13 – Lanzhou Site Survey – site locations
Latitude
Longitude
h0
t4
t5
t6
c8

(c)


PS13 – Lanzhou Site Survey – site locations
Latitude
Longitude
b1
c3
h0
b3
b5
c8

(d)


PS13 – Lanzhou Site Survey – site locations
Latitude
Longitude
p1
p2
h0
p5
p3
p4

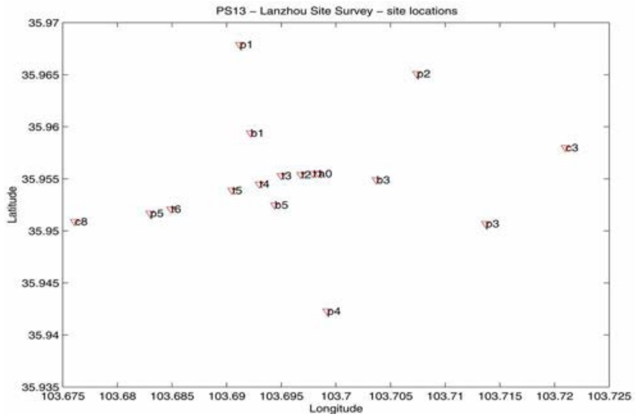


Figure 5(a)-(d). Configurations of PS13 site Survey deployment 1, 2, 3, 4 (top to bottom).

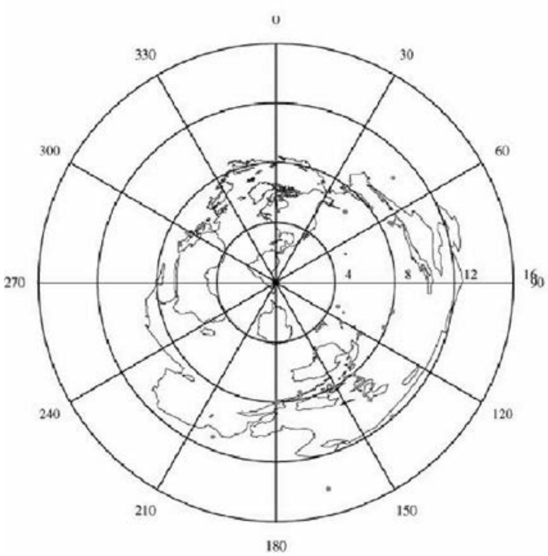


Figure 6. Whole coverage of PS13 site survey

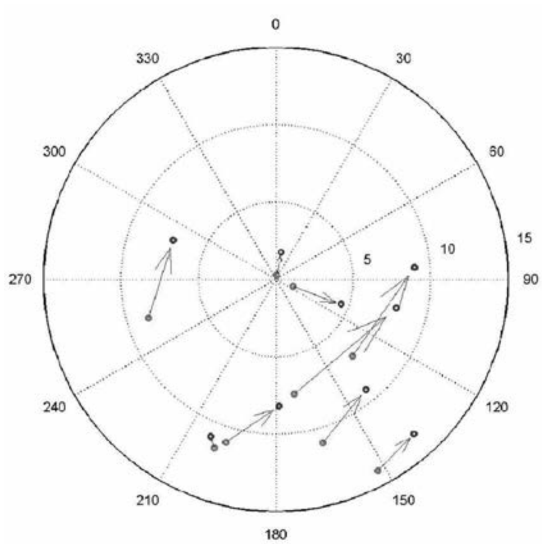


Figure 7. Events observed during PS13 site survey in a slowness-azimuth representation. The unit on slowness axis is in s per deg.

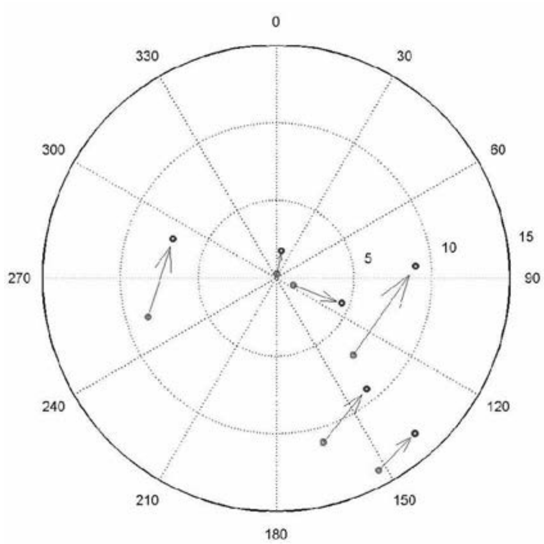


Figure 8. Preliminary mislocation estimation of PS13. The red dots represent the results from f-k-analysis, and the blue ones are the theoretical values based on IASP91 model. The concentric circles are spaced at slowness intervals of 5 second per degree.

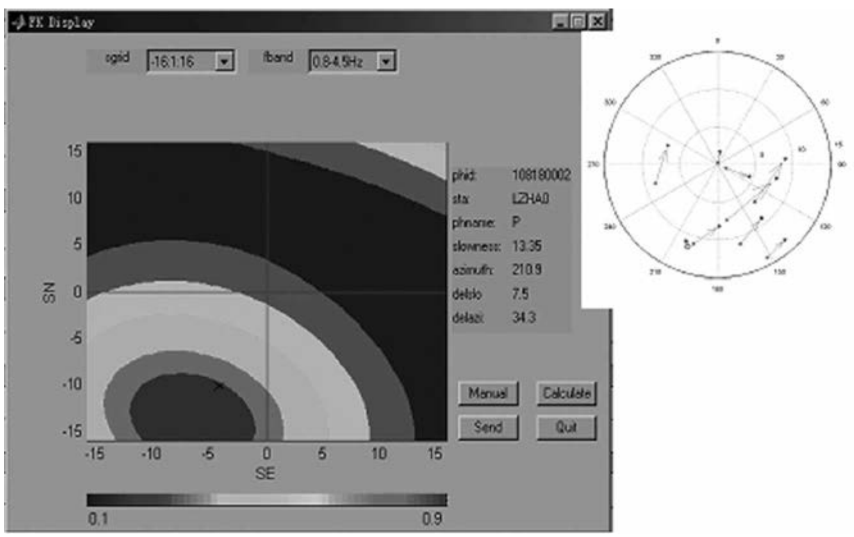


Figure 9. Mislocation vectors of deployment 4 of PS13 site survey. The ring-shape distribution of the deployment is almost the outer ring of the elements of the installed array (see also Fig. 5(d) and Fig. 8).

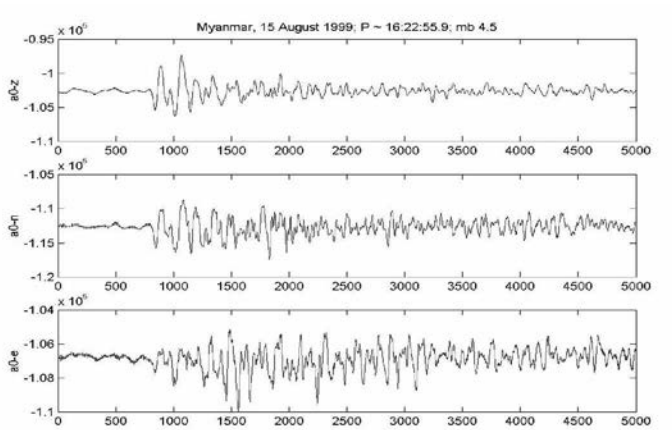


Figure 10. The result of f-k analysis of Myanmar event, LD3. The larger red dot showed in the right-top is where the event is (see also Fig. 5(c) and Fig. 8).

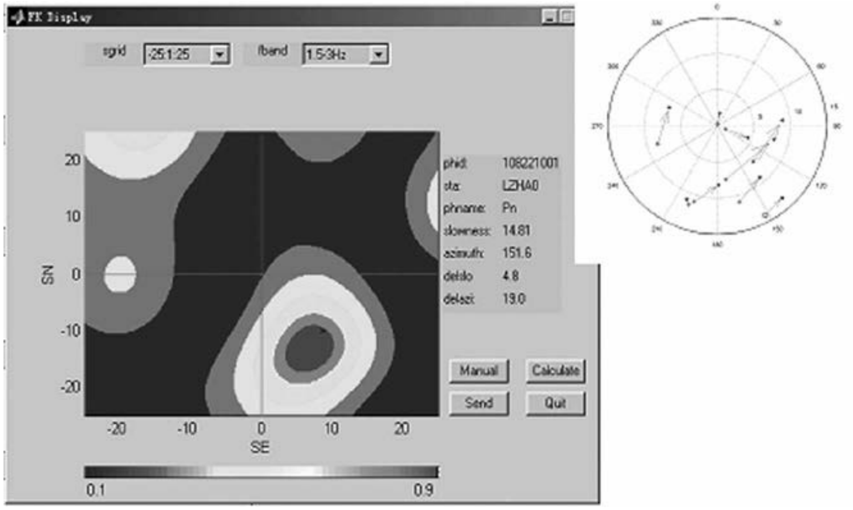


Figure 11. The Myanmar event waveform of A0 3-component element. The unit of Y axis is digital count, and X axis is number of samples. The sample rate is 40Hz.

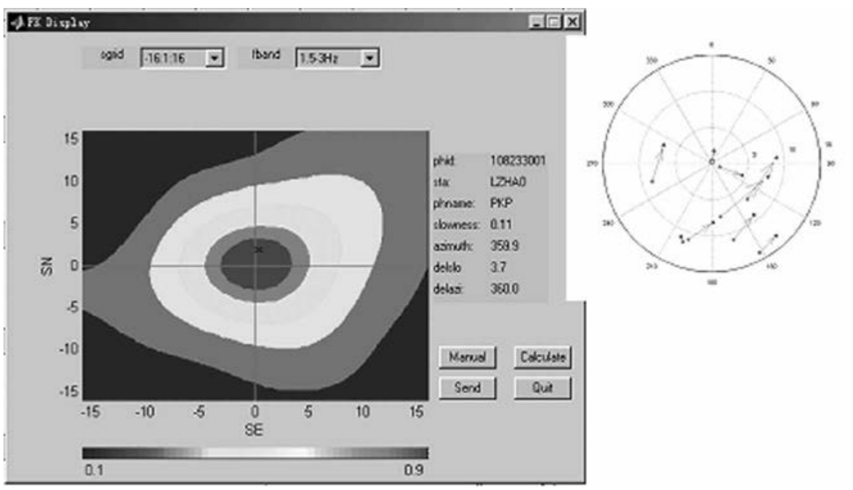


Figure 12. The result of f-k analysis of the event in southeast coast of China, LD4(see also Fig. 10).

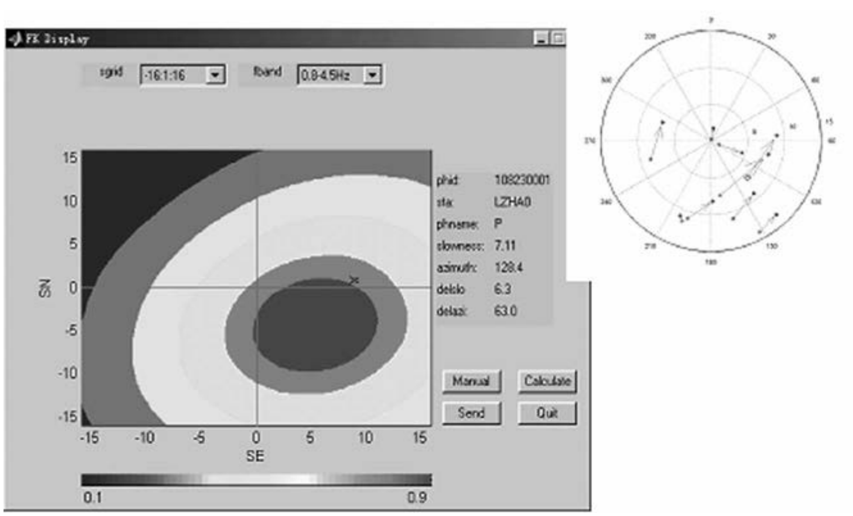


Figure 13. The result of f-k analysis of Costa Rica event, LD4(see also Fig. 10).

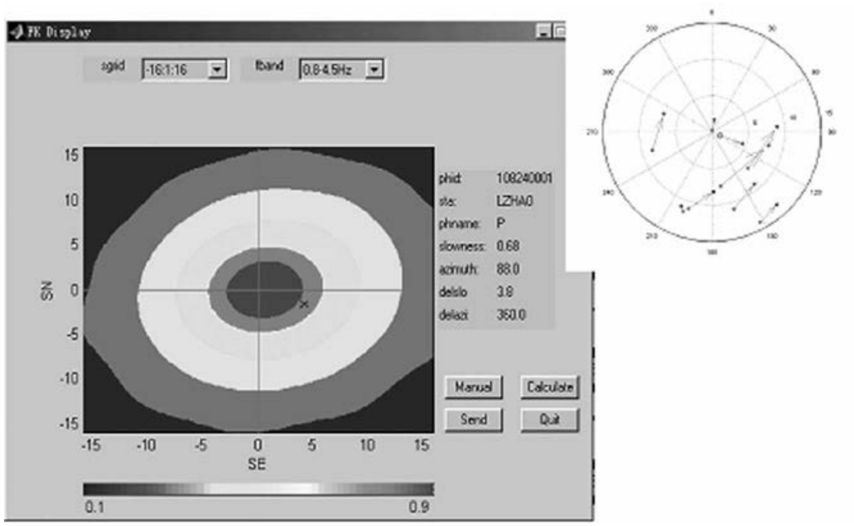


Figure 14. The result of f-k analysis of Honshu event, LD4(see also Fig. 10).

Results of PS12 site survey

Table 2. REB events recorded during PS12 site survey

Date Time	Lat Lon	Nph	Depth	Mag	Region
1999/09/08 11:52:17.9	57.27N 119.94E	12		mb 4.3	East Of Lake Baykal, Russia
1999/09/09 14:02:04.1	47.60N 154.26E	39	39.9	mb 4.8	Kuril Islands
1999/09/10 07:18:28.8	2.92N 127.07E	14		mb 4.6	Northern Molucca Sea
1999/09/10 08:45:23.2	46.08N 150.26E	33	76.3	mb 4.7	Kuril Islands
1999/09/12 03:03:14.1	28.89N 142.40E	30		mb 5.1	Bonin Islands Region
1999/09/12 13:12:21.6	2.89N 126.91E	27	35.4	mb 4.5	Northern Molucca Sea
1999/09/12 16:08:42.9	57.21N 122.35E	6		mb 3.7	Southeastern Siberia, Russia
1999/09/13 11:55:27.8	40.80N 30.14E	32		mb 5.3	Turkey
1999/09/14 12:54:31.4	31.56N 104.19E	20	20.5	mb 4.4	Sichuan, China
1999/09/14 22:17:30.0	15.09N 146.25E	18	129.8	mb 5.1	Mariana Islands
1999/09/15 03:01:27.4	20.50S 67.17W	27	221.1	mb 5.5	Southern Bolivia
1999/09/15 19:38:53.1	44.57N 149.33E	16		mb 4.6	Kuril Islands
1999/09/16 13:11:54.1	2.70N 127.84E	20	37.3	mb 4.7	Northern Molucca Sea
1999/09/16 14:18:40.7	44.35N 148.34E	27	55.8	mb 4.4	Kuril Islands
1999/09/16 17:34:54.9	46.44N 153.40E	25	36.2	mb 4.4	Kuril Islands
1999/09/17 14:54:46.9	13.81S 167.45E	43	168.5	mb 5.7	Vanuatu Islands
1999/09/18 06:50:53.4	6.56S 147.88E	19		mb 4.9	Eastern New Guinea Reg., P.N.G.
1999/09/18 20:11:41.8	1.23N 122.54E	25	50.8	mb 4.3	Minahassa Peninsula, Sulawesi
1999/09/18 21:28:34.0	51.26N 157.50E	39	49.6	mb 5.6	Near East Coast Of Kamchatka
1999/09/18 23:51:30.7	19.71S 169.44E	29	92.2	mb 5.3	Vanuatu Islands
1999/09/19 03:18:55.2	3.78S 150.98E	40	425.9	mb 4.7	New Ireland Region, P.N.G.

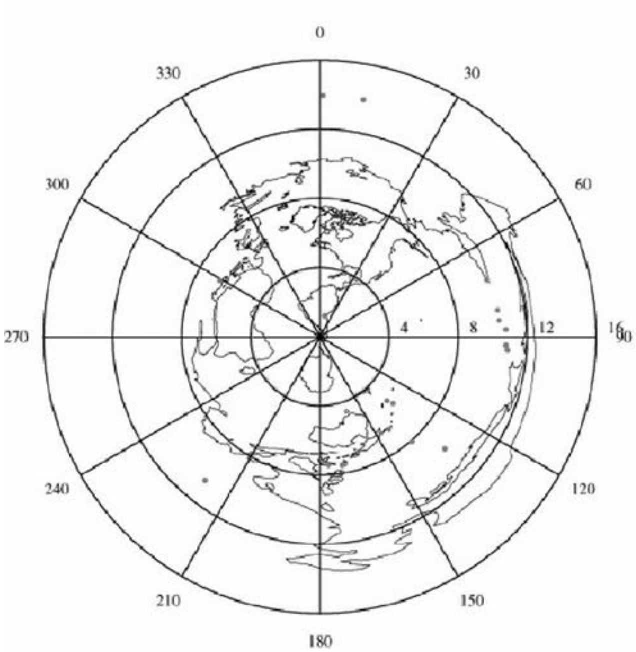
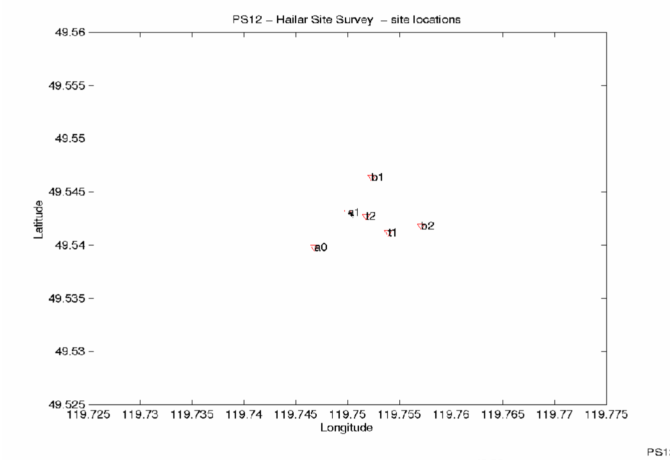
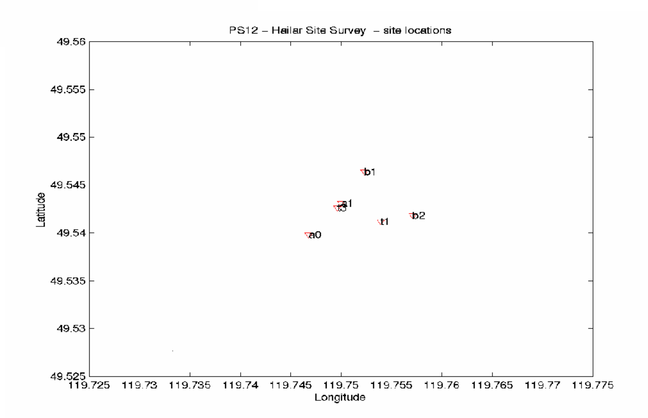


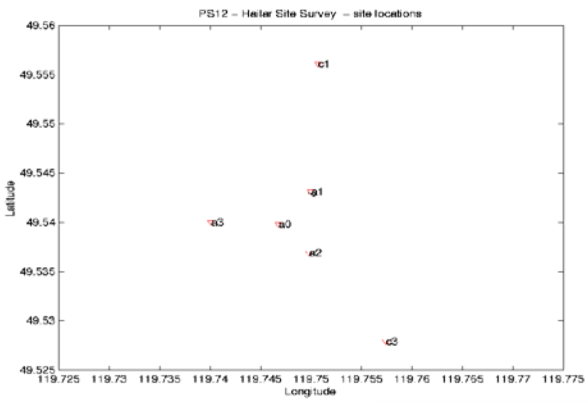
Figure 16. Events observed during PS12 site survey in a slowness-azimuth representation (see also Fig. 7).



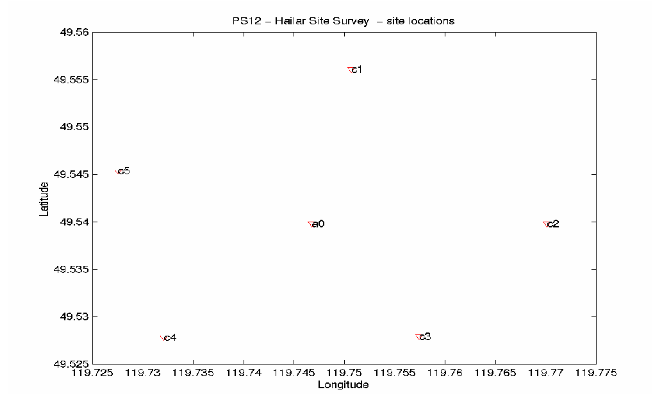
a



b



c



d

Figure 17(a)-(d). Configurations of PS12 site survey deployment 1, 2, 3, 4 (top to bottom).

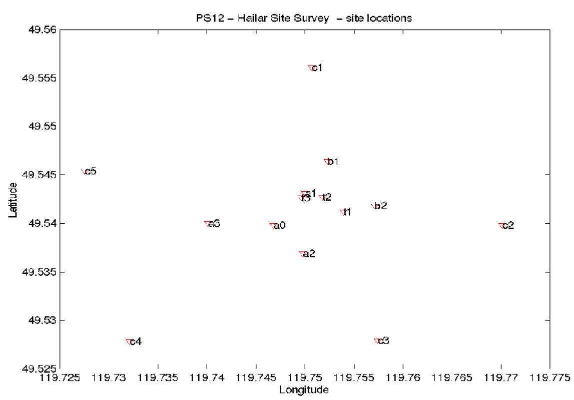


Figure 18. Whole coverage of PS12 site survey

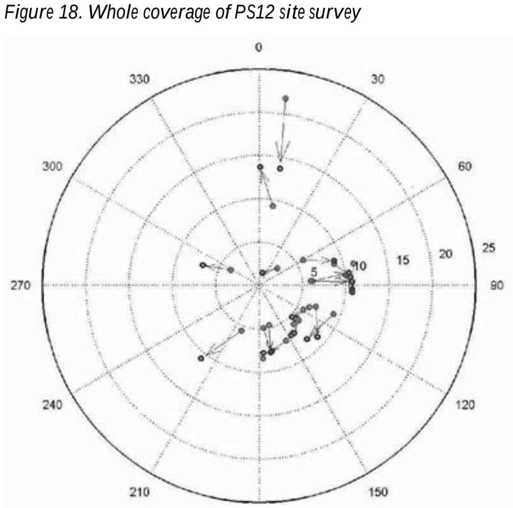


Figure 19. Preliminary mislocation estimation of PS12. The red dots represent the results from f-k-analysis, and the blue ones are the theoretical values based on IASP91 model. The concentric circles are spaced at slowness intervals of 5 second per degree.

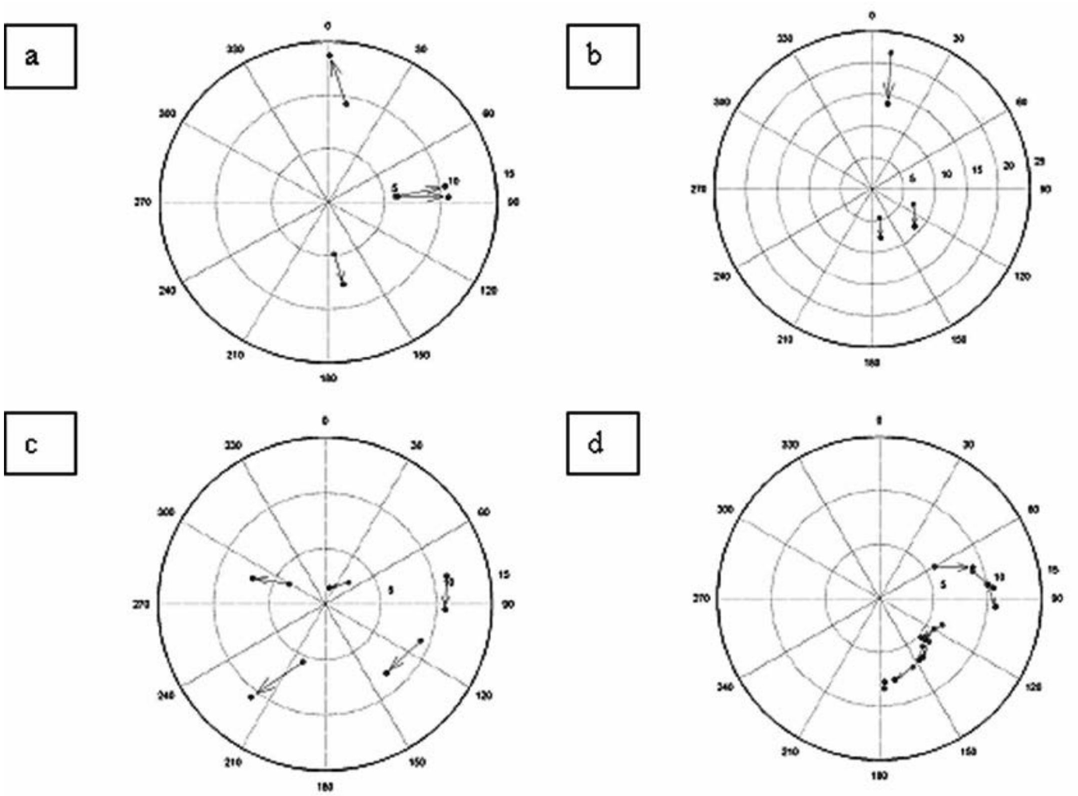


Figure 20. Preliminary mislocation estimation of PS12 by deployment 1, 2, 3, 4 in a, b, c, d respectively(see also Fig. 19).

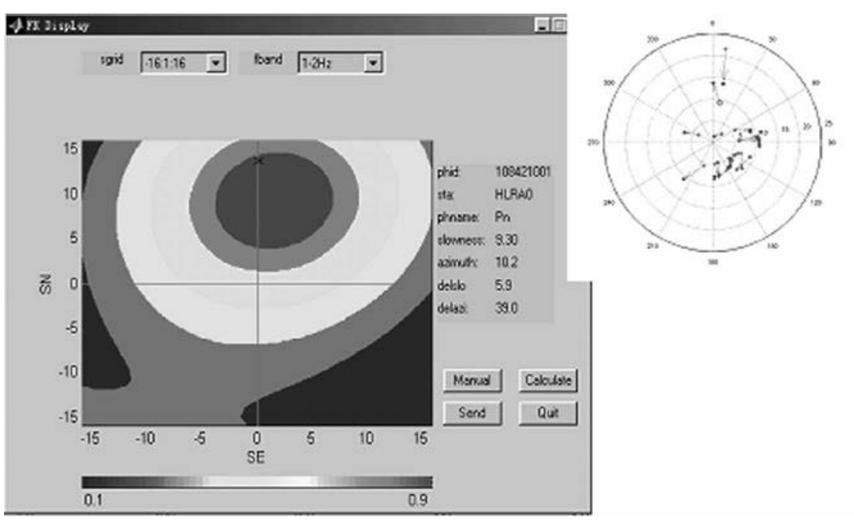


Figure 21. The result of f-k analysis of Lake Baikal event, HD1. The larger red dot showed in the right-top is where the event is (see also Fig. 20(a)).

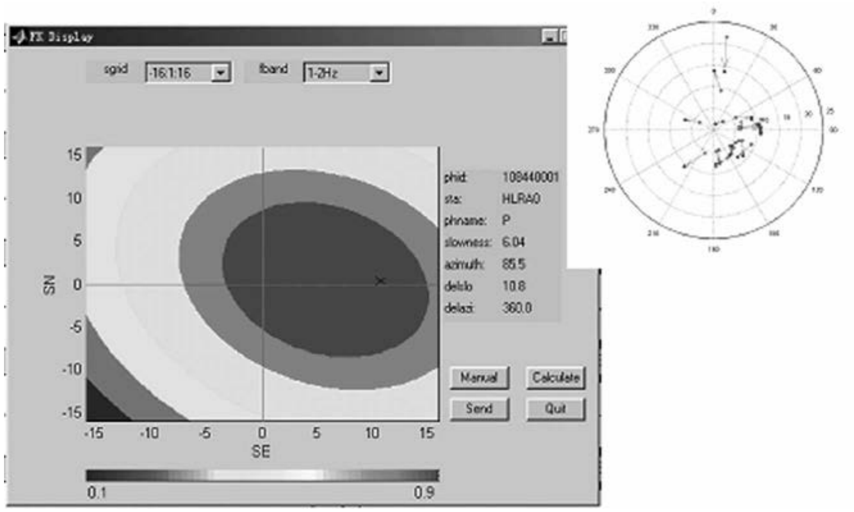


Figure 22. The result of f-k analysis of Kuril Islands event, HD1(see also Fig. 21).

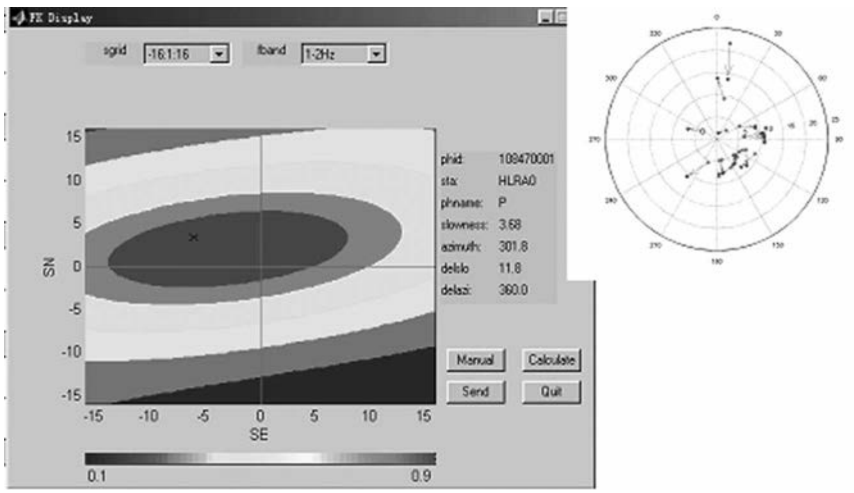


Figure 23. The result of f-k analysis of Turkey event, HD3(see also Fig. 21).

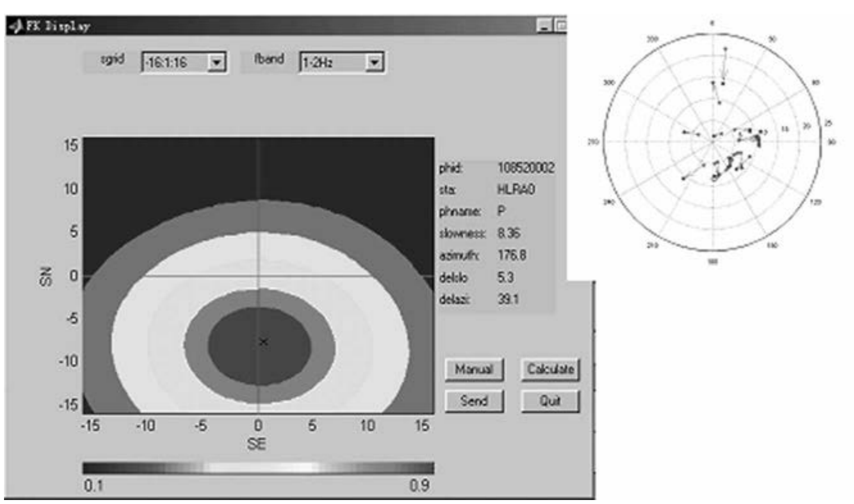


Figure 24. The result of f-k analysis of Sulawesi event, HD4(see also Fig. 21).

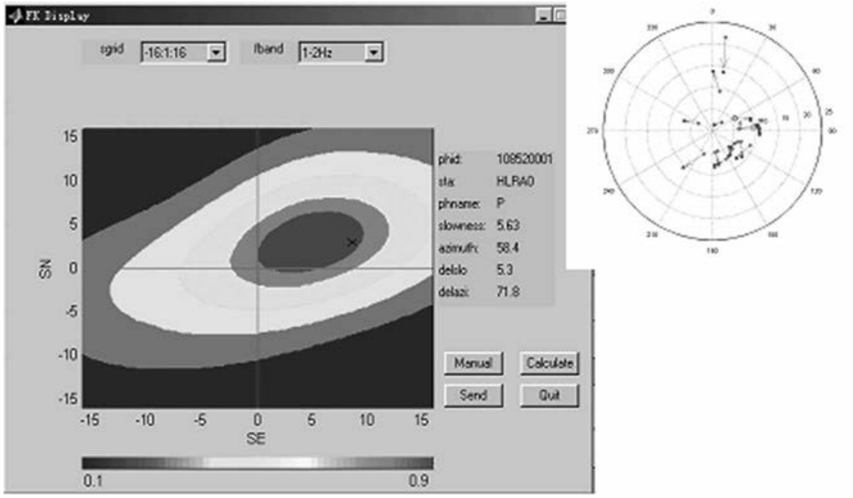


Figure 25. The result of f-k analysis of Kamchatka event, HD4(see also Fig. 21).

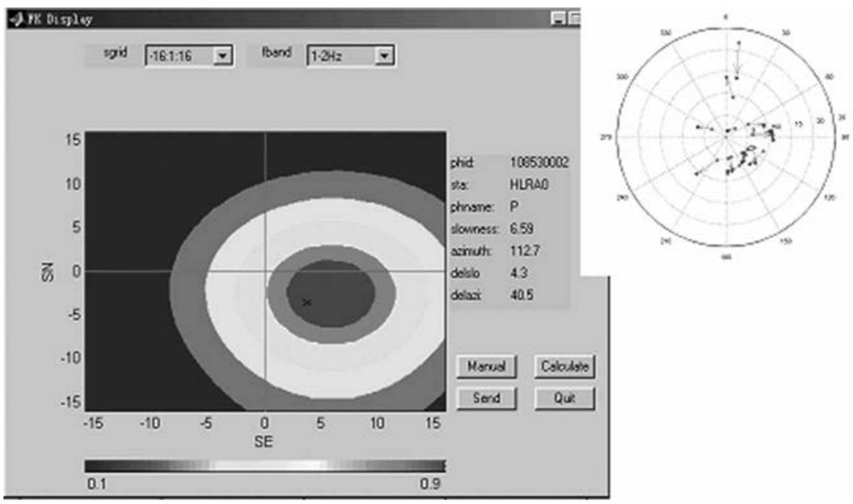


Figure 26. The result of f-k analysis of Vanuatu event, HD4(see also Fig. 21).

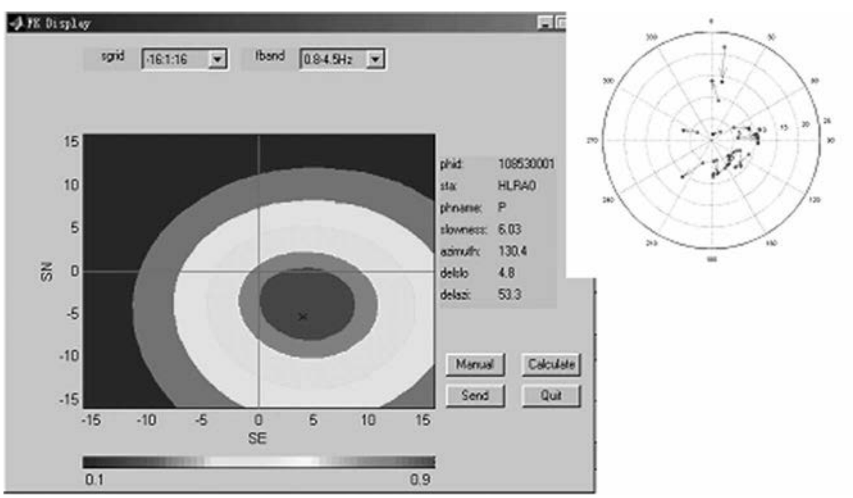


Figure 27. The result of f-k analysis of New Ireland, PNG event, HD4(see also Fig. 21).

SUMMARY

Here we show some results from the data of IMS site surveys. We would not like to try to get some certain conclusions at this moment since our data set is too small to reach some certainties. This work is at the very preliminary stage, we have been continuing our work on the newly installed two IMS arrays as the data gained as time goes.

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MULTI-FRONT APPROACHES OF EARTHQUAKE AWARENESS IN DEVELOPING COUNTRIES: A CASE STUDY OF NEPAL

B. H. Pandey, R. Guragain and A. M. Dixit

Abstract

Multi-front approaches on earthquake awareness to cover the all sectors of community and formal institutions including government have been taken in earthquake risk management of Kathmandu Valley. All available and affordable direct means of awareness raising, e.g., radio; public lecture, pamphlet, fliers, publications exhibition, shake table demonstration, drills and simulations and indirect means through participatory approach in risk assessment, planning and implantation of mitigation measure and preparedness actions are used as awareness tool. The effectiveness of awareness campaign has been observed with increased number of activities in earthquake risk reduction and increased demand for such actions from community level.

INTRODUCTION

In developing countries, the lack of awareness among people towards earthquake hazard and the level of risk attributed to their living practice is the reason why they put no or the least priority for the safety against the disaster. We have experience from recent earthquakes that the prime victims of such events are those who are least prepared. Moreover, lacks of knowledge of simple measures that are well within the common people's capacity to understand and implement towards the risk reduction lead even who percepts the risk follow the traditional fatalistic approach. The formal sector which decides the policy develops the program and, in most cases, implements projects also lacks to realize the importance of incorporating mitigation measure into development process and of planning for the response during the earthquake disaster.

In Nepal, efforts are made for earthquake awareness to address these issues with a multi-front approach through a number of programs. Incorporating awareness component in activities of hazard identification and risk assessment, planning and mitigation measures is a major aspect of the awareness campaigning besides visible awareness programs by means of rally, public gathering poster, pamphlet etc. The target groups of the awareness activities are all who are not aware of the risk, who think that the mitigation is not viable solution and government officers who are responsible for planning and execution of development project and operation of infrastructures.

Since last seven years when Kathmandu Valley Earthquake Risk Management Project (KVERMP) had been carried out by National Society for Earthquake Technology (NSET) in association with GeoHazards International (GHI), public and government awareness in earthquake has been increased by the project itself and by the follow-up projects in risk management in Nepal. As a result of increased awareness, several initiatives towards mitigation and preparedness are taken by local government bodies, national and international institutions, and media agencies. A visible demand is created to from community people for trained masons to build their house earthquake resistant. Municipalities incorporate Nepal National Building Code into their building permit process to integrate seismic resistance into the process of new construction in urban areas.

APPROACHES

Before KVERMP started campaign of earthquake awareness in 1997, there was very little knowledge in Nepal on earthquake risk and preparedness despite a long history of geological studies. The living memory of the last devastating earthquake of 1934 Bihar-Nepal almost faded with the society, and the lessons of the more recent 1988 Udayapur earthquake was not being propagated or respected. In this context, earthquake awareness was a major component of the KVERMP. After the project phase out, NSET continues the awareness program through other projects. Those includes School Earthquake Safety Program (SESP), Municipal Earthquake Risk Management Project(MERMP), critical facilities and lifeline vulnerability assessment, Community Based Disaster Management(CBDM) program, training and orientation program and Earthquake Safety Day (ESD). Every activity that NSET undertakes is shaped to raise the awareness of different groups - government officials, media, international agencies, etc. For example, emphasis in developing the earthquake scenario during KVERMP was not in producing precise, technically sophisticated results, but in involving all key institutions in developing and understanding simple technical results.

Awareness raising targeted all sections of the society: from officials and decision-makers at the central government through the municipal authorities and communities in the municipal and village wards. It also targeted the influential members of the private sector, and international community and representatives of donor agencies resident in Kathmandu Valley. Influential organizations abroad concerning Kathmandu Valley's earthquake risk were also specific targets of awareness-raising program. The awareness-raising programs try to cover different sector because all sector have responsibilities of disaster risk reduction. Students, teachers, parents, and school management systems were specific target groups. Similarly, the awareness-raising program included activities targeted towards professional engineers, architects, geologists, medical personnel, insurers, and masons.

All available and affordable means of awareness raising, e.g., radio; public lecture, pamphlet, fliers, publications and so on are considered as the awareness materials. Exhibition, shake table demonstration, drills and simulations, and study visits to the retrofit are also used as awareness raising tools.

Awareness raising is regarded much more than transferring of knowledge and information. It includes also internalization of the knowledge on earthquake technology produced in developed countries so that it can be accepted by the society. Propagating the "Stitch and Bandage" technology for retrofitting of masonry houses, simple model of shake table demonstration to mark the difference of seismic intervention in building are some examples.

The objectives of awareness raising are different for the different target groups. At the level of decision-makers and politicians, the objective is to convince them that disaster risk reduction is a development issue, and it is achievable even in a developing country such as Nepal. At community level, the objective is to enable them to understand the risk and to identify possible measures that could be taken to gradually reduce it. To create public demand for risk reduction is another objective in targeting the common people by awareness campaign.

TOOLS OF AWARENESS

Various tools are used for awareness campaign in earthquake. Some of the activities that primarily designed for awareness are listed as below. Details of the awareness activities is presented in appendix chart.

Earthquake Safety Day (ESD)

At NSET's request, Government of Nepal declared January 15 (or 16) as the Earthquake Safety Day of Nepal, and established an Earthquake Safety Day National Committee (ESD NatCom) for observing the Day annually throughout Nepal. ESD NatCom draws representatives from all emergency response organizations and critical facilities management. The Hon. Minister of Home Affairs chairs it. Establishment of ESD NatCom has provided the basis of sustainability of the earthquake risk management program in the country. ESD is the culmination of earthquake risk management works implemented in the country in the preceding 12 months, and allows taking stock of the achievements and shortcomings.

So far 5 ESDs have been organized. The ESD program typically has been 7-10 days, including:

a. Symposium of Experiences in disaster Risk Reduction, (usually participated by scientists of the region),
b. Awareness speech by the Minister Science & Technology in the morning,
c. Earthquake Safety Day Rally passing through the streets,
d. National Meeting with participation of dignitaries,
e. Annual press conference on NSET efforts in Earthquake Risk Management Action Plan Implementation
f. Earthquake Safety Exhibition with
    i. Shake table demonstration,
    ii. Real scale model of earthquake-resistant construction,
    iii. Exhibition of historical photographs of past earthquakes,
    iv. Organization of exhibits by 35 institutions on aspects of earthquake disaster response and preparedness. About 10,000 persons visit the exhibition typically.

Public talks about Kathmandu Valley's Earthquake Risk

Lectures are given about Kathmandu Valley's earthquake risk to various agencies, clubs and communities like Rotary Clubs, the Scout Jamborees, trade associations, international agencies working in the Kathmandu valley. Giving such talks not only inform the public about the Kathmandu Valley's earthquake risk, but it also give feedback on the concerns and perceptions of the public, which help tailor our public awareness campaign subsequently.

Radio/TV Programs

NSET and Sagarmatha, the local non-profit and highly respected FM Radio Channel collaborated to air weekly programs on Earthquake Safety. The program is successful and continued till date. Outside the Kathmandu valley, Annapurna FM in Pokhara city launches weekly program on earthquake safety with the help of NSET. Nepal Television, the only government TV media also broadcasts a weekly program on Kathmandu valley's earthquake risk and its management upon the request from NSET. Increasingly, NSET management and professionals are invited by national and international radio/TV channel to deliberate on aspects of earthquake risk in Kathmandu.

Engineering students in building inventory and vulnerability assessment

Building inventory and their vulnerability assessment in Kathmandu valley for the purpose of "Study on earthquake risk and mitigation option for Kathmandu" was carried out with the involvement of about 100 students of different engineering colleges. The students learned during the process significant aspects of earthquake vulnerability analysis of existing building. This aspect is usually not included in the traditional curricula of engineering studies.

IMPACT OF AWARENESS ACTIVITIES

NSET did not carry out specific survey to estimate the impact of KVERMP awareness-raising efforts. Limited survey undertaken in 1998, about 12 months after the start of KVERMP to assess the level of awareness and the readiness of Kathmandu resident's to invest in earthquake risk assessment showed high level of awareness as well as readiness. There are several evidences that indirectly show the positive impact in raising earthquake awareness in Kathmandu Valley and in Nepal due to multi-front programs of awareness. Some of these are listed below:

1. In the last part of KVERMP there was a sharp increase in the number of request for lecture on earthquake risk of Kathmandu and ways to reduce it from various communities and organizations including VDCs, municipalities, professional groups, business community, international agencies, UN agencies, academic institutions, and NGOs/INGOs. Such requests are constant nowadays.
2. There has been a sharp increase in the number of earthquake-related articles in print media. The topic is covered in electronic media also very frequently.
3. Many of the producers of construction materials (steel, bricks, cement) refer now to the earthquake hazard for marketing their product as giving earthquake-resistance.
4. Implementation of the national building code in construction in municipality. Lalitpur Sub-Metropolitan City (LSMC) has decided to incorporate Nepal National Building Code into building permit process, which incorporates earthquake resistant features of building construction, as municipal bye-law.
5. The health sector disaster preparedness and emergency response plan considers MMI IX as the worst-case scenario to base the plan.
6. The Ministry of Home Affairs implemented a JICA-sponsored project for earthquake disaster mitigation planning for Kathmandu Valley during 2001-2002. This is the direct consequence of increased awareness in formal sector.
7. There is an increase in the number of request for technical assistance for the construction/retrofitting of public and private schools. Agencies that assisted communities to construct school building now approach NSET for technical assistance in increasing numbers.

LESSONS

1. Establishment of the Earthquake Safety Day helped much in awareness raising. There is an opportunity for replicating the successes of School Earthquake Safety Program (SESP). NSET is now working very closely with the Ministry of Education and its subordinate agencies. The response received from various institutions of the replication cities of Pokhara and Dharan has been very positive. Planning process has been initiated to identify optimal programs for the cities for earthquake risk management.
2. There is a marked increase in the level of awareness on earthquake risk and possibilities of preparedness among the general public of Kathmandu Valley. A simple survey of 1500 households, carried out by GHI and NSET showed a relatively high level of felt-need for seismic safety. Obviously there is a shift in attitude from the traditional fatalistic approach to that of action.
3. Representatives of the business community, especially those producing

construction materials such as bricks and steel, and those producing/trading in supply of emergency materials are increasingly interested in working with NSET to learn more about their role in disaster management and emergency response planning.

4. Training programs organized by NSET for the media representatives during the past two years have a positive imprint in the quality of coverage on the media. There were more than 12 interviews aired through the radio, more than 4 TV interviews and chat programs. Total coverage of KVERMP and IDNDR Day activities during the past two years by the national print media exceed 200 items.

5. Scenario and action planning process helped propagate pertinent suggestions and advice from the science of seismology, earthquake engineering and geology to administrators, decision/policy makers and the common man. It helped create gradually a demand for a practical use of science in disaster mitigation.

6. Awareness raising became part of all project components. Raising awareness was originally stated as a project objective, but in long run it became clear that raising awareness is, in fact, a crucial component of each earthquake risk management activity. Every activity is shaped to raise the awareness of different groups - government officials, media, international agencies, etc.

7. It is surprising that to find that release of the results of loss estimates did not create any panic in the population. It rather made a larger part of the society wanting to improve the situation. Now , it is believed that the traditional belief of possible generation of panic should not be used as an excuse for not releasing information on risk.

ACKNOWLEDGEMENT

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APPENDIX: AWARENESS ACTIVITY CHART

Awareness Raising Strategy	Partnering institutions	General public	School Children	Teachers	Municipal Authorities	Professionals	Decision Makers	Policy Makers	House Owners	Masons, Technicians	Donors	Remarks
POLICY INITIATIVE												
Earthquake Safety Day												
National Meeting					√		√	√			√	
Symposium					√	√	√					
ES Rally	√	√	√	√	√	√	√	√	√		√	
Earthquake Safety Exhibition	√	√	√	√	√	√	√	√	√	√	√	
Shake table demo	√	√	√		√	√	√	√	√	√	√	
Street Drama		√	√									
Essay & Poem Competition at national scale			√									
Art Competition for Kathmandu Valley School Children			√									
Earthqauke Damage Scenerio and Action Planning	√				√	√	√	√			√	
Publications												
Earthquake Scenario of KV (Nepali, English		√			√	√	√	√	√		√	Convincing Tool
KV Earthquake Risk Management Action Plan	√					√	√	√			√	
Flier, Poster, Video		√	√	√						√		
Calendar	√	√	√	√	√	√	√	√	√	√	√	Focused on non engineered constructions
Manual for Earthquake-resistant construction of school buildings ***: Protection of Educational Buildings Against Earthquake***				√			√	√			√	
Bhaicha; a comic book	√	√	√	√	√	√	√	√	√	√	√	
FAQ on Earthquakes	√	√	√	√	√	√	√	√	√	√	√	
lectures, seminars and orientation programon EQ Risk and ERM												
Rotary/Lion Clubs		√										program per month
International agencies, donor agencies resident in Kathmandu											√	About 6 programs per year
Flier, Poster, Video		√	√	√						√		
Consultation to house owners												
Friday consultation to house-owners		√										Very successful program
Community based training program												
To school teachers, parents, community leaders		√										
To residents of municipal wards		√			√							

SCHOOL EARTHQUAKE SAFETY PROGRAM

A. M. Dixit, B. H. Pandey, R. C. Kandel, R. Guragain, S. N. Shrestha, M. Nakarmi, and S. P. Acharya

Abstract

The Kathmandu Valley Earthquake Risk Management Project (KVERMP) was implemented during September 1997 – February 2001 jointly by the National Society for Earthquake Technology – Nepal (NSET-Nepal) and GeoHazards International (GHI), as a part of the Asian Urban Disaster Mitigation Program (AUDMP) of the Asian Disaster Preparedness Center (ADPC), with core funding by the Office of Foreign Disaster Assistance of USAID.

A project design workshop in March 1997, attended by representatives of most of the government and non-governmental institutions in Kathmandu Valley related to disaster management helped to define KVERMP's objectives as: 1) to evaluate Kathmandu Valley's earthquake risk and prescribe an action plan for managing that risk; 2) to reduce the public schools' earthquake vulnerability; 3) to raise awareness among the public, government officials, the international community resident in Kathmandu Valley, and international organizations about Kathmandu Valley's earthquake risk; and 4) to build local institutions that can sustain the work launched in this project.

KVERMP included a wide variety of activities aimed at beginning a self-sustaining earthquake risk management program for Kathmandu Valley. Project components included the following: 1) development of an earthquake scenario and an action plan for earthquake risk management in the Kathmandu Valley, 2) a school earthquake safety program, and 3) awareness raising and institutional strengthening.

The project was implemented with strong participation by national government agencies, municipal governments, professional societies, academic institutions, schools, and international agencies present in Kathmandu Valley, in advisory committees and various workshops, seminars, and interviews. The process of earthquake risk management is continued now by NSET by implementing, since September 2000, the Kathmandu Valley Earthquake Risk Management Action Plan Implementation Project (APIP). OFDA is providing financial support to NSET for the implementation of APIP, which also contains SESP as one of the major components. APIP will be continued through August 2003

While the whole of KVERMP and APIP process and almost all of the project components strongly incorporated community-based approaches, in this paper we try to highlight the content, implementation process and experiences of the School Earthquake Safety Program (SESP). Some lessons learned during the process are also presented.

SCHOOL EARTHQUAKE SAFETY PROGRAM (SESP) CONCEPT DEVELOPMENT

Why Schools?

Public schools in Nepal, both their buildings and their occupants, face extreme risk from earthquakes. This is because of the fact that the majority of the school buildings, even those constructed in recent years, are generally constructed without the input of trained engineers in design or construction supervision. Management of the public schools is largely the responsibility of the local community: the government provides the curriculum, and the salary of the teachers. The rest has to be managed by the community. Usually very low budget is available with the school management system. Such condition increases the likelihood that poor materials or workmanship are used in the construction of the school buildings making them structurally vulnerable to earthquakes. High vulnerability of schools was evidenced during the 1988 Udayapur earthquake (M 6.6 Richter) in eastern Nepal. Six thousand schools were destroyed in this event, luckily during non-school hours. Such massive damage to the school infrastructure disrupted the affected community: approximately 300,000 children were not able to properly attend schools for several months after the event.

The other obvious reasons for KVERMP to focus on public schools were based upon the following facts:

Public schools in Nepal are the center of social and cultural life, especially in rural and sub-urban areas. Hence, there is a greater chance of propagating earthquake awareness from school to the families, and from families to the communities

Public school buildings can serve as emergency shelters. Usually they have open grounds that could be used for establishing tents for shelter or field hospitals following an earthquake

Children of public schools are the future of Nepal. Usually they come from low-income group hence constitute the more vulnerable community.

School children are also particularly vulnerable to natural disasters, especially the youngest children. Usually, children going to the public schools are from middle- to low-income groups. These are also the highly vulnerable strata of the society.

The loss suffered by a community in the collapse of a school is psychologically much greater than the loss faced by collapses of other building types: schools house an entire generation and a community's future.

Schools play a crucial role after an earthquake in helping a community to get back on its feet. Since schools are typically well distributed throughout neighborhoods, they are an ideal location for homeless shelters, medical clinics, and other emergency functions. Functioning schools provide a feeling of normality to a community, helping people get back on their feet after a disaster.

Schools are also particularly tractable for earthquake safety programs. Schools structures are typically very simple and relatively small, unlike other critical facilities. Therefore it is inexpensive to build new schools in an earthquake resistant fashion and it can be affordable to retrofit existing schools. Also, by raising awareness in schools, the entire community is reached because the lessons trickle down to parents, relatives, and friends.

VULNERABILITY ASSESSMENT OF PUBLIC SCHOOL BUILDINGS

At first, the initial days of KVERMP, the SESP included a vulnerability assessment of Kathmandu Valley's public schools as an example of how to conduct earthquake risk mitigation projects in Nepal. The purpose of this assessment was not to identify individual schools as vulnerable, but to quantify the risk faced by the entire system.

Assessment Methodology

First, the project team created a questionnaire that could be filled out by school headmasters. This questionnaire included topics such as size of buildings, density of students, year(s) of construction, whether or not an engineer was involved in the building design or construction, etc. Additionally, simple questions were asked about structural characteristics, presented through illustrations and descriptions. The project conducted 17 seminars with school headmasters from 65% of the total 643 public schools in the Valley to teach them about earthquake risk, about the necessity of planning for earthquakes in their school, and how to fill out the project questionnaire. Subsequently, the headmasters conducted the survey and data on 430 schools were returned to the project. The conclusions were extrapolated to the entire building stock of the existing public schools of Kathmandu Valley.

A more detailed inventory and vulnerability assessment of the school buildings on the conventional way would have required several years to complete.

Alarming Findings

The following were the findings of the survey.

More than 60% are built using traditional materials (such as adobe, stone rubble in mud mortar or brick in mud mortar) that behave very poorly during earthquakes.

The remaining (less than 40%) of the buildings uses more modern materials such as brick in cement mortar or reinforced concrete. Even though modern materials are stronger, these modern Nepali schools are not necessarily safer. Traditional artisans build almost all of these schools without any inputs from an engineer. School buildings built with modern materials are typically taller, have larger rooms and larger windows and doors than buildings built with traditional materials. These features make many modern buildings as dangerous as the traditional ones.

Of the nearly 700 school buildings, only three buildings were constructed meeting the stipulations of the Nepal National Building Code (draft). An additional four to five percent buildings had some seismic resistant design features, such as reinforced concrete bands at the lintel level. The vast majority of buildings were built without considering seismic forces at all.

Many school buildings are not only poorly constructed, but they also lack proper maintenance. Approximately ten to fifteen percent of buildings were in extremely poor condition due to sub-standard material or workmanship, lack of maintenance, or extreme age. Many buildings have floors that are on the verge of collapse or walls that could crumble and fall at any time. These buildings are dangerous to occupy even in normal times. Another twenty-five percent of the buildings were found to have serious maintenance problems, such as decaying timbers or severely cracked walls that, if not repaired quickly, will deteriorate into extremely dangerous conditions.

Table 1: Seismic Vulnerability of Public School Buildings in Kathmandu Valley

Particulars	Details	%
Total number of Public Schools/buildings	643/1100	
Typology of traditional school buildings	Adobe (sun-dried bricks) or Earthen Buildings (mud cake buildings)	5
	Stone/brick masonry in mud mortar	56
	Rectangular block (Brick or hollow concrete block or semi-dressed stone in cement mortar)	28
	Reinforced Concrete Frame (RC Frame)	11
Existing Condition (with extrapolation for 643 schools)	Hazardous for use at present (Pull down and reconstruct ASAP!)	10-15
	Can be saved (with structural intervention, Retrofit, Repair and Maintain ASAP)	25
	Good for vertical load (but not for lateral shaking), need retrofitting	65
Vulnerability Assessment (for intensities IX MSK shaking)	Collapsed Grade	66
	Severe Damage or partial collapse (not repairable/not usable after shaking)	11
	Repairable Damage	23

MAIN PROBLEMS OF EXISTING SCHOOL BUILDINGS

In summary, the main characteristics of the public school buildings of Kathmandu Valley are the following.

