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Paper No. 161. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ESTIMATION AND ABATEMENT OF THE URBAN SEISMIC RISK

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ABSTRACT

The seismic risk (SR) assessment and urban seismic safety provision are the problems at issue. It is born out that built (buildings, structures, lifelines, infrastructure) vulnerability is an increasing, decisive and controllable factor of seismic safety by means of which we can and must manage the SR. The offered standard Programme of Preventive Seismic Safety (PRESS) consists of the Programme for Risk Analysis (PRANA) and the Programme for Risk Management (PRIMA). The new approaches, rules and recommendation for EQ-reliability of existent buildings and structures, which are considered as a crucial factor of the urban seismic safety, were elaborated. The main approaches to and definitions of vulnerability degrees, SR levels, disaster unpermissibility and acceptability, etc. are given. The certification of buildings and structures, DataBase and GIS creation, damage estimation methodology and disaster damage scenarios (DISC) technique are developed. The special methods of preventive aseismic strengthening of buildings, bridges and reservoirs have been worked out. As a result of implementation of the PRANA on the seismic-prone urbanized region (SPUR) of Kamchatka, Russia and in response to the increase of the public SR-awareness a new improved Govermental Programme "Seismoprotection" was approved for Kamchatkan SPUR and is step-by-step being realized. The consequences of possible EQs on the SPUR of Kamchatka are being assessed by means of the DISC and a special scale for disaster measuring"DIMAK".

KEYWORDS

Built environment; sustainable development; earthquake disaster scenario; seismic vulnerability; risk analysis and management.

INTRODUCTION AND BACKGROUND

The urban seismic risk growth

At present the seismic reliability of existent buildings and structures, the seismic safety of old settlements and big cities is becoming more pressing then the seismic stability of new buildings, which are designed in accordance with the modern seismic codes. The tragic consequences of the recent Hyogo-ken Nambu EQ (Japan, 17.01.95) and Neftegorsk EQ (Russia, 28.05.95) brought out again that even progressive seismic codes could not stave off the buildings collapse and human losses. On the one hand, the human activity (large artificial water-reservoirs, mining, underground explosions, etc.) leads to the EQ-provokation, and on the other hand, a population density and industrial concentration cause the numerous secondary disasters, difficulties in rescue works, of survival and provision for the steady functioning of the growing urban agglomerations. The development of the seismic observation network, the improved scientific approaches and the recent quite unexpected EQs (Gazly, 09.04 and 17.05.76; Newcastle, 29.12.89) result in more high-level estimation of seismic hazard and reconsideration of seismic zoning maps. Thus, the number of urbanized regions, which are considered to be seismo-prone ones (SPUR) is growing in the world. So the urban seismic risk (SR), during which an urban vulnerability is play a dominant and crucial role, has considerably grown. In some cases even not very intensive EQ may cause a big disaster on the vulnerable and unprepared SPUR.

Existent structures and urban vulnerability

To withstand the future strong EQs succesfully and to realize the reasonable Disaster Mitigation Policy for Safe and Sustainable Urban Development we need both the comprehensive approaches to this problem and the revision of some of our views and concepts. It largely relates to the existent buildings and structures in operation, the EQ-resistance of which determine the urban vulnerability to EQs, the potential direct damage and, thus, a SR on the SPUR.

Among the reasons of special interest to the urban SR and to the existent buildings are:
- the fact that the EQ-disasters are possible on the SPUR only and the degree of disaster is determined by vulnerability of one or other SPUR to EQs;
- the still deficient attention to existent structures as the main objects for urban invulnerability and safe sustainable development as a whole;
- influence of actual designing art, constructional quality, design durability & service life, real age and deterioration, wear-and-tear, maintainces & repair, etc. upon the physical state of the existent constructions, its EQ-resistance and seismic vulnerability;
- when designing a new structure we create an integrated model of a building in which construction materials with average features are used, whereas in the case of existent buildings we can use the detail inspection results and performance data about the physical state of the structure. It has an important impact on the mathematic method of solution, which has become more deterministic than probabilistic;
- distinctions in the current varying criteria of the permissible and real SR for just designed and existent buildings;
- evolution of our EQ-knowledge and experience which refines the maps of seismicity, improves the building codes, etc.

It is expedient to make distinction between two main groups within the builting environment: BE-1, i.e. - residential buildings and common industrial facilities for which the up-to-date scales of seismic intensity (MSK, MM) can be carried over; and BE-2, i.e. - special structures, lifelines & facilities, which must by considered differently than the BE-1. So it is a new philosophy and a special way to study the existent builting environment, which have been developed since 1987 (Klyachko, 1987, 1995 a).

We examine the Socio-Economic System of Urbanization (SESURB) as an integral interrelated combination of the human surrounding, i.e.: (a) - natural (geo-ecological), (b) - builting (economic) and (c) - social (legal, tax, credit, insurance, population health, Civil Defence, etc.) environments.