- Almost all buildings are non-engineered,
- Most buildings were constructed using informal production mechanisms,
- The buildings are constructed using mainly the traditional materials (low-strength masonry, flexible floors and roofs mostly of timber),
- Most are elongated (rectangular) in plan
- Most buildings are load bearing masonry structures, and
- Most are highly vulnerable to earthquakes.

Major problems so far identified in the various types of existing buildings belonging to the public schools are: a) use of weak construction materials, b) heavy wall and roofs, c) poor quality control of construction process, d) untied gable wall, is the lack of integrity between different structural components/elements.

The Initial Dilemma

Many advisors of KVERMP and well-wishers of NSET warned not to initiate any program on such a huge problem as seismic improvement of public schools. Further, people were skeptic about the feasibility of “retrofitting” in Nepal, considering it excessively expensive.

On the other hand, NSET looked at improvement of seismic performance of existing school and residential buildings, structural and non-structural, as an alternative that deserved high priority for exploration. The country has about 25,000 public schools, and it will take very long time for each of them to have new earthquake-resistant building unless some radical means are found and implemented.

Subscribing to the concept of incremental seismic safety, NSET opted to explore further the feasibility of structural intervention for reducing existing vulnerability of the school buildings. The results are described in the following sections.

Benefits from Intervention

Two scenarios were considered, no intervention and intervention cases, for seismic improvement of school buildings. In the no intervention scenario, the expected loss is more than 29,000 school children dead or injured, and more than 77% of the buildings incurring direct building loss the cost of which has been estimated at around US$ 7 million (Table 2). The resulting societal trauma, need for rescue and relief, degradation in life standard would be of unimaginative scale. By intervening structurally, we can save the lives of some 24,000 children and protect our school buildings, one of the biggest assets of a community. Besides, it will also provide an opportunity for social dialogue, increased awareness, preparedness planning, and masons' training thereby the opportunity for replication- hence inculcating a culture of safety. The imperative is to act now!

Comparative Evaluation of the two Options - Retrofitting Versus Demolish & Reconstruction

Table 3 presents two options available for seismic improvement of school buildings and makes a comparative evaluation of the options. The options are i) demolish and reconstruct, and ii) retrofit. The first option seems easy from technical point of view. It is also attractive but there remains very high excitement, societal impact and opportunity to learn more in second option. On economic ground also the first option is far expensive than the second option (refer Table 6). It is not only cost but also, magnitude and duration of disturbance to existing school functions will also be very high in first option (more than 1 year in comparison to 3-4 months in second one).

Table 2: Comparative Evaluation of the Benefits of Structural Vulnerability Reduction of School Buildings

Criteria		Intervention Scenario at different Intensities of Shaking (MSK)			Non-Intervention Scenario at different Intensities of Shaking (MSK)		
		VII	VIII	IX	VII	VIII	IX
Building Loss		%	%	%	%	%	%
Level of Damage	Collapse	0	0	11	0	11	66
	Un-repairable Damage	0	0	46	4	65	11
	Repairable Damage	61	100	43	73	24	23
Life Loss				5000		?	29,000
Direct Economic Loss due to Building damage							US $ 7M
Societal Trauma		Low			High		
Requirements for Rescue / Relief		Low			High		
Earthquake awareness / preparedness planning, establish dialogue		Very High			None		
Mason Training Opportunity, Replication Potential		Very High			None		

Table 3: Comparison between Retrofit and Reconstruction Options

No.	Criteria	Demolition & Reconstruction	Retrofitting
1	Involved Costs	High	Low
2	Time for Building strengthening	More than a year	3-4 months
3	Disturbance to School Function	High	Low
4	Problem associated with Disposal of Scrapped Materials	Big Problem	No Problem
5	Technology (adaptability)	Usual (hence no excitement)	New (hence high excitement, but need to train)
6	Societal Impact (Replicability)	Low/Medium	High

Table 4: Comparison between Retrofit and Reconstruction Costs (as of 1999)

Building Type	Demolition and Aseismic Reconstruction (to the same standard as present) (NR/ m^2)	Seismic Retrofitting (Including Repair & Maintenance, R&M), (NR/ m^2)			Benefit of Retrofitting over Reconstruction	
		Retrofit	Repair & Maintenance	Total	Retrofit without R&M	Retrofit with R&M
Masonry in Mud Mortar	2,500	725	375	1100	75	60
Masonry in Cement sand mortar	3,118	710	180	790	77%	75%

Table 5: Retrofitting cost per student

S. N.	Name of School	Influnced Population	No. of students before intervention	No. of students after intervention- (2002)	No. of students sitting in intervened building	Cost of retro./ recon.(NRs.)
1	Bhuwaneshwory Lower Secondary School	5446	169	195	195	642,510
2	Gadgade Primary School	4185	156	175	175	331,512
3	Upayogi Primary School	4660	65	63	63	199,113
4	Vaisnabi Secondary School	49135	302	311	60	451,806
5	Bal Vikash Secondary School	3931	395	480	300	521,742
7	Himalaya Primary School	47451	60	74	74	750,000
	Total	**114,808**	**1147**	**1,298**	**867**	**1,922,661**
	Cost in US $					**24,970**
	Per Student cost					**29**

Note: The cost includes the construction cost only.

SESP PROGRAM

Approach

With the aim to provide oversight to the program, NSET has established two standing SESP Advisory Committees at the central and district levels. These committees are chaired respectively by the Regional Director (Education) and the Chairperson of the District Development Committee (district level government). Other members drawn into the committee are representatives from the government and non-government agencies and political leaders. These committees meet at least once a year; NSET reports the progress to these committees, and submits annual work plans for their endorsement. Constitution of the advisory committees has helped widen the outreach of the program and its ownership.

NSET encourages the local community to establish a School Earthquake Safety Committee (SESC), with several sub-committees, at each SESP site. The Chairperson of the School Management Committee heads SESC. The sub-committees established under SESC are i) Construction Management Subcommittee, ii) Mason Training Subcommittee, and iii) Earthquake Response Planning Subcommittee, and a School Earthquake Safety Club (students).

Because of the involvement of a very wide section of communities and institutions, SESP has proven to be a strong awareness raising activity.

To measure the impact, SESP conducts a social survey at the start and end of the construction program in the communities. A baseline survey is conducted with 100 randomly selected respondents in each school community. A repeat of the survey is done soon after the completion of the construction program at each school.

Program Components

Currently, the School Earthquake Safety Program consists of three closely inter-knit sub-components, namely, (1) Training of masons, (2) Training of teachers, parents and students on earthquake preparedness and preparedness planning, and (3) seismic retrofit or earthquake-resistant reconstruction of public school buildings.

Selection of Target Schools

Each year, NSET carries out selection of target schools following a set of screening criteria (Annex 1). The criteria emphasize on the level of commitments of community participation in the program, visibility of the school (replicability potential), availability of temporary class run options, absence of dispute on land and building ownership. Additional consideration made are availability of local masons in the vicinity, potential of local contribution (cash or kind or labor), socioeconomic conditions (financial condition of parents, homogeneity/ heterogeneity of community, caste, ethnicity), and availability of construction materials (sand, aggregate, timber) in the vicinity, acceptance to run training of masons, teachers, and possibility of preparing emergency response planning. Charts in Annex 1 and 2 show the weights given to these criteria.

Pre-implementation Management Activities

This consists in convening a meeting of the District level Advisory committee on SESP and signing a MOU between NSET and the School management committee setting out the terms and conditions for the implementation of the program. The MOU specifies that NSET would: 1) provide only technical support and that the actual resources have to be identified/ mobilized by the local community, 2) NSET would help the community in fund-raising, 3) the community would provide in-kind or cash or materials contribution, 4) the communities establish the School Earthquake Safety Committees (SCC) with the chairperson of the School Management Committee heading it. IT requires also that the school would have established Construction Management Subcommittee, Mason Training Subcommittee, and Earthquake Response Planning Subcommittee, and a School Earthquake Safety Club (students).

Technical Assistance during Construction

NSET carries out survey, design and assists the construction committee to implement the construction. Usually, the local masons are engaged in the construction; contractors are avoided.

NSET also provides construction supervision. During construction, the masons are trained in aspects of earthquake safety. A mason who had been trained earlier is posted at each construction site at NSET's cost. He supervises the day-to-day construction and trains the local masons on-the-job.

NSET engineers conduct classroom training in the evenings. Usually, such training programs are attended not only by the masons, but also by the parents ,Students and other members of the community.

Training Curriculum Development, and Earthquake Kit preparation

Kit for the teachers has been prepared, and a training curriculum has been developed. During the training, the teachers are guided to prepare simple earthquake safety program for the school.

Box 1: Applicable Methods for Retrofitting School Buildings

The methods identified as applicable for the seismic improvement of reinforced concrete, and masonry buildings. Firstly, it is recommended to amend conceptual deficiencies (configuration, load path) in existing buildings. Secondly, enhancement of strength (jacketing of framing elements) and ductility (following ductile detailing) are recommended for reinforced concrete framed buildings, and enhancement of the integrity between structural elements (using stitches, splint and bandage, floor/ roof bracing) and enhancing ductility are recommended for masonry buildings.

Additional Program Components

SESP has undergone several changes and additions. More new players are becoming partners in implementing earthquake-resistance into the construction of public school buildings in Nepal.

Collaboration with other partners

NSET has entered into a MOU with a NGO Room to Read (RTR) for mutual collaboration for the incorporation of earthquake safety elements in the school buildings constructed by RTR. The collaboration has extended wider to cover areas of mason training, earthquake safety of the school and also financial assistance to the communities where NSET-assisted schools are being retrofitted.

Similar collaborative arrangement is being contemplated with other NGOs and INGOs that are investing in the construction of school buildings in Nepal.

Collaboration with government

The government of Nepal is negotiating a financial assistance from funding agency for implementing secondary education improvement program that will invest significantly in infrastructure improvement of public schools. The Department of Education has asked NSET for cooperation in integrating earthquake safety into the project activities.

With such collaborative programs, NSET expects to widen the outreach of its SESP to other parts of the country very soon. This is necessary because the whole of the country faces high earthquake hazard.

PROGRAM ACHIEVEMENTS

Affordability of Seismic Improvement of School Buildings Established

The School Earthquake Safety Program has so far accomplished seismic retrofitting of four brick masonry buildings belonging to the following schools:

1. Bhuwaneshwory Lower Secondary School, Nangkhel, Bhaktapur District
2. Bal Bikash Secondary School, Alapot, Kathmandu District
3. Upayogi Primary School, Sirutar, Bhaktapur District and
4. Gadgade Primary School, Nagarkot, Bhaktapur Distric

Additionally, the Program could reconstruct to the standards of Nepal National Building Code two

Box 2: Use of Appropriate Technology and Localized Solution

Kabhresthali is a village located in the northern fringe of Kathmandu Valley at the foot of the Sheopuri mountain range. The Kabhresthali public high school was recently reconstructed to earthquake safety under SESP. Together with the local people, NSET engineers decided to reconstruct the dilapidated stone-masonry building. But opinion differed: the community wanted to reconstruct in brick masonry, while the engineer thought it to be the ideal site for the use of stonecrete blocks that could be manufactured locally, by breaking the dismantled stone into smaller pieces and molded into cement blocks.

It required lots of patience for the engineers to convince the community on the appropriateness of the technology.

First, they were told about the benefits to be derived: a) trucking of bricks from kilns located in the south of the valley is expensive, and sometimes impossible because of the poor quality of the road to Kabhresthali, and b) stonecrete blocks can be molded locally, at household level, especially during periods of field fallow, using stones that were scattered all around the village and sand that abounds in the nearby stream. Members of the School Construction Committee were taken to Kirtipur where the community was proud to have accepted the technology a year ago. This created the required peer pressure and paved way for enhancing confidence.

Further, the molded stonecrete blocks were tested in the laboratory of the local government-run engineering institute. Kabhresthali people were very delighted to learn that the stonecrete blocks were several times stringer than the usual bricks.

The school building was constructed at much lower cost. The economy resulted not only at the low cost of locally molded stonecrete as against the imported bricks, but also because of the relatively lesser time necessary for laying the blocks.

At present, the people of Kabhresthali not only demonstrate the technology to the newcomers, but also mould these blocks during off-season. A new livelihood option has thus been initiated.

With the new technology of block making and building construction, Kabhresthali will get each year safer from earthquakes.

very hazardous buildings belonging to the following schools:

5. Bhuwaneshwory Lower Secondary School, Nangkhel, Bhaktapur District
6. Vaishnavi Secondary School, Kirtipur, Kathmandu District
7. Kabhresthali Lower Primary School, Kabhresthali, Kathmandu District
8. Himalaya Primary School, Bhaktapur District
9. Nateshwory Primary School, Bhaktapur District (nearing completion)
10. Shree Krishna Secondary School, Dhapakhel, Lalitpur District (NSET is providing technical assistance to this school; financial assistance comes from SNV, Netherlands)-on going from 2002.
11. Vidyodaya Primary School, Jochhen, Kathmandu-on going from 2002
12. Shree Saraswoti Secondary School Thecho, lalitpur-on going for 2003
13. Shree Saraswoti Secondary School, Thakalmath, Bhaktapur –on going for 2003

Two more schools of Dhading district under the Room to Read program received technical assistance from NSET. The assistance included survey, design, construction supervision, mason training, training of parents and community leaders. NSET has provided one trained mason on the site for full construction time.

14. Amarkhu Secondary School, Dhading
15. Tin Kanya Primary School, Dhading

Recently Handed over School Building of Himalaya Primary School-Thimi Bhaktapur.

(Minister of Education is awarding certificate to trained masons)

Mason Training

The whole execution of project is designed as a tool of developing skilled manpower in earthquake resistant construction in local level. In all the process of seismic retrofitting and reconstruction, Engineers of NSET-Nepal work with masons showing them the details and explaining the complete procedures. Focus was placed in explaining the meaning of the processes of curing of

The program implementation provided to develop a better idea about the prevalent building typologies, the inherent problems, and the likely solutions for enhancing their structural safety. The experience gained is being consolidated in the form of a Hand Book for Seismic – Resistant Construction and Retrofitting of School Buildings in Nepal.

- *Box 3: Remembering what the grandfather said .*

Everybody was happy at the smooth pace of construction works at Bhuwaneshwory Lower Secondary school. NSET was assisting the local community to retrofit the existing brick masonry building that was about 15 years old. NSET engineers were happy that the masons were bending the bars and laying the bricks exactly as they instructed. But they were glad also because the mason earlier asked, "O. K. Sir, we do as you instruct. But could you please explain why you want things this way and not the other way. Please explain the difference." That was the demand for training, the NSET engineers understood, and started the mason-training program.

Classroom lectures for the masons started being held in the evening, in one of the classrooms of the school. The classes were visited not only by the masons, but also by parents and elderly people.

One evening, an elderly person attended the lecture. He was given special seat at the front as everybody respected him. He was the oldest mason, already in his eighties.

At the end of the lecture, he told the NSET engineer how his grandfather taught him the skills of building construction. He summarized:

- Always put a wooden (tie) band around the building at sill level, lintel level and at the floor level. Carve it in "naga" (snake). It will protect your house.
- Secure every third or fifth or seventh joist to the wall plate by driving a lock wedge driven through the joist.
- Multistory high buildings, Arches, existence of numerous windows, brick wall without good "teeth joints", use of brick pieces in the middle of wall width, masonry wall without bands, buildings with heavy upper stories, building in mud mortar are relatively weak.
- For larger buildings, the quality of materials is as important as the quality of construction. Better to consider both.
- For smaller, low-cost dwellings, 1) do not make more than 1 story if constructed with a combination of burnt and un-burnt bricks, 2) dress the stones for construction of stone-masonry buildings in the hills, 3) make the roof as light as possible, 4) use lime mortar for bricks, 5) limit height of brick masonry buildings to 34 hat (50 ft), 6) assure good connection between walls at joints, the whole house should behalf like one structure during an earthquake, 7) construct in one wyeth rather than using pieces to increase the wall section in masonry construction, , 8) avoid columns in brick masonry; better use a timber column
- Build at those places where the past earthquake did not have much affect
- Dig the foundation right up to the rock

The young NSET engineer asked himself a question – who is teaching whom?

concrete, proper reinforcement details, what does the earthquake -resistant elements do? How the retrofit elements such as splints, bands, corner pins, etc function to withstand the earthquake force.

Besides the training in the form of explaining as you go, separate training classes were organized in evenings. The main target group was the craftsmen of the respective village, but the classes are typically open to all interested. The technical knowledge of earthquake resistant construction is given to them systematically. Participation of villagers and craftsmen was always higher than the number of masons directly involved in the construction process in the village. This was due to the raised level of awareness on earthquake. They have seen their future in this 'modern' Technology that they should be equipped with. They were very enthusiastic.

Obviously, the common people, during the training session, show high concerns over the matters that how their own houses are built, and the weaknesses of the prevailing construction practices. Masons pay much attention to know about for and against aspects of their conventional practices, need to adopt new methods, extent of change, solution to problems that the change may bring about and its harmony with seismic retrofitting and reconstruction of school, which they witnessed. It is noteworthy that once trainees be convinced and equipped with seismic resistant techniques, they also asked the methodology to convince and teach others about it.

The training courses follow hierarchical procedure starting from problem identification to end at testing of methods of learned. Several tests are conducted to support the knowledge in relation to effect of placement of reinforcement rod in beam/slab, quality of work governed by material and workmanship like excess water effect, curing effect etc

Local masons understood the language of retrofit, earthquake-resistance design, the importance of quality control. They could remember the advice of their great grandfathers regarding earthquake resistant design

About 25 masons from the five school communities have been trained in the skills of seismic retrofitting, earthquake – resistant construction and quality control. Four of these masons have been trained as Trainers. In fact, these four masons from Nangkhel Village were given the responsibilities of supervising the construction works at four different schools under the program. Additionally, 20 other junior masons and construction labors were given the training.

Based on the experiences gained from the mason training, a curriculum/guideline for Mason Training has been prepared.

Awareness Raising, Training of Teachers, Parents, and Children

SESP was implemented with maximum participation of the government institutions (Central Region Education Directorate, District Education offices of Kathmandu and Bhaktapur Districts), District Development Committees and Village Development Committees, the school management systems, and the parents and the students. The government agencies provided funds and policy guidance, while the actual implementation of construction works was handled by the school management committees with technical inputs and supervision from NSET. Such implementation mechanism, together with the formation of Central -, District -, and school level advisory committees, considerably widened the outreach of the program and its ownership.

All this has resulted in greater awareness in the communities on earthquake disaster risk and risk reduction. A qualitative judgment on the impact will be made following the completion of the second leg of the social impact survey. However, it is seen that new constructions in the settlements surrounding the schools are incorporating seismic-resistant elements, mostly by consulting the SESP masons. A strong replication potential of the program concept, and hence sustainability of efforts, is thus evident.

Kathmandu-Kobe Exchange Program

Kobe-Kathmandu Collaborative Exchange Program on Earthquake Safety is a logical continuation of SESP in Bal Bikas Secondary School, Alapot, Kathmandu District. Greatly influenced by the performance of the local community, teachers and students of Bal Bikas in terms of their dedication to enhancing earthquake safety of their school, NSET and UNCRD (Disaster Management Planning Hyogo Office) facilitated this program. The program aims to enhance cooperation between the students of Kobe and Kathmandu through learning experiences and sharing knowledge in disaster mitigation. The goal is to raise awareness for disaster preparedness among students, teachers, and other members of the community.

Replication

In all the communities where SESP has conducted, the house owners of respective locality have been replicating the construction methods employed in school building to construct their private houses without intervention from NSET-Nepal. Except some minor features, newly constructed houses adopt all basic earthquake resistant construction technology like bands, wall stitching, vertical tensile bars etc. It shows higher level of perception on what masons are trained. Obviously, it can be said that the process of replication would multiply in future to set a new technological culture in construction. In this aspect, the retrofitting project of school has much higher social value compared to other risk reduction programs that hardly are able to translate technology in real ground in root level.

Trust Building

All related government institutions, including the Ministry of Education, were involved in the project activities right from its planning phase. The Project subsequently provided regular information to the ministries and other related institutions. Such flow of information and "keeping everybody informed" helped NSET to build up and sustain the trust despite the fact that there were frequent transfers of related personnel in the government offices.

The fact that the schools were also involved in the SESP process right from the headmasters' seminar also created an environment of trust. Even the schools that were not included in the process were invited regularly in the SESP events. Creation of the advisory committee and its meeting provided the transparency that helped build trust.

Considering the high level of interest from the community, NSET organized several meetings with the parents and the school management committee. Such meetings were costly in terms of time, but they helped consolidate mutual trust, helped explore additional potentials for cooperation, and solve outstanding issues.

EVALUATION OF ACHIEVEMENTS

Running project 2002, Shree Krishna Ma. Vi. Dhapakhel is one of the project where initially most community people were worried about the construction management and wanted to give it in contract but after starting the construction by community on SESP model they are very happy with construction on very low price due to transparency. Local Engineer is also impressed on the method and although initially he has no interest on construction now a day he is visiting site and discussing on earthquake resistant construction issues. Replication on community is highly anticipated.

Focus on School Earthquake Safety drew criticism

NSET and KVERMP were initially criticized for focusing only on public schools. Many people questioned why private schools and hospitals, a critical facility for post-earthquake response, were not chosen. Additionally, people asked why cinemas, private schools and colleges were not examined. The project team continued explanation for its focus on school did not quell the criticism. However, given the limited resources available, NSET continued the focus on schools, noting that the work on schools was building NSET's capacity to evaluate the vulnerability of other systems in the future. The school survey examined many previously unknown attempted activities: the costs of conducting a survey of building vulnerability, the technical expertise required for this type of survey, the costs involved in strengthening existing vulnerable buildings, the types of techniques to use for strengthening typical Nepalese structures, the interest of the community in strengthening buildings, the ability to attract funds (local and international) to this type of work, and the levels of earthquake risk acceptable in Nepalese society.

Initial Skepticism was Short-lived

Low level of awareness and uncertainty of earthquake event brought criticism during initial stage of the program implementation. NSET being an NGO was another reason for an initial apathy because of generally tarnished image of several of NGOs. However, open financial policies and transparency exercised, limiting the role of NSET as technical/management assistant, giving the local school management committees the decision-making responsibilities helped develop the required level of mutual trust, and the program ultimately received all out cooperation from all concerned.

Retrofitting a School is an important awareness raising opportunity

The lesson was not simply that a school could be retrofit. More important lesson was that for an additional $10-15k, local masons could be trained while retrofitting the school and the villagers could have their earthquake awareness raised. Strengthening the school was important and attractive, but more attractive outcome of the project was training the masons, convincing the masons that the good techniques are better than the poor techniques, raising the awareness of the villagers, teaching the children and teachers what to do during and before an earthquake. All these extras come for a small relative increase in the cost of retrofitting, and they could be possible only because of the retrofitting.

Community-based Approach is Key to Risk Management Efforts

Despite the traditional fatalistic outlook, issues of disaster management are becoming popular with the people. The traditional thinking of only the government being responsible for relief and prevention works is being replaced by realization of the need to start working at the community level. Disaster risk reduction is not the highest priority of the people in view of more pressing needs such as infrastructure, sanitation, health, education and environment. Moreover, most communities do not have enough financial resources. Therefore, making disaster risk reduction programs self-sustaining is rather difficult, and requires innovative thinking. At the same time, since the benefit-cost ratio is very high in view of the prevailing low level of preparedness, ways should be identified to initiate and support community-based disaster management programs.

Training Program for Mason is essential for a Successful School Earthquake Safety

The training program helped much to convince the local masons on the affordability and possibility of constructing earthquake -resistant buildings using slight improvements in the locally employed methods of construction. Trained masons from SESP have already started to construct buildings safer from earthquake in different part of the Kathmandu valley. Construction of new buildings with Earthquake resistant elements as well the retrofitting of existing buildings are increasing day by day in city. The increasing demand of the trained mason shows the need to train more and more mason on each site.

On the Job Training as well Lecture on Earthquake Awareness and Earthquake Resistant Building Construction

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PROMOTING SAFER BUILDING CONSTRUCTION IN NEPAL: EXPERIENCES OF NSET

R. Guragain, Y.K. Parajuli, and A. M. Dixit

Abstract

To date, most residential buildings (even in urban areas of Nepal) do not receive any rational design for strength. Even though most municipalities (58 altogether) do have a system of building permits, there is no provision in the process to check strength criteria. The building permit process takes into account only the compliance related to planning (ground coverage, FAR) and building by-laws (height, provision of toilet, sewer and solid waste disposal). Kathmandu and Lalitpur municipalities now require some structural drawings (not design) for buildings with more than three stories or a 1000 sq. ft. plinth area. Thus, there is poor institutional and technical capacity within the local authorities for implementing strength-related provisions if they were to be introduced in to the building permit process.

On the professional front, too, there is no system of controlling the professional standards of engineers/designers through reference to professional qualifications/ membership, peer review process or by legal means. Owner-builders who follow the advice of local craftsmen build more than 98 % of the buildings in Nepal. Neither the owner builder nor the crafts persons are aware of the possible disastrous consequences from an imminent earthquake. Neither do they have adequate access to information related to safer building practices and incorporation of simple earthquake-resisting features at nominal extra cost. Even the building construction projects funded by national and multilateral agencies do not spell out any requirements related to seismic safety when they hand over the terms of reference to their consultants.

"As many as 60 percentages of all buildings in Kathmandu Valley are likely to be damaged heavily, many beyond repair" is the result of loss estimation during earthquake scenario preparation under Kathmandu Valley Earthquake Risk Management Project, which was implemented by the National Society for Earthquake Technology – Nepal and GeoHazards International, as a part of Asian Urban Disaster Mitigation Program of the Asian Disaster Preparedness Center with core funding from the Office of Foreign Disaster Assistance of USAID.

This paper is focused on analysis of existing construction mechanism and trends, implementation strategies, difficulties and lesson learned from the initiatives that have been taken by NSET-Nepal towards safer building construction in Nepal.

BACKGROUND

To date, most residential buildings (even in urban areas of Nepal) do not receive any rational design for strength. Even though most municipalities (58 altogether) do have a system of building permits, there is no provision in the process to check strength criteria. The building permit process takes into account only the compliance related to planning (ground coverage, FAR) and building by-laws (height, provision of toilet, sewer and solid waste disposal). Kathmandu and Lalitpur municipalities now require some structural drawings (not design) for buildings with more than three storeys or a 1000 sq. ft. plinth area. Thus, there is poor institutional and technical capacity within the local authorities for implementing strength-related provisions if they were to be introduced in to the building permit process.

On the professional front, too, there is no system of controlling the professional standards of engineers/designers through reference to professional qualifications/ membership, peer review process or by legal means. Owner-builders who follow the advice of local craftsmen build more than 98 % of the buildings in Nepal. Neither the owner builder nor the crafts persons are not aware of the possible disastrous consequences from an imminent earthquake. Neither do they have adequate access to information related to safer building practices and incorporation of simple earthquake-resisting features at nominal extra cost. Even the building construction projects funded by national and multilateral agencies do not spell out any requirements related to seismic safety when they hand over the terms of reference to their consultants.

"As many as 60 percentages of all buildings in Kathmandu Valley are likely to damaged heavily, many beyond repair" is the result of loss estimation during earthquake scenario preparation under Kathmandu Valley Earthquake Risk Management Project (KVERMP), which was implemented by the National Society for Earthquake Technology – Nepal and GeoHazards International, as a part of Asian Urban Disaster Mitigation Program of the Asian Disaster Preparedness Center with core funding from the Office of Foreign Disaster Assistance of USAID.

The Earthquake Risk Management Action Plan, created by KVERMP included among the top 10 priority actions the followings:

NSET will request the Ministry of Housing and Physical Planning to constitute the Building Council and direct it to draft the rules and procedures for implementing and enforcing the building code, and formally adopt requirements to implement and enforce the building code.

NSET will work with the Ministry of Housing and Physical Planning and others to prepare training materials and provide training for building inspectors, masons and engineers on applied aspects of design and construction of buildings to conform to the Building Code.

NSET will manage and co-ordinate the "School Earthquake Safety Project" which will (1) inform selected communities about the vulnerability of their schools and what can be done to reduce the risk; (2) prepare school-specific plans for improvements in seismic safety; and (3) mobilize support to improve the safety of the school buildings.

NSET will encourage engineering institutes to develop and offer short courses for practicing engineers on earthquake engineering principles and procedures.

Implementation

NSET's current effort is directed towards implementation of part of the Earthquake Risk Management Action Plan for Kathmandu Valley. Among others the promoting safer building construction is one of the focus areas.

Analysis of Existing Building Construction Mechanism

With the aim to better define the problem and its mitigation NSET's approach has been to look into the prevailing building construction mechanism.

Type of building construction mechanism

There are three distinct types of building construction mechanism in practice in Nepal.

A. Engineered Constructions:

These are the structures (e.g., buildings) that is designed and constructed as per standard engineered practices. In case of buildings, engineered construction are those that are supposed to have undergone the formal process of regular building permit by the municipal or other pertinent authority. The formal building permit process is supposed to require involvement of an architect/engineer in the design and construction for ensuring compliance to the existing building code and planning bylaws. In Nepal, formal building permit process is implemented only in urban areas. Building code exists but not implemented strictly! Consideration of seismicity on building design depends upon the individual initiative of the designers and the availability of fund.

B. Non-engineered Constructions:

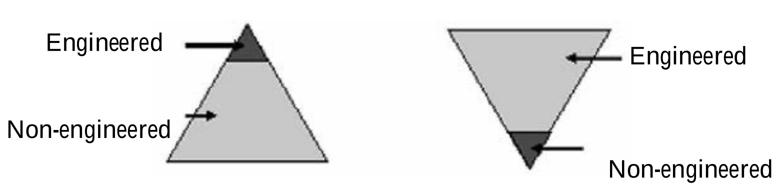
These are physical structures (e.g., buildings) the construction of which usually has not gone through the formal building permit process. It implies that the construction of non-engineered building has not been designed or supervised by an architect/engineer. Such buildings are obviously prevalent in the rural or non-urban (including urbanizing areas in the periphery of municipal areas). Although building by-laws exist and complied within municipal areas, they do not demand structural design considering earthquake effects during building permit process. Thus, a large percentage of the building stock even in Kathmandu Valley is non-engineered as the structural design is not considered in during design and there is no involvement of engineering professionals during construction phase in most of the cases. In the urban areas of Kathmandu, it is estimated that more than 90 percent of existing building stock are non-engineered (partly because there are many old historic buildings), and every year about 5000 more such non-engineered buildings are added.

C. Owner-built buildings:

These are buildings constructed by the owner at the guidance and with the involvement of a head-mason or a carpenter who lacks any modern knowledge on earthquake resistant construction. Traditional construction materials such as timber, stone rubble or brick (fired or un-burnt) and mud as mortar are used. There is usually no input from any engineer. These are usually rural constructions. However, such constructions are seen also in the poorer part of a city, or in the city suburban areas.

There is an increase in the prevalence of frame-structures now days. Unfortunately, many of them are non-engineering, which is a potentially high vulnerability situation.

Resources distribution in comparison to construction mechanism



Building production mechanism

Resources to train necessary manpower

The ratio of the number of buildings with different construction mechanism and efforts to prepare necessary manpower and documents can be compared with these two inverted triangles. The first triangle shows the ratio of buildings by different construction mechanism and second one the existing resources allocation. For real implementation of earthquake resistant measures the scenario should be changed.

Implementation Strategy for achieving seismic safety in Buildings

Towards promoting safer building construction NSET has been playing instrumental role in advocating the issues related to general and specific seismic safety requirements including in owner built buildings. Through a partnering approach with various organizations and stakeholders NSET is supporting the launching of public awareness programs, in conducting training programs at community levels, in integrating seismic resistance into the process of new construction, in increasing the safety of school children and school buildings, in improving the seismic performance of existing buildings and in increasing the experts knowledge of the earthquake phenomenon, vulnerability, consequences and mitigation techniques etc.

Considering rapid erection of new buildings in Kathmandu Valley and by taking account the large number of existing unsafe building stocks; two-pronged strategy is taken to achieve earthquake resilience of buildings in Nepal, as given below.

New Construction: Stop Increasing Risk, all new construction should be earthquake resistant so that there is not increase in risk.

Existing Buildings: Decrease Unacceptable Risk, existing structures should be either retrofitted or reconstructed to withstand reasonable shaking.

Three Approaches of Implementation

As there is existence of different construction mechanisms, the different approaches are necessary to meet the purpose. Either formally or informally, three major approaches have been taken for promoting safer building construction practice in Nepal. The three major approaches are: A) Top-Down approach B) Bottom – Up approach and C) Horizontal Networking.

Top – Down Approach

The easy way to improve the earthquake resiliency of engineered construction is formulation and implementation of good seismic code of practice. Now the "Building Act" has been passed by the parliament and laws are being formulated for actions. As a second way of implementing building code, it is now passed by Nepal Bureau of Standards and Metrology as Nepal Standard, in the initiation of NSET.

गोरखापत्र २०५८ साल पुस २५ गते बुधबार

निर्देशन

काठमाडौं, पुस २४ गते। उद्योग, वाणिज्य तथा आपूर्तिमन्त्री पूर्णबहादुर खड्काको अध्यक्षतामा आज नेपाल गुणस्तर परिषद्को ७७औं बैठक बस्यो।

बैठकमा गहुँको पीठो, स्टिल ट्युब फर स्ट्रक्चरल परपोज, डोमेस्टिक वाटर मिटर, ब्रान्डि, जीन, भोड्का, नेसनल बिल्डिङ कोड फर सेस्मिक डिजाइन अफ बिल्डिङ इन नेपाल, कोड अफ प्राक्टिस फर डकटाइल डिटेलिङ अफ रिइनफोर्सड् कङ्क्रिट, स्ट्रक्चर सबजेक्टेड टु सेस्मिक फोर्सेस, पेट्रोलियम र यसबाट उत्पादित वस्तुहरूको परीक्षण विधि भाग १९-२७ सम्मको गुणस्तर स्वीकृत भयो।

बैठकमा मन्त्री खड्काले नेपाल गुणस्तर तथा नापतौल विभागको कामलाई समयसापेक्ष र प्रभावकारी बनाउन सङ्गठनात्मक सुधारतर्फ अग्रसर हुन निर्देशन दिनुभयो।

बैठकमा उद्योग वाणिज्य तथा आपूर्ति सहायकमन्त्री प्रकाशबहादुर गुरुङ, उद्योग, वाणिज्य तथा आपूर्ति मन्त्रालयका सचिव भानुप्रसाद आचार्य तथा परिषद्का अन्य सदस्यहरूको सहभागिता थियो। रासस

Bottom – Up Approach

As most part of the buildings fall under non-engineered construction mechanism, more effort has been paid to intervene this type of construction mechanism by various ways.

<u>Calendar:</u> A step of building code implementation is publication of calendar with simple earthquake resistant construction technique, and is the most effective and successful event. Many municipalities, inside and outside the valley, are now using our calendar during their building permit process. The number of involvement of different municipalities per year is increasing.

<u>Mason Training under SESP:</u> Different means are employed to transfer the technology to community grass- root. The whole execution of project is designed as a tool of developing skilled manpower in earthquake resistant construction in local level. In all the process of seismic retrofitting and reconstruction, Engineers of NSET-Nepal work with masons illustrating them the details and complete procedures. It is observed that the conventional teaching and instructions to them can not yield the desired quality work. But, the perception of masons seemed much higher, given the instructors (Engineers) themselves do the work at first, telling them reasons behind it. This method avoids the improper reasoning and judgments made by masons in the ground of their previous knowledge and level of thinking. However indigenous knowledge and effective techniques gained from their long experiences are duly

considered and employed to the best possible. It makes them work as usual practice, in highest precise level. It is all in form of on-job- training. Besides it, separate training courses about construction are conducted in form of classes. The training is placed at respective Schools. The target group is craftsmen of village but it is opened to all those are interested. The technical knowledge of earthquake resistant construction is given to them systematically. The presence and participation of villagers and craftsmen is higher as expected attributed to raise awareness level of community people about earthquake by means of other supplementary activities and craftsmen's feelings on need and importance of such earthquake technology. They have seen their future in this 'modern' Technology that they should be equipped with and took part in it with much enthusiasm.

Obviously, the common people, during the training session, show high concerns over the matters that how their own houses are built. Masons pay much effort to know about for and against aspects of their conventional practices, need to adopt new methods, extent of change, solution to problems that the change may bring about and its harmony with seismic retrofitting and reconstruction of school, which they witnessed. It is noteworthy that once trainees be convinced and equipped with seismic resistant techniques, they also asked the methodology to convince and teach others about it.

The training courses follow hierarchical procedure starting from problem identification to end at testing of methods of learned. The training are basically in form of interaction including speeches, Photographs display, presentation of slides and drawings in overhead projectors, visit to place where methods are being employed in school and tests. Attention is paid to the level of trainees' knowledge and perception capability while presenting any items during training.

Once weak points of prevailing construction are described and consequences are presented through photographs of past earthquakes, it stroke trainees' mind and so they start to mull over it. Solutions are explored from their side and shaped to standard techniques. All the knowledge and skill are backed by practical real structures in school retrofitting and EQ resistant new construction. Several tests are conducted to support the knowledge in relation to effect of placement of reinforcement rod in beam/slab, quality of work governed by material and workmanship like excess water effect, curing effect etc.

House Owner Consultation Program: A weekly program to give advice and orientation about earthquake resistant construction is run for house owners who are going to construct new house. Small improvement in design and construction of buildings can make large change to its overall earthquake resilience. NSET engineers describe with the help of photographs, slides show and small physical models about the prevailing and recommended construction techniques. The program is fruitful to the public who has not access to engineers.

Nepali Version of Mandatory Rules of Thumb and Design Guidelines: NSET Nepal has now translated five documents (Three mandatory rules of thumb and two design guidelines) into Nepali and they are under publication.

Horizontal Networking:

National Forum for Earthquake safety: National Forum for Earthquake Safety (NFES) which consist of several professional organizations, municipalities and government offices and of which NSET is a member is now formulated and also working towards implementation of National Building Code of Nepal. Lalitpur Sub-Metropolitan City (LSMC) is now taken as pilot project area and work is started. LSMC has now made following decisions:

NBC shall be applied from May 15, 2002 within LSMC

All applications for building permit for new buildings will be subjected to additional procedures for application of NBC and warranty of Earthquake Safety Requirements.

Working with Institute of Engineering: NSET-Nepal is taking some M. Sc. Students of structure as intern and accepting some groups of (1-2 groups consisting of 5-6 students in each group) as project researcher which allow to students to understand the earthquake risk of Nepal and necessity of earthquake risk mitigation and preparedness in general and earthquake engineering principles and procedures in particular. As the graduates of academic institutions, vocational training centers, trade schools etc. are the ones who will be shouldering responsibilities at different levels in the professional field, NSET Nepal has recommended incorporating seismic resistant design and detailing as well as guidelines/manuals in the regular academic curricula of bachelor's level of engineering but it is still to implement.

Working with WHO and Ministry of health: NSET-Nepal conducted the project "Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley" jointly with, World Health Organization and Ministry of the Health, HMGN. The purpose of this study was to develop/apply appropriate methodology for the evaluation of earthquake vulnerability of the medical facilities in general, and to understand the actual situation of the reliability of the medical facilities in Kathmandu Valley, in particular.

Another project "Non-Structural Vulnerability Assessment of Hospitals and Health Institutions in Nepal" will be started in August 2002 and major work will finish in October 2002.

LESSON LEARNED

Institutionalization is long-term process

To achieve better seismic performance of buildings the approach and processes should address the needs at more than one level and take into account the grass-root realities. It must create an awareness that leads to an increase in demand for safer buildings and accompanying skills. It must strengthen capabilities at all levels. It should allow some flexibility in how the various levels of safety norms/standards are adopted.

These should be applied incrementally in keeping with the varying and increasing need of the target groups and target buildings. Such an approach will create a climate of easier acceptance and will be simpler to implement.

Two pronged strategy should be taken

Analyzing socio-economic level and availability of human resources, it is very difficult to retrofit all residential buildings. The cost involved in retrofitting is also more in comparison to the cost involved in incorporating earthquake resistant features in new construction. Thus, in case of residential buildings, the easy way to intervene is for new construction. But, in case of important public buildings for example schools, health centers or police centers should be retrofitted as these buildings play vital role.

In Urban Areas: Retrofit Masonry Buildings, Construct Earthquake Resistance RC Buildings

Trend shows that adobe and mud based construction in urban area is significantly reduced and a remarkable growth in brick-in-cement and RC frame constructions started in these years. So, to stop increasing risk RC construction should be intervened to make earthquake resilience. For decreasing existing risk, existing masonry (Brick in Mud, and Brick in Cement) structures should be retrofitted.

But in Rural areas, intention should be paid to incorporate earthquake resistant elements in brick in mud or stone in mud buildings.

Retrofitting is a better and feasible option

For decreasing existing risk of structure to earthquake there are two options. Either pull down the structure and reconstruct it, or retrofit it. From cost comparison, it is seen that retrofitting is quite a promising option unless the building has lost its structural value and cannot be saved or the modern day's functional requirements of the building have changed.

The following table is based upon the experience of SESP/NSET, and suggests to undertake retrofitting upon condition of technical feasibility.

Table: Comparison of Options

Criteria	Demolition & Reconstruction	Retrofitting
Involved Costs	High	Low
Time for Construction	> 1 year	3-4 months
Disturbance to School Function	High	Low
Disposal of Scrapped Materials	Big Problem	No Problem
Technology (adaptability)	Usual, so no excitement	New, so high excitement, need Training.
Potential Impact (Replicability)	Low/Medium	High

Only one approach may not work

Seismic safety of buildings has to be improved by better use of material and improved technology and skill in one front and by legal enforcement and awareness rising in the other. The approach of creating building act and laws can provide legal environment where as awareness at community level or training to masons transfer the ownership and the process will be sustainable.

Approach should be taken as gradual increasing safety

Although, inherently weak materials and its improper use and poor technology/skill make the owner built buildings unsafe and earthquakes in Nepal are recurrent leading to high casualty, destruction and economic loss result from unsafe buildings; it is almost impossible to change the construction scenario at once where locally available materials will continue to be basic building materials for the majority of buildings.

In technological aspects, the local craftsmen play pivotal role. Technicians and engineers have little control over the construction of owner built buildings. Proper training of craftsman can built his confidence, in using the technology and skill to construct safer buildings.

Thus, the appropriate technology should be developed or transferred. For example, instead of changing very high strength construction material or applying higher technology in construction, stitching the walls, providing bands, tying roofs and floors and vertical rods at corners etc. in case of masonry buildings and improving ductile detailing, and workmanship in case of RC buildings are important than adopting new construction material.

Programs like school earthquake safety programs should be continued

In all the villages where SESP has conducted, the house owners of respective locality have been replicating the construction methods employed in school building to construct their private houses without intervention from NSET-Nepal. Except some minor features, newly constructed houses adopt all basic earthquake resistant construction technology like bands, wall stitching, vertical tensile reds etc. It shows higher level of perception on what masons are trained. Obviously, it can be said that the process of replication would multiply in future to set a new technological culture in construction. In this aspect, the retrofitting project of school has much higher social value compared to other risk reduction programs that hardly are able to translate technology in real ground in root level.

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NEPAL-GUJARAT MASONS EXCHANGE AND TRAINING PROGRAM: A COMMUNITY BASED SUB-REGIONAL INITIATIVE

B. Upadhyay, A. M. Dixit and R. Guragain

Abstract

January 26 2001 Bhuj Earthquake devastated large areas in Gujarat killing thousands and rendering millions of people homeless. Sustainable Environment and Ecological Development Society (SEEDS) India, was among those who initiated to reduce hardships of the victims by supplying them with relief materials. After a series of interaction with the victim community, other agencies involved in the rescue and relief including Gujarat State Disaster Management Authority (GSDMA), SEEDS Patanka Navajeevan Yojana (PNY) was formulated. PNY intends to facilitate the earthquake victims to rebuild their homes, plan and implement various activities pertaining to sustainable rehabilitation with active community participation in Patanka.

Institutions and individuals from India and abroad have supported this rehabilitation initiative undertaken by SEEDS. NGOs-Kobe and GAP Inc. have generously contributed for the rehabilitation. Various agencies have shared their expertise and experiences in community based earthquake resistant construction. These agencies include Geo Hazards International USA, The United Nations Center for Regional Development, Japan, Fredrich Ebert Stiftung Germany, National Center for People's Action in Disaster Preparedness India, the Earthquake Disaster Mitigation Japan.

SEEDS was facing some challenges in implementing simple earthquake resistant construction techniques appropriate to Patanka. National Society for Earthquake Technology – Nepal (NSET-Nepal) agreed to facilitate SEEDS's efforts based upon past experience in this field. This NSET-SEEDS joint venture the "Nepal Gujarat Masons Exchange and Training program" (NGMET) was initiated in August 2001 and will continue till the completion of PNY. This paper traces the beginning activities, the achievements so far; lessons learnt, including the potential of replicating the project in the South Asian Region.

BACKGROUND

Both Nepal and India have a history of recurring earthquakes, which lead to periodic death and damage. The extent of damage is generally very high because the majority of buildings in the region are built without considering seismic safety requirements. More than 95 % of the buildings in the region are believed to be *non-engineered*. These non-engineered buildings are constructed both in urban and rural areas, by traditional craftsmen, who usually do not take any training in seismic safety, play important role in building construction.

NSET-Nepal is working towards institutionalization of seismic safety culture at grassroots level through community-based programs like School Earthquake Safety Program and Ward Level Disaster Management Program since 1992. We strongly believe that seismic safety can be achieved only by rising public awareness, transferring ownership of appropriate technology to the grassroots level and by involving all stakeholders including the communities in disaster management issues.

NSET has gathered some experience in community based initiatives in earthquake preparedness and mitigation, especially the School Earthquake Safety Program (SESP) in the past 5 years under the Kathmandu Valley Earthquake Risk Management Project (KVERMP). These activities are continued at present under the Kathmandu Valley Earthquake Risk Management Action Plan Implementation Project APIP. An important aspect of SESP is the training of Local Masons. It is a hands on training imparted to the local masons during seismic retrofitting and reconstruction of public school buildings in Nepal. So far, NSET has been able to train about 20 skilled masons who could train other masons

Following the Gujarat Earthquake of 26 January 2001, SEED India started implementing the Patanka Nawajeevan Yojana, an earthquake reconstruction of the village Patanka of Patna District of Gujarat. Patanka, one of the 79 villages of Gujarat that was totally divested by the earthquake. More than 170 houses out of 253 were completely collapsed and most of the remaining was damaged beyond repair.

The post-earthquake reconstruction program at Patanka under the "Patanka Navajeevan Yojana", was considered as an opportunity by NSET-Nepal to learn from the Gujarat experience of rebuilding. Unfortunately, Nepal couldn't learn much from the aftermath of the 1988 earthquake when much of urban reconstruction went without the improvement of seismic strength.

The "Nepal Gujarat Masons Exchange and Training Program" (NGMET) was formulated as a joint program by NSET-Nepal and SEEDS to replicate the past experience of NSET-Nepal in identifying and implementing simple earthquake resistant construction technology transfer at the grassroots level through awareness and training.

OBJECTIVES AND STRATEGY

Masons are the pivoting key actors in translating the designs into reality. Optimum, efficient and effective use of building materials is not possible if the masons are unaware about the technology they are working with. There are many ways to train new as well as practicing masons. Masons Exchange Program is one of the new approaches in technology transfer. NGMETP was conceived to share the experiences of trained and experienced masons from NSET-Nepal to fellow masons from Gujrat and vice versa. Exchange visits of Gujrati masons to Nepal and Nepali masons to Gujrat were also expected to fortify the learning process as well as acquire new techniques to make safer buildings. Following objectives and strategies were taken under NGMETP.

Objectives

In general objective of the program was to start mitigation and preparedness through training and awareness at community level, in specific the objectives were:

- Train at least 20 local masons from Patanka in earthquake resistant construction technology while rehabilitating and or reconstructing the houses demolished by the earthquake.
- Organize at least three exposure visits of masons from NSET-Nepal and Patanka.
- Document and disseminate the outstanding achievements and explore its replication in the needy communities elsewhere.

Strategy

To meet the above-mentioned objectives the following strategies were taken

- Use of reconstruction process as an opportunity to institutionalize safer building culture
- Share of experience to the maximum at grassroots level
- Use of manual methods in construction rather than mechanization in reconstruction works.
- Due consideration to serviceability (Functional requirements) of building.
- Prime importance to locally available construction materials.
- Reuse of materials in reconstruction.
- Use of local manpower
- Technical instruction to craftsmen (local people) in form of advice with full understanding of reason behind it.
- Conduction of interaction program between Engineers and local villagers on the mitigation techniques.

Mason training program to upgrade local craftsmen's skill in quality construction and develop skillful working manpower in earthquake resistant construction.

ACTIVITIES

Analysis of existing situation

Two masons and one engineer arrived Patanka on 9th August 2001. The main objective of this visit was to assess the existing rehabilitation process, identify and prioritize existing issues. Planning the appropriate interventions and initiating them was the activities planned for the first exchange visit. The Nepalese team visited Patanka along with the PNY technical personnel to know the ongoing reconstruction process.

Construction Status

The first model building undertaken by PNY had reached the lintel level and other six buildings were at different stages of construction. The community members were in a hurry to build their buildings and wanted PNY to initiate all the buildings of the eligible victims at once. But the human resources of PNY and the masons available within the community did not permit this. Further the technology being used also required some alterations and improvements. The joint observation discovered some issues requiring immediate proper intervention. The identified issues were:

Lack of Proper Understanding Between Project Team and The Beneficiaries

Each victim within the community was desperate to construct his/her house as soon as possible, which is very natural in this context. On the other hand the PNY technical team had its own limitations. The time available to share about the problems and plans to solve them with the community was very little. The team had initiated to undertake six houses as a faith building program with the community. This itself had to be dome in such a hurry that the team some how even escaped the planning of the materials and resources required for the ongoing construction. This resulted in under utilization of the building materials resulting in poor quality of construction. The situation was becoming more and more complex. The victims did not understand the problems of the project team and the project team also some how could not honor the desperate desire of the victims. Frequent interaction on the problems and the potential option is the only solution to this kind of misunderstanding among each other.

Inadequate Level of Skill of the Practicing Masons

PNY was organizing one-day workshop for the practicing masons to upgrade their skill level. The training program included only the masons employed by the owner. The owner was required to pay for the wages of the masons being trained. The owners were not happy as they thought it was an extra cost to them. The owners did not like to spend more for training their masons. On the other hand the masons would not attend the training without getting paid. Obviously the one-day orientation training was not enough for the mason to acquire the basic skill of earthquake resistant construction. An alternative method to train the masons was an acute need of the hour.

Complexity of the Technology Being Used

All the building in Patanka were mostly stone masonry house built with mud mortar. Timber was extensively used for the roof structure and the minimal openings they had in their houses. Modern materials like cement and steel were introduced only after the earthquake. The masons in Patanka were not familiar with the properties of cement and the right way to use it. Further, the use of vertical steel and reinforced concrete bands in these small buildings was amusing them. On the other side there was enough room to simplify the construction techniques.

Making the masons to clearly understand the techniques and reason behind them was necessary to improve the construction quality.

The Intervention Approach

After developing a clear understanding on the existing issues the NSET- team came with a two pronged action to improve the ongoing construction activities. First the two Nepalese masons joined the construction process and worked with their Gujarati counterparts to transfer the skills of earthquake resistant construction of masons buildings. Their skills they had acquired in Nepal under the SESP of NSET. For example, toothed ends of stone masonry wall were replaced by proper stepping for later add – in of a walls. This provided a better bond in between the masonry units. Similarly, optimum use of bond and through- stones, including filling of cement mortar in the gaps avoided honeycomb in the walls. These few small interventions served as ice-breaker and established the foundation of trust between the Nepalese and local masons and the house owners.

The Nepalese engineer detailed the plan for subsequence interventions along with the PNY Team. The interventions made to address the identified issues are briefed in the following sections.

Community Interaction

The Nepali engineer developed a format to monitor the consumption of materials at site. This worked as a simple and easy tool to monitor as well as assure the quality of construction. Addition of the Nepali team though for a short duration eased the workload on the PNY technical team allowing them more time to interact with the community. Further the interaction was made on each issue raised by the community without getting diverted to another topic. This helped to develop a better understanding of the project team with the community. The existing indifferent attitude of the community now slowly turned out into a better coordination and understanding of the existing problems.

Upgrading Skill of the Masons

The masons seemed to understand every bit of earthquake- resistant construction technology explained by the engineers in the training sessions. But somehow this was not reflected in their work in the construction. This was disappointing as all the stakeholders were involved. There is no doubt on the competency of the engineers on understanding the technology. But the difference in the understanding level of the engineers and the masons was one of the reasons behind the dissatisfaction. The most important component of technology transfer is the proper communication in between the trainee and the trainers. This which requires an analytical approach. Several communication skills acquired through the experience of the Nepali engineer were implemented while the masons were working in the houses. The skilled masons from Nepal were used as a vehicle of the technology transfer process. The combined effort was effective in upgrading the skill level of the practicing masons in Patanka.

This was a short-term and immediate action taken to improve the ongoing construction. But it was not sufficient to produce the number of masons required to rebuild Patanka. A long-term plan on training of masons was conceptualized. The NSET-Nepal engineer produced an outline of the training program along with the PNY Technical team. Use of three-dimensional models along with other relevant audiovisual materials was proposed. One of the major components was the shake table on which the effectiveness of the seismic resistant components could be very well demonstrated. It was decided that the masons from Patanka would be trained to construct the building models, 1:10 in scale, that would be subject to testing in the shake table experiment. The engineer then facilitated the PNY team to fabricate a Shake Table Ahmedabad.

NSET- Nepal

Bageswor -India

Shake Table Demonstration by PNY Team

Subsequently, three masons and led by an engineer from PNY came to NSET-Nepal, Kathmandu and acquired the skill of fabricating the materials required for the model. They constructed one model: a prototype of Patanka house and conducted a demonstration test in front of NSET officials accompanied by journalists of Nepal. The event was widely covered by the daily newspapers including television channels in Nepal. The PNY team also conducted a shake- table test in Bageswor, Uttranchal, India. All these events not only imparted the required skill but also motivated them to keep on working on the technology. Back to their workstation they transferred the skill to other fellow workers and the improvement cycle was even more vitalized. The technical assistance from NSET-Nepal has so far upgraded the skill of 60 Gujarati masons including 20 from Patanka.

Upgrading Construction Quality

Workmanship

It was observed that the working masons including the beneficiaries did not clearly understand the importance of seismic- resistant components and the techniques of construction. Under-consumption of cement and presence of honey -comb in the newly -built walls evidenced it. Even after the intervention started, the people were not following the instructions properly. The Nepali masons were strict to dismantle the wrongly- built walls and reconstruct it properly. It was necessary to make the owners understand the effectiveness of the technology being used. At the same time the masons also needed to understand the techniques of incorporating seismic- resistant components properly.

Quality Control

NSET-Nepal team leader started with quantity assessment of the materials required for various stages of the buildings. It was revealed that a building completed with 42 bags of cement would consume not less than 75 bags if properly built. He developed a format to calculate the quantity of building materials based on length of the foundation. This worked as a basic tool to calculate the materials required for various components of building once the size of the building was finalized. This was used immediately to monitor the ongoing construction activity.

Bar- Bending

The masons were finding it difficult to bend the bars precisely. A set of bar bending die and a workbench was prepared. Nepali masons then took the lead to transfer the skill of bar bending by using the tools. Plough was easily available with each household, as they were farmers. The plough was used to make a workbench for bar bending. This made the work more easy and produced accurately -bent uniform reinforcement bars. A single vertical reinforcement bar at the center was placed instead of a bar at the end of each wall. This also simplified the construction process and eliminated the errors.

Stonecrete new construction material

Stonecrete block was introduced for the first time in Patanka. Stonecrete block is a masonry unit that can replace the stone masonry wall. Stones of irregular shape and size are embedded in lean concrete and compacted in a standard size of mold. It has to be cured with clean water for about two weeks. These units are laid in cement mortar to build a wall. Stonecrete block walls are normally used to optimize the wall thickness and reduce the construction cost without decreasing the strength and durability. The same process of making stonecrete blocks can be adopted to cast stonecrete walls eliminating the process of fabricating stonecrete blocks. One of the Patanka residents preferred the idea of stonecrete wall and used it to construct his building. Stonecrete wall was found to be about 30% cheaper as compared to the prevailing walling system.

Seismic Strengthening Of Existing Buildings

There are about thirty buildings built immediately after the earthquake without incorporating seismic resistant components. These buildings need to be retrofitted to make them safe against earthquake. Further, some damaged public buildings can be retrofitted. PNY has plans to retrofit these buildings. Enhance the skills of Gujarati masons in earthquake resistance construction seismic retrofitting is an important element. It is clear that without retrofitting skill the masons would not be fully trained. SEEDS and NSET-Nepal have agreed to undertake retrofitting skill transfer through NGMETP. The details are being worked out and will be implemented at an appropriate time.

Training Programs

NSET-Nepal has developed a training module to train new masons as well as for skill upgrading of practicing masons. NSET-Nepal has also provided SEEDS a tentative outline of the training program. This outline is being jointly developed to make training manual appropriate to Patanka. SEEDS is preparing detailed program of reason training event in the near future.

A shake table to demonstrate the effectiveness of earthquake resistant components in a building was recently fabricated in Ahmedabad with technical input from NSET-Nepal. This will be one of the major tools to train the masons in earthquake resistant construction technology. SEEDS conducted a successful demonstration of the shake table on July 22 with technical input from NSET-Nepal and in association with KASSAR Trust, the local NGO in Bageswor in Uttaranchal, India.

Exchanges Visit

The first team of Nepali masons worked for a couple of months as it was necessary to streamline the ongoing construction activities. The engineer from NSET-Nepal returned after streamlining the intervention and organizing logistics to the masons in coordination with PNY technical team.

A visit to Kathamndu was organized for a team of Gujarati masons. An engineer led this team which included one supervisor and two masons. The main objective of this visit was to interact and learn from the experience of various stakeholders involved in the seismic retrofitting works being implemented in Kathmandu by NSET-Nepal. They visited different school building projects under School Earthquake Safety Project (SESP) acquired relevant information. This was very useful for the team as they had the opportunity of working in an entirely different situation. The team returned with a high spirit and a feeling of dignity and increased self-confidence. This worked as a motivating factor to improve on what they were doing in Patanka.

During the Earthquake Safety Day 2002, one of the directors of SEEDS along with the PNY project architect visited Nepal. The main purpose of this visit was to present a joint paper on the activities of PNY in the symposium organized by NSET-Nepal in Kathmandu. The team also visited the Earthquake Safety Day Exhibition ongoing in Kathmandu. Demonstration of series of Shake Table Test was the main attraction of the exhibition. The team was highly motivated by the experiment and decided to fabricate a shake table in Ahmedabad to carry out similar demonstration to train their masons in Gujrat. NSET-Nepal heartily accepted to provide technical assistant for this endeavor.

A new team of Nepali Masons replaced those in Patanka. This was done so as to expose an maximum number of masons for mutual benefit. They carried out similar activities. Their main task was to train maximum number of masons and assist in monitoring and supervision of the ongoing construction.

A team comprising of the president and two engineers from NSET-Nepal visited Patanka during the third week of December 2001. This visit was done at the eve of the first Shake Table test organized in Radhanpur by SEEDS in association with National Center for People's Action in Disaster Preparedness (NCPDP), India, other NGOS and professionals working in the field of Earthquake Engineering. An interaction program with the masons being trained was conducted in Patanka to assess their upgraded skill level. The program reveled that they had developed better understanding and this was reflected in their work. However, there was still some room to be improvement though the construction quality achieved more was much better than as compared to the initial stage.

The General Secretary of NSET-Nepal visited Patanka on the last week of December 2001 to get the first hand exposure of the ongoing rehabilitation activities. The duration was matched to the second Shake Table test in Radhanpur.

In February 2002 the NSET-Nepal engineer visited Patanka. Main objective of this visit was to work out details of the foreseen masons training program and facilitate the fabrication of Shake Table for the demonstration of effectiveness of earthquake resistant components. A training outline was developed which would be worked out in detail by the PNY team in coordination with the Nepali engineer.

A team of three masons led by an Engineer from Patanka came to Nepal to acquire the practical details of fabricating shake table and demonstration procedures during the second week of June 2002. The team learned to make the bricks and blocks to make the model for the demonstration. They made a model of a typical Patanka house and conducted shake table test in front of NSET-Nepal Officials and a couple of journalists. The event was covered by most of the major Nepali Daily Newspapers including one of the TV Channels. This team also departed Nepal with a sense of dignity and a lot of encouragement including an increased level of self-confidence.

IMPACT

It was quite difficult to define precise indicators for the impact assessment during the conception of the program and it was tried as an experiment. This experiment of the new approach worked out to be one of the effective ways of technology transfer. The ever increasing and encouraging positive impact on PNY was one of the major factors of continuing NGMET in the second phase.

At this level, the positive impact of NGMET can be clearly observed at three major levels. One of them is in the community level, the other is in the attitude of the masons trained and the most important is construction quality and safety level of the buildings reconstructed.

The community members have now a better understanding and faith on the construction technology introduced. They have accepting the fact that better construction process is important than having internal a thicker wall. The wall thickness in many cases are reduced to 14” from 18” thickness with stone masonry in cement mortar. This has not only reduced the rehabilitation cost but also would certainly contribute to the overall economy though in a small scale. This acceptance on the technology and availability of the skill human resources will certainly result in better sustainability of the technology.

The masons, who were initially confused and reluctant to the technology, are now confident on their work. Their performance in much better, However, The masons are becoming more and more popular. Their acceptance and demand by the community is not limited to Patanka, which has widened their employment opportunities. This is reflected by the fact that the people outside Patanka re looking for masons trained in Patanka to construct their buildings.

Most importantly, the construction quality, strength and durability including the safety level of the buildings, have been drastically improved. It is true that even without NGMET the masons would have incorporated the seismic resistant components in the reconstructed buildings. However, one could always doubt on the effectiveness and efficiency of such components provided in the dwelling units. It was observed that the damage ratio of these buildings would be reduced from an existing more than 100% to about 35 %. In this case the resources spent on this part would not be as beneficial and effective as it has been possible with NGMEP. Certainly, it will be unrealistic to claim that the damage ratio is achieved to an absolute zero level. But in case the same intensity earthquake repeating in Patanka may be reduced to a single digit, which is a great achievement.

ACHIEVEMENTS

PNY has so far facilitated 110 household families to reconstruct their houses. They are now happily living in the earthquake- resistant houses.

60 Masons in of Gujrat have been trained for earthquake resistant construction technology through NGMETP. 20 of them are from Patanka itself and the remaining 40 are outsiders, mostly the Patan District. This group of trained masons will not only enhance their employment opportunity but also contribute to the quality of construction, strength, durability and safety level of the buildings to be built even after PNY. As in Nepal, they will continue building houses with the new technology. It gives a better enhance for sustainability of the process. Thus the technology introduced has been better sustainable.

The major achievement is the increased level of safety of buildings in a very small cost. This was possible only with the training of masons which cost a mere US $ 75 per person. One mason on an average was engaged in 3 houses. Thus the extra cost incurred by the training component of NGMET per house was only 25 US Dollars.

The average cost of construction per house is US $ 1000 including US $ 94 for the seismic- resistant components. The extra cost of building spent to attain the seismic safety including the mason-training component of NGMET totals to 119 US Dollars. This amount spent will save the persons living in the house. Assuming only four members per a household family, the cost of saving a life is as small as US $ 25.00

REPLICATION POTENTIAL

Masons play a vital role in the quality and safety of building construction including the effective and efficient use of building materials and construction technology. No matter how good and safe the design may be it is the masons who translate the paperwork planners architects and engineers into the ground. Effective communication and proper understanding between the masons and the engineers is a primary requirement for effective and efficient use of construction technology. Engineers need to learn to use the language that the masons can understand as the masons can not be expected to speak the engineer's language. This is because they have a completely different level of understanding. This is the major factor affecting the technology transfer process. NGMETP has proved to take this point into full attention so as to convert a dream into reality. Gap in between the understanding level of engineers and masons of the entire south Asian reason is very prominent. Thus it has a great potential of replication this process. Obviously it may require being adapted to suit the context of the area being replicated.

MAJOR LESSONS LEARNT

The mass construction activity in such a community rehabilitation and reconstruction is not merely a technical issue. It is interlinked with the social, economic and above all human behavior and attitude.

Effective implementation of such a community participatory project should be dealt with a holistic approach and not confined to technical aspects alone. In other words, it is a process- oriented endeavor rather than product oriented project.

An effective technical intervention is possible with the technological exchange approach at the grassroots level.

Language is not a barrier to the technology exchange.

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COMMUNITY-BASED APPROACH IN EARTHQUAKE DISASTER RISK REDUCTION: AN EXPERIENCE WORKING IN WARD 34

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Abstract

Implementation of the action plan for earthquake risk reduction cannot be achieved unless earthquake safety becomes a part of the society's culture. Common people started taking interest in earthquake issues and raising questions shortly after the implementation of Kathmandu Valley earthquake Risk Management Project (KVERMP) that was implemented by National Society for Earthquake Technology Nepal (NSET-Nepal). This prompted the project to work on an experimental basis with some of the wards of Kathmandu municipality. The residents of these wards have, on their own initiative, taken several actions to try to assess and decrease the risk of their neighborhoods. The enthusiasm and potential of these groups has been exciting and such community level work is now a part of NSET's work.

The first ward-level disaster management committee (WDMC) was set up in August 1998 in ward 34 of Kathmandu Metropolitan City, under the leadership of ward chairman. A three-days workshop on community level disaster management was organized. Up to now, Ward 34 DMC is largely funded by NSET-Nepal through a fellowship from the World Seismic Safety Initiative (WSSI). The WDMC has done much on preparedness and mitigation. Ward 34 DMC with NSET has organized several trainings within and outside the ward to raise awareness of people. The experience has been shared to other two wards of Kathmandu Metropolitan City to establish WDMC and also in Nagbahal (a community in Lalitpur Sub-Metropolitan City).

The most important lessons learnt from community-based disaster management work with ward 34 DMC are: 1) All activities should be based upon the participation of all stakeholders including community; 2) Take into consideration the lack of state-of-the-art knowledge and low awareness level; 3) Understand the nature of community; 4) Involve key people to gain credibility 5) Low-tech approach is optimal.

INTRODUCTION

History of earthquake disasters reveals that grass-root level community people are the first victims, first to respond in rescue and relief of their neighbors and the last to rebuild after the disaster. They are the source of local knowledge of historical scenarios of disasters, potential natural hazards and the existing traditional coping mechanism against the disasters. Local resources available, the constraints and the specific needs of the community are important factors to be considered for effective disaster risk reduction measures, and of course, community is the only one who better knows about these.

In view of these facts, it becomes crucial to involve the communities in disaster risk reduction processes. Risk reduction measures are most successful when they involve the direct participation of the people most likely to be exposed to hazards, in all levels of implementation of risk reduction measures.

Earthquake risk management efforts carried out in Ward No. 34 of Kathmandu Metropolitan City is one of the initiatives of community based disaster management, in Nepal. The initiatives are being carried out through the Ward Level Disaster Management Committee with support from the Kathmandu Valley Earthquake Risk Management Project (KVERMP) implemented by National Society for Earthquake Technology (NSET) along with other local, national and international institutions. Scope and effectiveness of the efforts has been increased with the participation of wide range of society.

Creation of DMC : Started as a training program but grew in scope

Common people started taking interest in earthquake issues and raising questions shortly after the implementation of KVERMP. Requests for conducting awareness raising trainings has been started to be received in NSET from many community based organizations. Having learned about the partnership of NSET with other institutions such as the United Missions to Nepal and the Lutheran World Federation in KVERMP, a local CBO of Ward No. 34, namely the Jana Shakti Yuva Club requested NSET to assist in conducting a training program on disaster management for the ward residents. A five-day training program on disaster management was organized in August, 1998 with participation of local residents, CBO's, NGO's, community members and municipality and was very successful since it received social and political endorsement. Furthermore, the training program ended up with establishment of a Disaster Management Committee and a disaster management fund.

The committee, being headed by ward chairman of the ward and having its member form local intellectuals, school teachers, police, ward members, community workers and young volunteers, has set its missions and visions of making people of the ward capable to cope with the disasters and lessen the effects of disasters by implementing awareness campaigns on disaster mitigation and preparedness, training and motivating professionals, workers and volunteers to work for disaster management in the ward and working collectively with other local, national and international institutions. An advisory committee consisting of highly reputed personalities of the ward has been formed for proper and effective guidance and supervision of the activities. NSET has been providing a minimum financial assistance through World Seismic Safety Initiatives (WSSI) Fellowship for years 2000 – 2002 and it is further seeking the funds for programs implementation.

Activities

Annual programs has been prepared for conducting of household level survey on risk management capabilities in the ward, implementation of training programs for ward residents, awareness raising activities and mobilization and training of young volunteers in disaster management issues and other activities. Several trainings, community meetings and awareness raising activities has been organized annually and has been planned for coming years too. Active participation of the DMC in the activities of Annual National Earthquake Safety Day programs is highly appreciated by various sectors of the society.

Hazard and Risk Assessment

The CBO volunteers subsequently prepared, with technical guidance from NSET, hazard maps for flood, fire, and environmental degradation. These are simple maps that requires further technical improvement for designing any structural mitigation works. But, the maps are found effective and impactive for awareness raising and problem identification. A simple fire hazard map, for example, shows streets that are narrow enough for the fire brigade to come in, and which has become an effective tool to convince people. The sheer number of such narrow streets compels the map viewer to think about the problems in the ward.

Earthquake risk maps has also been prepared during the training courses on Earthquake Vulnerability Reduction for cities (EVRC-1 &2) organized jointly by National Society for Earthquake Technology (NSET), Asian Disaster Preparedness Center (ADPC) in association with other international partnering institutions, working collectively with the training participants.

Neighborhood Survey

A neighborhood survey was conducted to identify the awareness level of ward residents, to identify the local resources to be utilized and to identify the potential persons to be involved in the activities and as volunteers. The motivation for the inventory was derived from the lessons of the recent earthquake disasters in Turkey and Taiwan. The survey is being modeled after a similar work done in San Leandro of California. The survey was also intended to identify, among others, local professionals who can contribute their time for organizing disaster management trainings so that such programs could be conducted within the ward at low costs.

Ward Level Consultative Meetings

Several ward level consultative meetings has been organized for awareness raising, policy and decision making and program endorsements. Strategic decisions and important programs are finalized in such meetings, creation of an advisory committee was an important decisions made by such meeting.

Awareness raising and Trainings

Continuing awareness raising activities among clubs, schools, institutions and individuals has created an increased awareness of the community; this is being reflected in the increased no. of participants, frequency of organizing the programs, increased no. of people coming in the DMC office and increased no. of formal and informal talks about the disaster risk and risk reduction measures.

Impacts

Although any systematic survey has not been carried out to assess the impacts, but there are many positive signs that indicate towards the positive impact. Some of the indicators that show the positive impact are:

The no. of participants in various programs, no. of volunteers interested and committed to work for disaster risk reduction, the frequency of meetings and training and awareness activities are significantly increased.

34 Ward DMC is recognized not only within the municipality, in country as well as in the region. There has been tremendous support to DMC from all corners of the society.

Some wards of Kathmandu metropolitan city are replicating the approaches and activities carried out in ward 34 in their wards and requesting ward 34 DMC to assist in organizing community level trainings. Ward 34 DMC has assisted other two wards of KMC in formulating Disaster Management Committees and running the activities.

The experiences has been shared with the similar initiatives carried out in Nagbahal of Lalitpur district.

DMC activities are globally disseminated through the Safer Cities-1 (January 2002), the serial publication of Asian Disaster Preparedness Center.

LESSONS

CBDM approach is becoming popular

Despite the traditional fatalistic outlook, issues of disaster management are becoming popular with the people. The traditional thinking of only the government being responsible for relief and prevention works is being replaced by realization of the need to start working at the community level.

Awareness raising should be a component of all activities

Raising awareness was originally stated as an independent project objective in NSET/KVERMP programs. But in due course of time it became clear that raising awareness was, in fact, a crucial component of everything that has been done. Every activity was shaped to raise the awareness of different groups. The community-level work in Ward 34 has tremendous awareness raising and educative value. Advisors learn about disaster and disaster management possibilities, and guide in the implementation aspects.

Needs External Support

Disaster risk reduction is not the highest priority of the people in view of more pressing needs such as infrastructure, sanitation, health, education and environment. Moreover, most communities do not have enough financial resources. Therefore, making disaster risk reduction programs self-sustaining is rather difficult, and requires innovative thinking. At the same time, since the benefit-cost ration is very high in view of the prevailing low level of preparedness, ways should be identified to initiate and support community-based disaster management programs.

"What is accepted by the Community" is more important than "What is necessary?"

The knowledge, program, technology and training to be given to the community for disaster management should be compatible to what they accept, and practice. It implies that the community-based disaster management package should start from low-cost, low technology options for mitigation and preparedness so that people not only understand the logic, but also accept and use it.

KVERMP consistently adopted simple technical approaches, which made the initiatives cost-effective and understandable to the lay persons. It also helped to focus the project on implementation of risk reducing actions, our major aim. In Nepal, people are tired of seeing millions of dollars spent on studies without any implementation of actions.

"Community" may not necessarily mean "poor", "rural", or "slum"

There are no slums in Ward No. 34 of Kathmandu Municipality. Ward population is mixed, and the general economic condition of the ward-dwellers should be way higher than average Nepali. However, the efforts could very well be classified as community-based, because the initiatives came from the ward residents.

The program was successful so far, and expected to be successful in future, because people are educated, they are exposed to disaster cases in other parts of the world, and they know the importance of community level initiatives.

Develop Synergy

Disasters affect everyone and everything in a community, and it is not possible for any one agency, or even the government as a whole, to manage all aspects of risk. Responsibility for managing disaster risk is diffused. All organizations and every individual in a community are responsible for some aspect of the risk. It is important to make organizations and residents of Ward 34 to understand what their responsibilities are so that it is known which actions need to be taken and by whom. Understanding this common responsibility and developing synergy so that little efforts from everybody could make a real difference.

Involve Everybody and Transfer Ownership

The Disaster Management Committee has decided to divide the Ward 34 into several "Disaster Management Neighborhoods". A group of volunteers will be identified in each of the five or six neighborhoods. Clubs and other CBOs will be given the responsibilities for their neighborhood.

Institution Building is a Long-term Task

The Ward 34 Program of NSET was an effort to institutionalize the earthquake risk management processes started in KVERMP. In order to reduce Kathmandu Valley's earthquake risk, this process needs to continue for many years. NSET needs to help the Disaster Management Committee of Ward No. 34 train its members and staff, develop a positive reputation through its actions, and help the Committee to identify and manage the resources available in the ward.

There is no Alternative to "Transparency"

Although difficult at times, it is necessary that all actions at the community level should be transparent. It is difficult at the level of urban municipal ward with 50,000 population. But sharing knowledge and information is absolutely necessary for achieving any success in community-based disaster management works.

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COMMUNITY-BASED DISASTER PREPAREDNESS AND MITIGATION ACTIVITIES IN THE KATHMANDU VALLEY: LESSONS AND FUTURE PERSPECTIVES

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Abstract

For promoting earthquake disaster management activities at the community level, a pilot study was conducted in Kathmandu, Nepal. In this study, social survey revealed the fundamental nature of society, and the damage estimation provided actual images of the future earthquake disasters in the Valley. Based on these, after sample communities were selected, numbers of community meetings and drills using the DIG (Disaster Imagination Game) technique were implemented to validate their effectiveness. Technical input, partnership with the local government, utilization of a participatory approach, and DIG were clarified to be effective for enhancing involvement of the community in reducing future disaster effects. This activities were conducted as a part of technical cooperation, "The study on earthquake disaster mitigation in the Kathmandu Valley" between Nepal and Japan through JICA.

Key words: Community, Participatory approach, Disaster management, Awareness, Mitigation, JICA

BACKGROUND

Kathmandu Valley consists of 5 municipalities (Kathmandu, Lalitpur, Bakhtapur, Madhyapur-Thimi, Kirtipur) and approximately 100 Village District Committees (VDCs), and is the exclusive centre for politics, and economy of Nepal. The population of the Valley is more or less 1.4 million in the area of 668km^2, in some city core area, population density amounts to more than 1,000 persons/ha. The population within the 5 municipalities is 870 thousand and its area is around 100km^2. On the other hand, for the 100 VDCs, the population is 520 thousand with area of 567km^2.

Kathmandu Valley has suffered a number of historical earthquakes. In 1934, strong earthquake hit the Valley, causing significant loss to lives and properties. It is said that this earthquake has a recurrent period of seventy years which points that a big earthquake hit the Valley at any time. The Valley was also affected by 1988 earthquake which suggests that the Valley is a high hazard prone area. In the next 30 years, the population is estimated to become double to 3 million. Unplanned urban growth, along with new building constructions has become prominent recently, and aggravated earthquake vulnerabilities. Thus, earthquake risks of the Valley needs urgent attention.

The secretariat of UN-IDNDR (UN International Decade for Natural Disaster Reduction) implemented the RADIUS (RADIUS 2000) (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) program in 1997 as one of the major activities of the last decade. The RADIUS program attempted to make some change in the international cooperative approach from the national government level to the city government level with both administrative and technical collaboration. It also succeeded in promoting autonomous citizen level earthquake disaster reduction activities in the case study cities and the member cities as well. This led to inter-disciplinary and participatory collaboration. For realization of earthquake disaster reduction, the inter-agency approach or multi-sectoral, multi-disciplinary approach has recently been discussed more, and RADIUS program made a first step in validating this approach.

The authors had an opportunity to try the combination of different approaches in "The study on earthquake disaster mitigation in the Kathmandu Valley" (JICA, 2002), and the results, experiences, lessons and approaches will be discussed in this paper. In the JICA study, the basic methodology of RADIUS was implemented with specific focus on the community-based disaster mitigation, where communities were empowered through participatory decision making process. The results of this community initiative are summarized below.

GOAL AND METHODOLOGY

The overall goal of the study was to formulate a holistic disaster management plan[3)]. In order to achieve this goal, the pilot study was designed aiming to get the feedbacks from the actual community activities. Three pilot areas of different characteristics were selected by examining the results. High vulnerability areas with high injuries and casualties, most of which locates in the city core areas, are regarded to be the most needed for taking prompt actions in this pilot study.

The methodology of the overall community based Disaster Management Activities consisted of several components as described briefly below. A reconnaissance survey, a social structure survey, a building observation by experts and a damage estimation for future earthquakes were conducted to characterize the social aspects regarding earthquake disaster management in the Kathmandu Valley (Fig. 1). For building improvement, since the strength of the buildings is a key factor for earthquake disaster mitigation, the building vulnerability of the pilot areas was surveyed and delineated to the community.

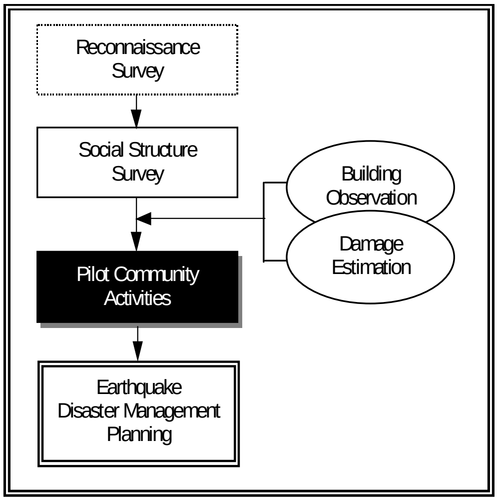

Fig. 1 Process of the Pilot Study

Based on these Surveys' results, pilot activities were designed to have three major components: 1) Awareness raising, 2) Participatory planning, and 3) Building improvement. Three communities representing the cultural and social context of the Valley were selected. A number of community meetings and evacuation drills were conducted. Then, the planning and disaster management activities started. DIG (Disaster Imagination Game) using actual maps in front of the participants to draw their opinions was introduced for an effective participatory approach. The results provided various input to formulate comprehensive earthquake disaster management planning.

SOCIAL STRUCTURE SURVEY

The main objectives of the Survey were to clarify, identify, and characterize the potential of earthquake disaster mitigation in the Kathmandu Valley in order to fulfil basic information for preparing a holistic disaster mitigation plan. Following were the specific objectives:

1. To understand the socio-economic characteristics of the residents of the Kathmandu Valley
2. To assess risk perception and preparedness among the residents, and
3. To explore mitigation possibilities

The Social Structure Survey consisted of four components;

- Personal Interview
- Focal Group Meeting
- Key Informant Survey
- Primary & Secondary Information Collection

Among the 4 components, Personal Interview was the major part of the Survey, and it covers all the five factors; Socio-economic profile, Risk & preparedness, Physical Infrastructures (City Structures and Disaster Management Resources), Social cohesion, and Disaster Experience. Other 3 surveys are supplementary conducted, based on the Personal Interview. Factors for each survey component are summarised in the Table 1.

Factors \ Components	Socio-economic profile	Risk Preparedness	Physical infrastructures	Social Cohesion	Disaster Experience
Personal Interview	*	*	*	*	*
Focal Group Meeting	*	*		*	
Key Informant Survey		*		*	**
Primary, Secondary Information Collection	*		**	*	**

Table 1 Social Structure Survey Components

Note: *indicates covering area, ** intensive covering area

Personal Interview

In order to gather information representing different communities in different localities of the Kathmandu Valley, samples were drawn from different social clusters. The clusters were defined based on the land use classification, settlement pattern, ethnicity, age of development, population density, etc. The clusters include various types: the city core area of the five municipalities, traditional settlements representing the Newar community living in the compact settlements which date back to the 17th century, habitations and settlements of the people in urban fringe area where rapid haphazard development is ongoing, planned settlement areas, and land pooling areas of different development ages. One hundred (100) individual interview surveys were conducted. The interview itself was carefully designed to become a dissemination process for earthquake disaster management. The questionnaire gave interviewees the chance of thinking about preparing for an earthquake disaster and interviewers were well trained to explain about earthquake disasters.

Focal Group Meeting

In order to get clearer perceptions about personal views on disaster management and mobilization possibilities of Community Based Organizations (CBOs) and cooperative atmosphere among citizens and public authority, focal group meetings were conducted among citizens, ward chairman, and members. Earthquake risk perception, preparedness, possibilities of mobilizing community based organizations, and mutual cooperation in the emergency situation were discussed among the participants.

Key Informant Survey

The last devastating earthquake around Kathmandu occurred in 1934. Survivors of the earthquake were identified by personal interview, and more detailed stories were collected from key informants. Most survivors who had clear memories are in their late 70's or 80's. Thus, their information was very rare. Following are the notable findings.

People became panicked and prayed to God. Some victims had to stay in a tent for about 6 months. The Government helped the victims with food and temporary shelters and extended loans for repairing houses.

Primary and Secondary Information Collection

To supplement the basic information and analyse the interview results, primary and secondary information was collected. Major research was done on city structure, physical disaster management resources in the community, CBOs, and the reactions of the disaster victims of the 1988 Eastern Nepal Earthquake and 1993 flood.

Findings of Social Structural Survey relating to Disaster Management Plan

Economic situations such as household economy, housing loan system, social issues such as religious thoughts, caste system, etc. are the key factors for basic understandings in conducting community based earthquake disaster management activities. Following are the highlights of finding of Social Structure Survey.

1) Awareness raising

- 30% of the households thinks earthquake is a deed of God.
- Education is thought to be more important than health care.
- Most households were sensitive to earthquake disaster.

2) Disaster Management Plan

- Water and food stocks are relatively sufficient (water for a few days, food for a month).
- Evacuation sites should be systematically prepared, considering caste sensitivity.
- Strong desire to strengthen houses within 15% increase over the original cost.
- Housing loan is not common, thus people expand or add floors when they get certain amount of money.

3) Mutual Cooperation

- Households were mostly religious minded and had the attitude of helping each other.
- Social & religious organizations are active in the city core area.
- Rescue & relief activities are the most concern for residents.
- For Newar, precedent inhabitants of the Valley, accounting for 42% of the total population at present, the Guthi system is a birth-related social organization which can play great deal in disaster management.

COMMUNITY ACTIVITIES

Area Selection

Based on the Social Structure Survey and damage estimation results, pilot areas were selected. In the social survey, it has become clear that there are roughly two types of communities; one is a traditional city core area of Newar (ethnic group of original inhabitants, currently accounts for 40% of the population of the Valley) community and the other is a new development area which characterizes the recent rapid growth.

City core area has two characteristics. One is a changing community, where traditions are endangered to change. The other is a traditional maintaining community. One pilot area for changing community is taken from Kathmandu City, and the other is from Lalitpur City. The ward 20 was selected, considering the area is placed for a strategic area of development by the Asian Development Bank. The challenge of this area was re-development and effective linkage among stakeholders. Nag Bahal is a representatives of the tight community of Lalitpur City and the challenge is to enhance cultural values and to maintain traditions in the rapidly changing urban trend.

Process

A total of about 15 workshops were conducted in 3 different communities during two and half months. The participants were residents, representatives of the local CBOs, Department heads of the municipality, school teachers, ward chairmen, ward members, local social scientists, urban planners, structural engineers and JICA specialists (geophysicist, structural engineer, public health & medical specialist and community based urban planner). The meetings were designed to the following steps: 1) Learn, 2) Think & Plan, and 3) Action.

Activities using different tools

"Learn": In the "Learn" process, knowledge of the science and technology, such as earthquake mechanisms, damage estimation, and building vulnerability is disseminated by the initiatives of municipalities. At the same time indigenous knowledge such as personal earthquake experience of 1934 or/and 1988, past earthquake damages in the area, roles and functions of the local communities, and CBO activities are introduced by the local residents.

"Think & Plan": In the second "Think & Plan" process, hazards and resources are visualized and necessary countermeasures are planned. "Community Watching", a walking tour of a community to identify hazards and resources along the designated route in small groups with experts such as a structural engineer, an urban planner etc, is an useful tool to know earthquake risks of neighbourhoods. During the tour, participants check evacuation routes, open space, water resources, public facilities, building vulnerabilities, and hazardous objects, carrying a map and taking photos. Based on this experience, DIG (Disaster Imagination Game) workshops were conducted. DIG is a map manoeuvre exercise on a bigger scale map, (at least 1/10,000 maps are recommended to be used) to mark hazards, resources, roads, bridges, public facilities, and plan countermeasures using the maps, assuming various situations. For more relaxed atmosphere, a Participatory Learning and Action (PLA) , is useful for children and rural illiterate groups to substitute for DIG.

After the series of workshops and discussion, certain consensus among the community were developed and a disaster management map for the community was produced using local materials, different colours of Tikka stickers, ladies' cosmetics. The PLA methods are also useful to Disaster Management and the map produced by their own hands and materials creates a sense of pride and ownership of protecting your neighbourhood by yourself.

Photo 1 PRA Resource Mapping Exercise

"Action": The "Action" process is to acquire direct experience and training. Getting a first hand experience is vivid and appealing. During the pilot project, most people were concerned about the two points; one is whether their houses are earthquake-resistant or not, and the other is how to react to earthquakes. These two points are basic questions of how to survive in earthquakes. The earthquake drill provides practical experience how to react in the real situation. The drill is to train safe evacuation process and procedures in the earthquakes, and impart first aid and rescue knowledge. The earthquake drills were done with collaboration of the police, Nepal Red Cross Society, schools, clinics.

LESSONS

Mobilising Community Based Organizations

Small wards or Village Development Committees (VDCs) are made up of a few thousands of residents, while bigger ones are more than 50 thousand residents. It would be more effective if there are Disaster Management Committees in smaller units in wards or VDCs. In some wards or VDCs, there are smaller units called toles, and in such units, CBOs often undertake social and cultural activities. Such organisations could be autonomous earthquake disaster management units for community level disaster management activities.

Reinforcing Linkages between the Community and Public Authorities

Close linkage between the community and public authorities such as ward and VDC offices and the Municipality will minimise the risks and damages. Ward and VDC offices are the most visible public bodies to the citizens. They would take initiatives to define roles and responsibilities of the CBOs and support them in preparing emergency guidelines.

While empowering CBOs for specific tasks, it is best to distribute responsibilities among different parts of the community for its effective response. It is advisable to clearly demarcate the responsibilities during normal times and emergency times, so that the organisations work well during the emergency period. This has to be decided by the community at the local level.

Key issues for Community-based Disaster Management activities

In conducting community based disaster management activities, there are two points to consider. One is the CBOs and the other is public administrative enforcement. About CBOs, the distribution of power, distribution of social roles, social ties, social status of the members, awareness of leaders and members, process of selecting leadership, decision making process, base of rationality of leaders (caste, family background, ability, age), expected qualities of leaders, gender-wise participation, social supporting system were carefully examined. About public administrative enforcement, the position of public officials, trust by the citizens, practical stance of law and regulation enforcement especially on buildings and land-use were examined.

Disaster Management gives practical survival knowledge

Participants are eager to know what are earthquake disasters and how to prepare for them, since it gives practical knowledge for surviving from earthquakes and everyone cannot be indifferent to it.

Children are the most perceptive target groups

Pilot activities included schools and a juvenile social welfare centre, where children under 16, working as domestic servants etc., come for study and play. In Kathmandu, a majority of the schools are not appropriate to designate for evacuation sites for local people, in terms of building structure and capacity of open space. It takes a long time to make school buildings safer. Thus it is important for children to be aware of disasters. In the pilot study, children were found to be the most perceptive target group and disaster management education for children has a ripple effect to their family.

Networks have been developing

Through the pilot activities in new developing areas, individuals and local CBOs were expanding their networks and developing trust and mutual understanding. Mapping exercises also encouraged people of unfamiliar faces to communicate and even of few words to talk. Trust and understanding of each person's and organization's capacity are the base for emergency activities.

OUTCOME

Following were the major outcome of the Study:

1. Local government is expanding DIG to other wards
2. Disaster Management Committee was established in the ward 20 during pilot activities,
3. CBO initiative area is continuing disaster mitigation effort and
4. Municipal level Institutional Framework is proposed

During the pilot activities, a Municipal Disaster Management Framework was proposed. This framework aims to strengthen the chain of command and communications among local city government, wards, CBOs and citizens. A Disaster Management Committee, directly under the Mayor, manages, leads and authorises all the disaster management activities.

The pilot study has also encouraged Kathmandu Metropolitan City (KMC) to formulate 4 technical working groups; Awareness Raising, Building Improvement, Rescue Activities, and Information Networking, to assist in the Disaster Management Committee and to suggest and research technical matters. Outside experts are suggested to be included. The KMC is trying to promote the enhancement of its Disaster management section to a department with increased employees.

CONCLUSIONS

Based on the current experiences, it can be concluded that to enhance the community initiative in disaster mitigation, following are the major points which need special attention in future:

Balance Best Mix: In earthquake disaster mitigation, the best mix of roles and responsibilities for different sectors and levels, such as municipality, ward, NGOs, CBOs, citizens, donor agencies, public sectors, and academic circles is important.

Emphasis on Participatory Planning Process : Nepal depends on international assistance from donor agencies, and they bring community based participatory methodologies. Public officials and the general public are flexible in accepting foreign inputs and participatory approaches, Nepal being one of the precedent countries for participatory tools and approaches.

Focus on Total Institutional Mechanism: It is important to institutionalise mechanisms to synthesise community based planning processes. As we have proposed in the Study, institutional frameworks which include community level activities into the total disaster management in the local government should be authorized.

Importance of Social Issues: To increase community resilience, comprehension of social factors is needed and social study findings should be systematically incorporated into the disaster management framework. A social index should be developed to enhance evaluation of the social characteristics of each area. The goal is to increase the community's potential by providing assistance with both "hard" and "soft" disaster management measures.

ACKNOWLEDGMENT

This study was conducted as a part of the technical cooperation between Nepal and Japan through JICA. The authors would like to express thanks to the JICA staff and local stakeholders who contributed to this study. Special thinks to NSET and SEEPORT for their partnership during the study.

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EARTHQUAKES IN CENTRAL KAZAKHSTAN – NEW VIEW ON SEISMIC HAZARD IN THE REGION

N. N. Mikhailova., and A. V. Belyashov

Abstract

Central Kazakhstan territory was traditionally considered to be non-seismic. According to earthquake catalogs of Kazakhstan not a single earthquake was registered here until 2001. According to the seismic zoning map of Kazakhstan, which is included in the construction codes and rules, only southern, southeastern and eastern parts of the republic are considered to be seismically dangerous.

Central Kazakhstan is not expected to be exposed to seismic impact over 5 points of MSK-64 scale. Seismic network of the National Nuclear Center created in Kazakhstan during last years detected a series of earthquakes in Central Kazakhstan from 1994 to 2002. The strongest and most interesting of them is Shalginsk earthquake of 22.08.2001 with Ms=5.0 and intensity of 6 points in epicenter. The earthquake sources are grouped in two zones and relate to deep faults in northwestern direction.

New data prove the necessity of the revision of seismic zoning for Central Kazakhstan.

Key words: Earthquake, seismic station network, Central Kazakhstan, source, aftershock, epicenter map, focal mechanism, seismic zoning map.

Instrumental seismic monitoring was carried out in Kazakhstan since the beginning of the XX century. Seismic station network began to develop from the southern parts of Kazakhstan, which was connected to catastrophic earthquakes that happened in this region at the end of XIX – beginning of XX centuries. The magnitude of two of them, Chilik in 1889 and Kemin in 1911, was above 8.

In 1970-1980 the number of seismic stations increased sharply, but they were concentrated in southern, southeastern and some of them in eastern territory. Earthquake catalogs composed on the basis of this monitoring contained mainly information about seismicity in these regions. Data was processed for only limited part of Kazakhstan. The estimation of seismic hazard is also substantially based on these catalogs. Of course, geologic-tectonic information is used for mapping general seismic zoning; however, seismological information, as revealed in practice, plays defining role. Figure 1 shows current map of general seismic zoning of Kazakhstan, which is included as a component to the Construction Norms and Regulations required for construction activities in seismic regions.

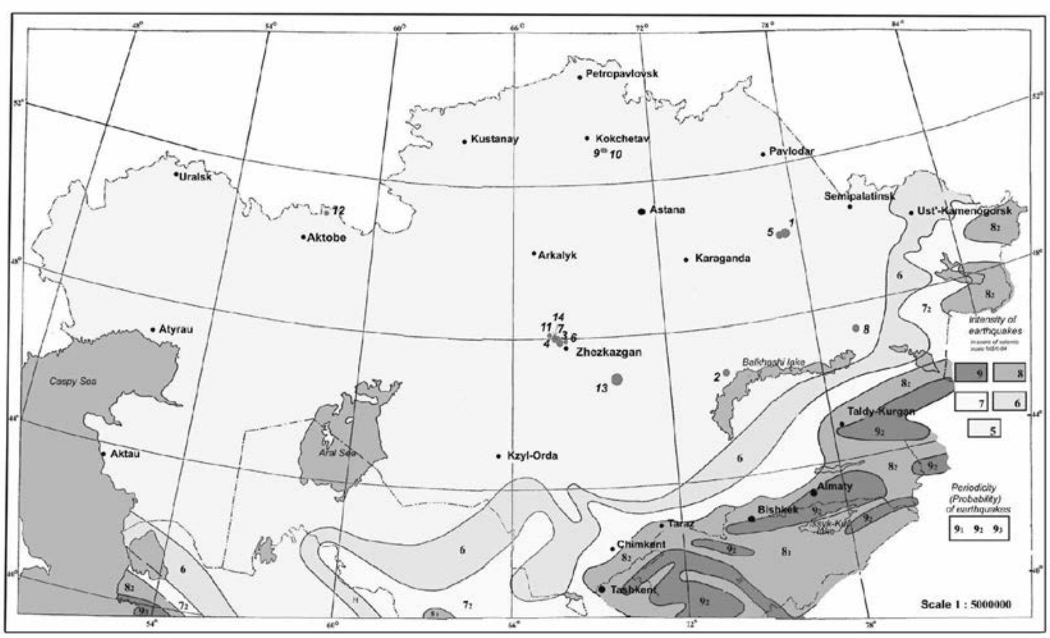


Fig.1. Seismic zoning map of Kazakhstan. Red circles show earthquake epicenters in so-called "aseismic" regions

It is clear from the map that southern, southeastern and eastern zones pose seismic hazard where expected intensity is up to 9 points (MSK-64). Central part of Kazakhstan is basically a "blank spot" relating to seismic hazard.

In 1994 new regional seismic station network of the National Nuclear Center of Republic of Kazakhstan was created. Its stations are located in different regions of Kazakhstan, mainly along the perimeter of the territory (Figure 2). These stations began to register events in other regions of Kazakhstan, too.

In August 2001 seismic network detected an event that increased interest in the study of seismicity of Central Kazakhstan. It happened on August 22, 2001 at 15:58:01 GMT. The earthquake was sensible on large territory; it was quite unexpected for seismologists. Basic parameters of the main shock are summarized in Table 1. All NNC RK stations perfectly registered this earthquake. Since the earthquake occurred in such an unusual region, special attention was paid for location of its epicenter. Solutions of different data centers with different responsiveness were collected and analyzed. The area of different solutions has approximate linear size of 30 km (Figure 3).

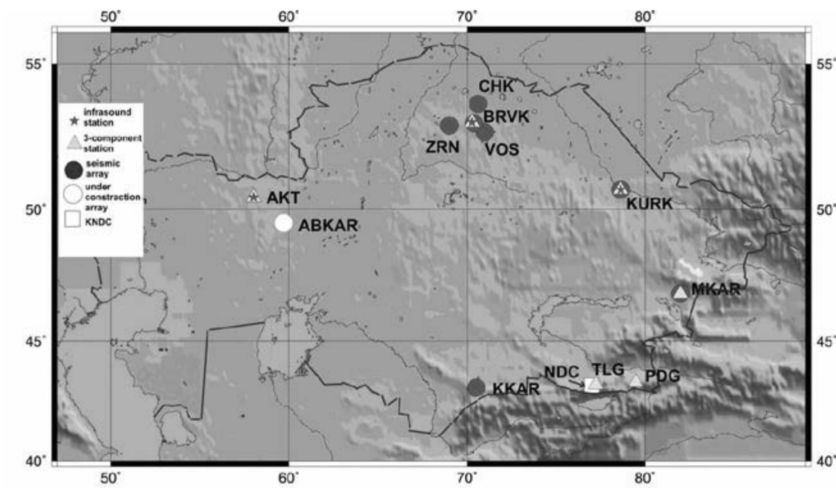


Fig.2. Map of NNC RK stations

Table 1. Parameters of main shock, 22.08.2001

#	Origin time, t_0	Lat. N	Lon. E	h, km	Magnitude Ms	Energy class K	Author
1.	15 58 01.82	47.16	70.20	Earth crust	5.0	-	NEIC
2.	15 57 59.24	47.11	69.95	0 (fix.)	4.7	-	REB
3.	15 57 58.8	47.20	70.14	Earth crust	5.0	-	OBNINSK
4.	15 58 00.4	47.19	70.24	13	M_{pva}=5.8	13.2	KNDC
5.	15.57.59.0	47.13	70.33	15	5.4 (M_{pva}=5.8)	14.2	IS MES

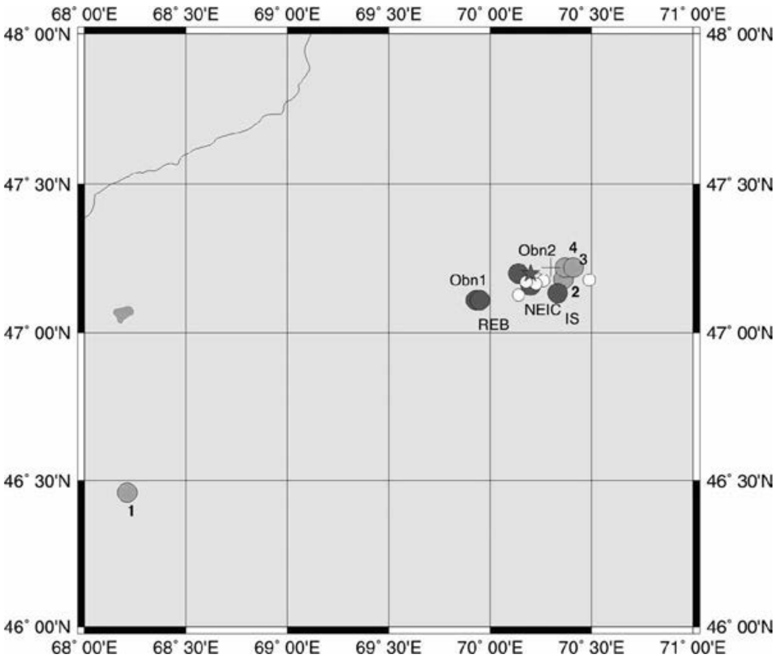


Fig. 3. Results of epicenter determination from the main shock and aftershocks.

1) KNDC – automatic solution;

2) KNDC – manual solution basing on real-time data;

3) KNDC – basin on NNC RK station network;

4) KNDC – basing on NNC RK and KNET station network;

Obn1 – online processing at “Obninsk” (GS RAS)

Obn2 – final solution at “Obninsk” (GS RAS)

REB – Solution by the International Seismic Data Ceter (IDC).

NEIC – Solution of the US Geophysical Survey

Cross – the most likely location of main shock epicenter

White circles – aftershocks of Shalginsk earthquake.

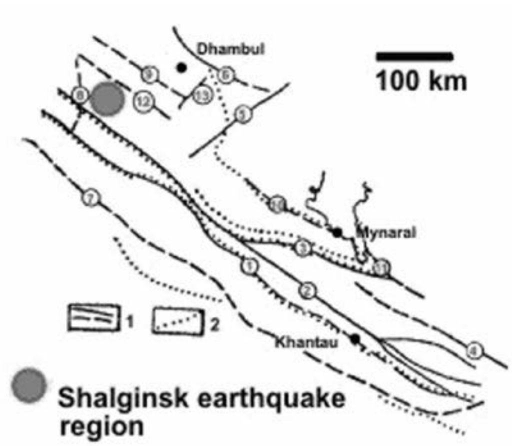


Fig. 4. Scheme of basic Chu-Ili faults
(Produced by Patalakha E.I., Abdulin A.A. et al.)

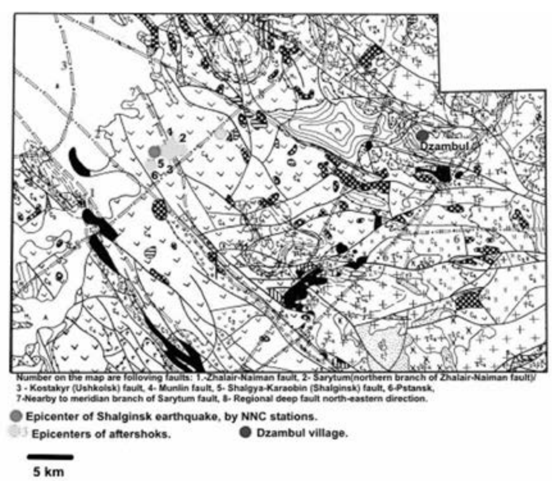


Fig. 5. Geologic structure schema of northeastern part of Chu-Ili region

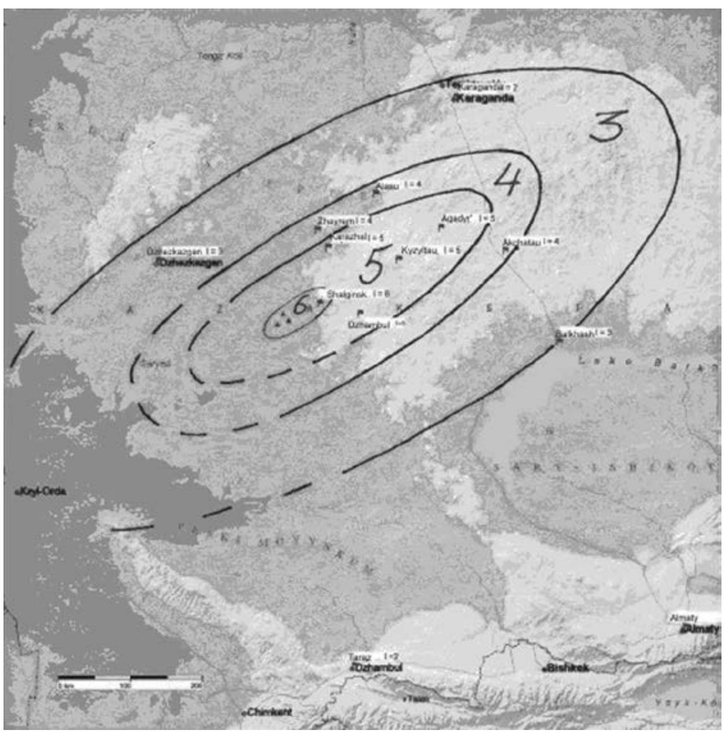
To research this earthquake in more detail Institute of Geophysical Research organized special expedition, the goals of which included macroseismic survey of epicentral zone and instrumental registration of possible aftershocks. Geological-tectonic conditions in the epicentral and nearby area were studied based on existing published information. The earthquake epicenter is located in the northwestern part of Buruntau anticlinorium, included in the Balkhash side of Chu-Ili mega anticlinorium, which is 750 km long till Northern Tien-Shan ridges. The structure of Buruntau anticlinorium is divided by differently oriented faults. The first one is the system of general stretch in northwestern direction. It includes Zhalair-Naiman fault and faults parallel to it. The second one is cross-sectional series of faults stretched in northeastern direction (Petan, Bektau thrusts and other) (Figure 4).

The epicenter region is directly connected to Sarytum deep fault, northern side of Zhalair-Naiman mantle fault where it joints with faults of northeastern and near-meridional direction (Figure 5).

Macroseismic survey from Almaty started in six days after main shock. Shalginsk village was the closest one to the epicenter; therefore, the earthquake was called Shalginsk earthquake. In this village the earthquake caused shocks of 6 points on MSK-64 scale. Figure 6 shows the map of isoseists of Shalginsk earthquake. One can notice that isoseists are stretched in northeastern direction.

Five KARS seismic stations were installed in the epicentral region to refine basic parameters of the main shock and register aftershocks. Registration was performed by three-component seismic sensors. Two cycles of registration were worked out. Five aftershocks were registered by temporary station network. One aftershock was registered by regional station network in three hours after the main shock before temporary network was set.

Main parameters of aftershocks are presented in Table 2 while aftershock epicenters are shown in Figure 5.



Isoseismic lines

3 – 6 - Points, MSK – 64 scale

Fig. 6. A map of isoseismic lines for Shalginsk earthquake of August 22, 2001

Table 2. Basic parameters of aftershocks of Shalginsk earthquake

#	Date	Origin time	φ° N	λ° E	h, km	Mpva	K
1	8/22/2001	18-37-01.0	47.18	70.24	15	3.0	6.8
2	8/31/2001	05-18-21.4	47.1754	70.2631	11.5		
3	8/31/2001	22-53-59.8	47.1648	70.2264	5		
4	9/01/2001	19-53-47.6	47.1782	70.4873	15		
5	9/04/2001	22-35-56.4	47.1711	70.1780	7		
6	9/07/2001	08-53-24.8	47.1273	70.1393	10		

Aftershock coordinates are determined very precisely because station network is located in direct proximity to their sources. Time of delay of shear S-waves relating to P-waves (S-P) on some stations is 1.65 s - 2.5 s, i.e. stations are located almost above hypocenters. It allows to assume that Shalginsk earthquake hypocenter is located namely in this region of aftershock concentration.

Based on initial arrivals of P-wave on Kazakhstan and Kyrgyzstan stations and also those taken from seismologic bulletins of Russian Geophysical Survey the solution of focal mechanism was found. One of the nodal planes is a steeply-falling plane of northeastern direction. The azimuth of this plane matches with isoseist ellipse axis as well as with the location of aftershock epicenters.

Beginning from 1994, based on the analysis of digital records of NNC RK stations the series of earthquakes in Central Kazakhstan was detected to the northeast of Shalginsk earthquake epicenter (Fig.1). Some of them had magnitude above 4.

The last one from the earthquakes in this region occurred on September 9, 2002, near Zhezkazgan city, which was also sensed in three populated localities with intensity of 4 point on MSK-64 scale. It was registered with confidence by NNC RK stations network. Location results are shown in Figure 7.

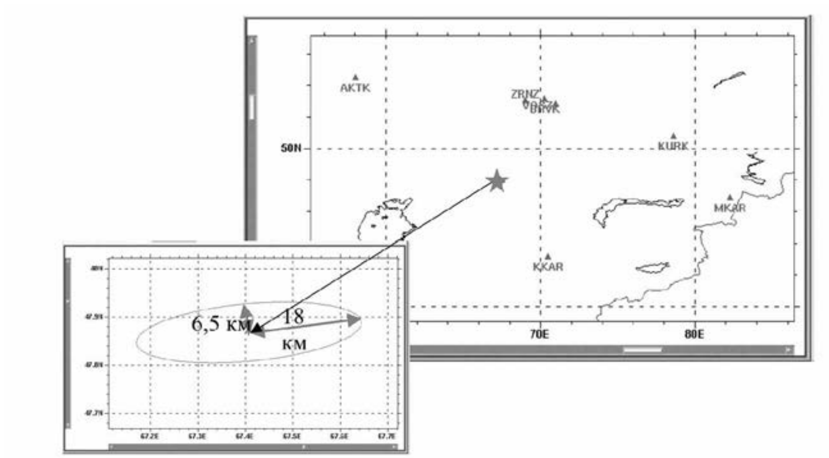


Fig. 7. Location results of earthquake near Dzhezkazgan, 9 of September 2002, t_0 22-26-59.7,

Lat. 47.87°N, Lon. 67.41°E.

m_b = 4.4, K=11.5.

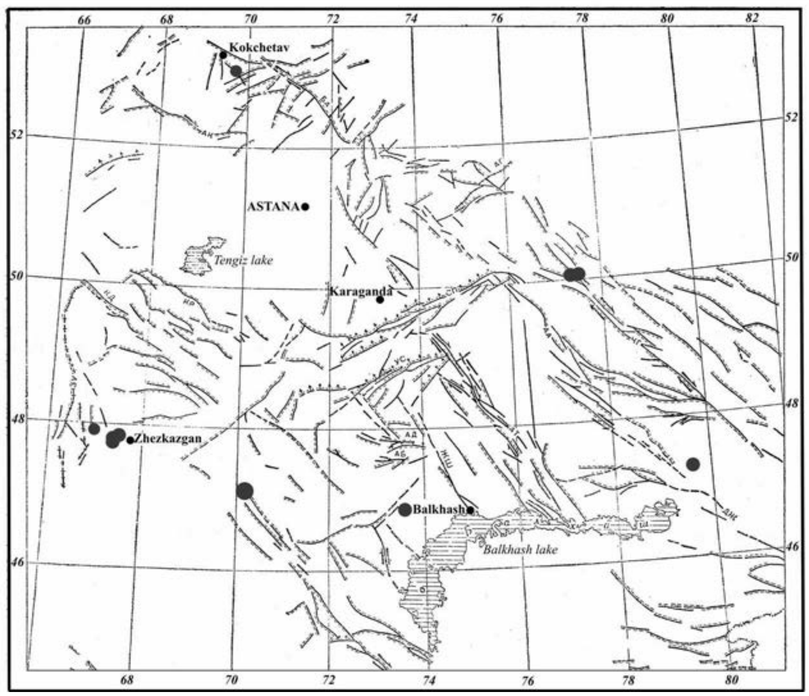


Fig.8. Map of large faults in Kazakhstan (A. Suvorov, 1960) with epicenters of earthquakes (1994-2002)

Comparison of epicenters of the strongest earthquakes in Central Kazakhstan with large faults of this territory indicates that both event groups, Zhezkazgan and Shalginsk, are connected to the northern part of Zhalair-Naiman fault series, which coincide to tectonic zone of northern Tien-Shan in south (Figure 8).

Each of source zones tends to the intersection points of faults that are orthogonal to Zhalair-Naiman series. It is interesting to note that fault movements in the source of Shalginsk earthquake are connected namely to cross-sectional faults. Of course, we would like to study the seismic regime of this region in more detail. However, the capabilities of current Kazakhstan seismic network are limited because the closest stations are 700 km away from these source zones, which determines the magnitude of registered events of this region $m_b > 3.0$.

Thus, the last data shows that

the territory of Central Kazakhstan is seismically active despite the contrary opinion existed up to date;

Existing methods of seismic hazard estimation are not perfect. As practice reveals, only having detailed information on instrumental seismic monitoring one can decide about real hazard. Geological materials alone do not allow to estimate the hazard adequately.

One or several seismic stations need to be installed in Central Kazakhstan for more detailed research of this region and also for quantitative estimation of existing seismic hazard.

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HETEROGENEITIES OF LITHOSPHERE AND ASTENOSPHERE IN THE TIEN SHAN REGION AND THEIR RELATION TO TECTONICS AND SEISMICITY

Yu. F. Kopnichev [1], and I. N. Sokolova [1,2]

Abstract

We have been considering variations of shear wave attenuation field in source zones of 10 large earthquakes in the Tien Shan region (M=6.4-8.3). We were analyzing characteristics of short-period coda from recordings of local earthquakes at distances of up to 100 km. It has been shown, that prior to large earthquakes an area of high S-wave attenuation is being formed in the lower crust and uppermost mantle. After the earthquake regular attenuation diminishing is observed within the depth range of ~50-220 km together with simultaneous attenuation increasing in the lower crust. An analysis of coda characteristics shows, that attenuation in the upper mantle is decreasing abruptly during 20-30 years after large earthquakes. Very quick (in geological time scale) changes of the attenuation field can be connected only with active fluid migration prior to and after large seismic events. Very intensive changes of the attenuation field structure allow us to use S-coda characteristics for the middle-term earthquake prediction.