Each part is determined by its own vulnerability to the EQ peril. However, to mitigate the forthcoming disasters we can use the building and social vulnerability. Here we will look more closely at the urban building environment and its vulnerability to EQs and to "triggered" effects. The "money questions" from the part "c" which are related to"a" and "b" can be also considered during a cost-benefit analysis. The urban buildins vulnerability varies in damaging causes-and-effects through the buildings & structures, namely:
- causes: planning and constructional vulnerability;
- effects: human (population) vulnerability - deaths, injured, health losses, suffering, homeless, etc. and economic vulnerability - structural damage and financial losses.

Today the most progressive part of mankind is aware of the impossibility of further safe and sustainable development without the planned Risk Management in the framework of the special Disaster Mitigation Policy for Preventive Seismic Safety (PRESS). This is reflected in general decisions of the IDNDR. Just due to this reason many countries develop and implement the Programmes for Risk Management (PRIMA). However to withstand successfully the forthcoming disasters and to minimize the possible consequences of EQs, first of all we should know as much as we can about what may happen on one or other urban area under EQs and triggered perils. Just this task is being solved in the framework of the Programme for Risk Analysis (PRANA) by means of Disaster Scenarios (DISC), which are based on the specially ordered GIS and are accompanied by the Scale for Disaster Measuring "DIMAK" (Klyachko, 1993, 1994, 1995 b, c).

GOAL AND TASKS

The ultimate goal of the PRESS Programme is an ensuring of the safe and sustainable development of the SPUR, especially of big cities. According to the SR determination (see table 1.) we must provide for the real SR within an admissible risk area.

Table 1. Determination of Risk Areas

	PROHIBITIVE RISK		
	HIGH LIMITING RISK		
ADMISSIBLE	TOLERABLE RISK		FEASIBLE
	SUITABLE	ALLOWABLE RISK	AREA
RISK		LOW LIMITING RISK	
	RISK	NEGLIGABLE (IGNORABLE) RISK	

Our current tasks are: in the framework of the PRANA:

- to develop the GIS & DISC's creation methodology, Damage Estimating Technique (DAMESTEC), Disaster Measuring Scale DIMAK, rules and recommendations for evaluating the urban seismic vulnerability and damagability and for the analysis and awareness of the urban SR;
- to create the standard DataBase, Bank of Experience, GIS and EQ-DISC for typical SPUR implement and test a standard DISC on the concrete SPUR for further dissemination;
- to clear up the most vulnerable spots inside the building environment;
- to set up the determination of disaster unacceptability and permissibility, ignorable, allowable, tolerable and prohibitive SR;
- to give opportunity for the decision-makers to aware the SR and to take all the best with as great care as possible to withstand the EQs and avoid an unacceptable disaster.

In the framework of the PRIMA:

- to develop the most effective methods and technologies for preventive aseismic upgrading and strengthening of existent buildings and structures under operation;
- to carry out the preventive low-cost & effective urgent countermeasures to improve seismically the existent building and social environment, to cope with the secondary industrial perils, to realize these short-term measures to withstand the EQ and long-term programme for the safe and sustainable development;
- to control the state of SESURB by means of a complex monitoring system;
- to be prepared to manage the emergency situation and to assure the quick reabilitation.

THE PROGRAMME FOR THE RISK ANALYSIS (PRANA)

The method of solution. In accordance with (Klyachko, 1994,1995 b, c) for the risk analysis in the framework of the PRANA the following matrix equations are used :

$$D = A_i \times W_k \times V_{ik} \times T_{st} \quad (1)$$

$$A_i = H_j \times U_i \times I_{ik} \quad (2)$$

where: D - matrix of the complex damage in the SESURB; A_i - matrix of multifactor actions on the SESURB, (i - index of influence); W_k - block-matrix of the SESURB's worth, (k - index of object under influence); H_j - matrix of hazards (dangers), (j - index of danger); V_{ik} - block-matrix of the SESURB's vulnerability; I_{ik} - matrix-identificator of influence of the damage-forming factors; U_i - block-matrix of the damage-forming factors; T_{st} - time-operator; s = 1,2,3,4 - season indicator; t = 1,2,...,24 - daytime indicator.

To complete the above-mentioned matrix and to solve the Eqs.(1,2) we apply the developed Method of Expert-Logical Evaluation and Systematic Analysis (MELESA) which uses the "Theory of Fuzzy Sets or Eroded Images", the principles of "Reasonable Sufficiency", "Economic Expediency", "Optimized Choice", "Risk Smoothing and Leveling" for BE-1 or "Weak Points Protection" for BE-2.