Key words: Shear wave attenuation field, coda, fluid, lithosphere, asthenosphere, Qs, coda envelopes.

DATA

We have been processing recordings, obtained by ~50 stationary and temporary seismic stations. The stations were equipped with digital broadband three-component instruments and with short-period analog (SKM-3) with frequency bands of 0.03-20 Hz and 0.7-10 correspondingly.

We have been considering seismograms of local earthquakes and quarry blasts at epicentral distances of up to 100 km. Magnitudes of these events were of ~1.0-4.0.

We have been analyzing coda characteristics in source zones of 10 large earthquakes in the Tien Shan region, first of all to the north from the Issyk-Kul lake (Fig.1, Table 1, with an exception of the Kashgar earthquake of August 23, 1985).

Table 1

Characteristics of large earthquakes in the Tien Shan region.

#	Date	φ°, N	λ°, E	h, km	M	Name
1	1716	41.2	80.3	30	7.5	Aksu
2	08.06.1887	43.1	76.8	20	7.3	Vernyy
3	11.07.1889	43.2	78.7	40	8.3	Chilik
4	22.08.1902	39.8	76.2	40	8.1	Kashgar
5.	03.01.1911	42.9	76.9	25	8.2	Kemin
6.	10.07.1949	39.2	70.8	16	7.4	Khait
7.	05.06.1970	42.5	78.9	15	6.8	Sarykamysh
8.	24.03.1978	42.9	78.7	30	6.8	Zhalanash-Tyup
9.	23.08.1985	39.4	75.4	20	7.0	Kashgar
10.	12.11.1990	42.9	78.0	20	6.4	Baysorun
11.	19.08.1992	42.1	73.6	25	7.3	Suusamyr

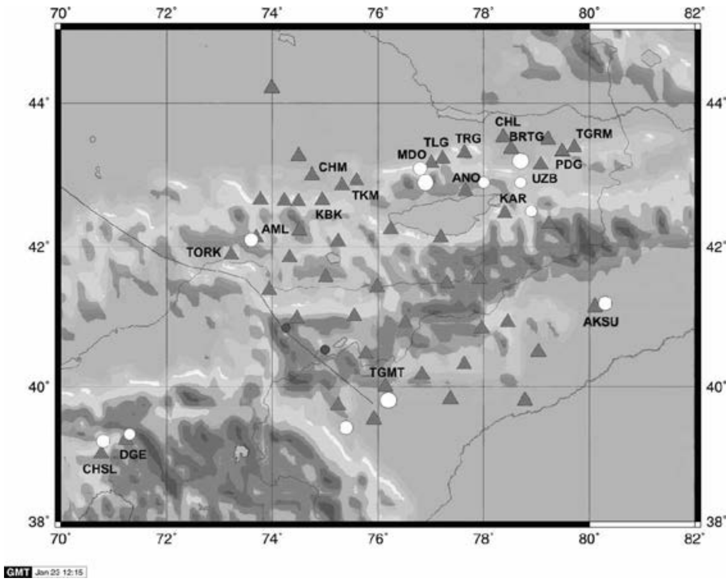

Fig.1. Map of the region under investigation. Open circles – epicenters of large earthquakes; diameter increase corresponds to M growth: 6.4≤M < 7.0; 7.0≤M < 8.0; M > 8.0. Solid circles – springs with maximum (submantle) ratios of helium isotopes, recorded in the Tien Shan region in 3 years after the Kashgar earthquake of 1985. Triangles – seismic stations. Talas-Fergana fault, dividing the Western and Central Tien Shan, is shown.

METHOD

We were using a method, based on the analysis of short-period coda envelopes. It has been shown earlier, that in the Central Asia region at frequencies of ~ 1 Hz S-coda is being formed by shear waves, reflected from multiple subhorizontal boundaries in the earth's crust and upper mantle [1]. In this case sections of steep and gentle slope at the coda envelopes are connected with areas of correspondingly high and low S-wave attenuation in the lithosphere and asthenosphere. We were comparing coda envelopes characteristics, constructed by recordings of narrow frequency band channel with central frequency of 1.25 Hz. Coda attenuation at various sections of seismograms was characterized by effective quality Qs. For the model of coda formation by single-reflected shear waves Qs value is determined using a formula [1]:

$$A(t) \sim \exp(-\pi t/QsT)/t, \qquad (1)$$

where t is the lapse time, T – period of waves.

ANALYSIS

In Fig.2 cross-sections of the attenuation field in the source zone of the Suusamyr earthquake of August 19, 1992 (AML station) and close to it are shown. A layer of very high attenuation has been formed at depth of 45-180 km in the area of TORK station, located at distance of ~20 km to the south of the source zone, for 2-4 years before the earthquake. Relatively high attenuation was observed directly in the source zone at depth of 40-125 km. According to the AML station data, in 1-2 months after the earthquake the intermediate attenuation was observed at depth of 20-200 km. In 7 years after the earthquake, attenuation diminished essentially at depth of 20-90 and 170-200 km and increased – in the depth range of 90-170 km.

It has been shown earlier [2], that for 1.5 years prior to the Baisorun earthquake of November 12, 1990 the area of very low Qs values has been formed in the source zone at depth of 20-45 km; the attenuation field structure changed essentially after the earthquake.

In Fig.3 the envelopes of weak event recordings, obtained within source zones of three large Tien Shan earthquakes, are shown. For all zones recordings of aftershocks, obtained in first months after main shocks, are considered. The coda envelopes for "remote" aftershocks, recorded in 7-13 years after these events, are adduced for a comparison.

The common envelope features are long intervals of relatively fast amplitude decay, formed at the interval from 15 to 100 s. t_b and t_e are beginning and ending time intervals respectively.(Table 2).

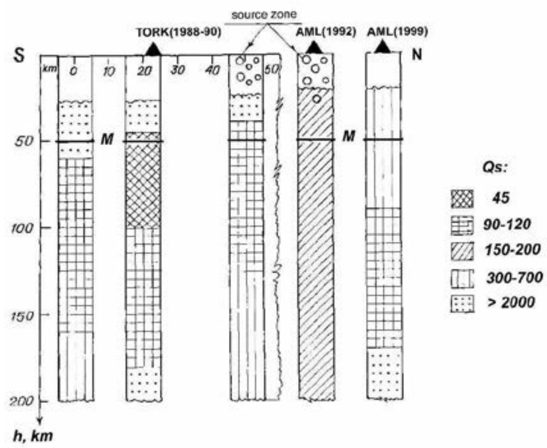

Fig.2. Cross-sections of S-wave attenuation field for the Suusamyr region.

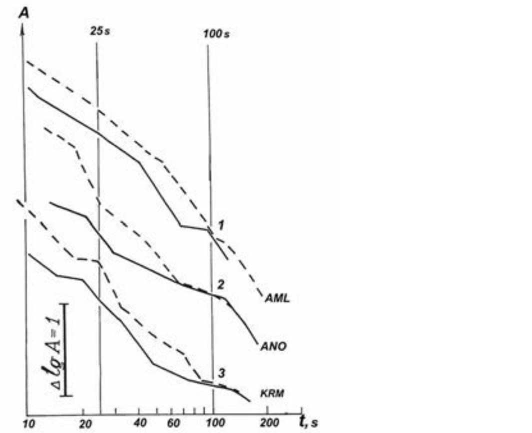

Fig.3. Coda envelopes from recordings of events with epicenters in the source zones of large earthquakes. Dashed line – the early aftershocks. The earthquakes: 1 – Suusamyr, 2 – Baisorun, 3 – Zhalanash-Tyup.

Table 2

Characteristics of intervals of rapid decay in the coda waves of aftershocks.

Earthquakes	Years	Area of aftershoks		t_b	t_e	Q_s	Q_s (25-100c)
		φ° N	λ° E				
Zhalanash-Tyup	1978	42.85-43.05	78.18-78.65	24	85	140	170
	1990-1991					320	370
Baysorun	1990	42.82-43.00	77.80-78.05	18	65	85	300
	1999-2000					320	2100
Suusamyr	1992	42.08-42.17	73.63-73.92	55	105	160	180
	1999					240	250

From Table 2 one can see, that t_b and t_e values vary in broad diapason – correspondingly from 18 to 55 s and from 65 to 105 s. As a whole, Qs values are very low for the first aftershocks of the all earthquakes (85-160) and increase abruptly with time after these events. Qs values for the interval of 25-100 s are also adduced in the Table 2. Enough high attenuation was observed for the all source zones in the first months after large earthquakes (Qs values vary from 170 to 300). In 7 years after the Suusamyr earthquake Qs value changed notably in this interval (from 180 to 250). Stronger changes in the attenuation field structure took place in the Zhalanash-Tyup earthquake zone in 12-13 years after it: Qs value increased from 170 to 370. Quality factor changed most strongly in 9-10 years after the Baisorun earthquake (from 300 to 2100).

In Fig.4 coda envelopes for five source zones of large earthquakes (M≥7.3) are presented (Aksu, Vernyy, Kashgar 1902, Kemin and Khait, see Table1). The envelopes are constructed through pretty large time intervals after these events (correspondingly >280, 100-110, ~100, ~ 90 and 30-40 years). The envelopes are characterized by relatively high attenuation for t < 25 s and very low - in the interval of 25-100 s. At the second interval the minimum Qs value is equal 700, and for three source zones Qs >2000.

In Fig.5 data scatter for the coda envelopes of recordings, obtained in source zones of nine large Tien Shan earthquakes through big time intervals (from 10 to 280 years) after these events are shown. The envelopes are matched by t = 100 s. The effective Qs value varies from 700 to ∞ in this interval. The envelope slope increases abruptly by t < 25 s (Qs values changes from 30 to 90).

The data scatter for the envelopes from recordings of 46 digital and analog stations, installed in the Central Tien Shan region (Fig.1), is also shown in Fig.5. Here, the data for events with epicenters, located in the mountain areas of the Tien Shan, are picked out. Besides that, the data for the source zones of large earthquakes considered with abnormally weak coda attenuation, are excluded. In this case the coda amplitudes in the range of 25-100 s drop much faster and Qs values vary from 105 to 400.

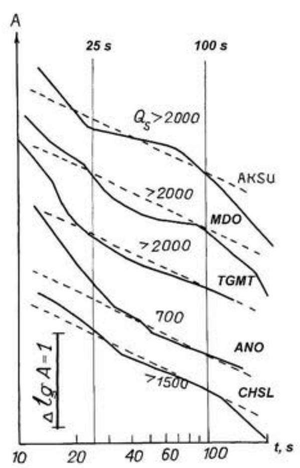

Fig.4. Coda envelopes from recordings, obtained through big time intervals after large earthquakes. Dashed line – t^{-1} function.

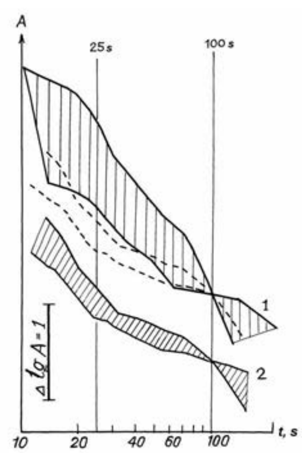

Fig.5. Data scatter for the coda envelopes, constructed by weak event recordings in source zones of 9 large Tien Shan earthquakes (2; see Table 1, with an exception of Djirgatal, Kashgar (1985) and Suusamyr earthquakes). 1 – data scatter by recordings of 46 stations in the Tien Shan region. Dashed lines – an area of the data scatter (2).

DISCUSSION

The data obtained testify, that the attenuation field structure in the source zones changes essentially both before large earthquakes, and after them. It follows from Fig.3, that the notable variations of the attenuation field structure at depth of 50-220 km begin to be observed in 7-10 years after earthquakes with M > 6.0. Even more short-period variations of the attenuation field are recorded during preparation for large shallow earthquakes [2]. So quick (in geological time scale) changes, obviously, can not be connected with processes of melting and crystallization of the rocks. Thus, the effects discovered can be explained only by active fluid migration on the earth's crust and upper mantle.

It follows from Fig. 2,3, that fluid concentration at depth of 50-220 km in source zones a few years before and in the first months after large earthquakes is high enough. Attenuation diminishing at these depths with time testifies, that fluids ascend gradually from the upper mantle into the crust, which correlates with the data on high attenuation in the middle and lower crust (Fig. 4,5).

It is supposed on the grounds of magnitotelluric data, that the lower part of the earth's crust is characterized by high fluid content, while the middle crust presents an impenetrable bulkhead for fluids [3]. The effects of essential growth of the total springs debit [4] and increase of mantle helium component [5] (see also Fig.1) within source zones show, that by large earthquakes this bulkhead can be destroyed. As a result of this, deep fluids burst through it to the earth's surface through subvertical or inclined channels. Such channels in the earth's crust are traced by the data on shear wave attenuation [6] and magnitotelluric data [3].

When fluids ascending from the upper mantle, rather big energy can be released due to essentially smaller fluid density in comparison with solids. Thus, we suppose, that one of important functions of large shallow earthquakes is to let out juvenile fluids. This leads in the end to the diminishing of the Earth's gravitational energy.

According to the data obtained, the essential changes of the fluid structure begin to be observed in 7-10 years after the earthquakes with M > 6.0, and in 30-40 years after such events the largest part of free fluids, probably, is leaving the uppermost mantle in some local zones. After this during enough long time (by the data for the Aksu earthquake zone – a few hundred years) a section of the upper mantle in the source zone remains relatively "dry". Nevertheless the data on coda characteristics in paleodislocation zones [7] allow us to suppose, that through some time interval a new episode of the fluid ascent is beginning in the given area. Probably, just cycles, connected with fluid migration in the upper mantle, stipulate well-known recurrence effect of large earthquakes in some areas.

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INVESTIGATION OF SEISMIC NOISE ON KAMCHATKA

V. Saltykov, Y. Kugaenko, V. Sinitsyn, and V. Chebrov

Abstract

The investigation of seismic noise on Kamchatka is carried out for the control of the environment stress condition and search of the strong earthquakes precursors . The main directions of this researches are modulation of high-frequency seismic noise (HFSN) by the Earth tides and temporal variations of HFSN parameters connected with the strong earthquakes preparation.

HFSN is the seismic oscillations in frequency range of the first tens of Hz with the amplitudes about 10^{-9}-10^{-12} m. The seismic noise is considered as highly informative field now, it is containing the unique information about a medium, its structure and stress condition.

The first studies of HFSN were carried out under the management of Prof. L.Rykunov. The proof of the HFSN endogenous origin make up greatest complexity. The discovery of HFSN reaction on processes deforming the Earth as a whole may be such proof. The Earth tide is one of such processes. Many researchers worked above this problem. Their results are ambiguous and contradictory. The hypothesis about the HFSN endogenous origin and existence of HFSN tidal components remained nonconfirmed for a long time.

For reception of the statistically significant characteristics of HFSN and tides connection it was necessary to create the recording station and to carry out the long-term regime HFSN observation in the point, removed from anthropogenous handicaps as far as possible. The station of HFSN observation was organized in the settlement Nachiki (*53.1°N, 157.8°E*). The continuous HFSN registration was begun in 1990 and proceeds till the present time. The continuous data carried out on Nachiky station is unique and hasn't analog in the world practice.

In 2000 the second similar station of registration was made on the complex geophysical observatory "Karymshyna" (*52.8°N, 158.15°E*). The HFSN sensor is established in the borehole on the depth of 30 m. It is narrow-band (Q=100) piezoelectric seismometer, tuned to frequency 30 Hz. Sensitivity of the seismometric channel is about 10-12 m. Signal envelope is recorded and analyzed.

The research of HFSN structure gave the opportunity to allocate HFSN components connected with wind influence, with the Earth surface warming-up, with the anthropogenous factors, and also with Earth tides. Last point is most important, as confirms the endogenous origin of seismic noise. Last factor was manifested as follows:

1. the significant deviations in the HFSN average meaning for various phases of tide are revealed,
2. the periodic HFSN components with the basic tides periods are allocated,
3. characteristic two-week tidal trains correspond to reveal allocated from HFSN data.

Besides it was revealed, that the tide response doesn't stable in time: the sites of the tide components existence are replaced by sites of its absence, the amplitude-phase relation between tide and HFSN vary, while tides have constant in time parameters. The authors put forward a hypothesis about the connection of variations of the tide components in HFSN data with the tectonic conditions in region, and consequently, and about an opportunity of this phenomena use for the forecast of strong earthquakes.

HFSN phase component connected with a tidal wave O1 (T=25.8 h) was chosen as parameter. The choice of wave O1 is connected with its greatest noise-immunity. It was shown, that the stabilization of this phase is observed before earthquakes with M>6.0, occurred on the distance up to 250 kms from the HFSN registration point, within several months. Since 1996 such analysis of the HFSN response to tides is conducted in an operative mode, and only in one case from fourteen the strong earthquake precursor was not showed in any way. The estimations of the seismic environment in Kamchatka region received by the analysis of HFSN data from Nachiki and Karymshyna stations, are weekly represented to the Kamchatkan Branch of the Federal Center of Earthquakes Forecasting.

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Key words: Seismic noise, Earth tides, earthquakes precursors, noise seismotomography.

The investigation of seismic noise on Kamchatka was carried out in two basic directions. First - long-term observations in one point with the purpose to investigate the seismic noise characteristics and its response to external influences (seismic noise correlation with the long-period strain processes). For this observation the high-sensitivity equipment is used. The band-pass filtration and envelope of a high-frequency signal are applied. Second - the short-term registration with the use of dense observations systems (seismic arrays). These researches are directed to reception of the microseismic radiation sources distribution in environment and its image. The image reconstruction is carried out by focusing of the array directional characteristic to the some environment point. The second direction of noise researches is called seismoemissional tomography.

High frequency seismic noise (HFSN) is the seismic oscillations in frequency range of the first tens of

Hz with the amplitudes about 10-9-10-12 m. The seismic noise is considered as highly informative field now, it is containing the unique information about a medium, its structure and stress condition.

The seismic noise investigation is used for the control of the environment stress condition and search of the strong earthquakes precursors. The continuous data carried out on Nachiky station is unique and hasn't analog in the world practice. Type of registration was analog till 1995 and now it is digital. Primary analysis includes extraction of the HFSN envelope and calculation of its hourly mean values. The example of HFSN envelope is on fig.2.

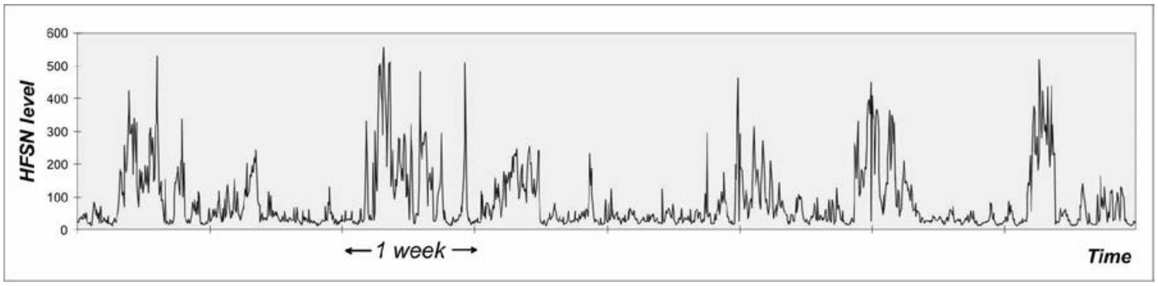

Fig.2. Example of the HFSN envelope (hourly average) during 2 months.

main investigated effects are modulation of HFSN by the Earth tides and temporal variations of HFSN parameters connected with the strong earthquakes preparation.

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For reception of the statistically significant characteristics of HFSN and tides connection it was necessary to create the recording station and to carry out the long-term regime HFSN observation in the point, removed from anthropogenous handicaps as far as possible. The first station of HFSN observation was organized in the settlement Nachiki (*53.1°N, 157.8°E*) (fig.1).

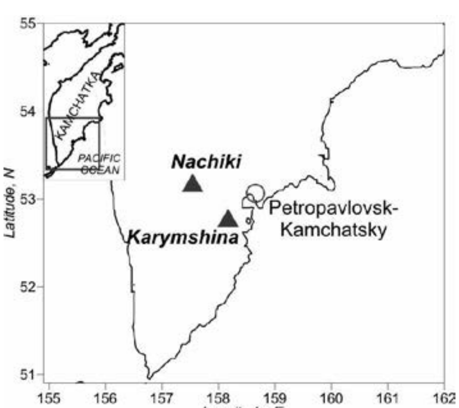

Fig.1. The map of HFSN observation points on Kamchatka.

The continuous HFSN registration was begun in 1990 and proceeds till the present time. The

In 2000 the second similar station of HFSN registration was opened on the complex geophysical observatory "Karymshyna" (*52.8°N, 158.15°E*). The HFSN sensor is established in the borehole on the depth of 30 m. It is narrow-band (Q=100) piezoelectric seismometer, tuned to frequency 30 Hz. Sensitivity of the seismometric channel is about 10^{-12} m. Signal envelope is recorded and analyzed.

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- the significant deviations in the HFSN average meaning for various phases of tide are revealed,
- the periodic HFSN components with the basic tidal periods are allocated,
- characteristic two-week tidal trains correspond to reveal allocated from HFSN data.

The tidal process consists of four phases usually following one after another and reflecting the growth and fall of tide/ These phases are distinguished by two indications: the sign of tidal-firming potential and the sign of the time derivative of potential. If the solar-lunar tides affect HFSN, one may expect the behavior of the noise in the various tidal phases to be different and manifested in the mean HFSN values for each of the four phases. The observed series were divided into four parts in accordance with the phase of the gravity potential, and the mean noise value was calculated in each of four intervals. The obtained values of HFSN are presented in fig.3

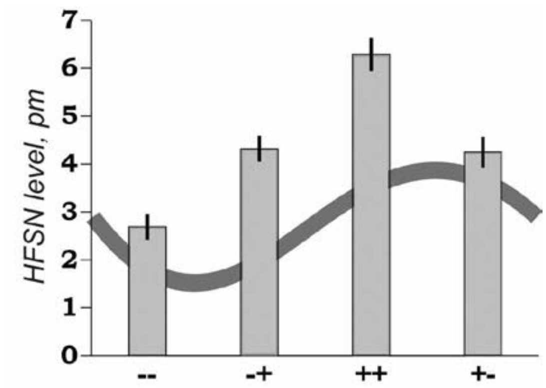

Fig.3. Mean values of the HFSN level in the four characteristic phases of the tidal potential (by results of registration in January-August, 1990). All data were divided into four parts in accordance with the phase of the tidal potential (increasing tide, decreasing tide, increasing ebb, decreasing ebb). The average values of the HFSN value are received for every interval.

The HFSN reaches the maximum of (6.3+ 0.4)*10-12 m in the phase of growing tide. This value is more than 2 times larger than the level of growing ebb - (2.7+ 0.3)*10-12 m

The most important criterion for the noise-tide relation may be given by the presence of harmonics, typical of tidal, in the noise envelope spectrum. This make it possible to reveal the fine structure of HFSN tidal component. The spectrum of the tidal potential has a few maximums of different amplitude, depending of the geographic position of the observation point, that are corresponding to a fixed set of frequencies.

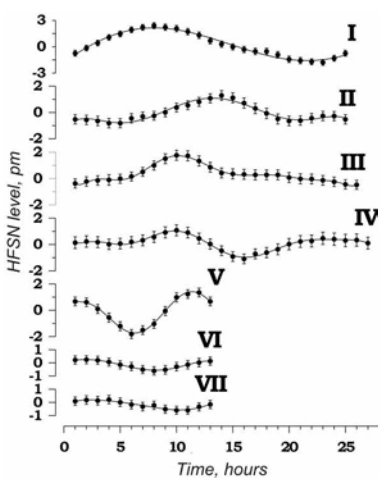

Fig.4. Extracted from the 7 month HFSN data components with periods 23.93 (I), 24.07 (II), 25.82 (III), 26.87 (IV), 12.00 (V), 12.42 (VI), 12.66 (VII) hours.

The periodical components with periods of the main tidal waves of diurnal (23.93 ч. - K1, 24.07 ч. - P1, 25.82 ч. - O1, 26.87 ч. - Q1) and semidiurnal (12.00 ч. - S2, 12.42 ч. - M2, 12.66 ч. - N2) groups are presented here. Extraction was made by the synchronous stacking (Buj-Ballot scheme). Note that the whole set of the diurnal HFSN waves has large amplitudes and is determined with a relative error smaller than that of the semidiurnal waves. This is corresponds to the ratio of diurnal and semidiurnal waves in the tidal potential.

Typical for tide two-weekly trains, which are stipulated by interference of O1- and K1 -waves (periods 25.8 and 23.9 hours), are extracted from the HFSN level. All maximums of the envelope of the interference between diurnal HFSN harmonics correlate with the maximums of the tidal trains. Tendencies in variations of the HFSN and tidal potential amplitudes are the same: amplitude maximum - third group, amplitude minimum - first group. The gaps between the oscillation correspond to the absence of HFSN data due to technical reasons.

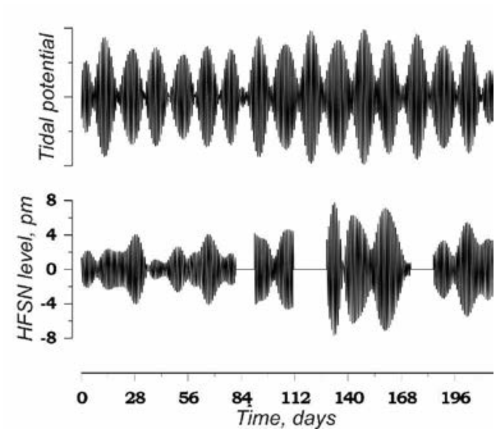

Fig.5. Filtered "diurnal" oscillations of the tidal potential (top) and the HFSN level (bottom).

For first part of uninterrupted registration the time shift of the maximum of the correlation function was calculated in a sliding window 28 days with step 7 days. Earthquakes with epicentral distance less than 250 km from the registration point were considered. Time if the abrupt change of time shift corresponds to the strongest earthquake during the period of the HFSN observation - March 1, 1990, M=6.0, epicentral distance 150 km. (When we say about correspondence, we take into account the value of sliding window).

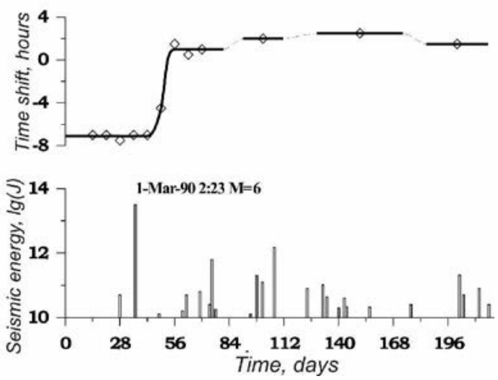

Fig.6. Comparison of change in time-shift of maximum of correlation function between real HFSN and the model of tidal noise (top) and energy of South-Kamchatkan earthquakes (bottom).

Besides it was revealed, that the tide response doesn't stable in time: the sites of the tide components existence are replaced by sites of its absence, the amplitude-phase relation between tide and HFSN vary, while tides have constant in time parameters. The authors put forward a hypothesis about the connection of variations of the tide components in HFSN data with the tectonic conditions in region, and consequently, and about an opportunity of this phenomena use for the forecast of strong earthquakes.

HFSN phase component connected with a tidal wave O1 (T=25.8 h) was chosen as parameter. The choice of wave O1 is connected with its greatest noise-immunity. It was shown, that the stabilization of this phase is observed before earthquakes with M>6.0, occurred on the distance up to 250 kms from the HFSN registration point, within several months. For 1992-1995 the medium state control by HFSN use was carried out as retrospective analysis. Since 1996 such analysis of the HFSN response to tides is conducted in an operative mode, and only in one case from fourteen the strong earthquake precursor was not showed in any way. The estimations of the seismic environment in Kamchatka region received by the analysis of HFSN data from Nachiky and Karymshyna stations, are weekly represented to the Kamchatkan Branch of the Federal Center of Earthquakes Forecasting.

The controlled variable was calculated in the following way: periodical component with O1-wave period was extracted from the HFSN data in the sliding 28-day window by the least-squares method. Theoretical value of tidal phase was calculated by use of famous equations from the static theory of the Earth tides. Obtained value of the phase shift corresponds to the end of temporal window.

Tabl.1. Catalogue of strong earthquakes on Southern Kamchatka in 1992-2001. Earthquake coordinates were received in Kamchatkan Seismological Department of Geophysical service, RAS (Petropavlovsk-Kamchatsky, Russia), magnitudes - in Geophysical service, RAS (Obninsk, Russia) and National Earthquake Information Center (USA). Strong aftershocks were removed from this table.

N	Date	Time	Latitude, *N*	Longitude, *E*	H, *km*	M_w	M_{psp}	M_s
1	1992-03-02	12:29	52.76	160.20	20		6.8	7.1
2	1992-07-13	15:34	50.78	158.13	20		5.8	5.9
3	1992-12-19	12:14	51.65	158.85	40		6.1	5.6
4	1993-06-08	13:03	51.20	157.80	40	7.1	6.5	7.4
5	1993-11-13	01:18	51.79	158.83	40	7.0	6.5	7.1
6	1994-02-14	11:14	51.88	159.07	25	5.9	6.4	
7	1994-08-02	14:17	52.26	158.68	140	5.9	6.2	
8	1996-01-01	09:57	53.90	159.43	0	6.6	6.5	7.0
9	1996-06-21	13:57	51.27	159.63	3	7.0		
10	1997-12-05	11:26	54.64	162.55	10	7.9		
11	1998-06-01	05:34	52.81	160.37	31	6.9		
12	1998-10-31	14:03	52.93	158.20	167	5.5		
13	1999-03-08	12:25	51.93	159.72	7	7.0		
14	1999-09-18	21:28	50.99	157.84	40	6.0		
15	2001-10-08	18:14	52.65	160.42	26	6.5		

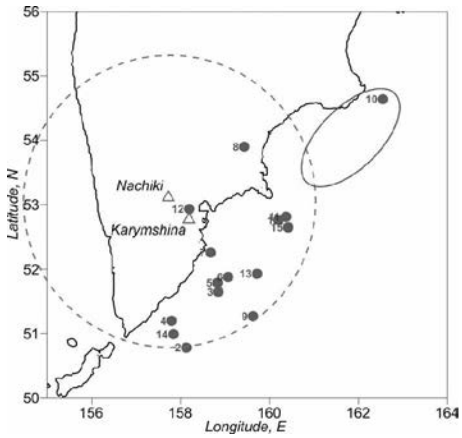

Fig.7. Map of the Southern Kamchatka with marked epicenters of strong earthqu-akes 1992-2001 (magnitude $M >= 6.0$, epicentral distance $D < 250$ км). Earthquake numbering is the same as in the table. The ellipse marks the source of Kronotsky earthquake Dec.5, 1997. 250-km zone is limited by the dotted line.

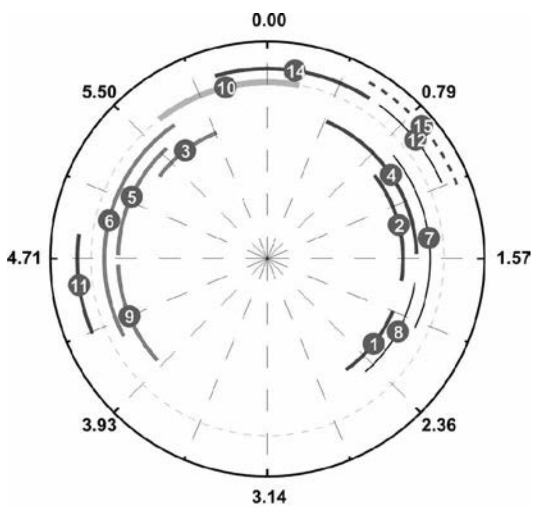

Fig.8. Values of the stabilized phase shift of the HFSN 1-component before strong earthquakes. Circle diagram is more visual presentation under comparison of phase values. Earthquake numbering corresp-onds to the table. Red, blue and brown confidence intervals correspond to neighbouring earthquakes. Dotted confidence interval-data of point "Karym-shina"

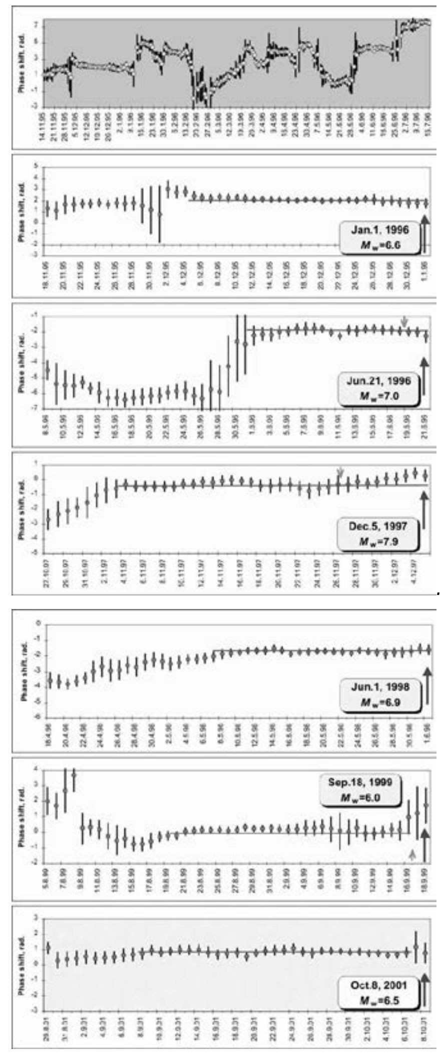

Fig. 9. Variations of the HFSN component connected with tidal wave O_1 action before strong Kamchatkan earthquakes ($M \geq 6.0$, $\Delta < 250$ км). All graphs are constructed with data from point "Nachiki" (exception: graph for earthquake October 8, 2001 uses data from point "Karymshina").

Seismoemissional (or noise) tomography

The ability to radiate a microseismic noise is one of the fundamental properties of the geophysical medium along with a heterogeneity, nonlinearity, variability in time. The seismic noise is considered as highly informative field now, it is containing the unique information about a medium, its structure and stress condition. The volumes of a medium in which stress condition is differ from background region stress, radiate most heavily. It is zones of increased concentration of cracks, the fractures, areas of high temperature gradients and geochemical processes, the hydroterms and volcanic areas. In this investigation we use the method of noise seismotomography for reconstruction of microseismic emission field, that was observed by seismic array. The source of information is the field of continuous endogene seismic radiation of the medium. It is a non-traditional source of the information.

For determination of seismic radiation sources the parameter Semblance (S) was employed. This parameter characterizes the parity between useful signal and hindrance. It is applied to selection of a weak useful signal, when the level of the hindrance is great. Semblance estimation is found as a ratio between the energy of a signal summed over all sensors (a_{ijk}) and the sum of signal energies at each sensor separately (b_{ijk}), and is calculated for each point of medium under the seismic array.

$$S_{ijk} = \frac{\sum_{n=1}^{N} a_{ijk}(t_n)}{M \times \sum_{n=1}^{N} b_{ijk}(t_n)}$$

$$a_{ijk}(t_n) = \left(\sum_{m=1}^{M} \beta_{ijkm} X_m \left(t_n - \tau_{ijkm} \right) \right)^2 \; ; \qquad b_{ijk}(t_n) = \sum_{m=1}^{M} \left(\beta_{ijkm} X_m \left(t_n - \tau_{ijkm} \right) \right)^2$$

M - quantity of seismometric channels, N - length of signal row,

n - number of count, $X_m(t_n)$ - value of the signal on the m channel, β_{ijkm} - geometrical spreading of the wave front, τ_{ijkm} - temporal shift of signal for synchronization.

The natural conditions of Kamchatka allow to carry out the investigation of seismic emission in the areas connected with volcanism of this region. Some Kamchatkan volcanic areas and hydrothermal fields are studied very well. So there is good opportunity to compare this data with the results of our investigation by noise seismotimography use. This research continues the investigation series, in which emissional seismotimography was applied as a method of the image reception for the environment objects radiating most intensively.

On Kamchatka the registration by seismic arrays was carried out on the specially organized ranges in young volcanic area (area of Tolbachik volcano eruption 1975-1976 гг.) and on two various hydrothermal fields: Mutnovsky deposit of steam-hydrotherms and Nachikynsky low-temperature deposit.

Mutnovsky Steam-Hydrothermal Field

For the recording of microseismic noise emission in a steam-hydrothermal area 16-channel seismic array was used. The disposition of the seismic array was designed for the control of the noise signals coming from the earth volumes adjoining to the North-east (NE) production zone of the Verkhne-Mutnovsky site of the hydrothermal field (Parameters of hydrothermal field: two phase conditions, 250-300 C). Overheated waters boil up at the depth. On the layer of boiling up the steamisation, degassing and decrease of temperature together with compound physical-chemical transformation of steam-hydrotherms take place. NE production zone is in control by 4 wells and also natural steam manifestations. This zone has a NE strike and 60 SE dip. Two phase state (water and steam) of heat-transfer is observed from the elevation about 1000 m. Thickness of production zone is 0.6-1.0 m.

The obtained area of active sources of microseismic emission connected with the production zone is revealed. The distribution of active sources in space is coordinated to:

- the production zone configuration by weels data and by the modeling temperature field
- the vertical distribution of temperature
- the depth of two-phase state of heat-transfer.

The sources of induced microseismic emission have been detected as the result of the passage of seismic waves from a teleseismic earthquake. It is confirm the high sensitivity of seismic emission to external influence.

Nacikinsky Hydrothermal Field

Natural thermal manifestation of Nachykinsky deposit occupies an area 200m x 75 m, There are 2 large and 56 weak outlets of thermal water. Thermal manifestation is close to large diorit Miocene intrusion , which structure is very fractured . The water temperature on the surface is about 80 C. Estimated temperature on the depth 1500 m is 96 C. Apparently the reason of hydrothermal activity is thermal anomalies connected with active break zones, it is a consequence of independent deep process. The circulation of water takes place in rather isolated cracks and zones of splitting in watertight rocks.

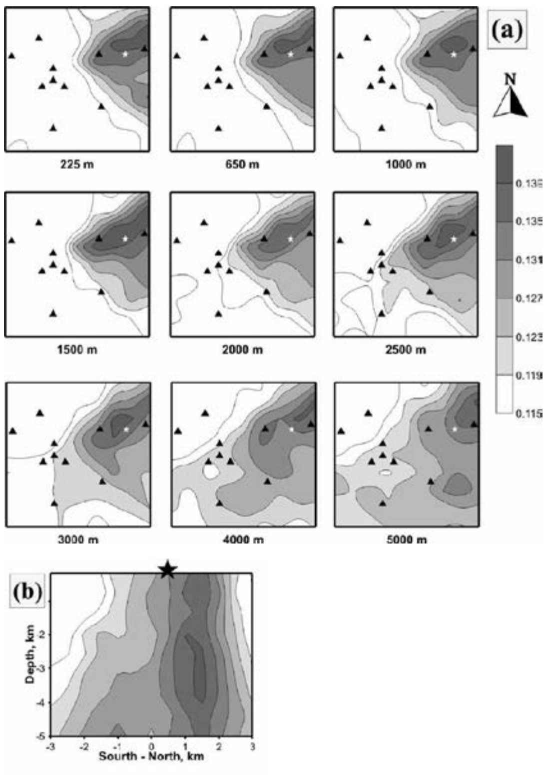

Fig.10. The distribution of seismic emission intensity in area of Nachikinsky hydrothermal field. Thermal manifestation is marked as "star", seismic stations are marked as triangles.

a – horizontal cuts of scanning volume;

b – vertical meridional cut through the thermal manifestation.

The maximum of microseismic radiation intensity coincides with negative magnetic anomaly allocated here by researches of geomagnetic field. The received anomaly is interpreted as the most shattered zone going along the large diorit intrusion and conducting thermal water to the surface. This interpretation agree with the modern conception about structural conditions of hydrothermal deposits localization.

AREA OF GREAT TOLBACHIK FISSURE ERUPTION

The registration was held in 1992, 1994, 1996 in the region of Northern breakthrough of 1975-76 Large Tolbachik Fissure Eruption. In summer 1975 three young volcanic cones with height from 150 to 300 m were generated here. The disposition of the seismic arrays was oriented on deriving of an information about volumes of medium, through which the fissure of eruption has passed, along which three young slag cones have grown.

Areas with noise activity under young cones were detected. The emission sources change depth, but their space position is under cones. Microearthquakes detected by array under the cones line too, confirm that there is the destruction process.

Emission anomalies are shown the most brightly in the period of volcanic tremor of Klutchevskoy volcano that is on the distance about 40 km from Tolbachik cones. So the external influence results in a reemission of the seismic energy by the crust heterogeneities. The results confirm the perspective of noise seismotomography application for study of structure and dynamics of a geophysical medium in active volcanic areas

What is the nature of found anomalies? Probably, they are connected with anomalies of temperature, lifting of gases on cracks, chemical processes, dikes systems under cones and underground structure of craters. Dikes and craters can be destroyed under cone pressure. These phenomena can generate a weak noise signal, because they are connected with a modification of volume and fissuring.

The results of data processing, obtained in a various time, agree among them selves. This fact evidences that mapping images correspond to real geological objects.

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MICROSEISMIC EMISSION IN THE MUTNOVSKY STEAM-HYDROTHERMAL FIELD

V. Saltykov, Y. Kugaenko, V. Sinitsyn, and V. Chebrov

Abstract

The seismic noise is considered as highly informative field, containing the unique information about a crust structure. The volumes of a crust in which stress condition is differ from background regional stress, radiate most heavily. These are zones of increased concentration of cracks, the fractures, the hydroterms and volcanic areas.

In this investigation we use the method of noise seismotomography for reconstruction of microseismic emission field, which was observed by seismic array. In the case when the spatially-coherent signal appears in multichannel recording of the array we can locate the radiation source and its intensity can be evaluated. For determination of seismic radiation sources the parameter SEMBLANCE (the ratio of signal energy summed over all sensors of the array to the sum of energies of individual sensors calculated for each point of medium under the array) was used.

The Mutnovsky geothermal field is located close to Mutnovsky volcano. The disposition of the 16-channel seismic array was designed for the control of the noise signals coming from the crust volumes adjoining to the production zone of the hydrothermal field. Its configuration is known by drilling.

The areas with the high seismic noise activity were detected. They are related to the steam-hydrotermal production zone. The spatial distribution of the active sources is consistent with the production zone configuration. Also, sources of induced microseismic emission have been detected as the result of the passage of seismic waves from a teleseismic earthquake. In this case the medium volumes adjoining to the production zone emitted stronger than the production zone directly. The probable reasons of this phenomenon are the various mechanisms of the stress dump or low-frequency resonance in the porous rock. The basic elements of the initial image are restored through some tens minutes.

Key words: Seismic emission, seismic noise, hydrothermal field, noise seismotomography.

INTRODUCTION

The ability to radiate a microseismic noise is one of the fundamental properties of the geophysical medium along with a heterogeneity, nonlinearity, variability in time. Some years ago the background noise signals were considered in a seismology as an annoying hindrance only. The conception of a power saturation, microactivity of rock and the seismic emission formed per last 20-25 years, have changed the relation to the natural origin seismic noise. The seismic noise is considered as highly informative field now, it is containing the unique information about a medium, its structure and stress condition. This conception is used in the directions of the geophysics connected with the application of the natural unexplosive endogene sources of seismic waves.

The seismic noise is a superposition of microearthquakes and macrocrashes appearing spontaneously in a medium under the influence of external and internal factors. The volumes of a medium in which stress condition is differ from background region stress, radiate most heavily. This is zones of increased concentration of cracks, the fractures, areas of high temperature gradients and geochemical processes. The hydroterms and volcanic areas are intensive sources of seismic radiation too. But high level of industrial noise within the large territories and low level of the useful signal are the reason complicating study of seismic emission and evoking the skeptical relation to the fact of this phenomenon existence.

In this investigation we use the method of noise seismotomography for reconstruction of microseismic emission field, that was observed by seismic array. The source of information is the field of continuous endogene seismic radiation of the medium. It is a non-traditional source of the information. The wave field is registered on a surface by the seismic array. Such approach allows to locate the subsurface sources of the endogene noise and to reconstruct the field of the emission intensity in the internal points of the medium.

The wave field, registered on the surface, has the character of the random process generated by multiple sources in a medium. In this case noise field registered by the array, is non correlated. But the situation changes if there are brightly expressed separate sources at the medium. In the case of the spatially coherent signal appearing in the multichannel recording of the array we can locate the noise sources and evaluate its intensity.

Technique

The data are analyzed by the extraction of the signals coming from the some points of the investigated volume. The temporal shift that appropriate to time of signal passing from an emitted point up to the recording point is entered. The hodograph for the researched region is known. Then the recording areas are summarizing. The obtained aggregated seismogram is used for calculation of a power evaluation, which quantitatively characterizes an emission power of a medium in a tuning point.

For determination of seismic radiation sources the parameter SEMBLA-NCE (S) was employed [1,2]. This param-eter characterizes the parity between useful signal and hindrance. Semblance estimation is found as a ratio between the energy of a signal summed over all sensors (a_{ijk}) and the sum of signal energies at each sensor separately (b_{ijk}), and is calculated for each point of medium under the seismic array.

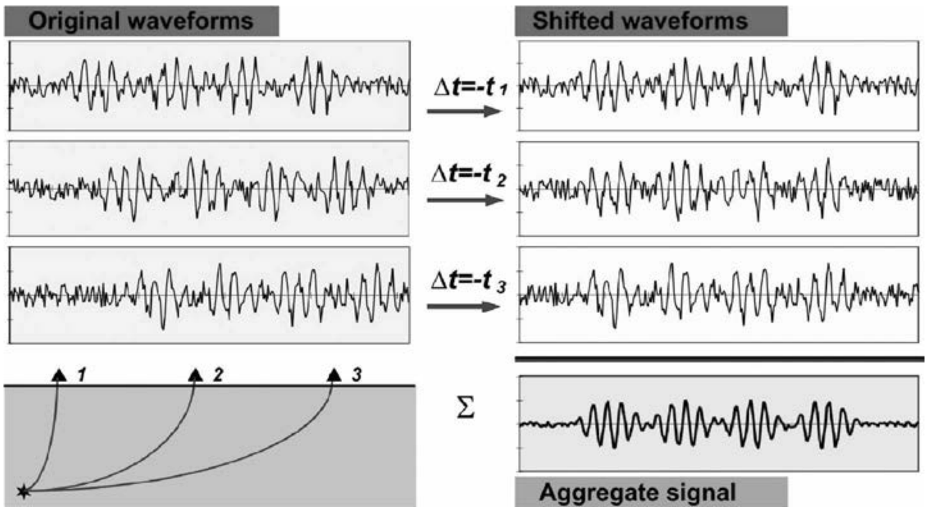

Fig.1. Scheme of the aggregated signal (signal summed over all sensors after temporal shift) construction.

$$S_{ijk} = \frac{\sum_{n=1}^{N} a_{ijk}(t_n)}{M \times \sum_{n=1}^{N} b_{ijk}(t_n)}$$

$$a_{ijk}(t_n) = \left(\sum_{m=1}^{M} \beta_{ijkm} X_m \left(t_n - \tau_{ijkm}\right) \right)^2 ; \qquad b_{ijk}(t_n) = \sum_{m=1}^{M} \left(\beta_{ijkm} X_m \left(t_n - \tau_{ijkm}\right) \right)^2$$

M - quantity of seismometric channels, N - length of signal row,

n - number of count, $X_m(t_n)$ - value of the signal on the m channel,

β_{ijkm} - geometrical spreading of the wave front,

τ_{ijkm} - temporal shift of signal for synchronization,

ijk - coordinates of the signal source.

SEMBLANCE is an evaluation such as signal to noise ratio. It is applied to selection of a weak useful signal, when the hindrance level is great. This evaluation reacts to presence of weak coherent components at the signals, registered by an antenna. This approach is known and used for analysis of multichannel recordings of wave fields of a various nature.

The search of emitting sources was made in frequency band 3-6 Hz. The filtration of an initial signal was conducted by the digital octave filter.

The seismic noise is a superposition of the various types of seismic waves, emitting by the independent sources. Unfortunately, the use of monocomponent seismometers does not allow to apply the tuning by signal polarization. It is necessary to be limited of tuning by a wave hodograf only. The parameter Semblance was carried out separately for longitudinal and transverse waves. Thus the array was turned on focusing of the body waves fields independently.

The results were summarized on several parts of recording for easy finding of the most systematically radiating objects.

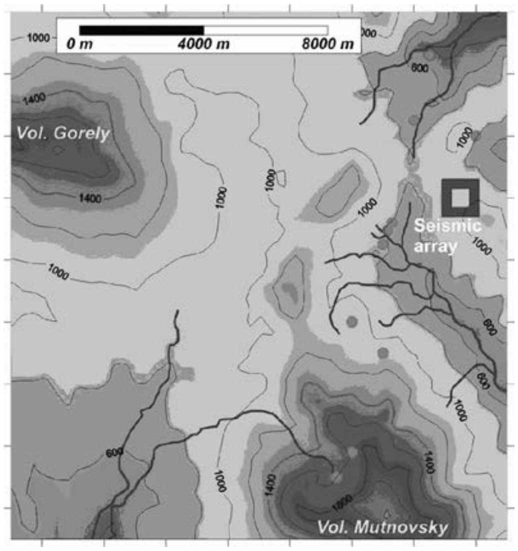

Fig.2. The map of the Mutnovsky geothermal field region. Red points – natural thermal manifestations.

REGISTRATION

The registration was held in the region of the Mutnovsky geothermal field (Southern Kamchatka, 52.45°N, 158.2°E). The Mutnovsky geothermal field is located 75 km south of the city Petropavlovsk-Kamchatsky, close to the northern foothhills of Mutnovsky volcano, at an elevation of 800-900 m above sea level. The Mutnovsky high temperature hydrotherms are located at the intersection of fracture system, in the vicinity of youngest ingeous rocks. The local seismicity is absent in this area. 3-D mapping of lithologic units and temperature distribution within Verkhne-Mutnovsky site of the Mutnovsky geothermal field were presented by A. Kiryukchin (1996).

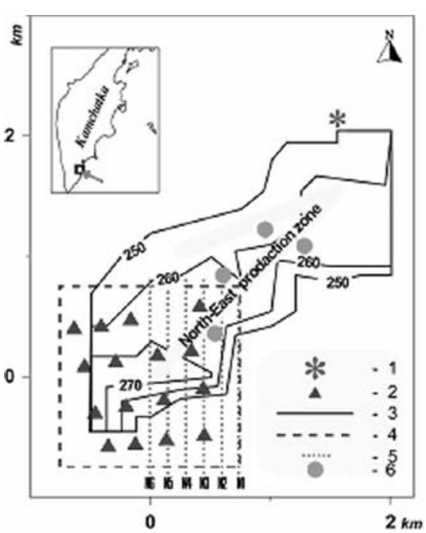

Fig. 3. Seismic array pattern, Verkhne-Mutnovsky site of Mutnovsky hydrothermal field, temperature distribution for the elevation –1000 m, prodaction zone and wells location.

1 - Verkhne-Mutnovsky natural steam manifestations;
2 - sensors of seismic array;
3 - isothermal lines (H = -1000 m);
4 - area of scanning;
5 - lines of vertical cuts;
6 - wells controlling North-East production zone

Main specification of steam hydrothermal springs is two-phase state (steam and water) in the seat of discharge. Overheated waters boil up at the depth. On the layer of boiling up the steamisation, degassing and decrease of temperature together with compound physical-chemical transformation of steam-hydrotherms take place. Down from the boiling zone the hydrothermal springs are leached and over the zone the "steam cap" is formed. Two phase conditions are evident from the elevation about 1200-1300 m.

For the recording of microseismic noise emission in a steam-hydrothermal area 16-channel seismic array was used. The disposition of the seismic array was designed for the control of the noise signals coming from the earth volumes adjoining to the North-East (NE) production zone of the Verkhne-Mutnovsky site of the hydrothermal field (two phase conditions, 250-300° C). NE production zone is in control by 4 wells and also natural steam manifestations. This zone has a NE strike and 60° SE dip.

Main parameters of registration:

number of channels - 16;	sensitivity of channels - 5 nm/s;
dynamic range - 72 dB;	frequency band - 0.5÷20 Hz;
digitization - 1/100 s;	interval of processing - 40÷200 s.

The employment of the monocomponent vertical seismometers only and the small number of sensors is the essential defect of the registration.

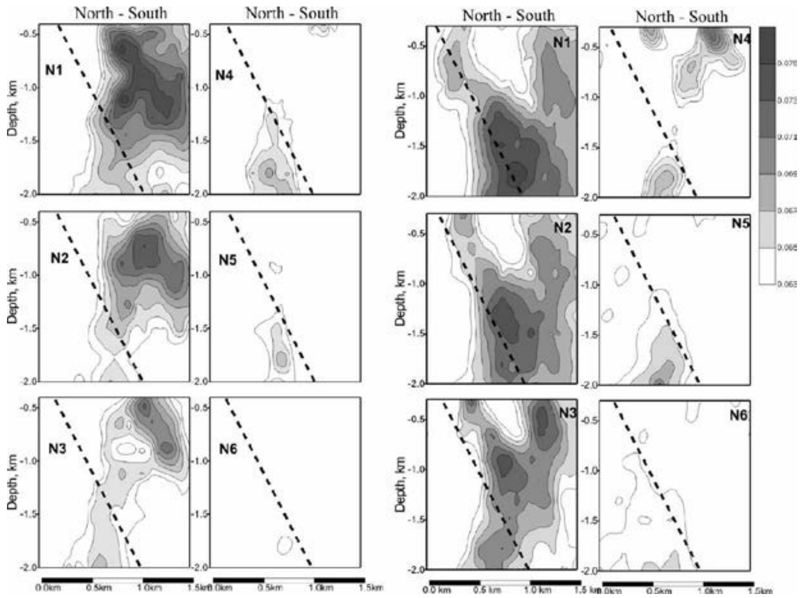

Fig. 4. The distribution of seismic emission intensity for the series of the vertical cuts. Focusing by the longitudinal (left) and transverse (right) waves separately. The dot line – North – East production zone of Mutnovsky steam-hydrothermal field. A most active volume of radiation is related to the NE production zone

DISCUSSION

The areas with the high seismic noise activity were detected (Fig.4). A volume of the active sources of the microseismic emission was related to the NE production zone of steam-hydrotherms. The spatial distribution of the active sources is consistent with the production zone configuration that is known by the boreholes data and the temperature field modelling.

The sources of the longitudinal and transverse waves are spaced. The main reason of this phenomenon is boiling up of the overheated water at the depth and the formation of the two-phase (steam and water) mixture. Two phase conditions are evident from elevations above -1200 m in this site of hydrothermal field. The dynamic processes in overheated steam-water mixture are the source of longitudinal waves. The field of the transverse waves is formed by fractures of the fault area and by the high temperature fluid circulation in the production zone.

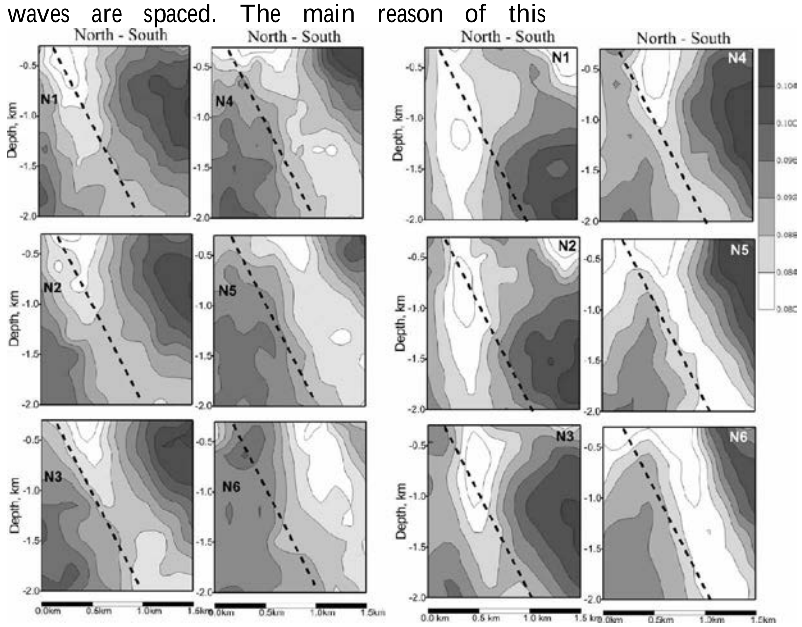

Fig. 5. The distribution of seismic emission intensity for the series of the vertical cuts during passage of the waves from far eathquake . Focusing by the longitudinal (left) and transverse (right) waves separately. In this case the medium volumes adjoining to the production zone are emitted stronger than the production zone directly .