The basic tools and main content of the PRANA are the Disaster Scenarios (DISC) including the Damage Estimation Technique (DAMESTEC) and the Scale of Disaster Magnitude DIMAK. The informative basis of DISC is a specially ordered GIS (Klyachko, et.al., 1993 b). DISC creation was demonstrated in (Polovinchik, et.al., 1995), so below is shown a brief description of DISC's composition.

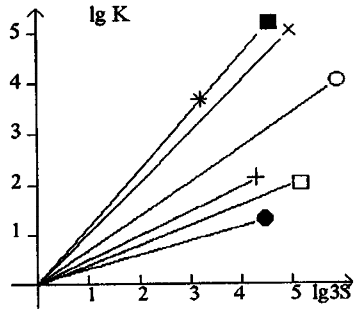
Study and Certification of the SESURB and GIS creation, including: refinement of seismic hazard and impact (a); revealing, location and assessment of secondary natural and man-made dangers (b); collection of the Database of the natural and man-made features, of the specific SESURB, where the certification and assessment of the EQ-resistance of buildings are carried out according with (Klyachko, 1987 c); the formation of the Bank of Knowledge and Experience (d); the creation of GIS ordering in correspondence with Eqs.(1,2) form (e) convenient for use; the formation of matrix H,U and W(f);

*Vulnerability Assessment_*, including:
(a) the study of Legal, Taxes & Insurance Vulnerability, Construction & Planning Vulnerability, Medical & Lifelines Vulnerability, Emergency Readiness, etc.;
(b) the examination and mapping of the damage-forming factors, its interrelation, significance in the damage forming process, influence on the components of the matrix W; formation of the matrix I;
(c) the mapping of the SESURB vulnerability; the formation of matrix V and A.

Risk Analysis, including:
(a) the development of DISCs depending on the perfection of SESURB's GIS: estimatation of direct damage caused by EQ (DISC-1), taking into account the secondary disasters (DISC-2) and a state of lifelines, survival and other factors of emergency readiness (DISC-3);
(b) the playing-out of various DISCs to estimate the losses and damages and to understand the SR; the mapping of risk for various seasons, day-times, weather conditions, DISC's levels, etc.;

The DAMESTEC, the special technique for estimation of damage in the buildings under Eqs which was being developing from 1988 to1993 (Klyachko, 1987, 1995 b, c) and taking into consideration an EQ-intensity on MSK, a level of EQ-resistance, construction type of each building, its vulnerability and damagability in accordance with the MSK Scale. The SR analysis for lifelines & special structures is an extremely important part of the EQ-disaster readiness because the stable operation of the life-systems permits to mitigate the disaster and to eliminate emergency situation. The importance of the life-systems determines the high significance of the DISC-3 for PRANA & PRIMA. However, the life-systems have some specific features which differ from conventional buidings. When analizing the

SR in relation to lifeliness & special structures the application of the MELESA is becoming the obligatory. In doing so we must take into account: the distribution of the life-system i.e. different distance of its elements from the EQ-focuses; the extension of the life-system; the disposition of the life-system elements in the most seismically dangerous places (faults, slopes, sea and river coasts, etc.; for example, bridges cut across faults & ruptunes and its intermediate pylons bear on the susceptible liquifaction soil-base); the different role and significance of the life-system elements the during emergency situation.



∗ - Neftegorsk, 28.05.95; Md = 4.53; p=1.06
○ - Hyogo-ken Nambu, 17.01.95; Md=6.67; p=0.69
● - Shikotan-Hokkaido-Toho-Oki,04.10.94;Md=3.36; p=0.31;
□ - Northrige, 17.01.94; Md=4.93; p=0.38;
■ - Manjil, 21.06.90; Md=6.3; p=1.06;
+ - Loma Prieta, 17.10.89; Md=4.80; p=0.42;
× - Spitak, 07.12.88; Md=6.45; p=0.94.

Figure 1. Magnitude (Md,p) of the recent EQ-disaster

The DIMAK Scale. For many years, in spite of a wide existed range of various scales for measuring the different phenomena of intensity, the scale for the disaster measuring are quite absent. Meantime it is impossible without it to assess and compare the happened and predicted disasters, to determine and pick out the more advantageous and effective preparatory measures for disaster prevention and mitigation, etc. Developed since 1989 the Disaster Magnitude Scale "DIMAK" adopts "one fate" (ft) and "one loss" (ls) as the units of any disaster. The amount of fatalities (K) and the size of financial losses (S, usd., mlns) are the basic parametres of this scale. In accordance with the DIMAK Scale we can conversate D_1, measured by "fates" to D_2 measured by "loss". In this case one injured is evaluated quantitatively in average by $ 10.000 and one killed - by $ 330.000. The last step of the risk analysis is the assessment of the EQ disaster by means of DIMAK and the comparison of estimated SR with acceptable SR. The classification of the Disaster Magnitudes in accordance with the DIMAK Scale is presented in table 2, the assessment (vector's length Md and p=lgK/lg3S) of recent damaged EQs is given in the Fig.1.