Also, the sources of induced microseismic emission have been detected as the result of the passage of seismic waves from a teleseismic earthquake (fig.5). We observe the image inversion. In this case the areas adjoining to the production zone are the most active. They are in conditions of high temperature gradients and active chemical processes. Significant quantity of energy collects here. This energy is liberated as microseismic radiation by the external initiating influence. Productive zone that has increased permeability and is penetrated by macrocracks radiates much more poorly. Probably, it is in the conditions which are not allowing to accumulate a stress. So the radiation and energy release by the spontaneous microdestruction can pass without external influence. The probable reasons of this phenomenon are the various mechanisms of the stress releasing or low-frequency resonance in the porous rock. The basic elements of the initial image are restored through some tens minutes (fig.6).

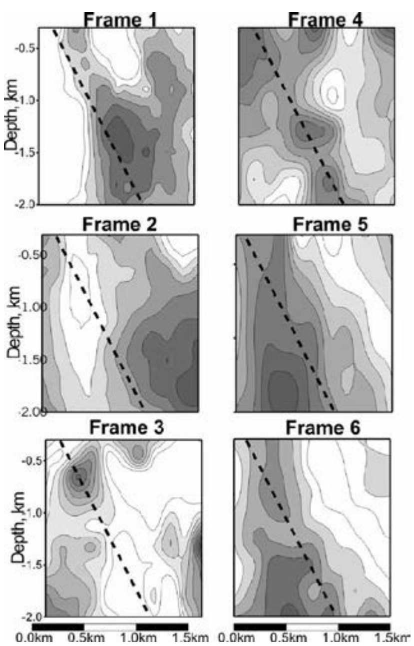

Fig. 6. Change of the emission sources distribution induced by the passage of far earthquake waves. The vertical cuts for the various moments of time are given. (Focusing by the transverse waves)

The use of the emissional tomography for research of environment structure and dynamics has some advantages. Application of seismic noise is possible everywhere, and not just in seismoactive areas. The method is simple and not high-priced. It does not require longtime registration and application of an additional source of a sounding signal. In conditions of the local seismicity absence the noise represents the unique information on an internal structure of environment and its dynamics.

Frame 1 – The distribution of the radiation sources before the moment of earthquake.

Frame 2 – The distribution the radiation sources initiated by seismic waves from earthquake.

Frames 3-6 – Reconstruction of the sources distribution through 2 mines., 10 mines., 20 mines., 30 mines after earthquake waves passage accordingly.

CONCLUSIONS

- Areas with noise activity related to the North-East production zone of steam-hydrotherms are detected within Mutnovsky hydrothermal field.
- Sources of the induced microseismic emission have been detected as the result of the passage of seismic waves from a teleseismic earthquake. The basic elements of the initial image are restored through some tens minutes
- The spatial distribution of the active sources is consistent with:
  - the production zone configuration that is known by the boreholes data,
  - the temperature field modelling,
  - distribution of two-phase state and mono-phase state of the heat-transfer in the production zone.
- The rezults confirm the availability of the noise seismotomography application for study of structure and dynamics of a geophysical medium in the hydrothermal areas.

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SEISMOTECTONICS OF HYDERABAD GRANITE PLUTON (INDIA): A REAPPRAISAL OF GRAVITY DATA

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Abstract

Using gravity data the subsurface batholithic proportion of the Late Archaean – Early Proterozoic Hyderabad granite pluton is delineated and its possible relation with the recurring local earthquakes in the city limits of Hyderabad-Secunderabad has been evaluated. The Bouguer anomaly map of the region shows that the pear shaped Hyderabad granites are emplaced as discrete plutons; though they may form part of a composite batholith. The residual anomaly map of the Hyderabad region reveals discrete gravity lows of about 11 mGal above the Jubilee hills and other adjoining granites. Modelling of the anomaly suggests a total horizontal dimension of 100*100 km^2 and vertical extension to a depth of about 4-5 km for the composite granite body. However, the discrete roots of this composite granite body extend to over 10 km depths. The delineated composite granitic body being of lower rigidity than the surrounding mass acts as the stress concentrator of far-field compression due to Indian plate motion. At the same time the pre-existing faults and weak zones in the form of morphotectonic knot in the Jubilee hill is suggested as the locked volume, which might be inducing the present day local earthquakes of the Hyderabad region even at a lower differential stress.

Key words: K-granite pluton, Bouguer anomaly, batholitic dimension, seismicity.

INTRODUCTION

Exposition of K-granite plutons at the surface of the continental crust in several shield areas has attracted attention of geoscientists trying to understand the origin and evolutionary history of the ancient continental crust. Their batholithic proportions and tectonic environment of emplacement are the vital information for the geodynamic investigation. The incidence of such K-rich granite plutons is widespread in the Eastern Dharwar craton and named after the place where they were studied in detail viz., Chittoor, Closepet, Karimnagar, Mahbubnagar, Ramgiri, Warangal, etc (Fig.1). They are generally isolated granitic plutons, stocks, bosses, parallel bands emplaced along major lineaments, as narrow bands and veins. In the north-eastern Dharwar craton, they attain batholithic dimension in which the older granitoids occur as xenoliths and enclaves. The least studied Hyderabad granite complex is largest in occurrence and has variations in compositions, which are emplaced into the polyphase gneisses popularly known as the "Peninsular gneisses". Its extension and possible association with the Karimnagar, Warangal and Mahbubnagar granites is the subject of speculation and debate (Rama Rao et al., 2001).

Besides, transcending the Archaean-Proterozoic boundary, younger granite plutons played a major role in crustal stabilization processes in the shield regions. In contrast the New Madrid seismicity is found associated with the granite plutons (Hildenbrand et al., 2001). Hyderabad granite pluton of southern Indian shield is no exception (Rastogi, 1999). Though reports of the historical earthquakes of 1843 and 1876 are available in the catalogues for pre-instrumental period the 3.5 magnitude earthquake of January 14, 1982 was the first earthquake recorded adjacent to the Osmansagar reservoir west of the Hyderabad (Soloman Raju et al., 2000). The Medchal earthquake on June 30, 1983 of 4.5 magnitude caused general alarm in the twin cities of the

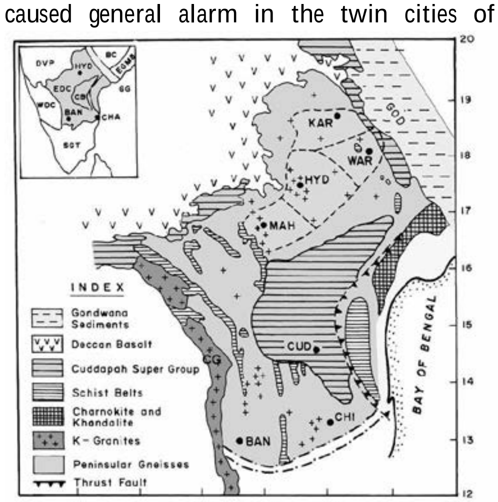

Fig.1: Simplified geological map of Eastern Dharwar Craton showing the distribution of major granite plutons. Dashed lines show the extent of the Hyderabad granite province with tentative boundary between the different granite plutons (after Rama Rao et al., 2001). DVP: Deccan Volcanic Province, EDC: Eastern Dharwar Craton, WDC: Western Dharwar Craton, BC: Bastar Craton, SGT: Southern Granulite Terrain, CB: Cuddapah Basin, CG: Closepet Granite, and GOD: Godavari Graben, HYD: Hyderabad, BAN: Bangalore, CHA: Chennai, KAR: Karimnagar, WAR: Warangal, MAH: Mahbubnagar, CUD: Cuddapah, CHI: Chittur.

Hyderabad and Secunderabad. On August 25, 1984 a tremor of magnitude 1.6 was felt in Kushaiguda and again on November 29, 1984 three tremors, the largest being 2.2 in magnitude, were felt in Saroor

Nagar. The Jubilee Hills experienced micro-tremor activities of magnitudes 2.0, 1.2, 1.7 and 2.7 in 1994, 1995, 1998 and 2000 respectively, which had created a near panicky situation in the locality (Ramakrishna Rao and Soloman Raju, 1995; Rastogi, 1999; Soloman Raju et al., 2000). After the deadly earthquakes of Latur, Jabalpur and Bhuj recurrence of local earthquakes in the city limits of Hyderabad is a matter of grave concern. Being a fundamental tectonic feature with possible relationship to present day local earthquakes the Hyderabad granite pluton warrants special attention.

These K-granite plutons are usually associated with large negative Bouguer anomalies caused by their relatively low-density contrast with the surrounding rocks. Using this property of gravity method Bott (1956), Bott and Smithson (1967) delineated the subsurface configuration of the granite plutons. It has been used even in India to delineate their batholithic dimension in the Indian shield (Qureshy et al., 1968; Krishna Brahmam and Kanungo, 1976; Krishna Brahmam, 1993; John Kurian et al., 2001). A detail investigation of the Bouguer gravity anomaly over the Hyderabad granite complex is thus made to delineate its subsurface batholithic proportion and then to explore mechanical model that might associate the inferred structure with the present day local earthquakes of the region.

GRAVITY DATA ACQUISITION

The Lacoste-Romberg (Model-G) gravimeter with sensitivity of 0.01 mGal was used for about 800 new gravity measurements along the roads crossing Hyderabad in all direction. In order to minimize the error due to drift of the instrument, secondary bases were established, which were tied to the base established in its campus by the National Geophysical Research Institute (NGRI), Hyderabad. The present accepted International Gravity Standardization Net (IGSN) 71 values for the nearest gravity base at Hyderabad Airport is 15.32 mGal less than the value measured in 1963 (Manghanani and Woollard, 1963). Therefore, the absolute gravity value of the other bases already established by the NGRI and used in the present survey is reduced by 15.32 mGal to bring the observed gravity values to the IGSN 71 system (Morelli et al., 1974). Tied to these bases, the gravity data is collected along the roads at an average interval of about 1.5 km. The gravity stations were selected to be easily locatable points on the 1:25,000 toposheets of the Survey of India. For elevation control, most of the stations were located at the Bench Marks and the Spot elevations whereas elevation for the other stations was derived from measurements made by American Paulin System altimeter and/or digital barigometer. However, due to uncertainty in elevation control points and the instrumental limitations, the error in the elevation may be of the order of 3-5 metres. Considering all these factors, the maximum possible error in the Bouguer anomaly, need not necessarily be the most probable error, may be about 1.5 mGal. After necessary corrections viz. tidal, drift, free air, and Bouguer, the Bouguer anomaly encompassing the Hyderabad region is computed for a standard crustal density of 2.67 g/cm^3. It may be mentioned here that selection of proper density value for the upper crystalline crust is essential in the reduction of gravity data. Average density (ρ) of representative rock samples of two major geological units viz. granite and peninsular gneiss exposed in the region are summarized in Table-1. Since the value of 2.67 g/cm^3 is more representative of the average density of surface rocks and hence an appropriate choice for the Bouguer reduction in the region. No terrain correction was applied, as the region is not rugged enough.

Table-1

Average density (ρ) of granite and gneiss of Dharwar craton compiled from different sources and used as a basis for present gravity data reduction and modelling. The density value of Balakrishna et al. (1971) is particularly for Hyderabad granites and measured with better reliability.

Rock Type	No. of Samples	ρ (in g/cm^3)	References
Gneiss	544	2.69	Subrahmanyam and Verma, 1981.
Gneiss	35	2.70	Subba Rao et al., 1983.
Granite	371	2.65	Subrahmanyam and Verma, 1981.
Granite	4	2.65	Subba Rao et al., 1983.
Granite	46	2.65	Balakrishna et al., 1971.

NATURE OF THE BOUGUER ANOMALY

The newly collected 800 gravity data were merged with about same number of the earlier data available with in form of station observation points (NGRI, 1978) and a new Bouguer anomaly map of the region is prepared (Fig.2). The northeastern part of the Bouguer anomaly map shows a gradient paralleling the NW-SE trend of the Godavari graben. The short wavelength circular highs (H1 and H2) are associated with the high-density garnetiferous granite rocks of Warangal and Karimnagar areas (Kanungo et al., 1976) and the granulite terrain of the Karimnagar (Rajesham et al., 1993), respectively. The interrelated high anomalies (H1 and H2) are also attributed to the intrusion of mantle material along the shoulder of the Godavari graben (Mishra et al., 1987) and/or the manifestation of the continental collision (Mishra et al., 2002). The southern flank is characterized by a prominent gravity low (L1) associated with the Proterozoic Cuddapah basin. The relative gravity high (H3) centred over the Vikarabad does not conform to the exposed Deccan flood basalts. As the Deccan trap cover in the region is quite thin, the high (H3) possibly indicates a sub-trappean high-density magmatic intrusion in the region. A short wavelength relative gravity high (H5) over Ghatkesar is the manifestation of the dolerite dykes observed in the region.

The small circular relative gravity lows (Ls) superimposed over the broad negative regional gravity anomaly, otherwise characterize the Hyderabad region (Fig.2). The isolated lows of 4-6 mGal over the Hyderabad (L2, L3, L4, and L5) and 6-8 mGal (L6, L7 and L8) over the Karimnagar is attributed to the low-density ($\rho = 2.65$ g/cm^3) granite outcrops and/or concealed underneath the gneisses. The Mahbubnagar gravity high (H4) of 6-8 mGal is an anomalous feature associated with the granites. Geochemically, the granite plutons of the Karimnagar, Warangal, Hyderabad and Mahbubnagar evolved from a single source with chemical differences owing to the source rock heterogeneity and the degree of fractionation (Rama Rao et al., 2001). Besides, proximity of the unweathered kimberlite pipes and the schist belts might have further accentuated the crustal bulk density leading to relative gravity high over the Mahbubnagar region. The map further reveals that the granitic boundary proposed by Rama Rao et al. (2001) is not apt to the observed Bouguer anomaly (Fig.2). Particularly the low (L2) indicates westward extension of the Hyderabad granite pluton concealed beneath the Deccan flood basalts. Apparently all the four granite provinces are emplaced by clusters of discrete granite plutons though collectively they may form a composite batholith in their respective regions.

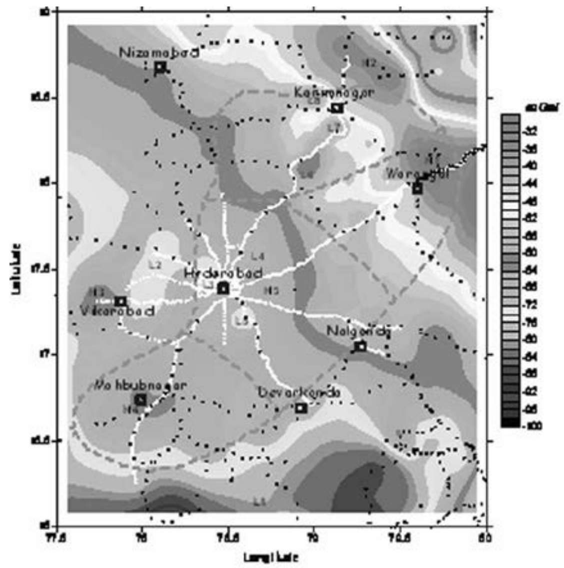

Fig.7.2: Bouguer anomaly map (in mGal) of the region. White stars show the new gravity data colleted for the present study and black stars show the earlier station observation points (NGRI, 1978).

SPECTRAL DEPTH ESTIMATES

It is well known that the interpretation of potential field data suffers from non-uniqueness. How-ever, a first order estimate of possible subsurface density source horizons can be provided by the technique of spectral analysis (Spector and Grant, 1970; Hahn et al., 1976). Thus an amplitude-frequency response of the Bouguer anomaly of Hyderabad region was obtained, in order to estimate the mean or average depth of the density interface. The computed spectrum of the gravity anomaly exhibits exponential amplitude decay with increasing frequency. Such a spectrum may be expected over an arrangement of sources at different depths, where the sources at greater depths are stronger (Fig.3). Each layer of the sources is well resolved and produces a linear spectrum. Two linear segments in the lower and higher frequency ranges are obtained by the standard least square technique, with equal weighting attached to data point in each segments. Considering that the depth to Moho around Hyderabad is about 33-34 km (Singh and Rastogi, 1978; Gaur and Priestley, 1997; Saul et al., 2000; Zhou et al., 2000) the first segment corresponding to low frequency is attributed to causative sources at Moho and the second segment corresponding to high frequency component may correspond to the lower interface of the intrusive bodies exposed in the area, respectively. A similar depth of 10 km was also suggested by Gaur and Priestley (1997) for the Hyderabad granite pluton.

REGIONAL-RESIDUAL SEPARATION

Interpretation of the gravity data normally begins with the decomposition of the gravity anomalies into its various source components (regional-residual anomalies), estimation of source parameters (position, size and shape) and finally translation of these mass distributions into the geological models. Hence, regional and residual separation of the gravity fields is a vital subject in gravity interpretation. One established procedure is to separate regional and residual fields through convolution. Another common procedure is the manual operation of smoothing (Lowrie, 1997).

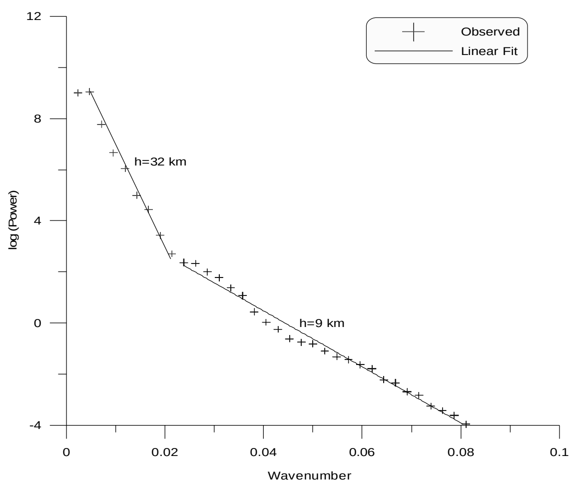

Fig.3: Radial power spectrum of the Bouguer anomaly map (Fig.2).The two decay segments gives the depths of 32km and 9km, respectively.

Simple band-pass filtering, though mathematically comprehensive and well-defined, is not readily comprehensible in physical terms. Subsequent local modelling based on the processed data requires that the separator be mathematically and numerically explicit, a condition which goes against using manual smoothing of contours to obtain the regional field (Jacobsen, 1987). A generalization of standard separation filters, denoted as uniformly sub-optimum filters, quantitatively supports the statement that a wide span of separation problems may be solved adequately using some convenient, small standard filter family. Recently a standard sub-optimum separation filter for the potential field maps is given by Mallick and Sharma (1999) using element shape functions that is numerically stable and is also physically comprehensive when applied to real, random anomalies. The computation being independent of any a priori assumption as to the form and depth of source horizon is another advantage of the method. The observed Bouguer anomaly map (Fig.2) is therefore subjected to the finite element technique for the extraction of the residual field associated to the Hyderabad granite pluton. The residual map encompassing the Hyderabad region (Fig.4) clearly shows the isolated lows (L2, L3, L4, and L5) coinciding with the various discrete cupolas of the Hyderabad granite pluton. As already discussed the gravity high (H3) possibly indicates a sub-trappean high-density magmatic intrusion and the gravity high (H5) is found associated with the dolerite dykes exposed in the region.

SUBSURFACE BATHOLITHIC DIMENSION, MORPHOTECTONICS AND SEISMICITY:

To have subsurface batholithic dimension of the Hyderabad granite pluton the negative residual Bouguer anomaly obtained by the finite element technique (Fig.4) is subjected to three-dimensional gravity inversion of single density interface ($\Delta\rho$ = -0.05 g/cm^3) between the host rock (ρ=2.7 g/cm^3) and the granite pluton (ρ=2.65 g/cm^3; Table-1). As the granites are exposed in the region the top layer of the model is fixed on the surface and bottom was left free to match the model calculation of the computed gravity values with the observed gravity field. The depth values are improved iteratively based on the differences between the observed and the calculated anomalies (Gramod, 1981). The final three-dimensional relief of the Hyderabad granite pluton (Fig.5a) shows an undulating basinal structure with an average depth of about 4-5 km. About 8-10 km deep isolated centres of depression with circular or elliptical cross-sections (Fig.5a) are the roots of discrete granite bodies all having same density that together makes the batholithic dimension of the composite Hyderabad granite pluton. The contacts between the steep-sided inward dipping conical roots of the granitic plutons with their host rocks are sharp, but occasional gradational contacts are also discernable.

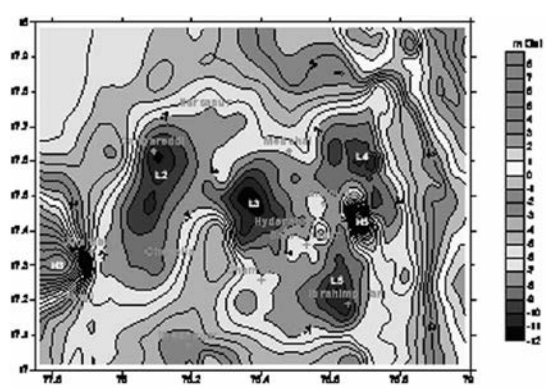

Fig.4: Residual Bouguer anomaly (in mGal) of the Hyderabad region indicating lateral extent of the various isolated granite plutons.

Physiographic expression of the Hyderabad granite pluton is classified as a circular morphostructure corresp-onding to Precambrian extrusives and intrusives (Rantsman et al., 1995). Within the margins elevated to 500 m to 700 m (Fig.5b) the central part of the Hyderabad granite pluton forms a circular bowl-like depression encompassing the Jubilee hill as the common centre. The failed arms towards NW and SE are occupied by the rivers Manjira and Musi, respectively. The Manjira River was originally flowing into the Musi River through Jubilee hill area. Their subsequent dissociation with a sudden U turn of the Manjira River after reaching about 30 km from the Hyderabad is attributed to neotectonic upliftment of the region (Pandey et al., 2002).

Concentric elements of topography are further criss-crossed by faults and lineaments (Fig.4c). The intersection of lineaments and faults, known as knots are important for stress accumulation and seismic activities (Gvishiani and Soloviev, 1981). These knots form a locked volume where deformation induced by the far-field stress leads to stress build-up (Talwani, 1988). A morphotectonic knot in Jubilee hills is well pronounced in the elevation map of the region (Fig.4b). Vertical adjustments associated with the mass inhomogeneity expressed as the Hyderabad granite pluton may have influenced the overlying structures, reactivation of which is manifested as seismicity in the region (Fig.5c).

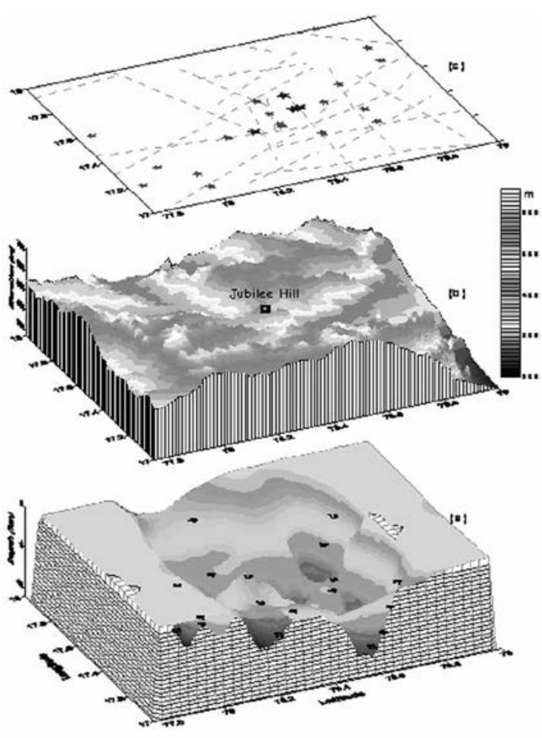

Fig.5: (a) Three-dimensional subs-urface batholithic dimension of the Hyderabad granite plutons, (b) their surface manifest-tation with Jubilee Hill sitting right on top of the morphotectonic knot, and (c) the dashed lines show-ing lineaments (line of faults and weak zones) with earthquakes (stars) felt in the recent past.

GEODYNAMIC LINKS:

Origin and evolution of the Late Archaean Hyderabad granite pluton and its association with the present day seismicity may be seen in the geodynamics of the region. The field association, mineral assemblages, overall geochemistry and the Sr-isotope signatures and the rare earth element patterns of Hyderabad granitic plutons suggest their derivation from crustal source regions (Rama Rao et al., 2001) in a convergent tectonic regime (Sarvothman, 1994; Subba rao et al., 1998). The Godavari graben, with symmetrical distribution of granulite belt along its flanks, is considered as the suture of that compressive regime (Radhakrishna and Naqvi, 1986; Roggers, 1986; Rajesham et al., 1993; Mishra et al., 2002). Stacking of crustal blocks through thrusting related to collision of microplates, in convergent tectonic setting must have result-ed into crustal thickening. In contrast recent seismic investin-gations suggest a thinned crust having an aver-age thickness of 34±2 km (Singh and Rastogi,

1978; Gaur and Priestly, 1997; Saul et al., 2000; Zhou et al., 2000) beneath the Hyderabad region. Apparently, these crustal thickness values are more representative of tectonically reactivated provinces rather than of stable Archaean crust (Saul et al., 2000). According to Pandey et al. (2002) the process is still going on and the entire region is being neotectonically uplifted possibly due to a major intrusive body situated at sub-crustal depth. The change of river courses seen in the form of palaeo-river channels further indicate a prolonged history of neotectonic activity and upliftment of the Hyderabad granite pluton which has been manifested today in the form of local seismic activity.

Alternatively the present day seismic activities are speculated to be due to the failure of pre-existing joints or fractures under compression by the northward movement of the Indian plate (Ramakrishna Rao and Soloman Raju, 1995; Rastogi, 1999; Solomom Raju et al., 2000). The generation of intraplate earthquakes in south India were also attributed to the movement of weak zones in response to the local stress perturbation due to topography, crustal density inhomogeneities and an assumed compression ridge push (Mandal, 1999). Further the epicentres of the seismic activity along the periphery of the broad gravity lows could be caused by the minor adjustments of the faults associated with the intrusive granite plutons

(Krishna Brahmam, 1993). Another explanation for localization of upper crustal seismicity around granite plutons of New Madrid seismic zone relies on the stress concentration mechanism (Hildenbrand et al., 2001). According to Campbell (1978) and Hildenbrand et al. (1996) the granite batholith acts as an elongate elastic inclusion of higher rigidity than the surrounding basement. The inclusion may concentrate the far-field compression (stresses) more than 20 percent above the regional values. With maximum differential stresses due to inclusion relatively low regional stresses could trigger local earthquakes in brittle granite inclusions. The pre-existing faults or weak zones over the granitic inclusions may lead to local stress concentration earthquakes even at further lower level of differential stress. It is quite possible that the delineated 3-D subsurface batholithic dimension of the Hyderabad granite pluton also act as the stress concentrator of the far-field compression due to Indian plate motion and/or epeirogenic upliftment. The pre-existing faults and weak zones in the form of morphotectonic knot over the Jubilee hills triggers the present day local stress concentration earthquakes occurring even at a lower differential stress in the region.

CONCLUSIONS

The present investigation shows that the Hyderabad granites are emplaced as discrete plutons; though they may form part of a composite batholith. About 4-5 km thick granitic batholith has several isolated conical shaped roots with steep inward dipping surface increasing towards centre to a maximum depth of over 8-10 km. The delineated granite batholith, because of its elastic property contrast with the surrounding rock, acts as stress concentrator of far-field compression due to Indian plate motion. With pre-existing faults and weak zones in the form of morphotectonic knot over the Jubilee hills the present day local stress concentration earthquakes are occurring even at a lower level of differential stress in the region.

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EARTHQUAKE PREDICTION RESEARCH IN XXI CENTURY

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Abstract

Earthquake prediction is one of the most complicated problems in seismology. It has two important aspects: scientific and social. The scientific aspect is intimately linked to the basic definition of earthquake prediction; type of prediction (long-term, intermediate-term, short-term, and imminent); general geodynamic conditions and local geology at the place of earthquake source location; size of an earthquake, etc. The social aspect is linked to prevention and protection of society against strong earthquakes, in order to save lives and protect economic and social assets.

After considering all pro and contra arguments with regard to earthquake prediction achievements, the author comes to the following conclusion. The optimistic and realistic preconditions exist for Asia to take the lead in successful development of earthquake prediction research in XXI century.

In the presented paper the author focuses on the almost unknown Highly-sensitive energy-active points (HEP Phenomena) of the Earth, which might be one of the keys for further understanding the physics of the earthquakes and further development of the earthquake prediction research.

Key words: Earthquake prediction research; Site selection; HEP phenomenon; Plate tectonics.

INTRODUCTION

Earthquake prediction is one of the most complicated problems in seismology. It has two important aspects: scientific and social. The scientific aspect is intimately linked to the basic definition of earthquake prediction; type of prediction (long-term, intermediate-term, short-term, and imminent); general geodynamic conditions and local geology at the place of earthquake source location; size of an earthquake, etc. The social aspect is linked to prevention and protection of society against strong earthquakes, in order to save lives and protect economic and social assets. Three various points of view summarizing the scientific achievements in the field of earthquake prediction research in XX century should be noted: pessimistic (about 90% of scientists), optimistic (about 9% of scientists) and realistic (about 1% of scientists). The pessimistic point of view has been formulated and shared in decreasing order mainly from USA to Europe and to Asia. The optimistic point of view has opposite direction - from Asia to Europe and to USA in decreasing order. The realistic point of view has pretty homogenous and diffusive character worldwide. It is shown that the above listed patterns in evaluation of the earthquake prediction achievements depend on: earthquake prediction definition and requirements, degree of country development; current scientific policy based on general state policy, priority of the earthquake prediction for country; personal understanding, research and experience of the expert in that field; experience of majority of experts, general opinion and scientific atmosphere, and emotions.

In the last decade approximately 100 authors published articles in reviewed scientific journals, in which they claimed to have found various precursors before large earthquakes. On the other hand, several reputed scientists doubt that these or other precursors exist. These doubts and lack of spectacular progress in earthquake prediction research, as well as negative field experience of several seismological organizations and ungrounded claims by individual researchers with low quality standards, have led to worldwide skeptic quiescence in earthquake prediction research. This situation is counter-productive.It stops the possible development and constructive discussions of the positive outputs in this critical field for seismic safety of the population in particular for earthquake–prone many developing countries, where there is no chance to achieve the seismic risk reduction in his full scale even during next 100 years, due to the poor economic power and rapidly growing population.

Summarizing the main arguments of the skeptics we can group them as the following. The earthquake unpredictability:

- has theoretical grounding;
- is supported by existence of negative experimental data;
- is based on insufficient statistics due to uniqueness of large earthquakes;
- is confirmed by ungrounded selection of pre-seismic anomalies.

Analyzing the earthquakes unpredictability arguments we came to the following conclusion:

- theoretical grounding of unpredictability is based on abstract mathematical models, which is not adequately considering real physical processes in real geological environment;

- negative experimental data is related mainly to the single observations, or to the dense in space monitoring with accidental, or ungrounded observation sites selection, or to the short-term observations, or to the poor tools of observations and data processing and analysis, or to the lack of sufficient software for observations time-series analysis, or to the lack of theoretical model of the “image” of precursor in research, or to the none informative parameters selection for observations in the given test-site, or to the ungrounded test-site selection;
- uniqueness of large earthquakes cannot be a reason for claiming unpredictability of earthquakes, and therefore stop the earthquake prediction research, because the pre-seismic phenomena might be observed in many various geophysical and geodynamical parameters of the deforming lithosphere, which will develop the representative statistics;
- ungrounded selection of pre-seismic anomalies depends on quality of research, but not a predictability of earthquakes.

After considering all pro and contra arguments with regard to earthquake prediction achievements, the author comes to the following conclusion. The optimistic and realistic preconditions exist in Asia to take the lead in successful development of earthquake prediction research in XXI century based on:

1. well organized, continuous (comparable with recurrence time of earthquakes $M \geq 5.5$), real-time, multi-disciplinary, cross national border and seismically active bands that represent plate divergent, convergent (collision and subduction zones), and transcurrent (transform and other strike-slip zones) boundaries, dense in space and time, monitoring network with specific monitoring sites selection (based on highly sensitive energy active points of the Earth (HEP phenomenon, S. Balassanian 1972-2002) with Virtual Center for data acquisition and processing for high quality field studies of the pre-,co-, post- seismic processes and phenomena;
2. probabilistic approach development, based on retrospective analysis of the long-term (comparable with recurrence time of earthquakes $M \geq 5.5$) monitoring of geosphere and biosphere for building up of the correct empiric models in parallel with attempts to develop the fundamental theory of earthquake prediction;
3. well organized and designed laboratory tests, adequately taking into account real physical processes occurring in real geological systems;
4. across-border, multi-national and multi-disciplinary cooperation of various scientific groups and individual experts, with particular focus on selected test sites (in accordance with specific requirements in various types of plate boundaries) integrated into united earthquake prediction information network;
5. national and international funding of the projects aimed at earthquake prediction research.

Supposing Asia to lead the development of earthquake prediction research in XXI century, the Asian Seismological Commission (ASC) of the IASPEI could take the initiative to develop the Earthquake Prediction Research International Program (EPRIP) implementing the following design principles:

1. earthquake Prediction Research (EPR) to address the protection of population from strong earthquakes;
2. the intermediate scientific results for end-users (including governments) to evaluate a current seismic hazard and to undertake the adequate countermeasures;
3. maintain high scientific standards and strong expertise of research outputs; ensure consensus and enlarge high level experts participation, including skeptics; enforce a multi-disciplinary approach to EPR that works across political and national boundaries; ensure EPR technology transfer; focus on key selected test sites in various types of plate boundaries; ensure implementation of the regional results in national policies.

Seismological studies of the Earth in the XX century, due to principally new opportunities posed by modern seismographs and the sharp increase of the number of seismic stations around the world, have allowed to determine many important patterns associated with the physics of earthquakes. Principal among these is that earthquakes form seismic belts that coincide with lithospheric plate boundaries. In this connection, most patterns of seismic events have been explained within the framework of plate tectonics theory [24, 29].

Since the beginning of the XX century besides seismographic recordings other methods, such as geodesic, geophysical, geochemical, etc., have been involved in studying earthquakes [27]. In particular, the horizontal deformations studied by Reid in the vicinity of the San-Andreas fault, at the time of the 1906 earthquake, led him to formulate the elastic rebound theory of earthquakes. This theory predicts permanent coseismic shear displacement similar to the 1906 observations. Furthermore, it becomes clear that earthquakes are characterized by pre-, co-, post-, inter- seismic changes of various parameters of the lithosphere in the seismic belts [20].

Transition from mono to multi disciplinary studies of earthquakes at the end of the XX century, has raised numerous new issues directly related to the physics of earthquakes. Some of these issues are the following:

- What are the forces and how do they act in the seismic belts?
- What is the mechanism of elastic strain accumulation?
- How are earthquakes and lithospheric plate movements related?
- What is the mechanism of aftershocks and foreshocks?
- Can an earthquake be triggered by another earthquake and what is the mechanism of earthquake source migration along the fault?
- Can various geophysical and geochemical precursory phenomena be observed at remote distances from the epicenter of strong earthquakes?

In the presented paper we would like to focus on the almost unknown phenomena for wide scientific community, which might be one of the keys for further understanding the physics of the earthquakes and further development of earthquake prediction research.

HIGHLY-SENSITIVE ENERGY-ACTIVE POINTS (HEP) PHENOMENON

It is known that field observations play an important role in studying earthquakes. At the same time, till now the main attention has been paid to the seismic recording systems, data processing and interpretation of complex seismic signals, density of observation networks and duration of seismic monitoring.

Studying various dynamic and non-linear geophysical phenomena since 1972, we have come to the conclusion that the observation site selection is the key issue to further understanding present-day geodynamic processes and consequent phenomena such as earthquakes [3]. Until recently, site selection has been considered by the majority of geophysicists as a technical issue: good signal-to noise ratio, convenient maintenance of observation stations, etc.

Studying specific patterns of the lithosphere, as a multiphase, polydispersive, heterogeneous system, we find that the areas characterized by the junctions of deeply penetrating active faults representing more permeable and therefore anomalous heterogenic zones of the lithosphere, are at the same time areas of the biggest concentration of elastic strains. This makes them the most thermodynamically unstable areas of geological medium, and consequently more sensitive to the external physical impacts of various types (HEP phenomenon, 1972-2000 [4,5,6]). In seismic zones, the regional forces of elastic strains are the most dominant of these external impacts. Due to the high capacity to accumulate, distribute, and release various types of energy, the highly-sensitive, very local zones of the lithosphere have been called the energy-active zones (points) of the Earth [3].

Figure 1 shows one of the typical energy-active points, the “Kajaran” site in southern Armenia.

Figures 2, 3 illustrate the unique sensitivity of the energy-active site “Kajaran” to external physical impacts.

These figures show that even the Earth tides are clearly pronounced in the spectrum of daily cycles of various parameters of groundwater, radon gas, water temperature, specific electric conductivity, and water quantity. This means that the “Kajaran” site has strain sensitivity down to 10^{-8} for periodic strain variations. The spectral analysis of various groundwater parameters at the “Kajaran” site have been carried out by the GFZ, German scientific group under the leadership of Prof. J. Zschau within the framework of the READINESS [39] and the Armenian-German scientific cooperation (NSSP, Armenia-GFZ, Germany).

The “Kajaran” energy-active site is located in one of the most complexly structured area in Armenia, on the junction of three active faults [6]. Typical geological features are widespread magmatic intrusions of granitoidal, alkaline and subalkaline composition. Beside active tectonics, the following facts give evidence of high weakness and permeability of the “Kajaran” area:

- sources of historical and modern strong earthquakes (Mmax = 6.5);
- existence of endogenous main deposits, due to injection of deep magmatic fluids;
- spread of fissure waters and huge amount of springs with various mineralisation and temperatures;

- presence of ^3He / ^4He = 3.9 x 10-6% in the isotope composition of He, confirming high permeability (up to mantle) of the "Kajaran" energy-active zone.

SOME PHYSICAL PATTERNS OF EARTHQUAKES OBSERVED AT THE "KAJARAN" ENERGY-ACTIVE SITE (SOUTH OF ARMENIA)

Figure 4 shows the 9-year observation of Helium content (*He*) dissolved in groundwater at the Kajaran" and other sites. From these data it is clear that all strong earthquakes that occurred in the region for this 9-year time period- Norman earthquake (*M* = 6.7, Turkey, 1983), Spitak earthquake (*M* = 7.0, Armenia, 1988), Roudbar earthquake (*M* = 7.7, Iran, 1990), Racha earthquake (*M* = 7.1, Georgia, 1991), are clear pronounced only at Kajaran site by deep co-seismic minimums of *He* content and afterwards a half-year post-seismic return period of He to its initial content. The *He* anomalies after the Racha (1992) earthquake are not well associated with Erzinjian (1992) and Barissakho (1992) earthquakes, because at least 0.5 years is needed for post-earthquake *He* content recovery, as it was actually seen in cases of the Norman, Spitak and Roundbar earthquakes. From these data (Fig. 4) it follows, that:

1. Strong earthquakes of the region (*M* > 6.5) are manifested in groundwater *He* content at the "Kajaran" observation site, at least co- and post-seismically, at the epicentral distance of many hundred kilometers.
2. All the strong earthquakes (*M* > 6.5) are manifested uniformly at the "Kajaran" site as the strong co-seismic minimums of *He* and post-seismic return period to initial content. It indicates that in case of a strong earthquake at any distance from the "Kajaran" observation site within the same seismic zone, the similar mechanism (compression tape) is affected co-seismically to *He* content in groundwater of "Kajaran" energy-active site.
3. No other *He* content observation sites are sensitive to strong earthquakes similar to the "Kajaran" energy-active site. This means, that the same earthquakes are manifested differently at the various observation sites, i.e. response of the observation site depends on the local geology (HEP phenomenon).

Figure 5 shows the highly precise data of the groundwater specific electrical conductivity (*C*) for the 1996-1998 time period at the "Kajaran" and other sites, observed within the READINESS project [39]. Figure 5 illustrates again, that all strong seismic events taking place all over the Arabian and Eurasian plates collision zone are clearly manifested only in the "Kajaran" site groundwater conductivity as the co-seismic minimums and post-seismic recovery to the initial state. One exception that can be explained is the *M* = 6.1 earthquake (February 1997, Iran) which was followed 3 months later by the next earthquake with *M* = 7.3 (May 1997, Iran). As a consequence, the post-seismic conductivity *C* return process after the *M* = 6.1 earthquake at the "Kajaran" site, was cut-short by the co-seismic conductivity *C* sharp decrease during an earthquake with *M* = 7.4.

Co- seismic decreases of *He* (Fig. 4) and *C* (Fig. 5) are related to the uniform response of the "Kajaran" energy-active site to the strong compression of the pores and microcracks in the surrounding rocks during a strong earthquake.

Figure 6 shows the unique observations carried out within the READINESS Project at the Kajaran" and other sites before, during and after the Izmit earthquake (17 August 1999, *M* = 7.4 Turkey). It is clear from Figure 6 that at the time of Izmit event sharp co-seismic increase of groundwater quantity (*Q*) and simultaneously sharp co-seismic decrease of groundwater conductivity (*C*) took place only at the "Kajaran" site located 1380 km distance from the epicenter of the Izmit earthquake. After the earthquake, the post-seismic return process of groundwater quantity and conductivity to the initial state for the 2.5 months is clearly seen (Fig. 6). It is also interesting to note pre-seismic anomalies of *Q* and *C* started simultaneously 5 months before the seismic event. Concerning the first negative anomaly of *C* being observed at the end of November 1998 then it probably does not have a seismogenic nature since it is not confirmed by the increase of *Q*.

Thus, to sum up the observations at the "Kajaran" site, leaving the consideration of pre-, and post-seismic anomalies, we must emphasize that like all other cases discussed above, the "Kajaran" energy-active site has responded to the strong Izmit earthquake by typical compression, being at the distance of 1380 km from its epicenter. Co-seismic sharp decreases of *C* and simultaneous co-seismic increase of *Q* favour this conclusion.

Analysing the co-seismic effects recorded at 10-minute intervals at the "Kajaran" site it must be noted, that:

- The strong and sharp increase in water quantity (*Q*) was observed within 8 min 21 sec $\le \Delta t \le$ 18 min 21 sec ($\Delta t = t_0 - t_1$) after the Izmit mine shock M=7.4 at the Kajaran test site located at the distance 1380 km from the epicenter of the Izmit earthquake, (where t_0 =

00:01:39 is origin time, t_1 = 00:10:00÷00:20:00 is time of strong and sharp change in water quantity at the Kajaran site)

- The time internal of *Q* change from pre- to post – earthquake state consisting of two parts, a fast one (30 ±10 min) and a slow one (3-5 hours);
- The strong and sharp conductivity decrease was observed for 1 hour 20 ÷ 30 min after the Izmit mine shock and 1 hour 10 ÷ 20 min after the water quantity's (*Q*) sharp increased;
- The time interval of *C* change from pre- to post – earthquake state was 1 hour 10 ÷20 min

Figure 7 shows the principal geological model, which explains the uniform co-seismic compression response of the "Kajaran" energy-active site to all the strong earthquakes taking place within Arabian-Eurasian collision zone.

In the case of sharp compression in the surrounding rocks at the "Kajaran" site due to the impact of external forces, the fresh water injects from the surrounding near-surface intensely fractured rocks through the pores and microcracks into the "Kajaran" observation well and mixes with the mineralized bedrock waters. As a result, the conductivity *C* of groundwater in the observation well will sharply decrease and the water quantity *Q* will increase.

On the qualitative level, the proposed geological model does not contradict with the above mentioned quantitative data, i.e. velocity, time interval, and magnitude of *Q* and *C* changes after the Izmit earthquake at the Kajaran site. However, the quantitative modelling will be definitely needed as a next step for better understanding of the mechanism of co-seismic Q and C changes at the "Kajaran" site.

Figure 8 shows the Armenian NSSP multiparameter observation network response in the territory of Armenia: before (June-July), during (August) and after (September-October) the Izmit earthquake. It is clear from Figure 8 that 12 anomalies of various kinds were observed in June in Armenia. The definition of anomaly for our case is the value of time-dependent geophysical, geochemical and other parameters, which deviate from the standard ones in more than three times. The number of observed anomalies was approximately the same (11) in July, but with some changes of their location. Afterwards the number of various observed anomalies has dramatically increased in August, i.e. 23 anomalies! Then quantity of anomalies has twice decreased in September, in fact to the preceding level (12 anomalies) and remained the same in October. The nature of different distributed phenomena is discussed in paper [6].

Thus, the whole territory of Armenia was covered by anomalies of various physical natures at the time period of the Izmit earthquake (August, 1999). It is noticeable also, that in August the number of earthquakes has dramatically increased all over the Caucasus (Fig. 9).

In the presented paper the high quality [38, 36] earthquake catalogue of the Armenian National Survey for Seismic Protection as it is mentioned by many seismologists is used for the region (38.2^0-42.0^0, N/42.0^0 - 47.0^{0}E). The data set contains the total number of 18.000 events with M≥2.0 for the 1962-2001 period.

DISCUSSION

Evaluating the above presented data, we come to the conclusion that mainly two possible mechanisms should be discussed, which are related to probable forces that initiated the HEP phenomenon at "Kajaran" site.

The first one is direct impact of the dynamic wave from the Izmit earthquake source on the "Kajaran" site because of velocity 2.754 km/s ≥ V ≥ 1.253 km/s (taking into consideration the passage of 1380 km during 8 min 21 sec-18 min 21 sec), which is very similar to the velocity of elastic wave propagation in case of V=2.754 km/s. The evaluation of direct impact of dynamic waves on the Kajaran site shows that it has low probability that can be neglected for the following reasons:

- The magnitude of the impact is comparable to the Earth tidal $10^{-7} \div 10^{-8}$ [13].
- There is no any evidence of response similar to the "Kajaran" site registered at other observation sites located much more closer to the Izmit earthquake source (Fig.6)
- There is no any extension other than compression impacts observed at the "Kajaran site".

The second probable mechanism is indirect impact of certain forces, which initiate uniform high magnitude co-seismic response, in form of strong compression of the "Kajaran" energy-active site to all the large earthquakes within the Arabian and Eurasian plate collision, apart from the distance between observation site and epicenters of the strong earthquakes. One of the possible hypotheses that can be considered and discussed is as the following.

Two main types of forces, external regional elastic stress ($\overrightarrow{F_E}$) and the internal elastic strain ($\overrightarrow{F_I}$), i.e. resistance force to external regional stress, are influencing every point in the collision zone, being in a quasi-equilibrium state before the seismic event

$$\overrightarrow{F_E} = -\overleftarrow{F_I} \qquad (1)$$

When the strong earthquake occurs, at every point within the collision zone the sum of the main acting forces in vector form, is:

$$\overrightarrow{F_E} + \overrightarrow{F_W} = -\overleftarrow{F_I} - \overleftarrow{F_S} \qquad (2)$$

where $\overrightarrow{F_W}$ is the stress and $\overrightarrow{F_S}$ is the strain produced by the dynamic wave that propagates outward from the earthquake source zone.

Since F_W and F_S in particular depend on earthquake magnitude *M* and distance between source and observation point, small earthquakes that occurred nearby the observation site should influence the site more strongly then strong earthquakes that occurred at a remote distance from the same site. However our experimental data (Fig. 4,5) show that the "Kajaran" energy-active site responds uniformly and only to strong earthquakes, independently of the distance between observation site and epicenter within Arabian-Eurasian plates collision. It is noticeable also that the "Kajaran" site's uniform response in all the cases corresponded to compression. Following these two arguments it is reasonable to conclude that $\overrightarrow{F_W} << \overrightarrow{F_E}$ and $\overrightarrow{F_S} << \overrightarrow{F_I}$ in all the cases. This means that $\overrightarrow{F_E}$ and $\overrightarrow{F_I}$ are the dominant forces determining the response of the "Kajaran" observation site to *strong* seismic events.

Now let us consider, at the energetic expression, the dominant forces behavior at the obser-vation site in case of strong earthquakes within the collision zone.

Before an earthquake

$$E_E = E_I \qquad (3)$$

where E_E and E_I are the energy of external (regional) elastic stress and the balancing energy of internal elastic strain, respectively.

During a strong earthquake, the accumulated huge strain energy was released (ΔE_I), which in accordance with the Newton's Low initiates immediate energy made up (ΔE_E) by external stress forces. In this case, E_E *(3)* becomes

$$E_E = E_I - \Delta E_I + \Delta E_E \qquad (4)$$

where

$$\Delta E_E = \frac{1}{2} F_E \cdot \Delta L \qquad (5)$$

i.e. the work yielded by $\frac{1}{2} F_E$ external forces. Our analysis of the probable source of acting external forces shows that one of the very preliminary and hypothetical external forces might be the Arabian plate movement at the ΔL distance towards Eurasian plate and correspondingly ΔE_E energy transfer from Arabian plate to collision zone.

In regard to ΔE_I , we note, that,

$$\Delta E_I \simeq \Delta E_T + \Delta E_F + \Delta E_W \qquad (6)$$

where ΔE_T is heat energy released at the source, ΔE_F is energy fracturing of the rocks in the source, ΔE_W is the portion of strain energy converted into seismic waves that propagate outward from the fault zone.

So far as energy release has occurred in the very local source area but initiated immediate energy makes up by Arabian plate movement towards Eurasian plate along all over the collision zone, it means that after the strong earthquake ΔE_I elastic energy can make up energy release in the earthquake source area only partly (ΔE_I^1), but another part (ΔE_I^2) will be spent to increase the stress along the collision zone, taking into account that $\Delta E_I = \Delta E_I^1 + \Delta E_I^2$

In case if the proposed hypothesis is correct, which should be verified by further mathematical and physical modeling and additional field studies, it follows that the ΔE_I^1 is able to induce aftershocks in the source area, and ΔE_I^2 can trigger weak seismicity (Fig.9), foreshocks of the strong earthquake, the strong earthquakes themselves, as well as excite any geophysical, geochemical, biological anomalies (Fig.8), at any remote distance from the epicenter within Arabian-Eurasian plates collision.

1. Summarizing the HEP phenomenon studies at the Arabian-Eurasian plates collision the following conclusions can be made:

- At least co- and post- seismic response of the various parameters of the lithosphere to all strong earthquakes within the same collision zone have been observed at the epicentral distance of many hundred kilometers.

- The same strong earthquakes are manifested at the various observation sites differently. This means that response of observation site depends on the local geology.
- The most sensitive to the external physical impacts generally and to the stress accumulation in particular are the so called energy-active points (HEP phenomenon).
- The HEP phenomenon has been discovered and studied by the author in the most thermodynamically unstable areas of geological medium and, consequently, more sensitive to the external physical impacts of various types.
- In case of Arabian-Eurasian plate collision all the strong earthquakes (M>6.5) are manifested uniformly (compression tape) at the particular "Kajaran" highly-sensitive energy active site (Armenia). It indicates that in case of a strong earthquake at any epicentral distance within the same seismic zone, the similar mechanism is affected co-seismically to "Kajaran" highly-sensitive energy-active site.
- One of the very preliminary and hypothetical mechanism, which should be verified by further mathematical and geodynamical modelling with additional field studies, could be compensative co-seismic sharp (sudden) movement of the Arabian plate toward Eurasian one in case of huge elastic energy release during a strong earthquake in the collision zone.
- The energy release in case of a moderate earthquake, probably can be immediately made up by co-seismic nearby microplate`s movement [31, 10]. And energy release in case of small earthquake, can be made up by co-seismic redistribution near source stress field [20].
- In case of a strong earthquake immediate elastic energy made up by sharp movement of the Arabian plate toward Eurasian one and correspondingly energy transfer from the Arabian plate to the collision zone is able to excite aftershocks distributed throughout the source volume, and to add sudden supplementary elastic stress in the entire collision zone.
- Sudden supplementary elastic stress, excited by the Arabian plate's movement toward the Eurasian one and correspondingly energy transfer from Arabian plate to collision zone, is able to cause strong compression throughout the entire collision zone, during each strong seismic event, and therefore to induce corresponding geophysical [27, 37, 25, 30, 6], geochemical [9, 7, 32, 34, 35, 8, 16, 21], hydrogeodynamic [33, 34, 22, 28] and other anomalies [12, 11, 17], as well as to trigger new earthquakes [26, 14, 23], i.e. foreshocks and main shocks, as well as aftershocks [1,19,18,20] migration of strong earthquakes along the active faults [2], depending on the accumulated strain in every point of the medium, at any distance from initial strong earthquake source, in the entire collision zone.
- In case if the above hypothesis is correct, strong earthquakes can excite lithospheric plate movement and lithospheric plate movement excites strong earthquakes. So, there is a possible chain of interstipulated and interrelated processes, acting in the nature: strong earthquake $\rightarrow$ plate movement $\rightarrow$ strong earthquake $\rightarrow$ plate movement $\rightarrow$ etc.
- The possible chain of interstipulated and interrelated processes, i.e. strong earthquake plate movement, can explain the mechanism of many pre-, co-, post- seismic phenomena that were not well understood before the present-day:

The mechanism of stress/strain accumulation within plate collisions, probably has two components, a slow one and a fast one. Slow stress/strain accumulation relates to slow movement of plates, due to convection currents in the mantle [15]. On the other hand, fast accumulation relates to the sudden plate movement triggered by strong earthquakes.

CONCLUSIONS

1. Considering all pro and contra arguments in regard to predictability of earthquakes, the earthquake prediction research must be continuous in the XXI century.
2. Taking into account the crucial social aspect of earthquake prediction in particular for highly populated developing countries, as well as the current status of the problem in different countries and their achievements in this field, Asia is considered to lead the further development of earthquake prediction research in the XXI century and the Asian Seismological Commission of the IASPEI could take the imitative to develop the Earthquake Prediction Research International Program (EPRIP)
3. The Highly-Sensitive Energy-Active Points (HEP Phenomenon) of the Earth could be

considered as one of the promising keys for further development of Earth Prediction Research

4. Based on the HEP Phenomenon multidisciplinary studies the possible chain of interstipulated and interrelated processes acting in the nature is discovered, the strong earthquakes can excite fast lithospheric plate movement and fast lithospheric plate movement excites strong earthquakes. The proposed hypotheses of existence of the fast component of the plates movement in addition to the well known slow one, due to convection currents in the mantle should be verified by further mathematical and geodynamical modeling with additional filed studies.

5. The existence of the fast component of plates movement may explain many of pre-, co-, post-seismic phenomenon, and support the further understanding of physics of the earthquakes for earthquake prediction research.

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SOURCE PROCESSES OF THE TWO LARGE BISLIG EARTHQUAKES ON MAY 17, 1992

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Abstract

Two large earthquakes (Ms 7.1 and 7.5) occurred off the eastern coast of Mindanao, along the Philippine Trench on May 17, 1992. These two events were separated by only 26 minutes and were strongly felt in the coastal towns near the epicentral area. Strong ground shaking and tsunamis had caused significant damage at the coastal area of Mindanao island parallel to the Philippine trench. Tsunami run-up heights are estimated to be 3-5 meters along the coast of Caraga and Manay [Daligdig & Tungol, 1992]. The source processes of the two earthquakes were estimated using teleseismic body waves, tsunami waveforms and eyewitness accounts. Results of the MTRF inversion for the determination of focal mechanism and best depth for both events depicts a thrust type mechanism with some left-lateral component. Using this results in the analysis of tsunami waveforms, it was found out that the first event had ruptured the southern part of the one-day aftershock area and the second earthquake ruptured the northern part. This result was confirmed by accounts given by the eyewitnesses.

Key words: focal mechanism, tsunami, moment tensor rate funct

INTRODUCTION

Two large earthquakes occurred off the eastern Mindanao, coast along the Philippine trench on May 17, 1992. These two events were separated by only 26 minutes and the NEIC Preliminary Determination of Epicenter (PDE) provides the source parameters as follows; for the first event, the origin time is 09:49:19.11 GMT; with an epicenter at 7.239ºN, 126.645ºE; depth is 25 km and magnitude, Ms 7.1. For the second event, origin time is 10:15:31.31 GMT; epicenter at 7.191ºN, 126.762ºN with depth of 33 km and magnitude Ms 7.5. These two events were strongly felt in the towns of Cateel, Banganga, Boston, Caraga, Manay and Tarragona in Davao Oriental and has caused significant damage at the east coast of Mindanao island due to strong ground shaking and tsunami. Tsunami run up heights are 3-5 meters along the coast of Caraga and Manay [Daligdig & Tungol, 1992]. One girl was washed away by the tsunami, she survived with minor bruises and was found by the fisherman in the following day [Narag et al, 1992]. The tsunami was also observed at a tide gauge in Davao, southern Mindanao.

SEISMOLOGICAL ANALYSIS:

A number of significant earthquakes occurred beneath the eastern side of Mindanao island, due to the subduction of the Philippine Sea Plate along the Philippine trench. High seismic activity confirms an active Benioff zone of mantle earthquakes concentrated between 5º - 14º N latitude. Earthquakes shallower than 50 kilometers cluster on the landward slope of the trench while earthquake sources with depths greater than 50 kilometers seems to lie within the intraplate convergence (Narag et al, 1992). The latest significant earthquake in the area prior to the May 17, 1992 events based on the NEIC catalogue was a Ms 6.0(Hrv) earthquake which occurred in April, 1991, and almost a year after the 1992 event a Mw 7.0(Hrv) earthquake occurred on May 11, 1993, while the most recent one occurred on April 14, 2002 with a Mw 5.6(Hrv). Hypocenter of these events are in the upper 50 kilometers of the converging boundary.

One-day aftershock distribution

Epicenter of the two main shocks and one-day aftershocks estimated by the National Earthquake Information Center (NEIC) were shown in Figure 1. The epicenter of the two large events are located very close to each other (about 20 km apart). Aftershocks are located trench-ward from the main shocks. This implies that the main rupture of the two large earthquakes occurred trench-ward from the epicenter of the two earthquakes.

Analysis of teleseismic body wave

The Moment Tensor Rate Function (MTRF) inversion [Ruff & Miller, 1994] was performed to estimate the focal mechanism and to locate the best depth of the earthquake. We re-inverted the seismograms at the above best depth and focal mechanism to estimate the source time function. The average P and S wave velocities from the ground surface to the hypocenter are assumed to be 6.7 km/s and 3.9 km/s respectively. For the first event, which occurred at 0949 GMT, 18 P-waves and 2 S-waves (Figure 2) recorded at IRIS stations were utilized for the analysis. The result shows that the earthquake had a thrust type mechanism with some left-lateral component (strike=168, dip=39, rake=56). The centroid depth was 14 kilometers (Figure 3) with the seismic moment of 0.53 x 10**20 Nm (Mw=7.1) which is similar with the result from the NEIC with minimal difference in the details of parameters. The source time history was consisted of one pulse with a duration of 23 seconds shown in Figure 4.

The second earthquake, which occurred at 1015 GMT in the same day was also analyzed using teleseismic waves, 6 P-waves and 1 S-wave (Figure 5). The result shows that this event has similar mechanism with that of the first event. It has a thrust type mechanism with left-lateral strike slip component (strike=198, dip=30, rake=42). The centroid depth was 24 kilometers which was deeper than that of the first event (Figure 6). The seismic moment was 0.44 x 10**20 Nm (Mw=7.2), with the source time function consisted of one pulse having a duration of 14 seconds (Figure 7). However, the resolution of the analysis for the second event was poor because the later phases generated by the first event caused large noises for the second event. The focal mechanism solutions from MTRF inversion in this study is consistent with the under thrusting of the Philippine Sea Plate beneath the Philippine Islands [Fitch, 1970].

TSUNAMI ANALYSIS

Tsunami computation and analysis of a waveform

The tsunami was numerically computed on actual bathymetry. Finite difference computations of the linear long wave equations were carried out with a grid spacing of 20 seconds of the arc [Satake, 1995]. The tsunami caused by the first earthquake was computed using the focal mechanism estimated from the MTRF inversion. We found that the fault was located on the southern part of the one-day aftershock area (Figure 8) in order to explain the first pulse of the observed tsunami recorded at Davao in Mindanao Island (Figure 9). If the fault located in the northern part of the one-day aftershock area (Figure 10) is assumed, the first observed tsunami wave arrived at the station much earlier than the first computed tsunami wave (Figure 11). The amplitude of the first pulse of the observed tsunami was explained by the computed tsunami waveform from a fault model that had a length of 80km, a width of 50km, and a slip amount of 37cm. The seismic moment is calculated to be 0.52 x 10**20 Nm by assuming that the rigidity is 3.5 x 10**10 N/m**2. This seismic moment is consistent with that of the estimated from the teleseismic body wave analysis from the MTRF inversion. The first pulse of the tsunami caused by the second earthquake was difficult to identify because of the interferences with the large later phases of the tsunami from the first event. However, we assumed that the second earthquake ruptured the northern part of the one-day aftershock area, because the first event had already ruptured the southern part of that area (Figure 12). The length and width of the fault model for the second event was assumed to be 70 km and 50 km, respectively. The slip amount was 36 cm to satisfy the seismic moment estimated from the teleseismic body wave analysis. The tsunami waveform at the tide gauge at Davao was computed using the above fault model and was added to the tsunami waveform from the first event. The observed tsunami waveform was compared with the computed waveform from the two events in Figure 13. We found that the observed and computed waveforms were consistent.

Eyewitness evidences

In Feb. 2002, the PHIVOLCS tsunami field survey [Besana et al., 2002] was conducted to investigate the geological and eyewitness evidences of the historical tsunamis. The eyewitnesses, along the southern half of the east coast in Mindanao Island, consistently told that the sea level retreated after the first large earthquake shortly before the large tsunami wave arrived. The arrival time of tsunami was about 5-10 minutes after the strong shaking. Figure 14 shows the snapshot of the computed tsunami at 1 minute after the origin time of the first earthquake. The fault is located southern part of aftershock area. The depression wave, blue parts, reaches the east coast of Mindanao Island faster than the large upheaval wave, red parts in Figure 14. This is consistent with the eye witnesses accounts. Figure 15 also shows the snapshot of the computed tsunami at 1 minute after the origin time of the earthquake, but the fault is located at the northern part of the one-day aftershock area (Figure 10). The first depression wave is not propagating to the east coast of Mindanao Island which proves to be inconsistent with the eyewitnesses accounts. These results suggests that the fault of the first large earthquake is located at the southern part of the aftershock area.

DISCUSSION

The two large earthquakes occurred at almost same location (about 20km apart). MTRF inversion results for the determination of focal mechanism of both events indicates a thrust-type fault motion, representing a plate interface event. This confirms that the events occurred in the convergence zone where the Philippine Sea plate subducts beneath the Philippine archipelago. Results of the tsunami analysis and consistency with the eyewitness accounts confirms that the first earthquake ruptured the plate interface to the south, and then the second earthquake was triggered by the first event and ruptured the plate interface to the north. The source area is located where thes direction of trench axis changes from north-south to NNE-

SSW. This may be one of the reasons that the two separated large earthquakes occurred within 30 minutes.

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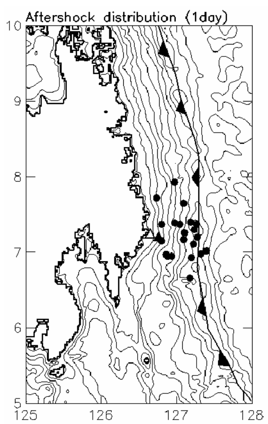

Figure 1. Plot of epicenters of main shock and the one-day aftershocks.

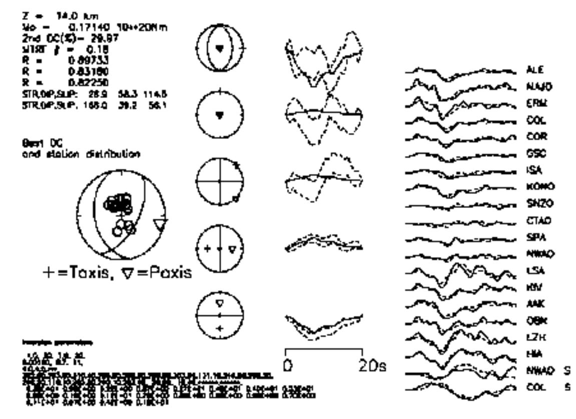

Figure 2. The result of the MTRF inversion of the first large earthquake

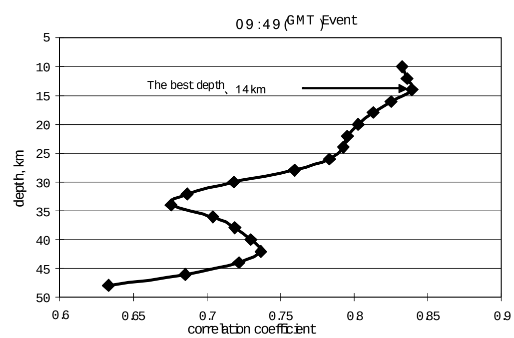

Figure 3. The correlation coefficient between the observed and synthetic body waves as a function of depth for the first event.

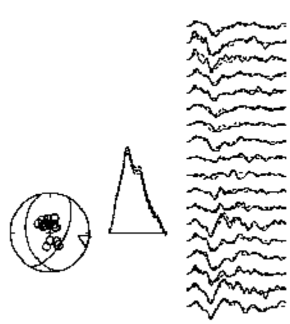

Figure 4. The source time function of the first event and the comparison between observed and synthetic body waves.

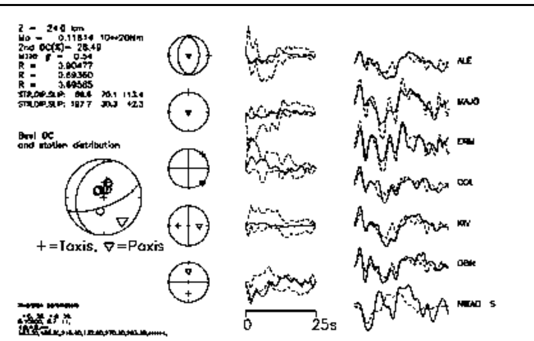

Figure 5. The result of the MTRF inversion earthquake.

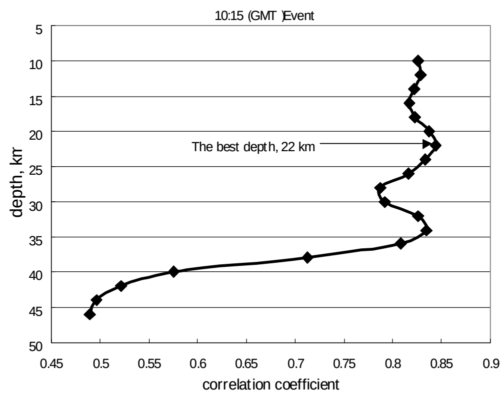

Figure 6. The correlation coefficient between the observed and synthetic body waves as a function of depth for the second event.

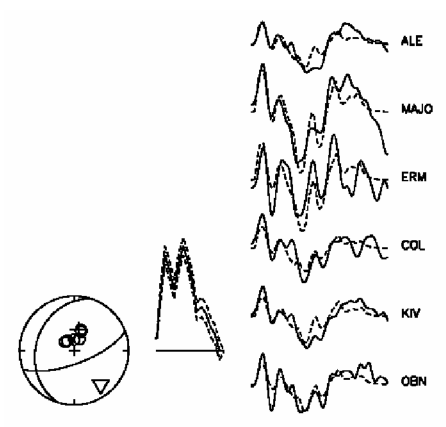

Figure 7. The source time function of the second event and the comparison between observed and synthetic body waves.

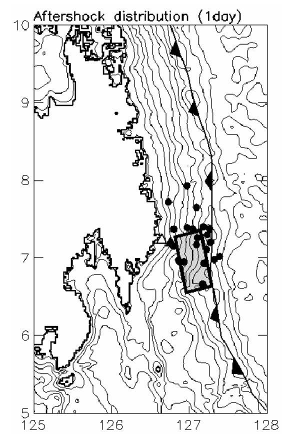

Figure 8. The best fault model of the first earthquake that is located in the southern part of one-day aftershock area.

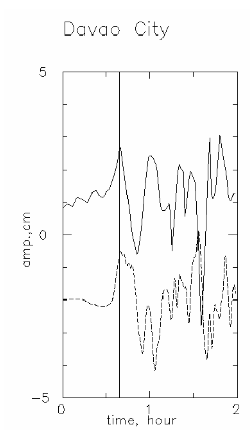

Figure 9. Comparison of observed and computed waveforms at the tide gauge station at Davao City for the fault model of the first event shown in Figure 8.

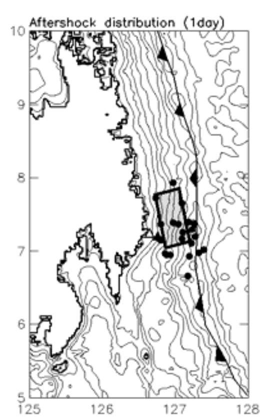

Figure 10. The fault model of the first earthquake that is located in the northern part of one-day aftershock area.

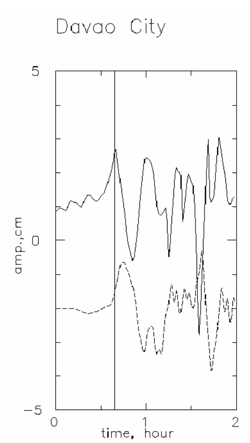

Figure 11. Comparison of observed and computed waveforms at the tide gauge station at Davao City for the fault model of the first event shown in Figure 10.

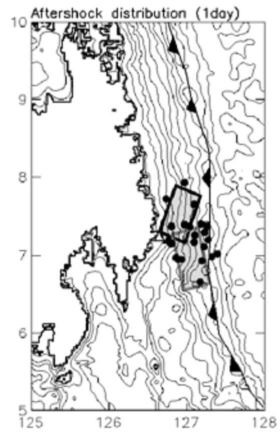

Figure 12. The best fault models of the first event (blue rectangle) and second event (orange rectangle).

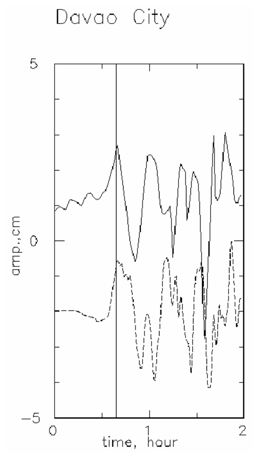

Figure 13. Comparison of observed and computed waveforms at the tide gauge station at Davao City for the best fault model of the first and second earthquakes shown in Fig. 12.

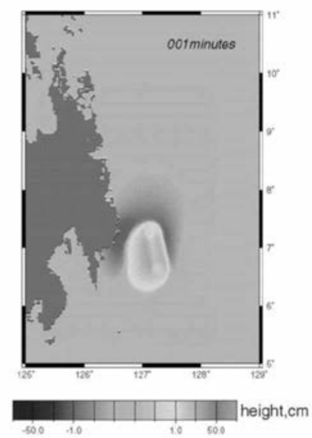

Figure 14. A snapshot of tsunami propagation at 1 minute after the origin time of the first earthquake using the fault model shown in Figure 8.

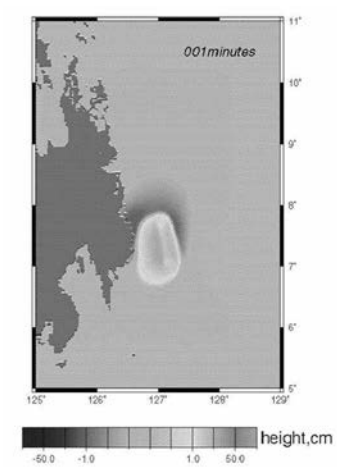

Figure 15. A snapshot of tsunami propagation at 1 minute after the origin time of the first earthquake using the fault model shown in Figure 10.

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EXPERIMENTAL APPROACH FOR THE HAZARD ASSESSMENT OF HISTORIC EARTHQUAKES IN KOREA

Kim Jae Kwan , Hyeuk Ryu, Chung Choong-Ki , Hyun Chang-Hun , and Chang Chun-Jung

Abstract

This paper summarizes the Korean effort intended to improve the reliability of historic earthquakes using experimental approach. The research work is divided into two categories. The first one is establishment of fragility relation between shaking intensity versus damage level of historic structures in the past earthquakes through shaking table test of model structures. The second category is investigation of local site effect on the intensity of ground motion in the regions where the severe damage frequently occurred to the structures and building due to the historic earthquakes. By combining the data on the fragility of the historic structures with the data on the site effects at the location where earthquake damage occurred, the seismic hazard assessment of historic earthquake can be more objective and quantitative.

Key words: Seismic hazard assessment, Shaking table test, Local site effect, Fragility

INTRODUCTION

Korea has a long history of earthquakes [1, 2]. Many descriptions on earthquakes and earthquake damages can be found in the historic documents such as the Royal Chronicles of the Chosun Dynasty. The earliest recorded event can be traced as far back as up to 27 AD. But the strong motions at or near the epicentral regions had never been recorded. Hence the reliability of the hazard assessment based on the historic records has been a subject of never ending debate among the policy makers, researchers and design engineers due to the large amount of uncertainty inherent in the hazard analysis done without actual strong motion records.

However the intensity of past earthquakes may be evaluated more accurately by the use of inverse method. If the failure mode of damaged structures can be reproduced by experiment, the intensity of past earthquakes that caused that particular failure mode can be estimated quantitatively [3, 4]. Of course that cannot be exact but at least the lower bound and, possibly, upper bound of the intensity can be obtained with reasonable accuracy. One more factor that need be clarified is the local site effect due to the subsurface soil profiles and the surface and subsurface topography. Otherwise the assessment on the historic records may be overestimated or unnecessarily conservative.

In this paper the seismicity of Korea will be briefly summarized first. Then methodology will be explained adopted in the present quantitative estimation of past historic earthquakes. The site investigation results preformed at the site where damaging earthquake occurred in the past will be reported. The fragility relation between shaking intensity versus damage level of historic structures in the past earthquakes through shaking table test of model structures will be presented.

SEISMIC CHARATERISTICS OF KOREA

Korea is located near the boundary between the Eurasian plate and Pacific plate. But still the distance to the boundary is far enough that the movement along the boundary does not directly influence its seismic activity. The seismic environment of Korea shows characteristics of Stable Continental Regions. Korean seismologists estimated that the magnitude of the largest historic earthquake was 6.5 or above on Richter scale. Based on their study, the design intensity of 475-year return period design earthquake is determined to be 0.11g on firm ground in new earthquake design standards [1] and the maximum credible earthquake 0.22g. Figure 1 shows the hazard map of earthquake ground motion of 2373 years return period. In general the damaging earthquake appears to have long return period. And the intensity is believed to be moderate level. Figure 2 shows the collapse of a traditional house during the 1978 Hongsung earthquake of which magnitude was 5.0 on Richter scale.

SEISMIC HAZARD ASSESSMENT IN KOREA

As briefly mentioned in the Introduction, the hazard assessment was done primarily based on the historic earthquake records. The seismologists evaluated the intensity of historic earthquakes relying on MMI scale in a very subjective manner. Hence the estimated intensity for the same historic record varies with wide margin depending on researchers. Another serious problem is that site effects were not taken into account in the current practice. These two facts resulted in the large amount of uncertainty in the hazard estimation using historic earthquake records.

METHODOLOGY OF PRESENT RESEARCH

For the hazard assessment of historic earthquakes, the records of past earthquakes are collected, and damage patterns are classified. Table 1 shows the classification of damaged structures in the historic earthquakes. The historic structures are selected for the further study that can be easily reproducible with confidence. Full scale or small-scale models are constructed through rigorous verification process. The models are mounted on the large shaking table and the relation between input intensity versus damage level for each structure has been obtained. These relations will provide quantitative criteria for the estimation of the intensity of historic earthquakes.

Typically, damage records abound at the alluvial site or sedimentary basin. The depth of surface soil layer used to be rather deep at these sites. When an earthquake occurs, seismic waves radiate away from the source and reach the ground surface. Even though two sites are at the same distance from the source of an earthquake, the extent of the seismic hazards greatly depends upon the characteristics of each site. In particular, soft soil deposits on bedrock tend to amplify significantly the seismic motion at certain frequency range.

To investigate the local site effect on the intensity of ground motion in the regions where the severe damage frequently occurred to the structures and building due to the historic earthquakes, in situ and laboratory tests were performed. At the selected sites, many bore holes were drilled and down hole and cross hole tests were performed along with Spectral Analysis of Surface Waves (SASW) tests to obtain the velocity profile of surface soil layers. From the wave propagation analyses in these soil profiles, the amplification factors were obtained.

The data on the fragility of the historic structures are combined with the data on the site effects at the location where earthquake damage occurred. The intensity on the rock site was computed as shaking intensity at which a specific damage patterns occurred divided by soil amplification factor of a specific site at which earthquake damage occurred as follows:

$$\text{Intensity on the outcrop rock} = \frac{\text{shaking intensity}}{\text{soil amplification factor}} \qquad (1)$$

The standard outcrop rock intensity can be used for the seismic hazard assessment.

Site effects investigation

Site investigation has been performed at three sites. The first is Kyeongju that had been the capital city of ancient Shilla Kingdom from the 1st to 10th century. The second is Hongsung where magnitude 5 earthquake occurred in 1978. The third is Hamie where parapet of stone rampart was collapsed due to historic earthquakes. At the three sites many bore holes were drilled and down hole test, cross hole test were performed along with Spectral Analysis of Surface Waves (SASW) test to obtain the velocity profile of surface soil layers. From the wave propagation analyses in these soil profiles, the effects on the characteristics of ground motion were obtained. The results were visualized on the map to show the spatial distribution of the intensity of ground motion.

For the site effects investigation of Kyeongju, various site investigations were performed for 10km by 10km area including the historic sites and present downtown area [5]. For the in situ tests, 16 boring investigations, 12 down hole tests, 4 cross hole tests, and 26 Spectral Analysis of Surface Waves (SASW) tests were executed in total 28 sites. Locations and contents of the boring and seismic tests in the region of study are shown in Fig. 3. And Fig. 4 is an example of typical representative shear wave velocity profiles determined by the combination of in situ seismic tests. Fig. 5 shows the distribution map of the mean shear wave velocity of top 30m in the studied area using GIS tools. Fig. 6 is a site amplification distribution map constructed using GIS tools. The numbers in the Fig. 6 denotes the peak ground accelerations of the sites and the darkness shows the amplification ratio.

Shaking table test of model structures

Three kinds of stone structures and one wood house were selected for the experimental study. As for stone structures, a full scale model of a five story stone pagoda in a Buddhist temple, a full scale model of parapet of stone rampart and a full scale model of beacon lighthouse were tested. And a full and a small scale model of traditional timber house with tiled roof were tested.

Figure 7 shows the prototype and a full scale model of five story stone pagoda. It was mounted on the shaking table and subjected to earthquake motions of different kinds of frequency contents. Two distinct failure modes were clearly identified: failure mode I, the initiation of instability at the first storey pagoda body due to sliding; and failure mode II, the overturning of the top component [Fig. 8]. The failure mode I occurred in the test with Coalinga earthquake and Whittier Narrows earthquake. The common feature of these two earthquakes is that short period component is predominant. The failure mode II was observed in the tests with Taft and El Centro earthquakes that are rich in long period component. In the post overturning test without top component the failure mode I occurred at higher intensity than the preceding failure mode II. The pagoda may have collapsed in mode I following mode II at higher intensity level.

If the input motion contained large amount of long period component, the top component overturned at the intensity 0.19g for Taft earthquake and 0.15g for El Centro earthquake on the average in the case of the model without dowel bar. And in the post overturning fragility tests, the first storey pagoda body became unstable at 0.20g for El Centro earthquake. For Taft earthquake the sliding distortion at the first storey pagoda body became very large at 0.22g. It indicated imminent collapse at intensity level higher than 0.22g.

The lower limit of the intensity of the 1936 earthquake motion can be estimated to be around 0.15g without ambiguity. If the overturning of the top component was caused due to the long period earthquake motion, then, the post overturning test results implies that the upper bound of the intensity may be set at around 0.24g. This is based on the argument that if the intensity exceeded than the upper limit, the pagoda might have completely collapsed.

Combination of Fragility test data with site investigation results

Using the fragility curves that denotes the functional relation between the intensity of ground motion and the damage index or damage state, the intensity of particular damage pattern observed in the historic earthquake can be more accurately estimated. If we know the soil amplification factor then, the intensity on the outcrop rock can be obtained from Eq. (1). Another possible application is that the upper bound of MCE can be easily predicted with certainty.

CONCLUSIONS

A new methodology of quantitative evaluation of the intensities of past historic earthquakes is briefly described. It is demonstrated that valuable data can be obtained from this study. Even though it is not conclusive yet that the experimentally obtained fragility curves provided lower and upper bound of the earthquake intensity.

Local site effects were investigated through in situ test and wave propagation analyses at the sites where damaging earthquakes occurred in the past. It is shown that the high potential of amplification in the deep alluvial layer at sites where historic earthquakes frequently occurred.

By combining the fragility test data of model structures with the site amplification data, standard rock outcrop motion can be obtained more objectively and quantitatively. But the present study is quite preliminary and further study should be done. Especially the effects of aging and construction quality should be investigated further.

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Table 1. Classification of damaged structures in the historic earthquakes

Type	Structures
Stone structures	• Stone pagoda • Stone parapet wall • Stone beacon lighthouse
Wood Structures	• Wood house with tiled roof • Wood house with thatched roof

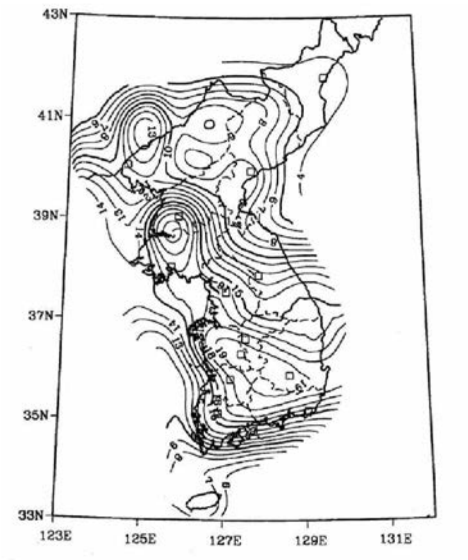


Figure 1. Seismic hazard map of 10% probability of exceedance in 250 years (2373 years return period)

Figure 2. Collapse of house during the 1978 Hongsung earthquake

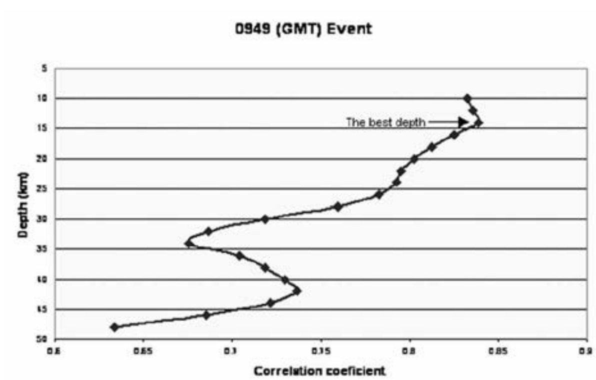


Figure 3. The correlation coefficient between the observed and synthetic body waves as a function of depth for the first event.

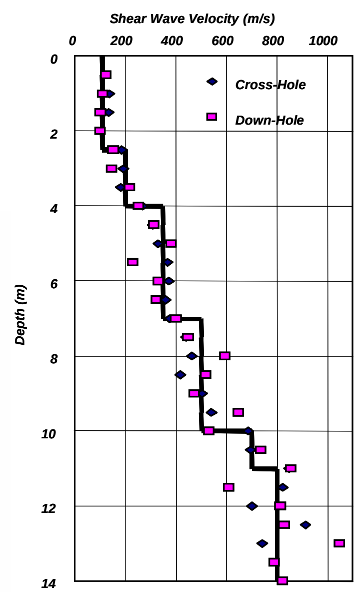


Figure 4. Typical shear wave velocity profiles

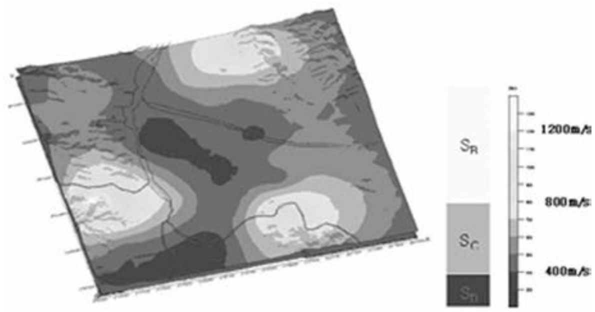


Figure 5. The distribution map of mean shear wave velocity of top 30m for 6km by 6km area

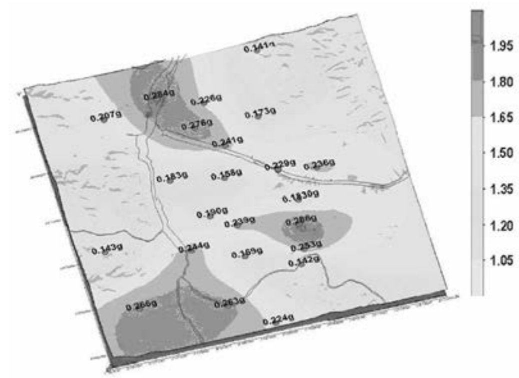
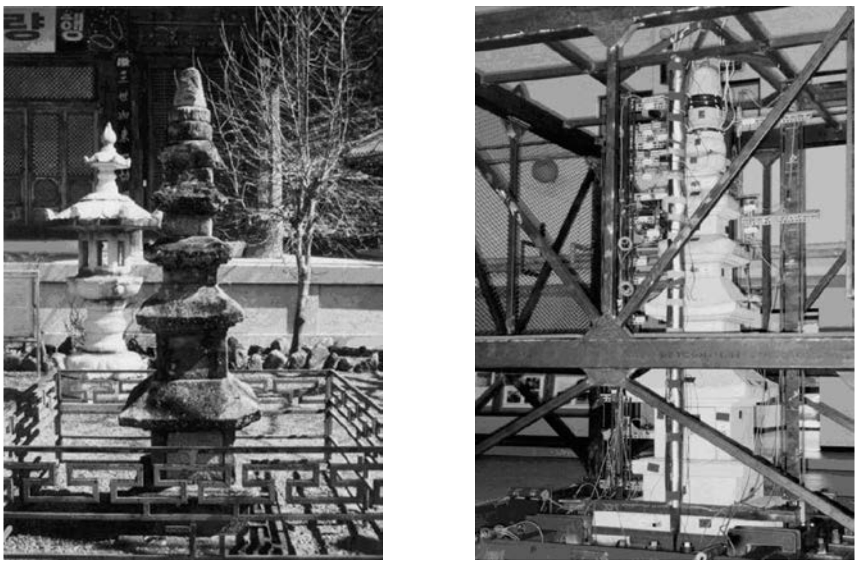
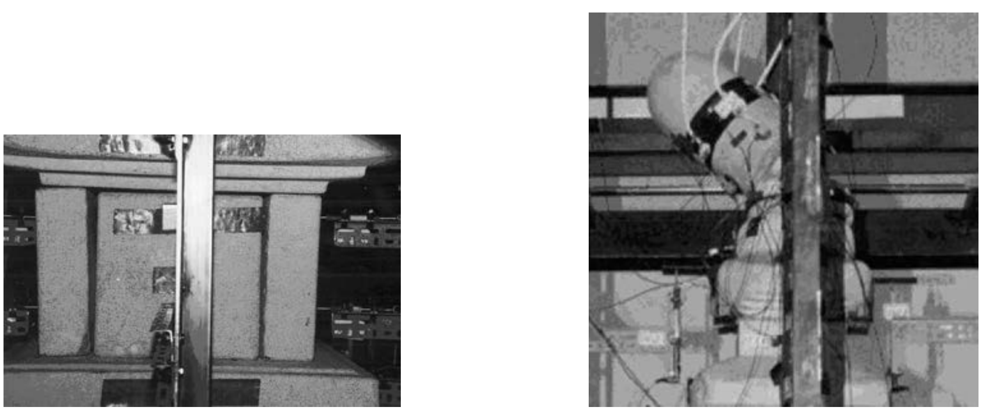


Figure 6. Site amplification distribution map (outcrop rock motion of 0.l4g)



(a) Prototype *(b) Full scale model*

Figure 7. Prototype and full scale model of a five storey stone pagoda



(a) Failure mode I; the initiation of instability at the first storey pagoda body due to sliding

(b) Failure mode II; the overturning of the top component

Figure 8. Failure modes of five storey stone pagoda model

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SEISMIC RISK ANALYSIS ON PORTFOLIO OF BUILDINGS IN JAPAN

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Abstract

In recent years, some risk analysis methods were proposed so that the quantitative evaluation of risk has been available. On the other hand, the treatment of the quantified risk has not been considered sufficiently, though it is important for carrying out the effective risk management. In this paper, seismic portfolio risk analysis method consistent with the existing seismic hazard analysis was proposed. Using this method, portfolio of buildings was analyzed from the viewpoint of risk management, followed by the following findings. (1) Seismic risk can be reduced by diversifying assets. (2) In case of diversifying assets in multiple sites, the examination of seismic hazard in each site is necessary. (3) Effectiveness of strengthening work can be measured using risk curve. (4) Contribution of risk of each asset to the portfolio risk is identified so that the rational strengthening work can be done.

Key words: Portfolio of buildings, Risk management, Seismic risk, Risk Control

INTRODUCTION

In connection with the operation of enterprises, standardization of a risk management has been examined. To owners of the enterprises, it is now requested to make decisions about selecting sites, seismic performance of facilities, retrofitting and etc on the basis of preventing casualties, and to carry out the rational risk management. Currently, a risk management procedure itself is of concern due to the trend of securitization of natural hazard risk and other derivatives.

It should be noted that it is very important to examine how to utilize the result of quantifying risks as well as to quantify the risks. Therefore, authors consider that a risk management procedure connected to realistic measures is necessary.

This study builds up the framework to evaluate a seismic risk of portfolio of buildings, and examine the feature and efficiency of some risk control schemes.

RISK MANAGEMENT

Framework of Risk Management

As illustrated in Figure 1, the risk management process consists of discovery, evaluation, treatment and reevaluation. Discovery is to identify all the risks. Evaluation is to analyze the identified risks in connection with their frequency, magnitude and effect. As illustrated in Figure 2, treatment consists of two schemes; a risk control and a risk financing. The former is to prevent and/or to mitigate risks by means of strengthening buildings or introducing base isolation system and etc., and the latter is to make up losses by an insurance and/or alternative risk transfers (hereinafter called ARTs).

When considering a seismic risk, it is considered practical to combine a risk control and a risk financing since seismic events may cause various aspects of damage that are very difficult to predict.

Index of Loss

Losses due to seismic events and their annual probability of occurrence are related as shown in Figure 3. This curve is called as risk curve, whose x-axis corresponds to the loss and y-axis to the annual probability of exceedence. In Figure 3, point A indicates the maximum loss, and point B indicate the probable maximum loss (PML) which is the loss corresponding to the given reference probability of exceedence. The area surrounded by the risk curve, x-axis and y-axis corresponds to the annual expected loss (AEL).

As described above, some definitions of loss exist and they are employed by different evaluators. For example, insurance companies dealing with the huge amount of risks employ AEL since their losses will be close to the expected value by the law of large number. On the contrary, the owner of the enterprise who is the concern of this study has to consider the losses greater than the expected value for his/her will of risk aversion. However, it must be noted that considering too much losses such as the maximum loss brings improper risk management.

Therefore, losses to be examined in this study should be greater than the expected value from the viewpoint of the risk aversion and be less than the maximum loss to avoid too much cost for risk management. Authors consider that PMLs are appropriate to express the loss and that estimation of the risk curve is the key in the risk management.

ESTIMATION OF RISK CURVE

As shown in Figure 4, the risk curve for individual building can be obtained from the seismic hazard curve and loss curve; the former indicates the relationship between the intensity of ground motion and its probability of exceedence, and the latter indicates the relationship between the intensity of ground motion and the conditional loss. In the estimation of risk curves, 90^{th} percentile values rather than medians are often employed.

On the other hand, the risk curve of the portfolio is not obtained by the method shown in Figure 4, since the seismic hazard curve cannot be assigned for the buildings located in different sites. So, authors propose the procedure based on the loss estimation for the large numbers of scenario earthquakes with their annual occurrence probability as shown in Figure 5. In this procedure, 90^{th} percentile value of the risk curve is given by Monte Carlo Simulation.

QUANTIFICATION OF PORTFOLIO RISK

Source Models and Attenuation Relation

In this study, two types of source models are employed; one corresponds to the region where large earthquakes characterized as the characteristic earthquake occur, and the other corresponds to the region where small earthquakes characterized as b-value model occur. Examples of source models are shown in Figures 6 and 7.

This study employs Annaka equation as the attenuation relation. Annaka equation is given below,

$$\log A = 0.614M + 0.00501h - 2.023\log(x) + 1.377 \quad (1)$$

$$x = (d^2 + 0.45h^2)^{0.5} + 0.22\exp(0.699M) \quad (2)$$

where A is a peak ground acceleration, M is a magnitude in JMA scale, d is a epicenter distance and h is a focal depth, respectively. A peak ground acceleration is assumed to have uncertainty of log-normal distribution with its log-normal standard deviation of 0.5 in natural logarithm.

Building

Buildings forming portfolio are assumes to have same vulnerability function and initial cost. Also the same is the damage ratio that is the ratio of repair/reconstruction cost to the initial cost. These are summarized in Table 1. Medians of vulnerability functions are given considering the current seismic design standard in Japan. Log-normal standard deviation and repair costs are the same as the existing research works.

Portfolio

As shown in Figure 8, three types of portfolio consisting of 25 buildings are employed. Case 1-1 corresponds to the enterprise who develops its business in Tokyo. Similarly, Case 1-2 for Kanto district and Case 1-3 for all over Japan.

Results

PMLs for buildings are summarized in Figure 9 with correlation factors, which show the correlations between losses of individual buildings and that of portfolio. In Case1-1, it is found that PMLs are almost the same and correlation factors are greater than 0.9, since all the buildings are located in the small area. On the other hand, PMLs are affected by the seismicity where the building exists and correlation factor decreases with increasing distance from the center of the portfolio where correlation factors are close to unity, as shown in Case1-2, and Case1-3.

Table 2 shows the effect of divergence, which is the ratio of PML of portfolio to the sum of PMLs of individual buildings. The lower the figure is, the higher the effect is. From Figure 9 and Table 2, it is concluded that effect of divergence is related to the correlation factor regardless of PML itself.

EFFECT OF RISK CONTROL

Redistribution of Assets

For some enterprise such as warehouse companies, redistribution of assets is a very cost-effective way to mitigate their losses. Figure 10 shows the portfolio of buildings located in the Kanto district with three areas in which asset of buildings are redistributed. For this measure of risk control, four cases are given as follows.

Case 2-1.0 : No redistribution is carried out.
Case 2-1.1 : Asset in area A is redistributed so that PMLs are under 40.
Case 2-1.2 : Assets in area A and B are redistributed so that PMLs are under 30.

Case 2-2.3 : Assets in area A, B and C are redistributed so that PMLs are under 20.

Table 3 shows the results. It can be seen that the effect of divergence remains almost constant after redistribution though the PML of portfolio is largely reduced. Newly introduced here is the efficiency of redistribution, which is the ratio of reduction in PML of portfolio to the amount of redistributed assets. The larger the figure is, the higher the efficiency of redistribution is. From the table, it can be concluded that the amount of redistributed assets has better be small if PML is within a suitable range, from the view point of efficiency of risk treatment.

Strengthening of Building

Another practical way for risk control is strengthening of the building. The portfolio to be examined is the same as used in the previous examination, and is shown in Figure 10. For this measure of risk control, seven cases are given as follows.

Case 2-2.0 : No strengthening work is carried out.
Case 2-2.1 : All the building are weakened by 25%.
Case 2-2.2 : All the building are strengthened by 25%.
Case 2-2.3 : All the building are strengthened by 25%.
Case 2-3.1 : Building in area A is strengthened by 50%.
Case 2-3.2 : Building in area A is strengthened by 50%, those in area B by 25%.
Case 2-3.3 : Buildings in area A and B is strengthened by 50%, those in area C by 25%.

In this study, strengthening means the increasing median capacity of vulnerability function of building. Similarly, weakening is the decreasing the capacity.

Tables 4 and 5 show the results. In case of strengthening of building, initial cost depends on the strength. In this study, it is assumed that cost will be increased by unity for the increasing the capacity by 25%. Though this assumption is not realistic, authors use this since the relative comparison is essential for this examination. From these tables, is can be concluded that strengthening work has better be small if PML is within a suitable range, from the view point of efficiency of risk treatment. This is the similar as stated in case of redistribution of asset. It is also noted that it is not effective to strengthen all the buildings. So, if the owner of enterprise wants to reduce his/her loss of portfolio by means of strengthening, he/she must identify the buildings with high contribution to the portfolio loss.

CONCLUSION

In this paper, the procedure to quantify the risk curve of portfolio of buildings was proposed and applied to the three types of portfolio consisting of 25 buildings. Through some examinations, it was found that the effect of divergence on the PML of portfolio can be related to the magnitude of correlation factors of individual buildings, and effective reduction in PML of portfolio can be done by examining both PMLs and correlation factors of individual buildings.

Moreover, some measure to mitigate seismic risk of portfolio were examined, followed by the conclusion that the risk control procedures have better be minimum from the viewpoint of efficiency, if the PML is within a suitable range.

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Annaka T. and Yashiro H.: A seismic source model with temporal dependence of large earthquake occurrence for probabilistic seismic hazard analysis in Japan, Risk Analysis, WIT PRESS, pp.233-242, 1998

Table 1 Properties of Buildings forming Portfolio

Damage State	Vulnerability Function		Cost	
	Median	L.N.S.D	Initial	Repair
Slight	160 cm/s/s	0.4	100	5
Moderate	480 cm/s/s	0.4	100	10
Severe	800 cm/s/s	0.4	100	30
Collapse	1120 cm/s/s	0.4	100	100

L.N.S.D: log-normal standard deviation

Table 2 Effect of Divergence

Item	Case		
	1-1	1-2	1-3
Sum of PMLs	274.12	408.71	274.80
PML of Portfolio	254.35	344.03	144.66
Effect of Divergence	0.928	0.842	0.526

Effect of Divergence = PML of Portfolio / Sum of PMLs

Table 3 Effect of Divergence and Efficiency of Redistribution

Item	Case			
	2-1.0	2-1.1	2-1.2	2-1.3
Sum of PMLs	408.71	377.09	362.45	329.56
PML of Portfolio	344.03	315.10	307.96	286.07
Effect of Divergence	0.842	0.836	0.850	0.868
Reduction in PML of Portfolio	-	28.94	36.08	57.97
Amount of Assets Redistributed	-	50.00	100.00	220.00
Efficiency of Redistribution	-	0.579	0.361	0.263

Effect of Divergence = PML of Portfolio / Sum of PMLs

Efficiency of Redistribution = Reduction in PML of Portfolio / Amount of Assets Redistributed

Table 4 Effect of Divergence and Efficiency of Strengthening for All the Building

Item	Case			
	2-2.0	2-2.1	2-2.2	2-2.3
Sum of PMLs	408.71	669.63	285.57	214.84
PML of Portfolio	344.03	565.64	223.90	163.56
Effect of Divergence	0.842	0.845	0.784	0.761
Reduction in PML of Portfolio	-	-221.60	120.14	180.47
Amount of Strengthening Work	-	-25.0	25.00	50.00
Efficiency of Strengthening	-	8.86	4.81	3.61

Effect of Divergence = PML of Portfolio / Sum of PMLs

Efficiency of Strengthening = Reduction in PML of Portfolio / Amount of Strengthening Work

Table 5 Effect of Divergence and Efficiency of Strengthening for Some of the Building

Item	Case			
	2-2.0	2-3.1	2-3.2	2-3.3
Sum of PMLs	408.71	377.16	351.02	309.21
PML of Portfolio	344.03	316.42	289.58	251.63
Effect of Divergence	0.842	0.839	0.825	0.814
Reduction in PML of Portfolio	-	27.61	54.45	92.41
Amount of Strengthening Work	-	2.00	4.00	9.00
Efficiency of Strengthening	-	13.80	13.61	10.27

Effect of Divergence = PML of Portfolio / Sum of PMLs

Efficiency of Strengthening = Reduction in PML of Portfolio / Amount of Strengthening Work

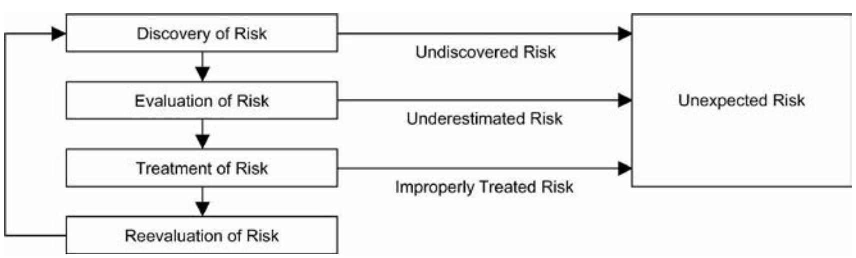

Figure 1 Process of Risk Management

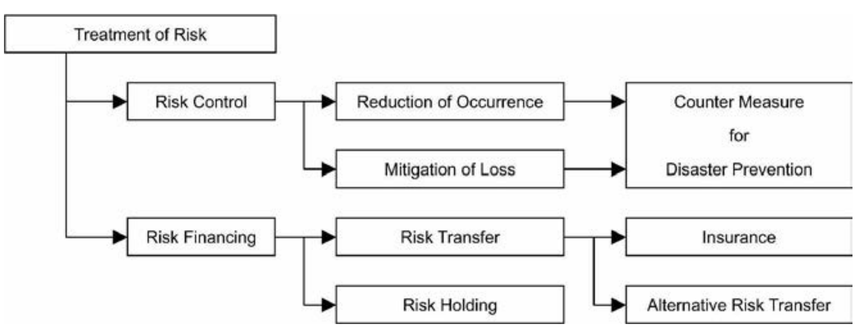

Figure 2 Classification of Risk Treatment Procedure

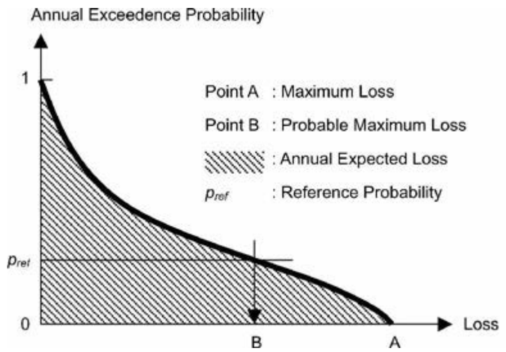

Figure 3 Some Definitions of Loss based on Risk Curve

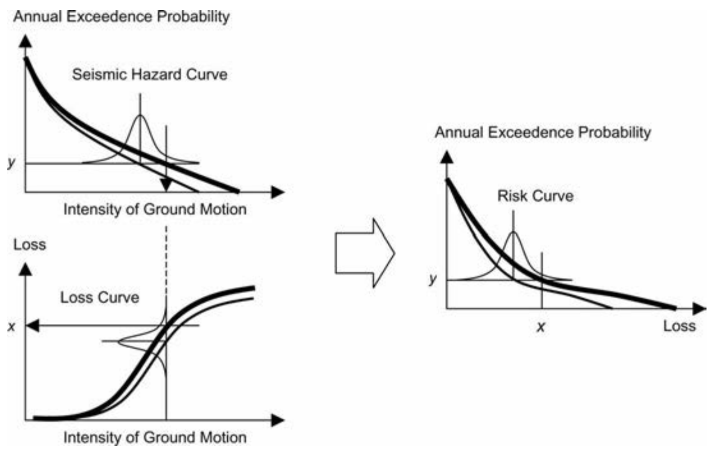

Figure 4 Procedure to obtain Risk Curve for Individual Building

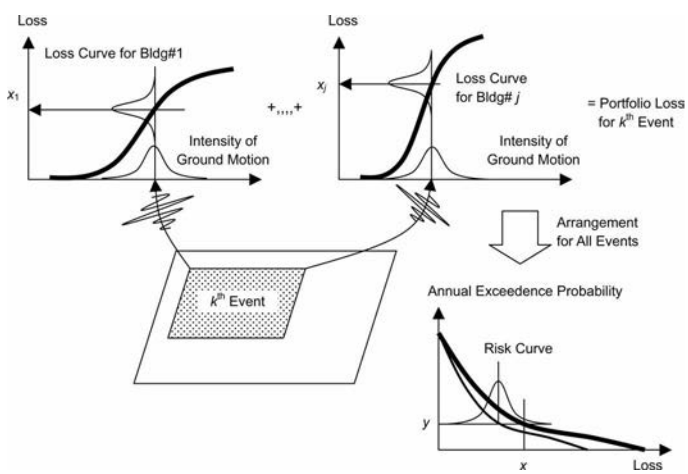

Figure 5 Procedure to obtain Risk Curve for Portfolio of Buildings

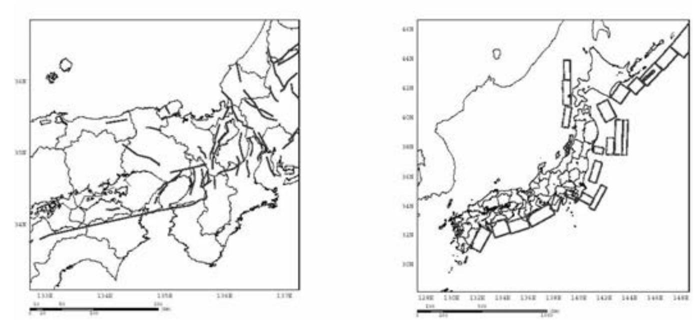

Figure 6 Example of Source Models for Large Earthquakes

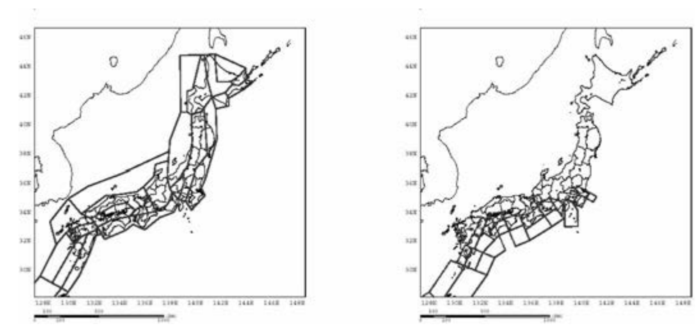

Figure 7 Example of Source Models for Small Earthquakes

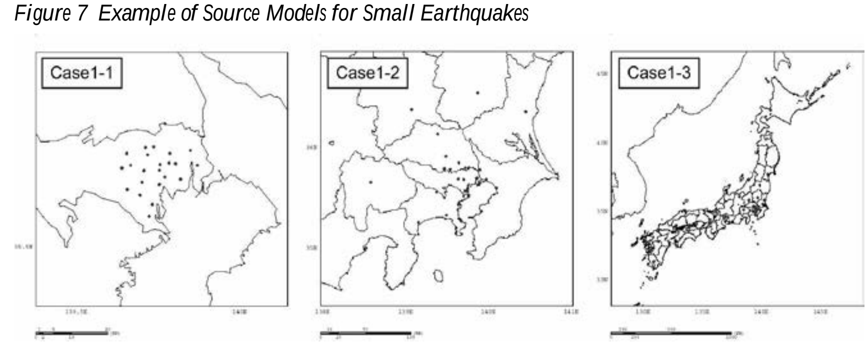

Figure 8 Arrangement of Buildings

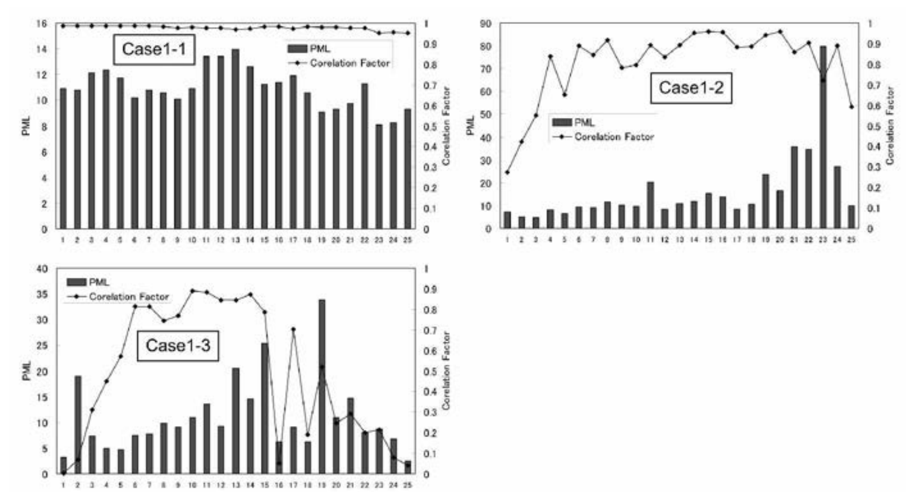

Figure 9 PML and Correlation Factor of Each Building

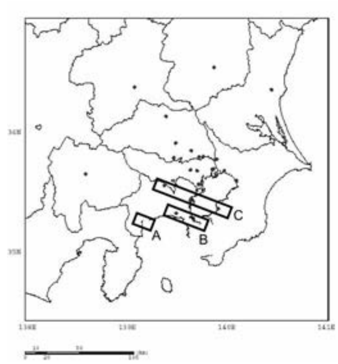

Figure 10 Arrangement of Buildings and Area for Risk Treatment

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SEISMIC VULNERABILITY ASSESSMENT OF HOSPITALS IN NEPAL: STRUCTURAL COMPONENTS

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Abstract

In recent years, the Kathmandu Valley Risk Management Project and other projects (e.g. The Study on Earthquake Disaster Mitigation in Kathmandu Valley), estimated high potential losses and casualty including the potential losses of medical facilities during a large earthquake affecting Kathmandu Valley. Although this is a seismic country, earthquake-resistant construction standards have not been effectively applied and special guidelines have not been considered for hospital facilities in general. For these reasons, there is high possibility of hospital buildings not functioning during a large seismic event.

Given such situation, the National Society for Earthquake Technology-Nepal (NSET-Nepal) undertook two studies recently to evaluate the seismic performance of the Bir Hospital. One was done in cooperation with US Army in 1999 and the other one with a group of expert-volunteers from New Zealand in 2000.

More recently, the project "Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley" was conducted jointly by NSET-Nepal, World Health Organization, and Ministry of the Health, HMGN. The purpose of this study was to develop/apply appropriate methodology for the evaluation of earthquake vulnerability of the medical facilities in general, and to understand the actual situation of the reliability of the medical facilities in Kathmandu Valley in particular. This study built upon the previous studies referred above.

The result of the study was qualitative assessment of 14 hospitals and quantitative assessment of one hospital. The assessment showed that if an earthquake of MMI VIII level of shaking occurs, most of the hospitals (about 90%) might withstand the earthquake without collapsing, among them 10% of the hospitals might be functional, 30% partially functional, and 50% out of services. About 10% of the hospitals might collapse.

INTRODUCTION

Nepal is located along the boundary between the Indian and the Tibetan plates, along which the southern plate is subducting at a rate believed to be about 3 cm per year. The existence of the Himalayan Range with the world's highest peaks is evidence of the continued tectonics underneath the country. As a result Nepal is very active seismically. There have been a number of devastating earthquakes in the past, many within the living memory. The seismic record of the region extends back to 1255AD, and suggests that earthquakes like The Great Nepal-Bihar Earthquake in 1934 occurs approximately every 75 years, indicating that a devastating earthquake is inevitable in the long run and likely in the near future. The Kathmandu Valley Earthquake Management Project (KVERMP, 1999) estimates that as many as 60% of all buildings in Kathmandu Valley are likely to be heavily damaged if the shaking of the 1934 earthquake was to be repeated today.

Although a seismic country, earthquake-resistant construction standards have not been effectively applied and special guidelines have not been considered for hospital facilities in general, in Nepal. For this reason, there is higher possibility of hospital buildings not being functional during a large seismic event.

Given such situation, National Society for Earthquake Technology (NSET) undertook two studies recently to evaluate the seismic performance of the Bir Hospital. One was done in cooperation with US Army in 1999 and the other one with a group of expert-volunteers from New Zealand in 2000.

In 2002, National Society for Earthquake Technology conducted the project, "Structural Assessment of Hospitals and Health Institutions of Kathmandu Valley", jointly with World Health Organization and Ministry of the Health, HMGN. The purpose of this study was to develop/apply appropriate methodology for the evaluation of earthquake vulnerability of the medical facilities in general, and to understand the actual situation of the reliability of the medical facilities in Kathmandu Valley, in particular. This study built upon the previous studies referred above.

OBJECTIVE OF STUDY

The main objective of the study was:

Development of a systematic approach towards assessment of structural vulnerability of hospital buildings and health institutions of Nepal by way of implementation of such assessment for hospitals in Kathmandu Valley

Identification of appropriate measures for improving earthquake resilience of the existing health infrastructure

Transfer of Technology and development of local capacity for such work in the country

Dissemination of the findings for facilitating implementation of the identified earthquake risk reduction measures.

METHODOLOGY

The structure is an essential part of hospital facilities. It serves as a skeleton to the human body, and support non-structural components such as architectural elements (infill non-bearing walls, parapets, windows, etc.), equipment and lifeline systems (utilities, medical gases, etc.). Most of the non-structural components are connected to the structure, in such a way that the structural system transfers earthquake displacements and forces to them. The structural behavior influences the non-structural performance to a large extent. The structural assessment methodology for hospitals by qualitative method that developed prior to the assessment is described as following major steps.

Step1. Identification of Building Type

Typology of the targeted building is identified in this first step. Building typologies defined in Nepal National Building Code was taken as the basis for defining different building types. Moreover, the results of building inventory survey during the project "The Study on Earthquake Disaster Mitigation in Kathmandu Valley" was also used to define the building types.

Using data from "The Study on Earthquake Disaster Mitigation in The Kathmandu Valley, Kingdom of Nepal – Report on building inventory survey, NSET – Nepal, 2001", the building stock in Kathmandu Valley was classified as shown in Table1 where type 1 is the worst and 5 the best regarding earthquake performance.

Table 1: Building types in Kathmandu Valley according to structural performance

Building Type	Structural Systems		Percentages of buildings	
	Type	Definition		
1	AD	Adobe (earth blocks in mud)	19%	34%
	ST	Stone in mud	7%	
	AD-ST	Adobe combined with Stone		
	ST-BM	Combination of Stone and Brick in mud	8%	
2	BM	Unreinforced masonry with brick in mud	18%	43%
	BL	Unreinforced masonry, brick-in-cement mortar		
	BC	Unreinforced masonry, brick-in-lime mortar	21%	
	BM-BC	Unreinforced masonry combination of BM-BC	4%	
3	RC-OMRF	Reinforced concrete structure and infill masonry walls, without earthquake resistant design. Most of 3 or more story buildings.	15%	23%
4	RC-IMRF	Reinforced concrete structure and infill masonry walls, with moderate level of earthquake resistant design. Mainly 1 or 2-story buildings.	8%	
5	RC-SMRF	Reinforced concrete structure and infill masonry walls, with special design for earthquake resistant design. Few hospitals and others	< 1%	< 1%

Step 2. Identification of Appropriate Fragility

Performance level for specific building type is taken which describes the performance of specific building type during past earthquakes. The description of damages both Structural and Non-structural is taken as the basis. For this evaluation the damage description at different intensities to different types of is taken from Nepal National Building Code. Mean damage factors and for the different vulnerability classes of European Macroseismic Scale 1998 (EMS 98) provided by World of Natural Hazards Munich re Group, 2002 was used to define probable damage to RC-IMRF and RC-SMRF. Figure 1 shows the fragility curves for different types of building according to Nepal National Building Code with slight modification during the project "The Study on Earthquake Disaster Mitigation in The Kathmandu Valley".

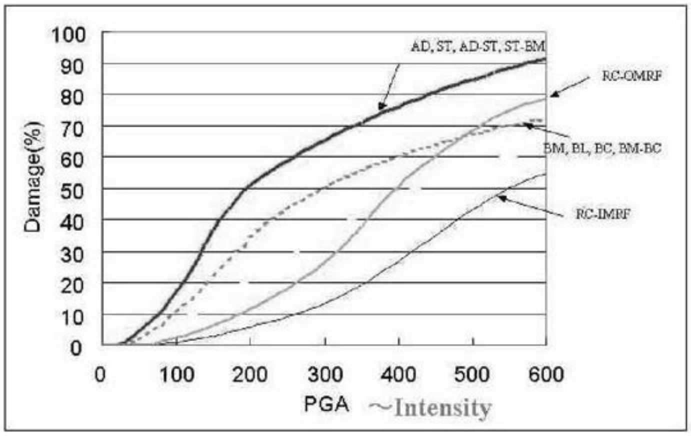


Figure1: Fragility Curves of different types of Building in Kathmandu Valley

Step 3. Vulnerability Factors Identification of Targeted Building

Different Vulnerability factors associated with different types of buildings will be checked with a set of appropriate checklist from FEMA 310, "Handbook for the Seismic Evaluation of Buildings"

The basic vulnerability factors related to Building system, Lateral force resisting system, Connections, Diaphragms, Geologic and Site Hazard and Non-structural Hazard are evaluated from visual observation. Based on the checklist the influence on seismic performance of the building by these factors is judged. If the building is highly influenced by vulnerability factors, the vulnerability of the building will be increased. Table2 gives an example of identification of the influence of different vulnerability factors to a particular building. The symbol X is given to show the different level of influence by different vulnerability factors to the building.

Table 2: Identifying probable influence by the different

Vulnerability factors to the seismic performance of buildings

Vulnerability Factors		Influence on the building's seismic performance				
		High	Medium	Low	None	Not know
Poor quality of materials	From construction stage					X
	Due to deterioration effect		X			
Plan Irregularities	Torsion irregularity	X				
	Re-entrant corners	X				
	Diaphragm discontinuity	X				
	Out-of-plane offsets			X		
	Nonparallel systems				X	
Vertical Irregularities	Soft story			X		
	Mass irregularity				X	
	Geometric irregularity			X		
	In-plane discontinuity			X		
	Weak story				X	
First-story weakness			X			
Short column effect			X			
Lack of redundancy of columns or bearing walls					X	
Pounding effect among structures		X				

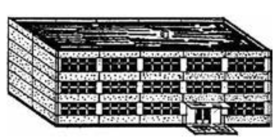
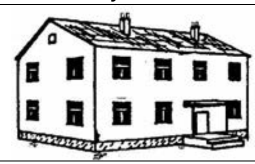
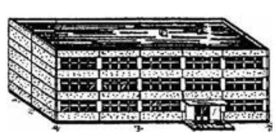
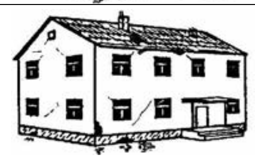
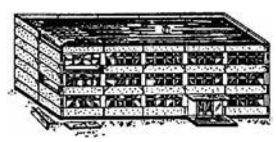
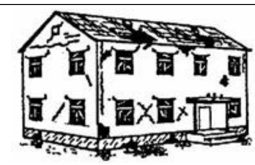
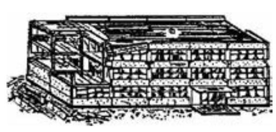
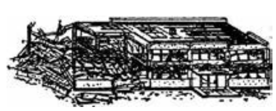
Step 4. Reinterpretation of the Building Fragility based on the surveyed Vulnerability factors

The probable damage to the building is judged from the general fragility curve chosen for the building incorporating the influence of different vulnerability factors to the building. It is judged that the specific building is general building of that type or one of the good buildings of that type or one of the weak buildings of that type. If the building is good it is interpreted that the specific building will behave better than average buildings of that type. If the building falls in weak category, it is expected that the building will behave worse than average building of that type.

Step 5. Making Safety Statement of the building

Although there might be variations of buildings' performance in Kathmandu Valley, buildings' classification had been set as simple as possible and according to the criteria used in the European Micro-seismic Scale (EMS).

Table 3: Damage classification according to European Micro-seismic Scale (EMS)

RC frame Structures	Masonry Structures	DamageCategory	DamageDescription
		Negligible To Slight	No structural Slight non-structural
		Moderate	Slight structural Moderate non-structural
		Substantial To Heavy	Moderate structural Heavy non-structural
		Very Heavy	Heavy structural Very heavy non-structural
		Destruction	Very heavy structural

The performance of the building in terms of structural and non-structural vulnerability is evaluated as per the qualitative assessment done above and statement will be made for different intensities. Table 4 shows a safety assessment of a typical building.

Table 4: Safety assessment of Building

	Performance of the Building			
	MMI = VI	MMI = VII	MMI =VIII	MMI = IX
Structural	Slight	Moderate	Substantial to Heavy	Very Heavy
Nonstructural	Moderate	Substantial to Heavy	Very Heavy	Destruction

Step 6: Reliability Assessment

After the safety assessment of structural and non-structural components of hospital buildings, assessment of Gas, Water Supply, Electricity and other systems within hospital was checked on the visual basis and overall reliability assessment was made.

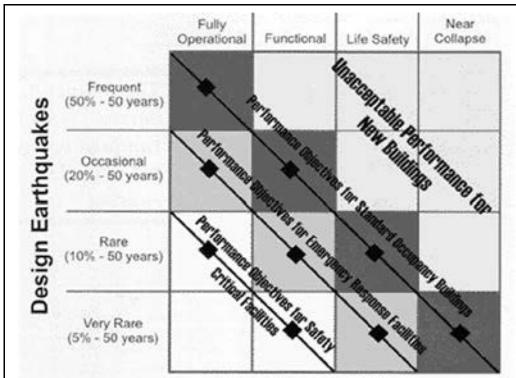
Table 5 shows the Standard Performance Level Definitions from Vision 2000, proposed by The Structural Engineer Association of California (SEAOC) which, was used to qualify "hospital's building-performance":

Table 5: Standard performance level definitions according to Vision 2000 (SEAOC, 1995)

Designation	Description
Fully Operational	Only very minor damage has occurred. The building retains its original stiffness and strength. Nonstructural components operate, and the building is available for normal use. Repairs, if required, may be instituted at the convenience of the building users. The risk of life-threatening injury during the earthquake is negligible.

Functional	Only minor structural damage has occurred. The structure retains nearly all its original stiffness and strength. Nonstructural components are secured, and if utilities are available, most would function. Life-safety systems are operable. Repairs may be instituted at the convenience of the building users. The risk of life-threatening injury during the earthquake is very low.
Life Safety	Significant structural and nonstructural damage has occurred. The building has lost a significant amount of its original stiffness, but retains some lateral strength and margin against collapse. Nonstructural components are secure, but may not operate. The building may not be safe to occupy until repaired. The risk of life-threatening injury during the earthquake is low.
Near Collapse	A limiting damage state in which substantial damage has occurred. The building has lost most of its original stiffness and strength, and has little margin against collapse. Nonstructural components may become dislodged and present a falling hazard. Repair is probably not practical.

In addition to the performance level the Risk acceptance level developed by SEAOC for different facilities was taken as standard to compare the hospital buildings in Kathmandu valley. (Ref: Figure 2)

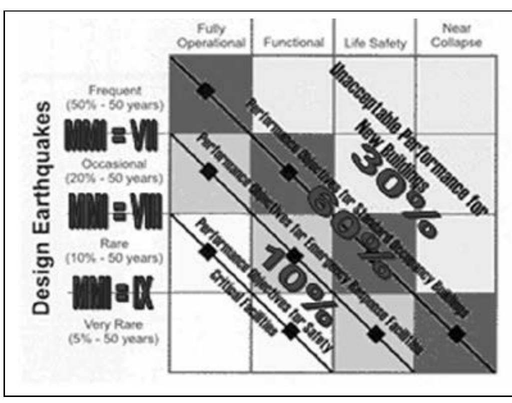


Source: Structural Engineers Association of California (SEAOC) – Vision 2000, 1995.

Figure 2: Risk Assessment Matrix for Structural Assessment

The result of the assessment of 14 major hospitals in Kathmandu Valley for different intensity earthquakes was found as given below. The overall performance of hospitals in different earthquakes is given in Figure 3 also.

1. *Frequent earthquakes of small intensity (MMI = VII).-* All or almost all hospitals might withstand the earthquake without collapse, 70% might be fully operational, and 30% partially functional.
2. *Occasional earthquakes of moderate intensity (MMI = VIII).-* Most of the hospitals might withstand the earthquake without collapse, 10% might be fully operational, 30% partially functional, and 60% out of service from which few of them (10%) might collapse.
3. *Rare earthquakes of high intensity (MMI = IX).-* Many hospitals might withstand the earthquake without collapse, only 10% will be partially functional, 60% out-of- service in complying with a life-safety performance, and 30% of the structures might collapse.



Building Performance of Governmental Hospitals of Nepal

Figure 3: Earthquake performance of major hospitals in Kathmandu Valley

CONCLUSION

After qualitative assessment of 14 hospitals and quantitative assessment of one hospital, over all scenario of reliability of medical system in Kathmandu valley is known. The result of the study, that shows that only 10% of hospitals will be functional after an MMI IX intensity earthquake revels the urgent need of improving earthquake resiliency of existing medical facilities in Kathmandu Valley. Though the detail quantitative analysis including material testing is necessary for retrofitting purpose, the qualitative structural assessment methodology developed and used for the study can be of use for the similar study for other hospitals and other buildings in Nepal.

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EARTHQUAKE DAMAGE ASSESSMENT IN THE KATHMANDU VALLEY AND ITS APPLICATION

Shukyo Segawa[1], Fumio Kaneko[2], Tsuneo Ohsumi[3] and Haruo Hayashi[4]

Abstract

"The study on earthquake disaster mitigation in the Kathmandu Valley (JICA, 2002) 1)" included earthquake source assessment, geological analysis, estimation of seismic motion of the ground, liquefaction, slope failure, and also damage estimation of buildings, lifeline facilities such as water and sewerage pipes, electricity poles, and infrastructures such as roads, telecommunications and airport etc. This assessment provided a miserable disaster when a future big possible earthquake happened 100km west of the Valley with magnitude 8. More or less 50 % of buildings will be damaged and 1.3 % of people will be killed. These percentages are the similar to the one cause by the 1934 Earthquake, but the number of damage increased five times. This clarified that the fragility of the Valley has less change and the risk increased much. Thus, since the main reason of the victims is supposed to the collapse of buildings, the buildings in the Valley totally have not strengthened and to be strengthened.

During the assessment, authors found that the fundamental data in the Valley are so poor. For examples, the total number of buildings and the distribution of building types were estimated from the number of households in the data of census and the limited inventory survey during the study respectively, the building vulnerability function was analysed from the existing functions and historical earthquake damage data in Nepal etc. But they were not completed and needed further study. Then, this paper discusses the problems to be solved in the earthquake disaster assessment in the Kathmandu Valley. As well as proposals for the improvement of the buildings in the Valley are issued. For instance, education for all the levels, Building Codes implementation, guidelines for small improvements in construction process and inspection of critical buildings for retrofitting etc. are discussed.

This study was conducted as a part of technical cooperation between Nepal and Japan through JICA.

Key words: *Kathmandu Valley, damage estimation, scenario earthquake, building structure, earthquake-resisting capacity, JICA*

INTRODUCTION

Recently, big disastrous earthquakes have occurred in Kobe of Japan, Chi-Chi of Taiwan, Kocaeli of Turkey, San Salvador of El Salvador and Gujarat of India, and they provided great damages and losses to relating areas as well as interrupted social development. Therefore, earthquake disaster management is one of the most serious problems for the earthquake prone areas in the developing countries all over the world because of their vulnerable and poor social/infra structures. For more appropriate earthquake disaster management planning, the fundamental process of establishing earthquake disaster planning and activities is as followings:

- To know enemy (earthquakes)
- To know own (disasters and current management)
- To think how and what to do in order to cope against the enemy
- To establish plan for action
- To act disaster management
- To check and improve plan and activities

Then, "To know earthquakes and own disasters and management" should be the first and basic procedure. This is called "Earthquake Damage Assessment". In the Kathmandu Valley, a simple earthquake scenario was produced several years ago and it has worked by one local NGO very effective for the local people all over the Valley to start discussing earthquakes and their disasters and management. However, the scenario could show overall feature but not in detail and it was derived from the records of the damage during the 1934 Bihal-Nepal Earthquake, even though after the earthquake, population and buildings increased more than 5 times during another 65 to 70 years.

Recently, Bilham et al. (2001) 2) has pointed out that there is high possibility that a huge earthquake will occur around the Himalayan region based on the difference between energy accumulation in this region and historical earthquake occurrence. It is a cause for great concern that the next great earthquake may occur in Nepal at any time. The Kathmandu Valley is the exclusive center of Nepal for politics, the economy, and society, with a large population of more or less 1.5 million. Once a great earthquake occurs, Kathmandu will suffer immense losses of life and property and will be unlikely to be able to function as the capital of Nepal. Under these backgrounds, "The study on earthquake disaster mitigation in the Kathmandu Valley (JICA, 2002) 1)" was conducted as a part of technical cooperation between Nepal and Japan through

JICA. The ultimate purpose of this earthquake disaster analysis is to recognise the phenomena involved when an earthquake occurs near the Kathmandu Valley in the future. Based on the disaster scenario, the disaster prevention plan can be established. The damage estimation of buildings and human casualties are written in the followings.

EARTHQUAKE MOTION ESTIMATION

Scenario Earthquakes

The scenario earthquakes are set based on the historical earthquakes, seismic activity and lineament in the Valley.

a) Seismic Activity

Nepal lies on an active seismic zone ranging from Java – Myanmar – Himalayas – Iran and Turkey, where many large earthquakes have occurred in the past. The epicentral distribution around Nepal [3] is shown in Fig. 1. Based on the historical records in the Valley, there are about 10 earthquake hazards in past 750 years. Table 1 is the recent reliable hazardous earthquake catalogue after 1833. In the event of August 1833, 43 people has been dead and 2000 buildings collapsed. The 4,296 death and 38,000 building collapse by 1934 Earthquake and 51 death and 1,751 building collapse by 1988 Earthquake are recorded.

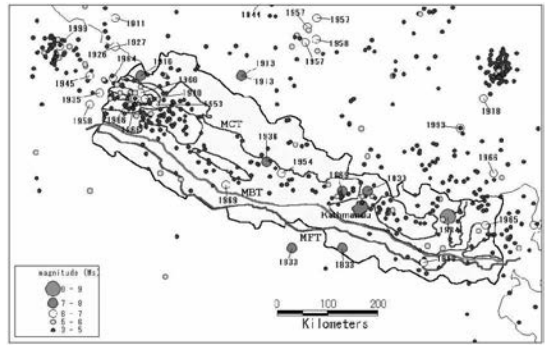

Fig. 1 Epicentral Distribution around Nepal from 1255 to 2001

** Location of some epicenters in ref. 3) have been adjusted, based on hazard records in Nepal.*

b) Lineament

There are several faults in the Kathmandu Valley. In order to identify the possible source of a small- to middle-scale earthquake occurring in the Valley, data about the lineament in the Valley were collected as shown in Fig. 2.

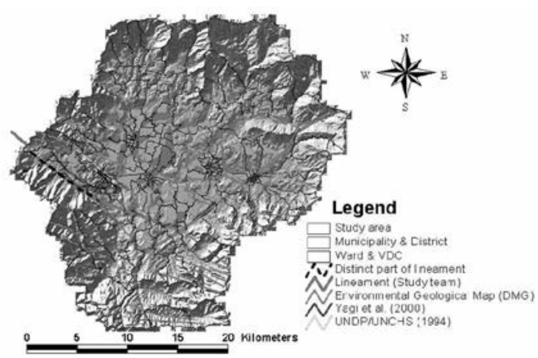

Fig. 2 Faults and Lineaments in the Kathmandu Valley

Table 1 Recent Hazardous Earthquake Catalogue

Year	Month	Day	Ms	Latitude	Longitude	Epicentral Distance from Kathmandu (km)
1833	8	26	7.0	28.00	85.00	38
1833	10	4	7.0	27.00	85.00	84
1833	10	18	7.0	27.00	84.00	151
1869	7	7	7.0	28.00	85.00	45
1934	1	15	8.4	27.55	87.09	177
1936	5	27	7.0	28.50	83.50	199
1954	9	4	6.5	28.30	83.80	163
1988	8	20	6.5	26.75	86.62	167

c) Set of Scenario Earthquake

Based on the historical earthquakes, seismic activity and active structure, following four scenario earthquakes are set. The location of scenario earthquakes are shown in Fig. 3 and the parameters are shown in Table 2.

- Mid Nepal Earthquake (Ms 8.0)

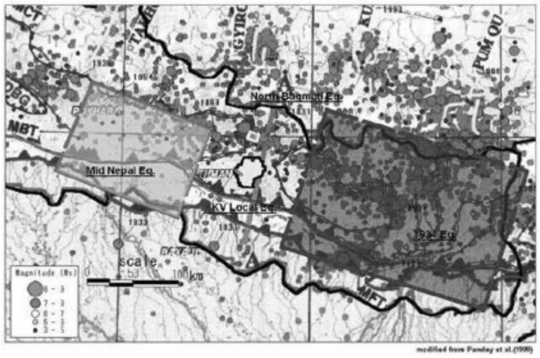

Fig. 3 Scenario Earthquake Fault Model

After Pandey et al. (1999) [4], the seismic gap with great urgent, which has been recognized about 150km west to the Valley, corresponds to the fault segment between 82 to 85 degrees of East Longitude in the Himalaya Frontal seismic zone. This huge earthquake modelled the east half of this segmented region.

- North Bagmati Earthquake (Ms 6.0)

As shown in Fig. 3, small earthquakes frequently occur about 40km north of the Valley [4]. This middle-scale model has been set based on this earthquake cluster.

- KV Local Earthquake (Ms 5.7)

This local underfoot earthquake model is set based on the distinct part of the lineament [5] in the Valley.

- 1934 Earthquake (Ms 8.4)

This model is the recurrence of the 1934 Bihar-Nepal Earthquake, which brought largest hazard in the history [6]. The damage in 1934 with the building and population condition at that time was also simulated to verify the analysis method.

Table 2 Scenario Earthquake Fault Model Parameters

Item			Mid Nepal Earthquake	North Bagmati Earthquake	KV Local Earthquake	1934 Earthquake
Fault surface	Length (km)		135	10	8	222
	Width (km)		95	9	(4)	150
	Azimuth (Clockwise from North) (degree)		290	290	308	286.5
	Dip angle (degree)		5	37	90	5
	Depth of upper edge (km)		5	10	(1)	5
Surface Wave Magnitude (Ms)			8.0	6.0	5.7	8.4
Moment Magnitude (Mw)			8.03	5.99	5.73	8.2
Location of epicenter		N (degree)	27.25	27.96	27.65	26.42
		E (degree)	84.62	85.43	85.27	87.80
Type of displacement			Reverse slip	Not specified	Not specified	Reverse slip

Ground and Soil Analysis

Since seismic ground motion closely relates with amplification characteristics in the shallow ground, soil composition and properties and topography were analysed based on existing about 700 drilling data and geotechnical engineering map. To check the composition of the soil layer and to get the geophysical characteristics of soil, 5 on-site drilling survey including P- and S-wave velocity logging were conducted.

a) Ground Classification

The soils and ground within the Valley were classified into 90 typical soil column models by 500 x 500 meter square grid, which cover the whole Valley with 2,862 cells. Fig. 4 shows the surface ground of each cell.

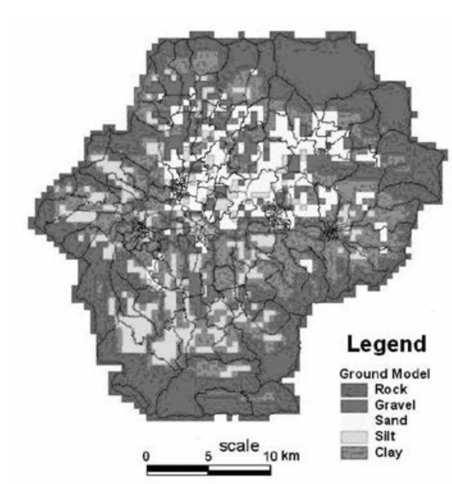

Fig. 4 Ground Classification

b) Geotechnical Properties of the Ground

Based on the existing data, PS-logging and laboratory experiment, S-wave velocity, density, N-value, groundwater level and mean particle size and suchlike geotechnical properties of the ground were defined.

Estimation of Earthquake Motion

A flowchart for the analysis is shown in Fig. 5. Based on the fault model, acceleration at engineering seismic base layer was estimated using empirical attenuation formula. The subsurface amplification factor is analyzed by response analysis with ground classification and geotechnical ground properties. The acceleration at the ground surface (PGA) is calculated from the acceleration at the engineering seismic base layer and the subsurface amplification factor.

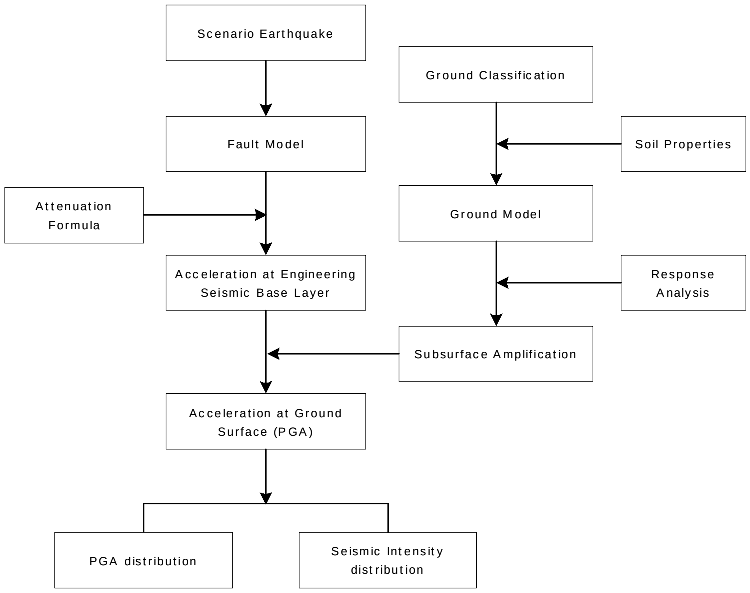

Fig. 5 Flowchart for Earthquake Motion Analysis

a) Acceleration at Engineering Seismic Base Layer

The acceleration at engineering seismic base layer caused by the scenario earthquakes was estimated, based on the empirical attenuation formula by Boore et al. (1997) [7], which is selected among 10 existing empirical attenuation formula through the validation test with the data at the 1988 Udayapur earthquake. The engineering seismic base layer was assumed as Vs=400m/s layer in 100m depth at the center of the Valley.

b) Amplification of Subsurface Layer

The amplification factors for each ground model are calculated with equivalent linear 1D (one dimensional) response analysis. The analysis model was made from 90 soil column model and geotechnical properties of Vs(Shear Wave Velocity) and density etc. The amplification factor by subsurface layer was almost 1 to 2.

c) Peak Ground Acceleration (PGA)

PGA was calculated in multiplying the seismic engineering base layer acceleration with subsurface amplification factor. The PGA distributions by the Mid-Nepal Earthquake and the 1934 Earthquake scenario are shown in Fig. 6.

- Mid Nepal Earthquake: Except for the mountainous areas, the Valley would experience 200 to 300 gal. Some area in the west would be covered more than 300 gal.
- North Bagmati Earthquake: The whole Valley would be provided less than 200 gal. The Valley would experience the smallest PGA in these four scenario earthquakes.
- KV Local Earthquake: The area along the fault would be suffered over 300 gal. The PGA would decrease rapidly as distance increase from the fault line. In the mountainous area of the Valley, less than 100 gal would appear.
- 1934 Earthquake: Most part of the Valley would be over 200 gal. Eastern part of the Valley would experience more than 300 gal.

DAMAGE ESTIMATION OF BUILDINGS

Building Inventory

To estimate the damage to buildings caused by the earthquake, the inventory of buildings, especially the distribution of buildings by structural type which closely related to their seismic capacity, is necessary. But there is very less statistical information on buildings in Kathmandu Valley. The following analysis is conducted to estimate such information.

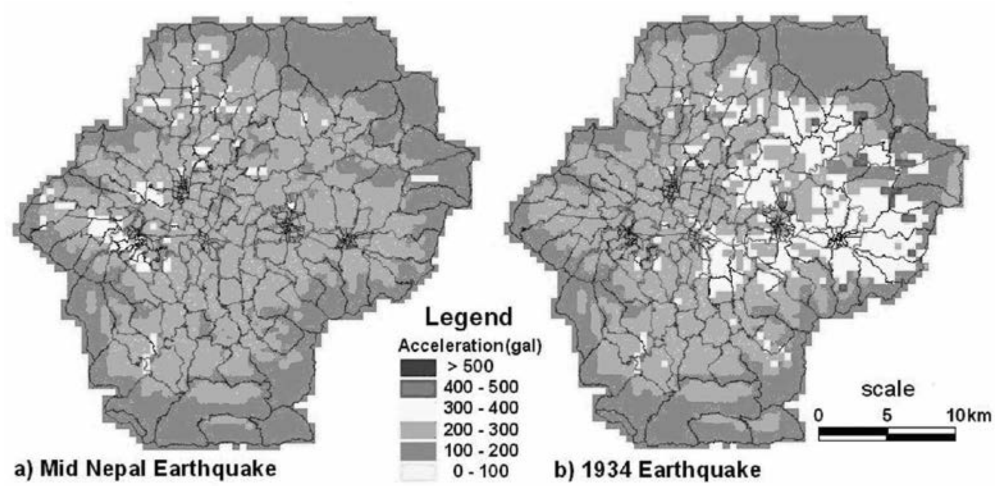

Fig. 6 PGA Distribution

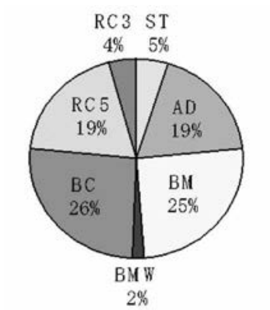

Fig. 7 Composition of Building Structure in the Valley

1) One family occupies one building in general in the Valley. The number of buildings was assumed to be the same as the number of households in 1998 projected on the basis of census data at 1981 and 1991 by ward/VDC (Village Development Committee). The total population and building number are estimated to be 1,387,000 and 256,200 respectively.

2) The damage is estimated by each 500m by 500m grid cell, where geological and seismic analyses are conducted. The building number in each cell is estimated from building number in ward/VDC, 1/50,000 geographical map and aerial photo overlaid by GIS.

3) The building structure type is classified into following seven classes based on the Inventory Survey [8]. The composition ratio of structure type in each cell is judged mainly from site survey.

   - Stone (ST)
   - Adobe (AD)
   - Brick with Mud Mortar (1), Poorly built (BM)
   - Brick with Mud Mortar (2), Well built (BMW)
   - Brick with Cement or Lime Mortar (BC)
   - Reinforced Concrete Frame with Masonry wall of 4 stories or more (RC5)
   - Reinforced Concrete Frame with Masonry wall of 3 stories or less (RC3)

ST, AD, BM and BMW are traditional masonry structure and basically non-seismic resistant designed. Many of them are old and vulnerable. BC, RC5 and RC3 are introduced about 20 to 30 years ago. They are seismically resistant than traditional structure because cement and reinforcing bar are used. But column and beam of them are thin, only 9 inches, and strength of them are far from sufficient. The construction technique is poor and the earthquake-resistant capacity of the brick wall is unreliable. The lack of earthquake-resistant capacity is getting more serious with more than 3 storied buildings in urbanized area.

The composition of building structural types in Kathmandu Valley is shown in Fig. 7. And, the predominant structure type of building of each cell is shown in Fig. 8. Typical photo of each structure is shown in Photo 1.

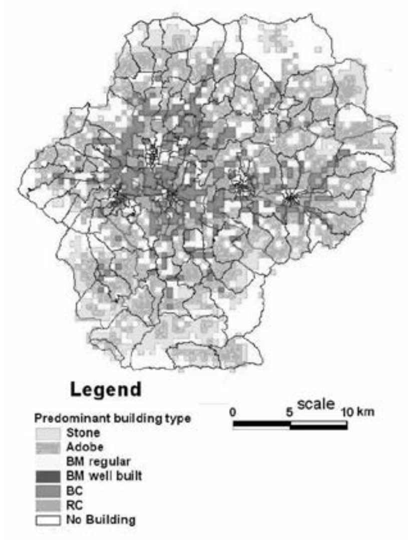

Fig. 8 Predominant Type of Buildings

Vulnerability Function

In this study, vulnerability function for the buildings in the Valley were prepared by calibrating the existing ones for Indian buildings prepared by Arya (2000) [9] as well as the existing curves for Western Nepal prepared by UNDP/UNCHS study [10]. The damage of the 1988 Udayapur earthquake recorded in Murakami et al. (1990) [11] and Dikshit (1991) [12] were analysed for the calibration. These reports give much large seismic intensity distribution comparing to the expected peak ground accelerations in the conventional relations. We have reanalysed the seismic intensity considering the weakness of the buildings in damaged area, most of them are AD and poor BM. The resulted vulnerability function, the relation between damage ratio and peak ground acceleration, for seven building types are shown in Fig. 9.

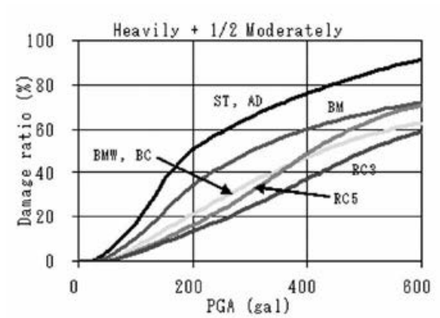

Fig. 9 Vulnerability Function for the Building

Estimated Building Damage

The building damage due to the four scenario earthquakes were estimated. As for the 1934 Earthquake, the damage if it occurs both in present and in 1934 were calculated. Table 3 shows the summary. "Heavily" damage means that the building is danger and unusable without repair or rebuild for living. "Moderately" damage means that it is usable still for evacuation but unusable without repair or rebuild for living. The actual number of total building damage due to the 1934 Earthquake from the record is about 38,000 (71%). The damage by 1934 Earthquake can be simulated well by the analysis method of this study.

Table 3 Estimated Damage to Buildings

Scenario Earthquake	Total Building	Heavily	Moderately	Total
Mid Nepal Earthquake	256,200 (estimation)	53,000 (21%)	75,000 (29%)	128,000 (50%)
North Bagmati Earthquake		15,000 (5.8%)	28,000 (11%)	43,000 (17%)
KV Local Earthquake		47,000 (18%)	69,000 (27%)	115,000 (45%)
1934 Earthquake (in present)		59,000 (23%)	78,000 (30%)	136,000 (53%)
1934 Earthquake (in 1934)	53,600 * (estimation)	19,000 (36%)	16,000 (30%)	36,000 (66%)

* Estimated from 1920 population data on the supposition that BC and RC building didn't exist at that time and that the building number corresponds to the population.

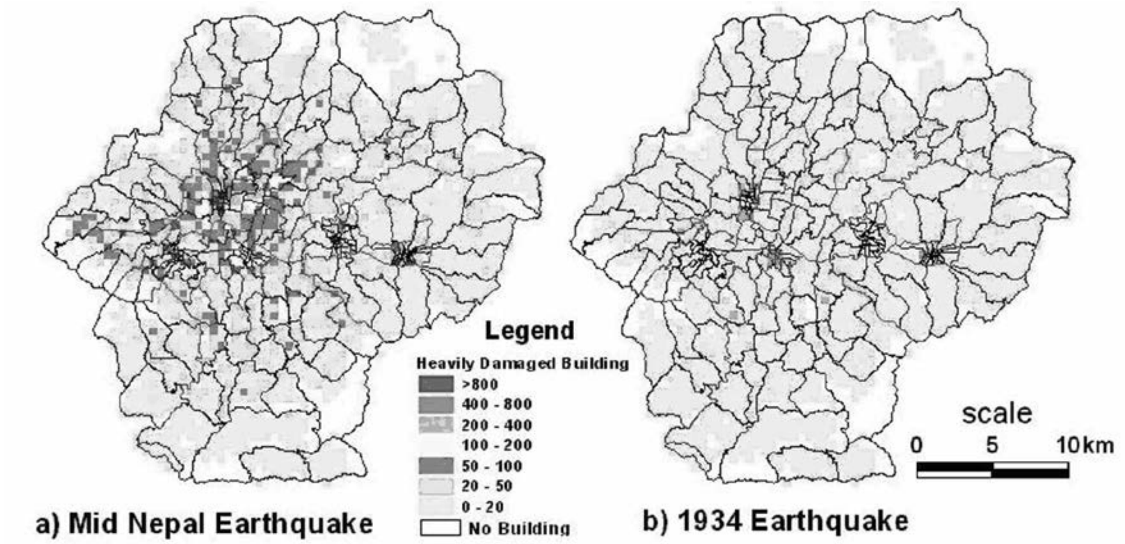

Fig. 10 Estimated Heavily Damaged Building Number

Fig. 10 a) shows the calculated total number of heavily damaged buildings in the Valley due to the Mid Nepal Earthquake, that was estimated as 53,000 (21%). In total, 50% of buildings were estimated to be heavily or moderately damaged. The estimated number of damaged buildings was large in the core areas of Kathmandu, Lalitpur and Bhaktapur municipalities. The reason for the large number seems to be due to the high density of buildings in these areas. As well as Fig. 10 b) shows the simulated number of heavily damaged building in case of the 1934 Earthquake. Since there were not so many buildings at that time, the estimated number of heavily damaged buildings is relatively small number. However, the damage ratio (66%) is larger than the Mid Nepal Earthquake (50%).

If the 1934 Earthquake occurs in present, the total damage ratio will become about 53%. The damage ratio has diminished only about 10%, from 66% to 53%, in these 68 years. In recent 30 years, concrete has been introduced that has caused BC and RC frame buildings to be widely constructed in the Valley. They are a little bit stronger than traditional ones, but the overall damage ratio has not been changed. Thus, a miserable phenomenon is estimated. The next problem is how to improve the estimated disasters.

ESTIMATION OF HUMAN CASUALTIES

Building collapse is the most notable cause to human casualties by the past earthquakes in the world. The damage data in Nepal and India, where is composed of almost same type building structure, show similar situation. Therefore, the human casualties caused by building collapse were analysed.

Analysis Method

In order to estimate the death toll, the empirical relation between the number of heavily damaged buildings and death toll was used. This empirical relation is strongly affected by the number of residents in one building and the ratio of fatalities to the number of residents. This condition is different by country or area, so the data in Nepal were used in this study.

Following formula is newly derived in this study based on the relation between heavily damaged or collapsed building number and death toll by the 1934 Bihar-Nepal Earthquake and the 1988 Udayapur Earthquake.

$\log D = 1.51 * \log T - 2.567$ (*D*; Death toll, *T*; Collapsed or heavily damaged building number)

To estimate the injured people, following formulae are made from the relation between death toll and injured people by the 1988 Udayapur Earthquake.

$\log Is = 1.048 * \log D + 0.301$ (Is; Seriously Injured people)

$\log Im = 0.967 * \log D + 0.845$ (*Im*; Moderately Injured people)

Estimated Human Casualties

Table 4 shows the summary of casualties. "Seriously" injured means the people who needs hospitalization.

Table 4 Estimated Human Casualties

Scenario Earthquake	Total Population	Death	Injured	
			Seriously	Moderately
Mid Nepal Earthquake	1,387,000 (estimation)	18,000 (1.3%)	53,000 (3.8%)	94,000 (6.7%)
North Bagmati Earthquake		2,600 (0.2%)	7,200 (0.5%)	15,000 (1.1%)
KV Local Earthquake		14,000 (1.0%)	43,000 (3.1%)	76,000 (5.5%)
1934 Earthquake (in present)		20,000 (1.4%)	59,000 (4.2%)	103,000 (7.4%)
1934 Earthquake (in 1934)	295,000 (estimation)	3,800 (1.3%)	11,000 (3.6%)	21,000 (7.2%)

Fig. 11 a) shows the calculated death density due to the Mid Nepal Earthquake. Total death toll was estimated as 18,000 (1.3%). The death density is high in the core area of the Kathmandu, Lalitpur and Bhaktapur municipality. Fig. 11 b) shows the simulated death density due to the 1934 Earthquake in 1934. Number of dead people was estimated as 3,800 (1.3%). The actual death toll due to the 1934 Earthquake is reported to be 4,296 [6)]. The damage by 1934 Earthquake can be simulated well by the analysis method of this study.

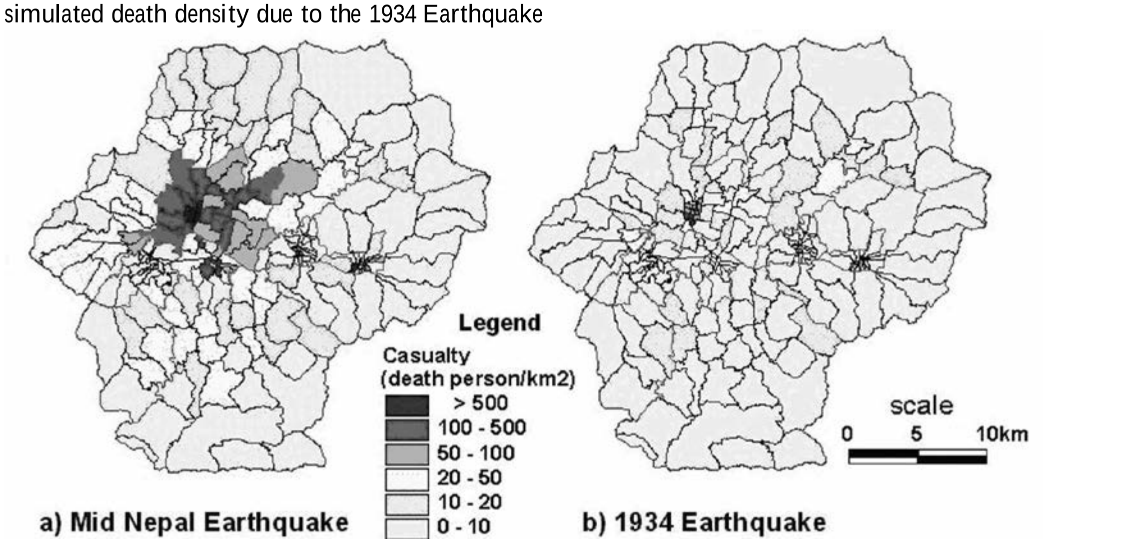

Fig. 11 Estimated Death Density Distribution

If the 1934 Earthquake occurs in present, the death toll becomes five times larger than the case in 1934, and the death ratio will become almost same. This means that the seismic resistant ability of the Valley has not changed so much after 1934, while the population concentrated to the Valley up to five times larger and risk increased much.

PROPOSALS FOR IMPROVEMENT OF THE EARTHQUAKE-RESISTING CAPACITY

There are many vulnerable buildings in the Valley and they should lead to miserable disasters. To minimize the damage by the urgent next event in near future, the following actions towards improving seismic capacity of buildings in the Valley are emergent task.

Implementation of the Draft NBC (National Building Code) within the next fiscal year throughout Nepal. Including revision of the Draft NBC on re-evaluation of structural performance factors, revision of sizes for plinth beams, columns and reinforcing bars.

Establishment of responsible and trustworthy building/construction institution and systems is also an effective measure. Preferably, establishment of registers and license system with incentives. And, the building construction system should include all the stakeholders such as owners, builders, engineer and officers.

Education, Training and Drills among all the stakeholders respectively.

Establishment of Guidelines and their dissemination: Some fundamental and detailed improvements in the construction stage can be accomplished by a small effort one by one, and thus providing effectiveness in seismic resistant force. NSET-Nepal already prepared a manual for designers and builders during the study[12].

More study on quantitative strength for each structure including retrofit technique with earthquake engineering. According to a preliminary case study, more than three storied RC buildings using the current Draft NBC must be vulnerable to future earthquakes.

CONCLUSIONS

Followings are concluded:

The building damage and human casualties by the plausible three scenario earthquakes of Mid Nepal Earthquake, North Bagmati Earthquake, KV Local Earthquake and the recurrence of 1934 Bihal-Nepal Earthquake are calculated. The estimated PGA and damage by the 1934 Earthquake case validates well to the actual damage.

The local building condition should be carefully studied if the seismic intensity is estimated from building damage. For this purpose, historical earthquakes and their damage data should be more studied.

Since there is little information about building inventory and their strength in Nepal, the necessary data are compiled from existing information and site survey. This method can be adopted in many developing countries, though the further study must be necessary.

The quantitative simulation and visualization of them has great and effective impact to public awareness.

The recommendations to existing structures, and the improving actions are proposed to improve buildings against great earthquake.

Thus, we must learn history, because it repeats itself. Also, we must develop this kind of study to other part of Nepal in order to mitigate the future earthquake disaster there.

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Stone + mud mortar (ST) (5%)	*Adobe (AD) (19%)*	*Brick + mud mortar (BM) (27%)*
		
Popular in rural areas, round riverbed rocks and squared dressed stones	*Old type of building composed of sun-dried bricks with mud mortar mainly in rural areas, can be found in old urban or sub-urban areas, mainly on elevated ground*	*Traditional style with burned bricks using timber on the floor or / and roofs, usually.*
Brick + cement mortar (BC) (26%)	*RC + masonry (RC) (23%)*	
		
Cement and Sand have become popularly used in last 30 years. BC becomes popular structure.	RC has been adopted in the last 20 –30 years. Vulnerable higher stories become popular.	

Photo 1 Typical Building Structures in Kathmandu Valley

THE SEISMOTECTONICS AND STATE OF STRESS IN EASTERN IRAN AND NORTHERN LUT REGION

Mehdi Zaré

Abstract

Most of great earthquakes in Iranian plateau with the surface earthquake fault ruptures have occurred in the last 35 years are occurred in eastern Iran. The present study intends to investigate the seismotectonic conditions and the state of stress based on surface earthquake fault evidences as well as the focal mechanisms. The regional principal stress axes are estimated based on the reported fault plane solutions. The Coulomb stress changes are estimated as well based on the existing data from two major 1968 and 1997earthquakes and their corresponding faults.

INTRODUCTION

The state of stress is studied in this region based on the focal mechanisms. The principal stress axes are estimated using a program written by A. Sisternas (EOST, IPGS Strasbourg), having the azimuthal position of two planes in the focal mechanisms and principal moment tensor axis. In order to estimate the principal stress directions, all of the data for the region are entered to a unique process (the region is not subdivided to minor sub-areas). According to this analysis, the principal stress axis (Sigma 1) is found to be between in the N12-15E azimuth.

This paper will summarize the results of a study on the state of stress in eastern Iran. There is tried first to explain the situation in the region based on the tectonic lines and focal mechanisms. Then the coulomb stress changes are explained along two major faults of the region (Dasht-e Bayaz and Ardekul – hajiabad- faults).

SEISMOTECTONIC

The principal stress directions are studied and the direction of Sigma-1 is found to be about N12-15E (assuming all of the mechanisms in one process). The coulomb stress changes are studies for two selected cases of the Dasht-e-Bayaz earthquake of 31/8/1968, Ms7.2 and the Ardekul earthquake of 10/5/1997, Mw7.2. The critical zone found based on the 31/8/1968 earthquake does not coincide with the epicentral region of the Ferdows earthquake of 1/9/1968, however the analysis determines the critically stressed areas, which are activated during the 1976, 1979 and 1997 earthquakes in the Ghaenat region. The analysis on the Hajiabad fault zone based on the 10/05/1997 earthquake shows the possibility of the future earthquakes along the Dasht-e-Bayaz fault zone.

The major faults in the eastern Iran and northern Lut region are shown in Figure-1. The majors fault trends can be classified in 4 major strikes;

- NW-SE: Tabas, Hajiabad, Ferdows, Nozad and the eastern segment of the Doruneh;
- NE-SW: Korizan, Posht-e-Badam and western segment of the Doruneh;
- East-west: the Dasht-e-Bayaz and Doruneh; and
- North-south: Esfandyar and Nayband.

These fault are arranged in a conjugate shear pattern, such that they make some major intersection zone which are seismically hazardous. The faulting mechanism could be justified with the simple Riedel shear model.

The seismicity data of the region for the events with a magnitude greater than 5.0 are shown in Figures-2 and 3, for the historical and 20th century earthquakes respectively. The list of the earthquakes is compiled based on the Ambraseys and Melville catalog (1982) and the NEIC data released on the WWW (July 2001). The earthquakes given in the other catalogs (Nowroozi, ISC, etc...) are compared to these data and are included in the cases of the lack of information in the mentioned catalogs.

The concentrations of the epicenters on Figures 2 and 3 show that the seismicity was mostly produced by the major faults (Figure-1). On the other hand, it is evident that the most of the seismicity of the studied region belong to an area between Tabas and Ghaen, along the NW-SE and east-west faults. The absence of the historical and 20th century seismicity along the major faults of Esfandyar and Nayband and the eastern Doruneh is notable and can be studied as a candidate seismic gap area.

The seismotectonic of eastern Iran can by explained based on the major active faults that are oriented in north-south, NW-SE and NE-SW directions, determining the major mountain to plain boundaries (Figure-1). The quaternary faults in this area are characterized as well by the changes in the drainage patterns and the rotation of the fold axes.

The focal mechanisms are reported in the studied region in different references (Jackson and Mackenzie 1984 and 1988, Niazi and Kanamori 1981, Berberian et al 1999, and in different web sites; Harvard Seismology, NEIC-USGS and ERI, Tokyo). The data are compiled on figure4. This figure shows the domination of the compressional and strike-slip mechanisms. The mechanisms along the NW-SE trends (Hajiabad fault) coincide with the right-lateral strike-slip movements, while the left-lateral movements can be assigned to the east-west fault trends (Dasht-e-Bayaz fault). The Tabas fault and the parallel faults located in its vicinity is mostly characterized by the compressional mechanism.

Based on Figure-3, these three major areas can be distinguished based on the reported focal mechanisms:

- East Ghaen and Dasht-e Bayaz area: with mostly strike-slip mechanisms of the earthquakes of 14/11/1979; Mw6.5, 7/12/1979, Mw6.0; 10/05/1997, Mw7.2; 16/6/1997, Mw6.0 and 10/4/1998, Mw5.7 (right-lateral movements)
- Dasht-e-Bayaz area: with mostly strike slip mechanisms of the earthquakes of 7/11/1976, Mw6.0; 24/11/1979, Mw7.0; 16/1/1979, Mw6.5; 25/06/1997, Mw5.8 (left-lateral movement).
- Tabas region: with mostly compressional mechanism of the earthquakes of 16/9/1978, Mw7.4; 13/2/1979, Mw5.5; 12/1/1980, Mw6.0 and 16/11/1990, Mw5.1.

Lineaments

The lineaments of the studied region are studied based on the major changes of the topographic levels (mountain to plain boundaries) and the changes along a system of the folds and the alignment of the edges of the mountains or depressions. Based on a digital topographic map, the interpreted lineaments are shown in figure-5. The landsat satellite image of the region (Figure-6) is used as well to infer the structural lineaments (Figure-7). Based on the figures 5 and 7, the major lineament trends could be observed in these 5 groups:

- N3E-14W (almost north-south) with mostly vertical displacements and right-lateral strike-slip components (parallel to Esfandyar and Nayband faults).
- N37-74E with compressional and right-lateral strike slip movements (parallel to Hajiabad, Nozad, Ferdows and Tabas faults).
- N85-90W (almost east-west) with left-lateral strike-slip movements (parallel to Dasht-e-Bayaz fault).
- N61-72E with left-lateral strike-slip movement (parallel to western segment of Doruneh fault system).
- N37-45E with right-lateral strike-slip movements (mostly in southern Tabas, that imposed the 'S' type rotation of the fold axes in this region).

Based on the figures 5 and 7, the edges of the major depressions in the northwest of Ferdows, northwest and south of Tabas, and east of Ghaen are determined by major structural lineaments (and faults).

The state of stress is studied in this region based on the focal mechanisms given in Figure-4. The principal stress axes are estimated using a program written by A. Sisternas (EOST, IPGS Strasbourg), having the azimuthal position of two planes in the focal mechanisms and principal moment tensor axis. In order to estimate the principal stress directions, all of the data for the region are entered to a unique process (the region is not subdivided to minor sub-areas). According to this analysis, the principal stress axis (Sigma 1) is found to be between in the N12-15E azimuth.

COULOMB STRESS CHANGES

The coulomb stress changes are estimated based on the existing focal mechanism data for the Dasht-e-Bayaz fault and Hajiabad faults based on the focal mechanisms of the 31/8/1968 and 10/5/1997 earthquakes. This study is done in order to observe the possibility of the determination of the candidate areas for a future earthquake, estimating the critical stressed areas after a major earthquake. The results are shown in figure-8 for the Dasht-e-Bayaz fault zone, based on four different scenarios; optionally oriented strike-slip, NW-SE reverse faults, left-lateral strike-slip and right-lateral north-south faults. This figure shows that non of the calculations performed based on different scenarios for the Dasht-e-Bayaz fault reactivation during the 31/8/1968 can not give the critical region around the western elongation of this fault, where the Ferdows fault is reactivation in the 1/9/1968 earthquake (Ms6.4). However this analysis determines the areas, which are activated during the future earthquakes in 1976, 1979 and 1997 in the Ghaenat region.

The estimation is equally performed for the 10/5/1997earthquake along the Hajiabad fault, based on 6 different scenarios: optionally oriented strike-slip, NNW-SSE strike-slip faults, north-south strike-slip, east-west strike slip, NW-SE reverse faults and SW dipping reverse faults (Figure-9). This figure shows that the coulomb stress changes can estimate the critically stressed region along the east-west Dasht-e-Bayaz fault (specially the optionally oriented strike-slip fault scenario).

CONCLUSIONS

This study performed on the eastern Iran, northern Lut region. The study showed the activity of the region and importance of the active faulting that controlled the geomorphic features. These active structures play the major role in the seismic hazard of the region. The major fault trends are grouped in four classes: NW-SE, NE-SW, east-west and north-south faults. The lineaments are studied as well in order to reveal the possible hidden suture zones and the elongation of the major faults. The lineaments are observed in the similar major fault trend groups. The fault and lineament determine the major mountain to plain boundaries as well as the edges of the depression zones. The active structures have equally impressed the fold trends and created the 'S' shaped folds. The fault movements in this region can be justified with the simple shear model.

The principal stress directions are studied and the direction of Sigma-1 is found to be about N12-15E (assuming all of the mechanisms in one process). The coulomb stress changes are studies for two selected cases of the Dasht-e-Bayaz earthquake of 31/8/1968, Ms7.2 and the Ardekul earthquake of 10/5/1997, Mw7.2. The critical zone found based on the 31/8/1968 earthquake does not coincide with the epicentral region of the Ferdows earthquake of 1/9/1968, however the analysis determines the critically stressed areas, which are activated during the 1976, 1979 and 1997 earthquakes in the Ghaenat region. The analysis on the Hajiabad fault zone based on the 10/05/1997 earthquake shows the possibility of the future earthquakes along the Dasht-e-Bayaz fault zone.

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FIGURES

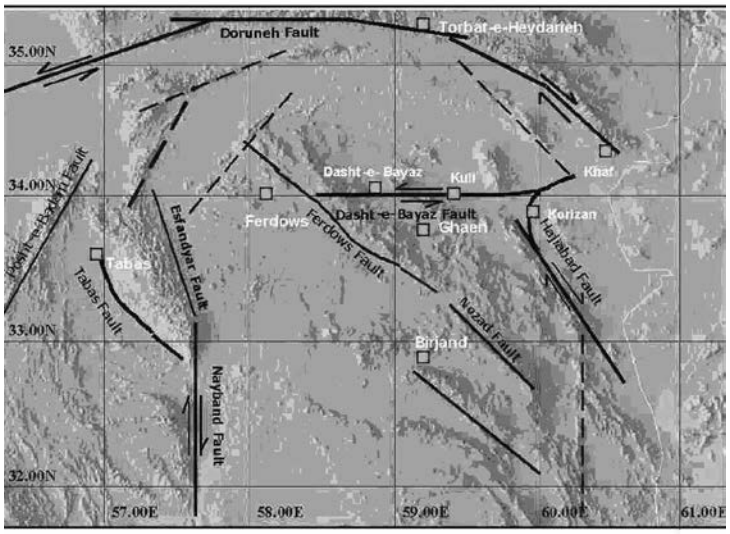

Figure-1: The major faults of the Region, which are compiled on a digital topographic map. (Base map: USGS, Digital Data Series 2001).

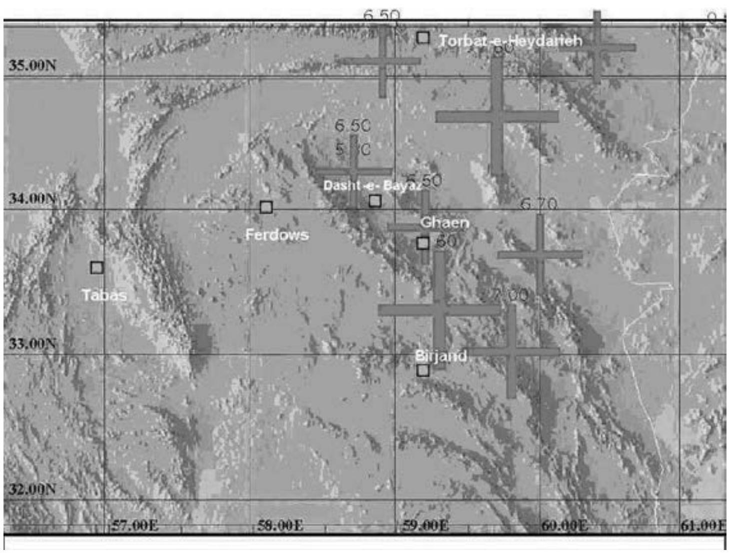

Figure-2: The epicenter of the historical (pre-20th century) earthquakes in the studied region. (Base map: USGS, Digital Data Series 2001).

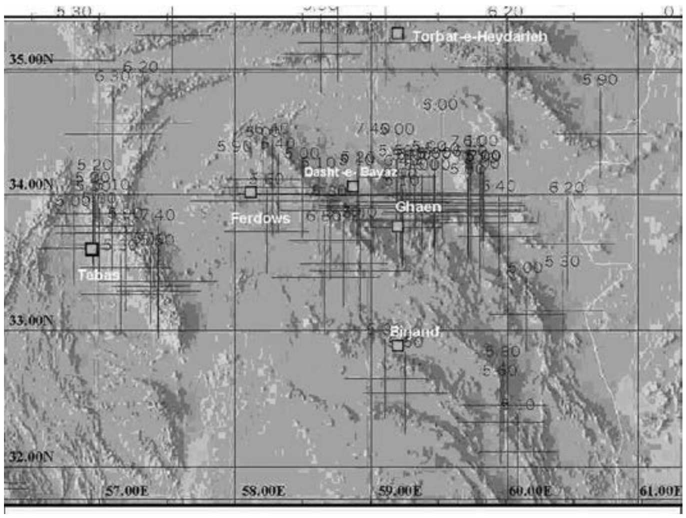

Figure-3: The epicenters of the 20th century earthquakes, with M > 5.0. (Base map: USGS, Digital Data Series 2001).

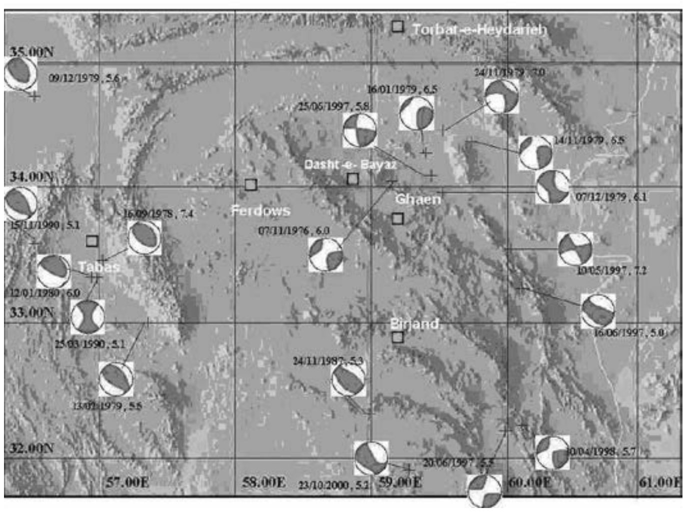

Figure-4: Focal mechanism of the major earthquakes between 1977 and 1997 (ref: Harvard, Seismology, Web site, July 2002), (Base map: USGS, Digital Data Series 2001).

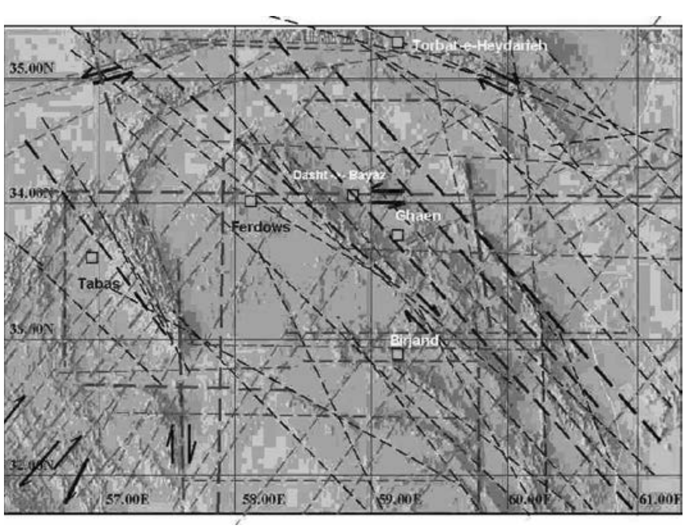

Figure-5: The inferred structural lineaments in the studied region.

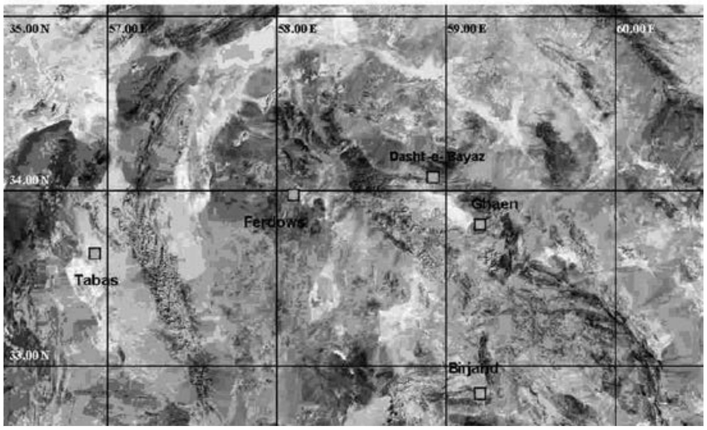

Figure-6: The landsat satellite image of the studied region.

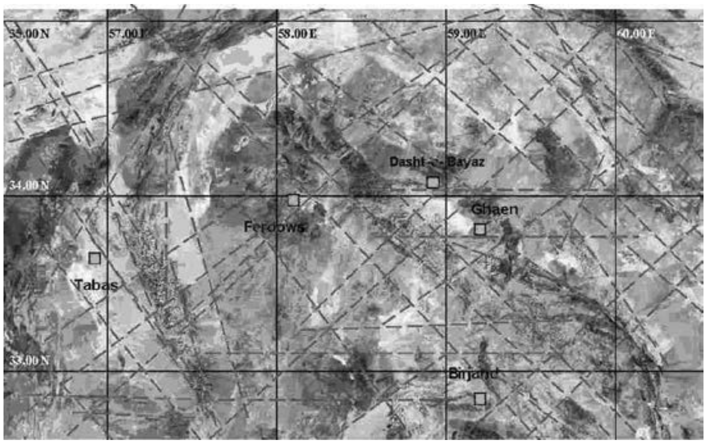

Figure-7: the inferred lineaments based on the landsat satellite image of the studied region.

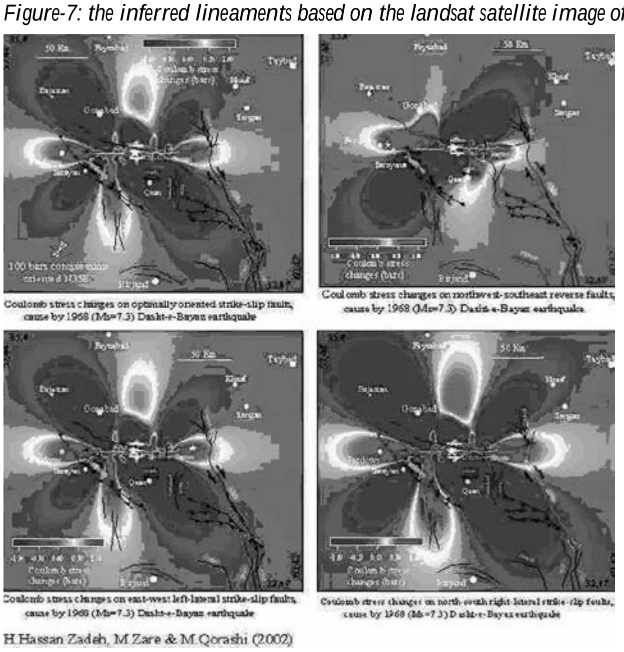

Figure-8: Estimation of the Coulomb stress changes based on the Dasht-e-Bayaz earthquake of 31 August 1968, for 4 scenarios: optionally oriented strike-slip (up-left), NW-SE reverse faults (up-right), left-lateral strike-slip (down-left) and right-lateral north-south faults (down-right) (Image developed by H. Hassanzadeh, 2002).

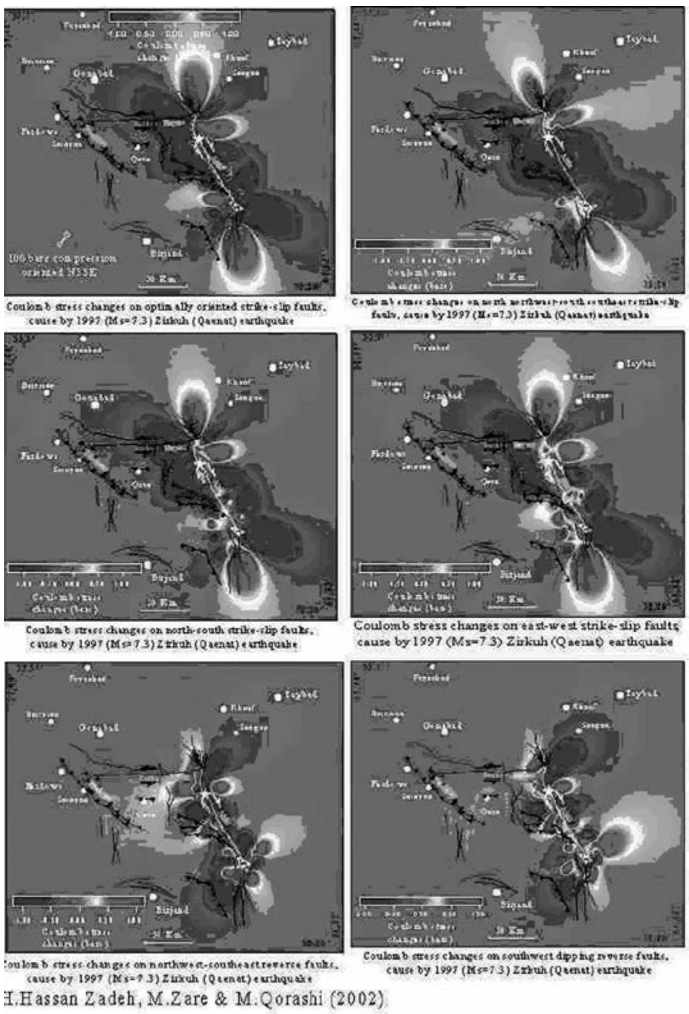

Figure-9: Estimation of the Coulomb stress changes based on the Ardekul, Ghaen earthquake of 10 May 1997, based on 6 different scenarios: optionally oriented strike-slip (up-left), NNW-SSE strike-slip faults (up—right), north-south strike-slip (middle-left) and east-west strike slip (middle-right), NW-SE reverse faults (down-left) and SW dipping reverse faults (down-right) (image developed by H. Hassanzadeh, 2002).

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INVESTIGATION OF EARTHQUAKE MIGRATION AND SEISMIC GAP ALONG THE MAIN RECENT FAULT, ZAGROS MOUNTAINS OF IRAN

Manya Mani, and Noorbakhsh Mirzaei

Abstract

Two major faults dominate the tectonics of northeastern boundary of the Zagros; the Main Zagros Reverse Fault and the Main Recent Fault. The Nahavand Fault is a segment of Main Recent Fault that itself is a major right-lateral strike- slip seismogenic structure, broadly parallel but quite distinct from and younger than the Main Zagros Reverse Fault which transects it in several places.

In this paper, we investigate the seismicity pattern of the Main Recent Fault, to search for the earthquake migration and seismic gap along this region.

INTRODUCTION

Two major faults dominate the tectonics of northeastern boundary of the Zagros; the Main Zagros Reverse Fault and the Main Recent Fault (figure 1).

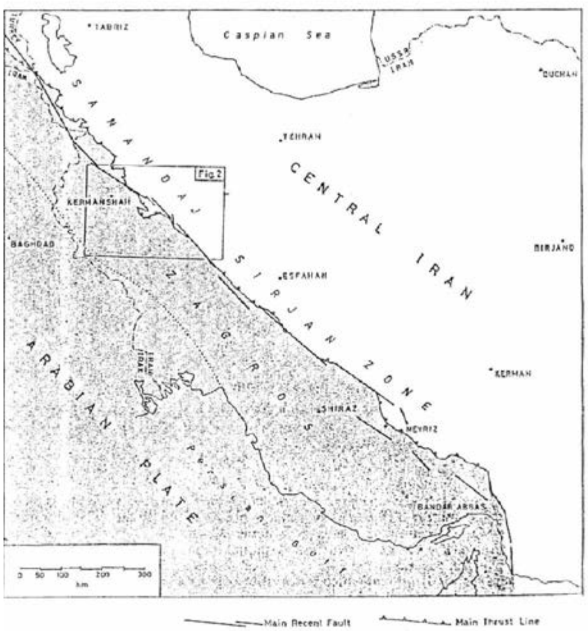

Figure 1. The Main Recent Fault and The Main Zagros Reverse Fault (Tchalenko and Braud, 1974)

The Main Recent Fault strikes NW- SE and can be traced as a narrow, linear series of fault segments from near the Turkey- Iran border at 37° N for over 800 km to the SE. Right- lateral strike- slip faulting also continues NW in broader zone through eastern Turkey to eventually join the North Anatolian Fault, thus forming a band of right- lateral shear linking Iran and Turkey (Talebian and Jackson, 2002).

Activity of Nahavand Fault is shown by displacement of Quaternary geological formations as well as by occurrence of earthquakes. Occurrence of 16 August 1958, m_b = 6.2 M_s = 6.6, caused 20 km of surface faulting. It was accompanied by a large foreshock of M_s = 5.7 and a considerable number of aftershocks in Firuzabad region of Nahavand. The Karkhaneh (Kangavar) earthquake of 24 March 1963, m_b = 5.3 M_s = 5.8, occurred on the same fault, a few kilometers to the northwest. Meisoseismal region of the larger earthquake filled the gap between the affected regions by the Firuzabad earthquake and Farsinaj earthquake of 13 December 1957, m_b = 6.5 M_s = 6.7, that occurred on a buried fault, most possibly in northwest continuation of Nahavand Fault. Considering the date and location, this event denies the seismic migration in this region.

If we relate the 1957 earthquake to the Nahavand Fault, according to the history of seismic activity and absence of significant earthquakes in last centuries, we can expect occurrence of considerable earthquakes in future, hence, we consider this region as a seismic gap.

The largest earthquake in this region was in 1909 with M_s = 7.4 and produced at least 45 km of surface ruptures, downthrown to the NE and following the SW side of the Boroujerd- Dorud depression. We can't see any considerable earthquake between this event and 1958, so we can consider this region as a seismic gap and expect intense seismic activity in future.

THE MAIN RECENT FAULT SEGMENTS

The Main Recent Fault is not a single structure but a narrow zone formed by a succession of individual fault segments, often arranged in a right- lateral en echelon pattern. From southeast to northwest the main main fault segments are (fig.2): the Dorud Fault, the Nahavand Fault, the Garun Fault, the Sahneh Fault and the Morvarid Fault (Tchalenko and Braud, 1974).

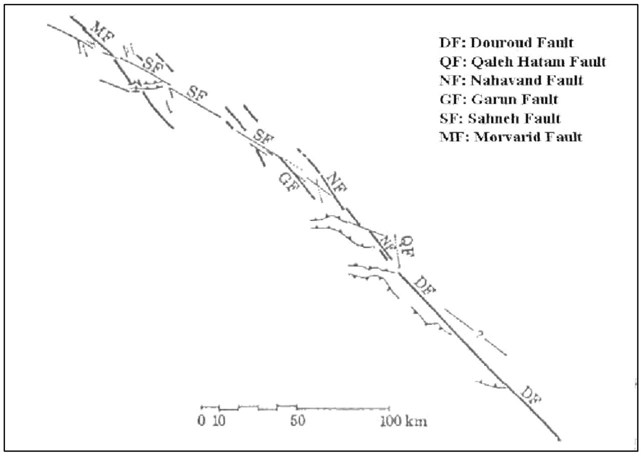

Figure2. The segments of the Main Recent Fault (Queted from Tchalenko and Braud,1974)

SEISMICITY ALONG THE MAIN RECENT FAULT

Historical eartquakes

Three pre- twentieth- century earthquakes which occurred near the Main Recent Fault have been partially documented. The first two were located near Dinavar in the northwest, and the third near Lake Irene in the southeast.

In 27 April 1008, there was a destructive earthquake in the central Zagros. Damage was concentrrated in the important city of Dinavar which was totally destroyed with the loss of more than 16000 people, apart from those who were overwhelmed by landslides. Ambraseys and Melville (1982) have estimated the magnitude of this event as large as M_s= 7.0.

On September 1107, an earthquake with M_s= 6.5 shaked the Dinavar region seriously (Ambraseys and Melville, 1982). The most probable epicentre for this event is 34.62ºN and 47.46ºE. There is no more information about this event (Mirzaei and Gheitanchi, 2002).

The lake Irene earthquake, for which documentation is less precise, occurred some time before 1889. The small mountain lake located on the Main Recent Fault southwest of Dorud is often connected in the local legend with a destructive eartquake which happened a few generations ago (Tchalenko and Braud, 1974).

Earthquakes of 20th century

Several significant earthquakes occurred on or near the Main Recent Fault in the last 100 years (Ambraseys and Mellvile, 1982; Berberian, 1994; Mirzaei and Gheitanchi, 2002; Talebian and Jackson, 2002).

23 January 1909: Silakhur earthquake

A catastrophic earthquake in 23 January 1909, devastated the Silakhur valley, southeast of Burujerd in the Zagros. Damage was particularly heavy not only in the densely populated valley of the Selakhur, but also further to the southeast in the mountain settlements as far as Arjanak. In all, 128 villlages were affected, of which 64 were totally destroyed with a loss of life estimated between 6000 and 8000.

The eartquake was associated with surface faulting which extended for a distance of forty- five kilometers. Ground deformations beyond this, further to the southeast, suggest that faulting perhaps extended longer. Field evidence and local information indicate that the average vertical displacement along the fault brek was between 1 and 2m, with the northeast side downthrown (Ambraseys and Melvile, 1982).

13 December 1957: Farsinaj earthquake

A catastrophic eartquake in 13 December 1957 devastated an extent region in southeast of Songhor, north and east of Sahneh. According to the studies of Ambraseys et al. (1973), meizoseismal regions of this earthquake were about 2800km^2. This event had a foreshock that occurred 26 hours before the main shock and felt in Kangavar. This event killed 1119 people, injured 900 people and 15000 people lost their homes. Farsinaj village at southeast of Songhor completely destroyed and 702 of its population were killed. After Farsinaj, Sarab-e- bidsorkh village at 28km southeast of Farsinaj and 9km east of Sahneh suffered most destruction and loss of life, in which 46 people killed and 44 people wounded (Mirzaei et al., 1999).

16 August 1958: Firuzabad (Nahavand) earthquake

Near 8 months after the Farsinaj earthquake, in16 August 1958, a destructive earthquake, m_b= 6.2 M_s= 6.6, occurred in Firuzabad region of Nahavand. This event destroyed 170 villages, killing 132 people and wounding 200 people; also created a faulting zone including an extension band of cracks, at least with 20km length and direction of northwest- southeast (Ambraseys and Moinfar, 1974). Firuzabad earthquake had an intensive foreshock, M_s= 5.7, in 14 August 1958 and many aftershocks (Ambraseys and Moinfar, 1974a; Mirzaei et al., 1999).

September 1958 earthquakes: Karaj- Kargasar (Dinavar)

In 21 September 1958, consecutive shocks occurred in Dinavar region. In Kargsar some houses cracked and in Karaj a house destroyed. Some hours later, on afternoon, A larger earthquake (M= 5.5?), destroyed 7 villages. The villages Kargsar, Karaj, Balajoob, Jamishan and Kolejoob destroyed and 16 people killed. It was more intense in Kargsar and Karaj, that wounding 57 people in these two villages. There is some evidence of ground deformation, possibly with tectonic origin, between Karaj and Kargsar (Ambraseys and Moinfar, 1974a; Mirzaei et al., 1999).

24 Mars 1963:Karkhaneh earthquake

After August 1958 Firuzabad earthquakes, the Main Recent Fault between 33 and 35°N underwent a point of relative quiescence. In 24 Mars 1963, an earthquake, M_s= 5.8, shaked Karkhaneh region of Kangavar. This event shaked an area about 300km^2. Meizoseismal region of Karkhaneh with a little overlapping, was located between meizoseismal region of Farsinaj at northwest and Firuzabad at southeast. Karkhaneh earthquake had no foreshock but followed by intensive aftershocks till one month. The effect of this earthquake was about 8km ground deformation in Kangavar valley (Ambraseys and Moinfar, 1974b; Mirzaei et al., 1999).

It was estimated at the time that a total of about 5000 houses were severely damaged and nearly 100 people injured (Tchalenko and Braud, 1974).

24 April 2002: Dinavar (Sahneh) earthquake

In 24 April 2002, an earthquake, M_s= 5.2, shaked Sahneh.From this event, 1 people killed, 56 injured, 10 villages destroyed and 50 village considerably damaged.

This event is caused by reactivation of Sahneh Fault, the meizoseismal region was in Dastjerdeh village.

Spatial Distribution of Earthquakes in 20th Century

Spatial distribution of Zagros mountains earthquakes are 10 years time intervals for 8ime span of, 1900- 2002, the are shown in figures 3-13.

In figure 3 we can see that in the years between 1900- 1909, on the Main Recent Fault, only one earthquake with Ms ≥ 6 (Silakhur earthquake, 23 January 1909) is occurred.

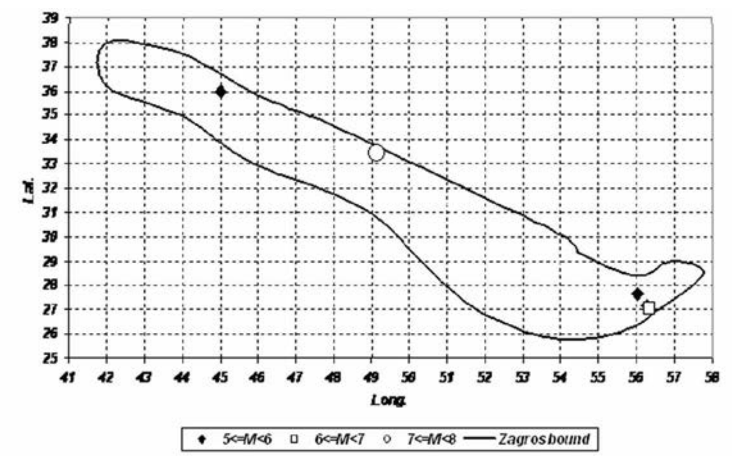

Figure3. The spatial distribution of earthquakes in Zagros recorded from 1900 to 1909

- As shown in figure 4 and 5, there is no important seismic activity in this region between 1910- 1919 and 1920- 1929.

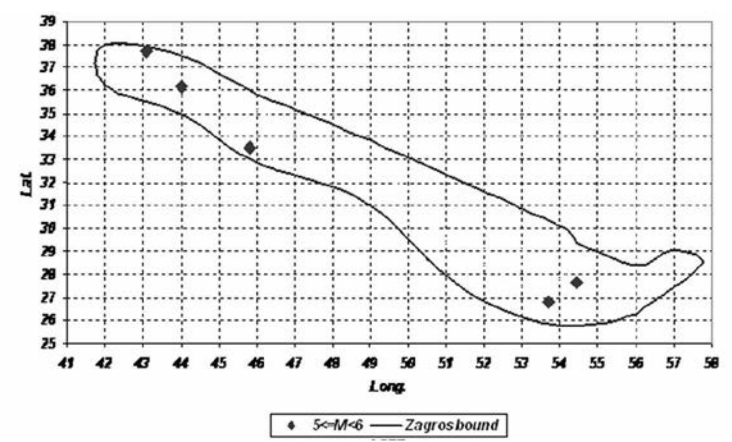

Figure4. The spatial distribution of earthquakes in Zagros recorded from 1910 to 1919

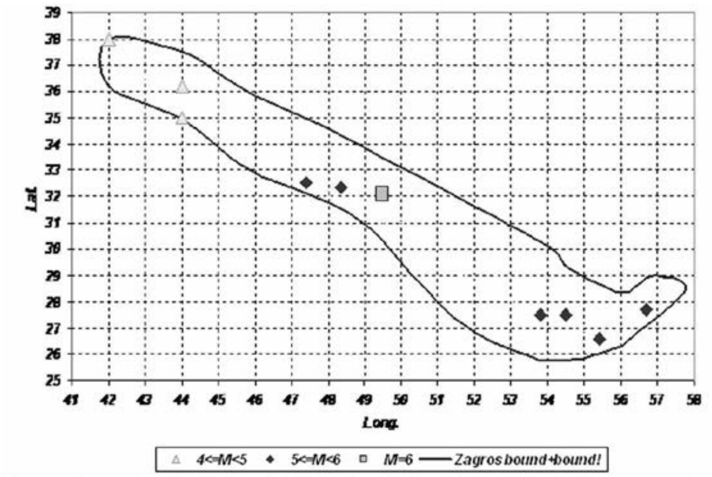

Figure5. The spatial distribution of earthquakes in Zagros recorded from 1920 to 1929

- Figure 6 shows that the seismic activity of Main Recent Fault became more at northwest in the years between 1930- 1939.

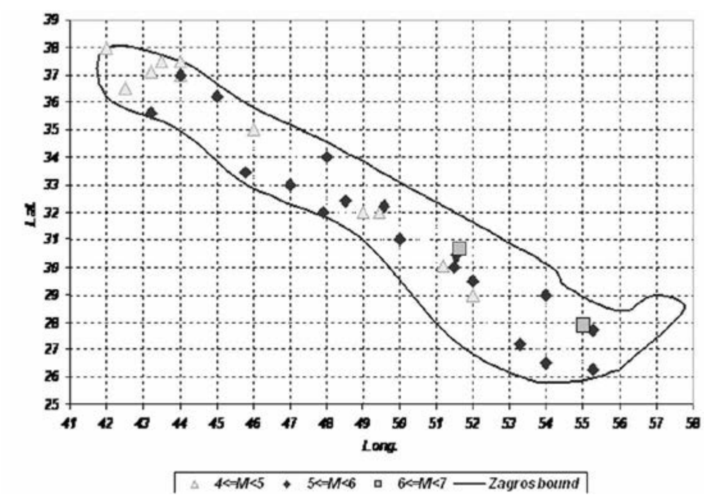

Figure6. The spatial distribution of earthquakes in Zagros recorded from 1930 to 1939

- The seismic activity of the region in 1940 decade is the same as last decade, figure 7.

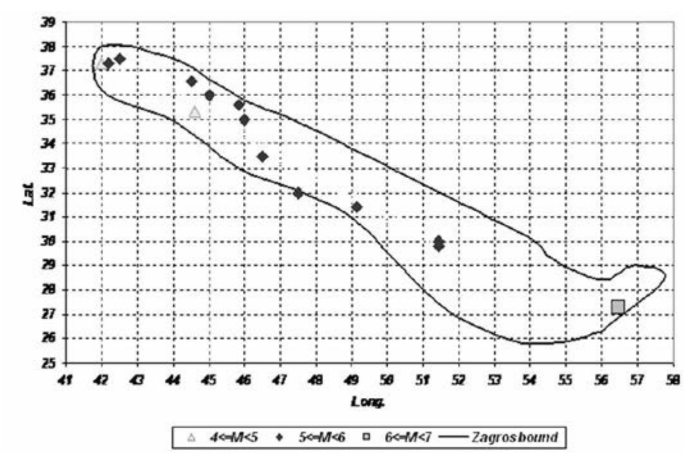

Figure7. The spatial distribution of earthquakes in Zagros recorded from 1940 to 1949

- In 1950 decade, 3 major earthquakes occurred in the Main Recent Fault: 13 December 1957, Farsinaj earthquake, $M_s = 6.7$; 16 August 1958, Firuzabad (Nahavand) earthquake, $M_s = 6.6$; 21 September 1958, Karaj- Kargsar (Dinavar) earthquake, $M_s = 5.5$; Figure 8, and there is no other significant earthquake occurred.

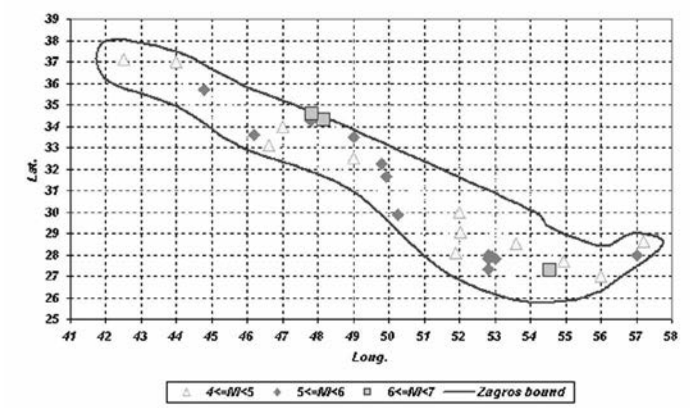

Figure8. The spatial distribution of earthquakes in Zagros recorded from 1950 to 1959

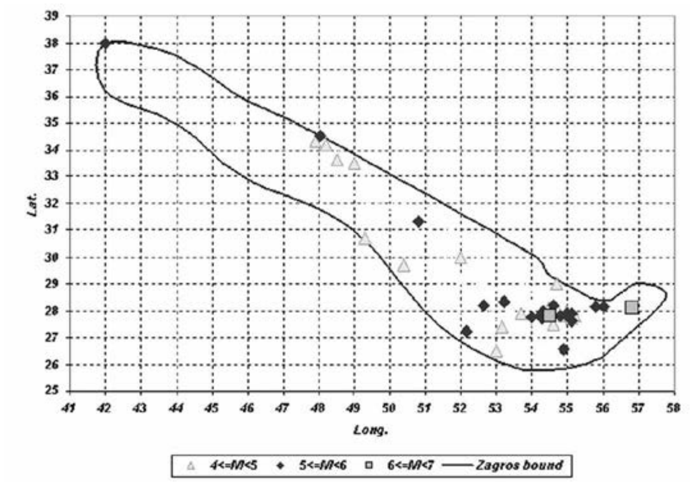

Figure9. The spatial distribution of earthquakes in Zagros recorded from 1960 to 1969

- From figure 9, we can see that the occurrence of 24 March 1963, Karkhane (Kangavar) earthquake, $M_s =$ 5.8, is the only event with $M_s \geq 5.0$ in the years between 1960- 69.

- In the years between 1970- 1979 there is no seismic activity in the region and we can see a relative quiescence of seismic activity there, figure 10.

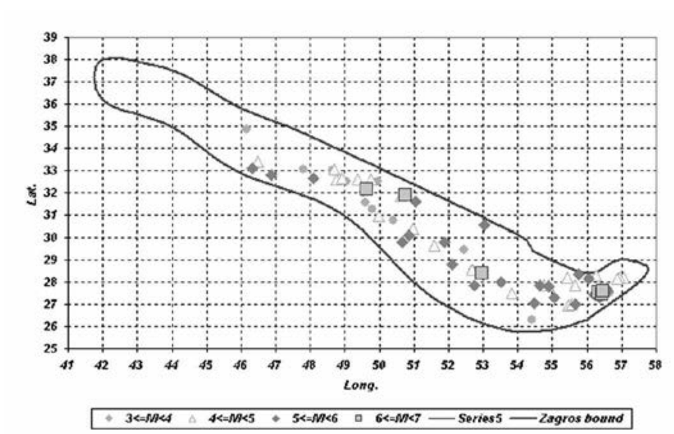

Figure10. The spatial distribution of earthquakes in Zagros recorded from 1970 to 1979

- Figure11 shows more seismic activity specially in northwest of the main recent fault in the years between 1980- 89.

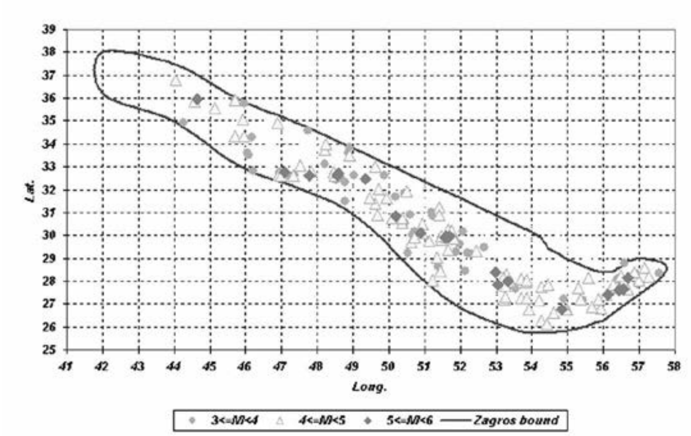

Figure11. The spatial distribution of earthquakes in Zagros recorded from 1980 to 1989

- Figure 12 shows more seismic activity in the region between 1990- 99; as we can see this is the same as last decade.

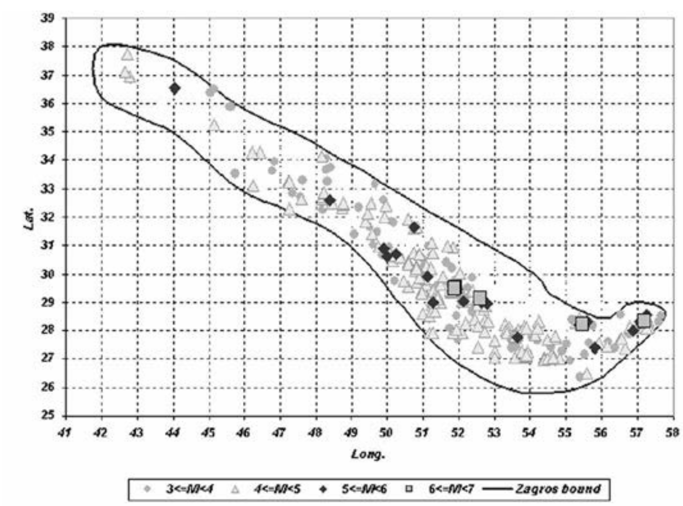

Figure12. The spatial distribution of earthquakes in Zagros recorded from 1990 to 1999

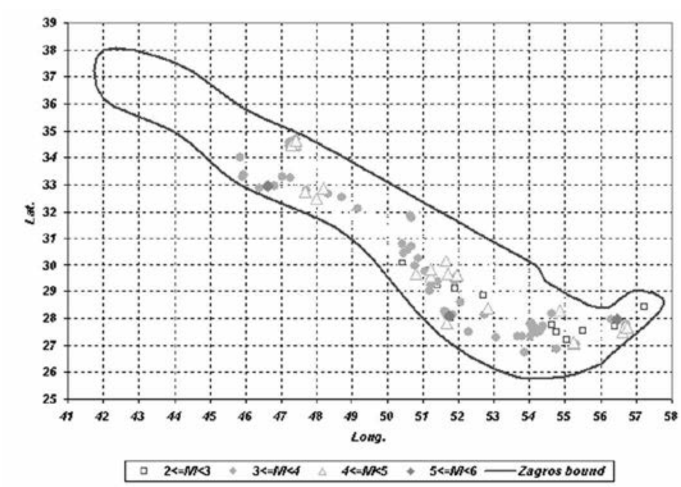

Figure13. The spatial distribution of earthquakes in Zagros recorded from 2000 to 2002

- Figure 13 shows the seismic activity of the Main Recent Fault in the years between 2000-2002, and shows the Dinavar (Sahneh) earthquake, on 24 April 2002, Ms= 5.2.

DISCUSSION

The Dorud Fault segments enters the region near Arjanak, and can be traced in a straight line (N 315º) for about 100 km until the vicinity of Borujerd (where it meets a short nearly N- S fault (precisely N 350º), the Qale Hatam Fault. This fault displaces very rrecent horizontal conglomerates and clays, with the eastern block downthrown by at least 10m. Topographically, the Silakhur valley may be considerd as limited in the northwest by the Qale Hayam Fault). The small town of Dorud, situated approximately ad mid-point of this trace, may be conveniently used to distinguish a southwestern section contained in the Shuturan Kuh mountains, from a northwestern section contained in the Silakhur Valley (Tchalenko and Braud, 1974).

After the 1909 Silakhur earthquake (Fig.14) the documented activity of the Dorud Fault is confined to two earthquakes of magnitude over 5, in 1958 and in 1963, located on the main Recent Fault to the southeast of Dorud. The earthquake which damaged Razan in 1955 may also possibly be connected with the Dorud Fault.

The Nahavand Fault (Fig.2) starts in the southeast near Wenai (west of Borujerd) and extends in a N320º direction to Gushe (northwest of Nahavand), a total length of about 55 km.Its direction is the same as that of the Dorud Fault, but its trace is displaced by about 3km to the northeast. The Qale Hatam Fault previously described separates the Nahavand from the Dorud Fault (Tchalenko and Braud, 1974).

The Garun Fault is approximately paraallel to the Nahavand Fault (Fig.2) and located about 10km farther southwest. It can be followed for about 25km, from the Taznab region in the southeast, its length it marks the southwestern limit of the Nahavand valley, separating the young alluvium from from the metamorphic formations of the Kuh Garun. At its northwestern end, near Qilab and Kirdian, it departs from the mountain front and enters the alluvial valley where its trace is marked by a topographical step several meters high. This section was reactivated during the 1958 earthquake (Tchalenko and Braud, 1974).

Activity of the Nahavand and Garun Faults is shown by the displacement of Quaternary and modern alluvial formations, as well as by the occurrence of earthquakes (Tchalenko and Braud, 1974). Occurrence of 16 Augst 1958, $m_b = 6.2$ $M_s = 6.6$, caused 20 km of surface faulting. It was accompanied by a large foreshock of $M_s = 5.7$ and a considerable number of aftershocks in Firuzabad regionof Nahavand. The Karkhaneh (Kangavar) earthquake of 24 March 1963, $m_b = 5.3$ $M_s = 5.8$, occurred on the same fault, a few kilometers to the northwest. Meizoseismal region of the later earthquake filled the gap between the affected regions by the Firuzabad earthquake and Farsinaj earthquake of 13 December 1957, $m_b = 6.5$, $M_s = 6.7$, that occurred on a burried fauit, most possibly in northwest continuation of Nahavand Fault (Fig.14).

The Sahneh Fault (Fig.2) which connects the Garun Fault in the southeast to the Morvarid Fault in the northwest is about 100Km long and strikes between N295° and N300°. Its direction is exceptional compared to the other segments of the Main Recent Fault, which are characteristically at about N315°. The Sahneh Fault maybe divided into three sections of approximately equal lengths referred to here as the Southeastern, Central and Northwestern sections (Tchalenko and Braud,1974).

The Sahneh Fault can be followed through Karapian and as far as Shaini. At Karapian however,it is crossed by the Morvarid Fault striking N310-315° and extending north beyond the limits of the region considered here. Near Kamyaran, the Morvarid Fault froms the northeastern limit of an extensive outcrop of volcanic rocks displaying strong hydrothermal alteration along the fault trace. The freshness of striations on the fault plane indicates very recent fault movments (Tchalenko and Braud, 1974).

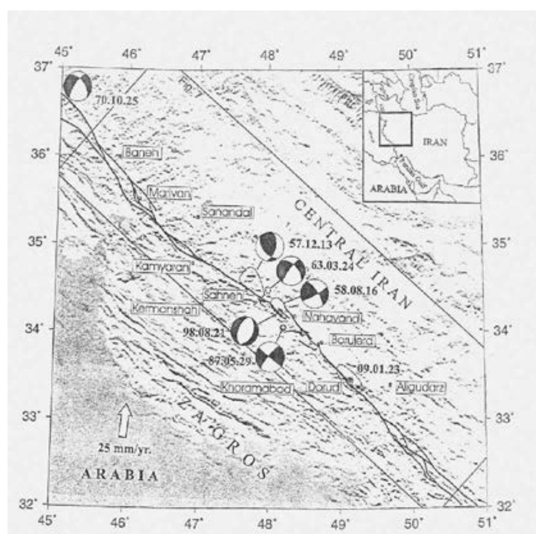

Figure14. The most important earthquakes that occurred on the Main Recent Fault (Talebian and Jackson, 2002)

CONCLUSION

As we said before, the largest earthquake in this region was in 1909 with $M_s = 7.4$ and produced at least 45km of surface ruptures, downthrown to the NE and following the SW side of the Borujerd-Dorud depression. We can't see any considerable earthquake here except some moderate earthquakes near Dorud, so we can consider this region as a seismic gap and expect more seismic activity in future.

Occurrence of 16 August 1958, $m_b = 6.2$ $M_s = 6.6$, caused 20 km of surface faulting. It was accompanied by a large foreshock of $M_s = 5.7$ and a considerable number of aftershocks in Firuzabad region of Nahavand. The Karkhaneh (Kargsar) earthquake of 24 March 1963, $m_b = 5.3$ $M_s = 5.8$, occurred on the same fault, a few kilometers to the northwest. Meizoseismal region of the later earthquake filled the gap between the affected regions by the Firuzabad earthquake and Farsinaj earthquake of 13 December 1957, $m_b = 6.5$ $M_s = 6.7$, that occurred on a burried fault, most possibly in northwest continuation of Nahavand Fault. Considering the date and location, this event denies the seismic migration in this region.

If we relate the 1957 earthquake to the Sahneh Fault, according to the seismic activity and absense of significant earthquakes in this region, we can expect occurrence of considerable earthquakes in future, hence, we assume this region as a seismic gap.

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SEISMIC RETROFITTING OF NON-ENGINEERED BUILDINGS OF EARTHQUAKE PRONE AREA REGION OF MADHYA PRADESH

Amit Kumar, and A. K. S. Parmar

Abstract

As the adages go "Earthquake Doesn't Kill People But Buildings Do". About 75% of people are killed due to collapse of buildings during earthquake. Increasing population in developing countries continue to be housed in such weak non-engineered buildings. Replacing these poorly built houses with new one is not a viable solution. Seismic retrofitting of these poor buildings is one of the most important methods for mitigating seismic hazards of earthquake prone areas.

SEISMIC HISTORY OF STUDY AREA

In view of seismic activities; study area Khandwa was considered to be a stable region. But seismic activity in the Central India is on the up over the years. The very recent Jabalpur earthquake (22nd May 1997) and some more earthquakes of moderate and small magnitudes in the region have confirmed that once the area considered to be stable; has now become susceptible to earthquake of MSK intensity VI and more. The detailed study has revealed that Khandwa region has had a record of minor earthquakes in the past. The Bureau of Indian Standards has classified the entire country into five zones on the basis of earthquake history. Khandwa district falls in Zone III of Earthquake Hazard Zone Map of India, i.e. Moderate Earthquake Seismic Risk Zone. District is in the Sone-Narmada- Tapti Lineament, which is considered to be a weaker zone.

Khandwa & its adjoining areas have experienced 7 earthquakes of magnitude 4 to 6.5 on Richter Scale between the years 1847 and 1992. Out of these, two were of magnitude more than 6; hence, an earthquake of magnitude between 6 and 6.5 is a likely phenomenon in the area.

BUILDING STOCK SCENARIO

In Indian context, the buildings are mainly categorized into four types based on roofing and wall material. Buildings are further categorized as per sloping and flat type of roofing. These are:

A Type :	Adobe, Rubble, Stone and Rammed Earth
B Type:	Burnt Brick Masonry
C Type:	Perfect timber frame /RCC frame structure
X Type:	Conventional light material construction.

NATIONAL BUILDING STOCK

In view of national scenario of building stock, it is observed that approximately 49.43 % of buildings fall in A type, which are most vulnerable to earthquake. B and X type of construction holds 35.33 and 11.61 % of building stock respectively. Only 3.63% of construction is RCC or Wood Construction, which is considered to be safe. The Country has about 95% of building stock, which can be partially or completely affected by earthquake. In past record, adobe/mud construction has performed poorly during earthquakes due to their brittle characteristics. The Khandwa district has about 96% of building stock, which will require retrofitting measures.

Frequent tremors in the region raised the concern for the safety of buildings. The Ministry of Agriculture & Cooperation, Government of India funded for conducting the research for developing retrofitting techniques for non-engineered poor residential construction. 21 villages of Pandhana tehsil of Khandwa district of Madhya Pradesh (figure1) were selected for study, which were highly effected by the seismic tremors. The scope of the paper limits the discussion of techniques for retrofitting of mud and brick buildings.

The Statistic reveals, in the study area about 71% of buildings were of mud wall, 28% of brick wall and only 1% includes RCC and thatch type wall construction.

Features of Existing Mud Wall Construction

The Traditional mud wall construction practiced in Khandwa region is unique i.e. the construction is partially load bearing and partially framed structure. The details of the mud wall construction may be referred at (Figure-2)

Foundation

For mud wall construction, generally spread footing foundation is practiced. The depth of foundation confines to about 60 cm. The foundation is made up of random rubble masonry with mud mortar. The thickness of footing varies from 60 to 75 cm. In many cases, the width of foundation continues above plinth level and gradually taper down to wall thickness.

Wall Construction

The mud wall is used for partition and separation. The thickness of mud wall varies from 45 cm to 75 cm. The quality of mud for construction is not satisfactory. The soil behavior is inconsistent with extreme weather. During rainy season, the soil swells extensively and during summer it shrikes and causes cracks. Similar behaviour has been observed in old existing mud walls and requires immediate attention. Sometimes the wall is constructed by mixing mud with field stone pebbles.

Beam & Column Arrangement

The columns are erected from the foundation. The timber columns of 200 mm dia are provided at the interval of 2 to 2.5 meter. The columns are arranged longitudinally and transversely. Generally houses are of one storey with attics. The timber columns are extended upto roof level. The joineries of the column and beam are found to be satisfactory but require maintenance. The column and beam arrangement may be referred at figure 2.

Roofing Pattern

Roofing elements are made up of timber and covered with Galvanized Iron Sheet, which is light in weight. Linkage between roofing elements are found to be weak and require strengthening.

RETROFITTING MEASURES

The retrofitting technique has been developed on the basis of the locally available resources, skill and construction material. Mud buildings are highly vulnerable to seismic forces and perform erratic during ground shaking. The objective of strengthening is to integrate the building elements together so that building can act as a single unit. Mud buildings are strengthened using bracing at weaker sections. Further walls are joined with timber frame; after that those are linked with roofing elements.

Steps for Retrofitting Mud Buildings

a. Removal of Excess Heavy Roof Covering
b. Introduction of Timber Frame
c. Strengthening of Timber Frame
d. Mud Wall connection with Frame
e. Roof Strengthening
f. Water proofing of Mud Wall
g. GI Sheet of Tile Roof Fixing

a. Removal of Excess Heavy Roof Covering i.e Tiles, Timber Planks, GI Sheets, Clay Tiles Etc.

   Earthquake induced seismic forces are directly proportional to the mass of structural elements; larger the mass, larger are seismic forces to be resisted by the structure. Therefore, weight of a roof must be reduced to the possible extent. The following procedure has to be adopted:

   a. Remove clay tiles or GI roofing sheets carefully without altering the existing load path of system.
   b. Careful removal of roofing and truss materials, the roofing elements should not be repositioned unless until all other retrofitting work at and above eave level has been done.
   c. Place the wooden purlins and rafters (50-75 ϕ) at spacing of 250 mm center to center. The purlins are placed firmly with proper grooving in rafters. The rafters are fixedly placed on wooden band "Eaves Band" with steel strap, placed all around the top of wall.

b. Insertion of Timber Frame

   Frame structure is having its own strength and acts perfectly well during the ground shaking. The load bearing structures perform comparatively poor, so the effort is to convert the load bearing structure to framed one. It is observed that the rural construction is partially framed and less effort is required for making framed structure.

   The loads coming from super-structure to foundation is to be studied. In required position, columns are to be inserted ensuring proper foundation. The eaves band positioned on the wall is to be properly fitted by making grooves in the inserted column.

c. Strengthening of Timber frame

   The strengthening is done by bracing the frame and wooden members. It includes installation of timber band knee bracing diagonal and horizontal bracing of timber frame.

   (i) Installation of Timber Band

   The top most portion of the wall should be dismantled just below the eaves level and timber band should be installed at this level, and parapet wall should be reconstructed by using the same material. In addition, the timber frame structure should be braced in diagonal or horizontal direction to prevent tilting of the walls inwards. The timber band is to be also provided at gable tops.

   (ii) Knee Bracing of a Timber Frame

   The knee bracing should be introduced at top of each timber post wherever (figure 3) to reduce the chances of lateral sways and to strengthen timber frame against a possible earthquake. On the other hand, two bracings are required for at corner post and four bracing are required for at inside posts in a multiple column-beam system. There are several possible types of Knee bracing, depending on the availability of construction materials (steel or timber). Length of Knee bracing should be approximately 60 cm. When steel bracing is employed, rolled steel angle of a minimum size 35 X 3 mm should be used. For a timber bracing, timber plank of 30x80-mm cross-section may be used.

(iii) Diagonal and Horizontal Bracing of Timber Frame

As an alternative to knee bracing, bracing of a timber frame by means of either diagonal bracing elements or horizontal struts is recommended. Purpose of providing diagonal and horizontal bracing is:

a) To prevent swaying of a timber frame during an earthquake and
b) To prevent tilting of the wall to the inside of the house and / or to reduce the effective wall height.

Bracing of the core house area, particularly all the bedrooms, is of the highest priority. Subsequently, diagonal or horizontal bracing should be provided firstly inside, and then on the outside of the house.

Diagonal bracing elements in the adjacent spans should have alternate directions, as illustrated in figure 4. For the diagonal bracing applications, a minimum of two bracings should be installed in the adjacent spans. Alternatively, the "X" bracing should be installed within one frame span. Timber planks used on diagonal or horizontal bracing should be at least 30x80 mm in cross section.

d. Mud Wall Connection With Frame

It is important to connect the timber frame with the mud walls. The grooves of 60 cm are made on both sidewalls; adjacent to timber column at the vertical interval of 60 cm. The timber flats (100/75/75) are placed in the grooves and joined with the column. Further both sides of timber flats are joined together. Then grooves are filled with prepared mud mortar.

e. Roof Strengthening

a. Welding or clamping suitable diagonal bracing members in the vertical as well as horizontal planes should brace roof truss frames.
b. Anchors of roof trusses to supporting walls should be improved and the roof thrust on walls should be eliminated. Figure 5 and 6 illustrates one of the methods.
c. Where the roof or floor consists of prefabricated units like RC rectangular, T or channel units or wooden poles and joists carrying brick tiles, integration of such units is necessary. Timber elements could be connected to diagonal planks nailed to them and spiked to an all round wooden frame at the ends.

f. Water Proofing of Mud Wall

Major technological problem with mud is the threat of water. By the action of water, mud walls not only get eroded but on account of wetting, the walls become soft and loose their compressive strength. The mud walls are therefore invariably subject to damage due to rain and seepage. Non-Erodable Mud (NEM) is plastered on to the mud walls for their protection against erosion and wetting. The NEM is prepared by mixing bitumen cutback. The NEM plaster has been adopted very successfully, which has proved its effective adoptation and economy.

g. GI Sheet or Tile Roofing

It is observed that a suitable connection between the roof structure and the walls is absent in most of the cases. A GI sheet, when improperly supported directly on the roof band, requires a cut in portion of a band. Cut in band is also required to embed the rafters or purlins. However, such a cut in the band is not permitted. Instead one or two courses of burnt brick masonry should be provided to hold the GI sheet roofing. On the front side, the bolts can be embedded in the burnt brick masonry over band and GI sheet held preferably by an flat 30x3 mm which in turn should be embedded at the end in Parapet walls. The details are given in figure 7. Alternatively, on the front side a purlin can be used along the inner or outside of the band and J bolts used through this purlin and flat on top to hold the GI sheets in places.

FEATURES OF EXCISING BRICK WALL CONSTRUCTION

Foundation

The foundation of brick buildings is similar to mud type. The brick construction is generally done above plinth level and the foundation is made up of random rubble masonry with mud mortar. The features of brick building construction may be referred at figure 8.

Wall Construction

The quality of brick is poor in this area. The irregular size, improper burning, lumps of minerals in brick section are serious concern for quality. The bonding at joints and corners are not proper. The poor mud mortar is being used for the masonry work.

Roofing System

Sloping roofs are similar to mud wall roofing. Some-times, thin stone slab(100 mm) with steel build up sections are used for roofing. In general, T or I sections are used for supporting stone slabs. The built up sections are placed at regular interval of 0.90 to 1.25mt. The stone slabs are supported on built up section and joints are filled up with lime or cement mortar.

Steps of Retrofitting Brick Buildings

a. Installation of RCC bands or seismic bandage and cross ties at the eave level .
b. External binding or wall
c. Corner strengthening
d. Pointing of external wall
e. Strengthening of roofing elements

a. Installation of RCC Band or Seismic Bandage and Cross Ties at the Eave Level

This encompasses construction of RCC band, RCC Bands atop a Partition or Common Wall, Steel Cross Tie Bars and Installation of a Seismic Bandage.

i. RCC Band

A RCC lintel or roof band represents an extremely important " line of defense" in a house subjected to an earthquake. During strong earthquake each wall starts vibrating on its own and upon reaching its ultimate capacity, it eventually collapses. In fact, the RCC band/ bandage acts as a " seismic belt". In all (brick/stone/concrete block) masonry houses; those that have been originally constructed without the RCC bands, the RCC band should be installed at least at the eaves level, Parapet walls, which are likely to collapse during an earthquake causing injuries or even casualties, should be dismantled. After the RCC band construction has been completed; the parapet should be reconstructed by using the same material in an improved manner.

ii. RCC Bands atop a Partition or Common Wall

For a house having more than one room RCC band should be provided at the roof level atop all the walls; both the exterior as well as the interior partition ones. Similarly, for two-house owner living in a same building separated by a common wall, a RCC band should ideally be provided atop all the walls (including the common wall) at the same level, as illustrated in figure 9.

iii. Steel Cross Tie Bars

If the room length is over 5 m or more, or a common wall is dividing two properties, it may not be possible to introduce RCC band atop all the walls in a house. In such situations, steel tie bars should be introduced as a substitute for RCC band (figure 10). At least one tie bar of 12 mm diameter should be provided for a light roof structure such as GI sheet roof. Ideally a tie bar should be provided at the mid span of the room. Installation of tie bar should be carried out simultaneously with the construction of RCC band.

iv. Installation of a Seismic Bandage

To ensure integral action of walls during an event of an earthquake, installation of the seismic bandage at the lintel level is recommended for UCR stone masonry. The seismic bandage is also recommended for the Burnt Brick and Solid Concrete Block Masonry walls.

Seismic bandage is alternative for RCC band at the eave level, and it should be provided whenever it is not found feasible to install RCC band at the eaves level by dismantling a portion of the parapet. Also, when the masonry work is not in good condition, the bandage can be provided, without dismantling a portion of wall.

In addition to the RCC roof band, the seismic bandage can be installed, whenever;

a) Height of the wall (from the ground level to eaves level) is over 3 m, and
b) Distance between the top of the openings (windows) and the eaves level is at least 1m. In such a case, seismic bandage should be installed at the lintel level.

Construction of a seismic bandage should be carried out as per the following procedure as illustrated in figure 10.

- Clean a 80 cm wide horizontal strip of the exterior wall face all around the buildings, stating at the lintel level.
- Remove the plaster from the wall surface. Rake the joints between the stones to a depth of approximately 20 mm. Surface should be cleaned with a wire brush until all vegetation and dust particles are removed.
- Provide an opening for shear key (approximately size 150 x 150 mm) by removing one brick from the wall below

the roof level. Shear keys should be spaced horizontally every 2 m.

- Two pair of “U” shaped stirrups (6mm diameter mild steel bars) should be inserted in each shear key. Four longitudinally bars of 8 mm diameter TOR steel should be placed in the corners of “U” stirrups.
- Fill the space in the shear keys with micro concrete (1:2:4 mix, Maximum 6 mm diameter aggregate)
- Fix a 60 cm wide strip of welded with mesh reinforcement of 2-3 mm diameter @ 25-50 mm c/c spacing (i.e. wire mesh of size 25 x25 x 2 mm or 50 x50 x3 mm or with intermediate diameter and appropriate spacing) to the walls at the roof level by means of long nails. The mesh should be also connected to the shear key reinforcement with the binding wire.
- A 10 mm wide gap should be provided between the mesh and the wall
- Overlapping the mesh should ensure continuity of reinforcement. The overlapping length should be approximately 60 cm.
- Wet the wall surface by sprinkling water. Apply a 15mm thick layer of 1:3 cement-sand mortars to cover the mesh.
- After one hour, apply another layer of 1:3 cement sand mortar of the same thickness (15mm).
- Cure the belt continuously for 14 days by sprinkling water.

b. External Binding of Masonry Wall

External binding (concrete jacketing) is recommended whenever damaged or undamaged portions of a burnt brick / UCR stonewall need to be strengthened to improve their resistance to earthquake effects. External binding should be carried out along with corner strengthening and lintel bandage for an integrated action. Feasible locations for application of external binding in case of a single story building are outlined in figure11.

c. Corner Strengthening

a. Strengthening With Wire Mesh

Two steel meshes (welded wire fabric with an elementary mesh of approximately 50x50mm) are placed on the two sides of the wall; they are connected by passing steel rods (each 500 to 750mm apart), Figure 12. A 20 to 40 mm thick cement mortar or micro- concrete layer is then applied on the two networks thus giving rise to two interconnected vertical plates. This system can also be used to improve connection of orthogonal walls.

d. Pointing of Exterior Wall

After repairing, the joints of the brickwork shall be racked out to a depth of 20 mm (3/4″) and the surface of the wall washed and cleaned kept wet for two days before pointing. The materials of mortar cement and sand, or lime and surkhi or sand, kankar lime as specified, shall be of standard specifications. The materials of mortar shall be first dry mixed by measuring with boxes to have the required proportion as specified (1:2 or1:3 for cement sand mortar, 1:1 for Lime surkhi (Crushed burnt brick bats) mortar of kankar lime mortar), and then mixed by adding water slowly and gradually and thoroughly mixed.

Mortar shall then be applied in the joints slightly in excess. Extra mortar if any is removed and surface is finished. Mortar shall not spread over the face of bricks, and the edges of bricks shall be clearly defined to give a neat appearance. After pointing the surface shall be kept wet for seven days.

e. Strengthening of Roofing Elements

The strengthening of roofing elements will be similar to measures suggested for mud buildings.

CONCLUSION

In view of strengthening the non- engineered buildings; focus was on maximum utilization of locally available resources to cut down the expenditure. The cost is worked out for retrofitting of these building typologies. It was found that for mud buildings, the average cost of retrofitting comes to 5.27% of reconstruction cost and similarly for brick building, the retrofitting cost arrived to 5.8%.

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