From Fig.1 it is clear that the urban vulnerability is a main affected factor determining the disaster magnitude (Md); doing so the population vulnerability level determines the relative amount of fatalities (factor p). It is an important fact for deep attention that the EQs in the former USSR (1988 and 1995) and Iran (1990) caused the most relative amount of killed & injured people (p>0.9).

Table 2. Classification of Disasters Magnitude according to the "DIMAK" Scale

Degree of disaster	Terms for Discription (Qualitative estimate)	Score (Quantitative estimate) Md	Examples of the EQ-disasters
0	No disaster	<1,0	Incidents
1	Minor disaster*	≥1,0 - 2,5	Australia,Newcastle , 1989
2	Disaster	≥2,5 - 4,5	Montenegro ,1989; Indonesia ,1992 Shikotan-Hokkaido, 1994
3	Major disaster*	≥4,5 - 6,0	Guatemala ,1976; Romania ,1977; India, Lahor,1993; USA, Loma-Prieta, 1989; USA, Northridge, 1994; Russia, Neftegorsk, 1995
4	Terrible disaster*	≥6,0 - 7,0	Italy , 1980; USSR, Spitak , 1988; Iran , Manjil 1990; Japan, Kobe ,1995
5	Catastrophe	≥7	China, Tagnshagn,1976

Note:*for refining the degrees of disaster it is allowed to use the additional terms "rather" and "very".

THE ADMISSIBLE SEISMIC RISK DETERMINATION

In doing this we are guided by efficient considerations based on the next approaches, criteria and conditions of disaster undesirability and permissibility.
Approach 1. Any disaster is undesirable and community must take a great care to prevent the disasters.

However due to a limitedness of our knowledge and potentials the big expenses will be not advantageous and even the maximum efforts will be impossible to prevent disasters entirely, i.e. the reasonable disaster mitigation policy, regquired.

Approach 2. The disaster must be permissible. By this is meant that disaster have not to be socially unacceptable. At this joint the some criteria of disaster permissibility are possible, namely:
Criterion A: The risk of death or health losses must not be higher-than-normal risk level for one or other person. This target criterion is rather close to the approach 1 and ignorable SR.
Criterion B is softer than the criterion A. It corresponds to the approach B and permits a higher-order just high SR i.e.allowable SR.
Criterion C:The property losses must not be very big or should be recompensed by insurance.

By reference to the experience of the past EQs (Fig.1) the next conditions of the disaster permissibility are offered.

Condition 1: the disaster with hard social consequences is unacceptable, i.e. according to DIMAK the Scale index of the relative social vulnerability p=lg K/lg 3S must be $p<[p_1]=0.5$ (for developed countries) or $p<[p_2]=0.75$ (for developing countries)

It is clear that if a condition 1 is met ,the disaster magnitude Md is mainly determined by the economic losses. Thus the *condition 2* of the disaster permissibility is: the degree of disaster must be below 2, i.e. Md<4.5.

To assess a possible influence of disaster on the concrete country (state, territory in its own right) of various economic power and its potential to eliminate the emergency we need additional *condition 3* of disaster permissibility: a relative score of disaster magnitude must not exceed 0.5 (dm≤0.5).

The disaster is considered as relatively permissible one, if the conditions 1 and 2 are met. The disaster may be considered the fully permissible one for any SPUR if all three conditions are met.As an example the Shikotan-Hokkaido Toho-Oki EQ (04.10.1994) causes a permissible disaster both for Russia and Japan, but according to the condition 3 this disaster was "fully permissible" for better prepared and more economically powerful Hokkaido Island in contrast to the Kuril Islands, Russia.

Correspondently the relatively permissible seismic vulnerability of one or other SPUR is considered a vulnerability of such SPUR when the action of designed EQ causes a disaster satisfying conditions 1 and 2. Fulfilment of condition 3 is required for fully permissible EQ-vulnerability of SPUR.

THE PROGRAMME FOR THE RISK MANAGEMENT (PRIMA)

In the context of safety of the building environment the PRIMA provides the satisfactory seismic reliability of existent buildings, structures and lifelines to preventan unacceptable disaster. To upgrade and strengthen the hospital, school and residential buildings, bridges, reservois, etc. many various manuals, new effective and low-cost decision and typical projects was made. Among them are the methods of pneumoseismoprotection of reservoirs, of Upper Dampering Storey, of Superimposed Stiffness, etc. The standard designs of the bridge reinforcement are carried out with and without seismoisolation devices. Application of most of these decisions is also the improved post-tensioning or exterior frames used in the Russian SPUR in the framework of the Programme of preventive seismic strenthening of structures(PRESESS), which is a special subprogramme of PRESS.

IMPLEMENTATION

Since 1988 the PRESS is step-by-step being developed and implemented on the SPUR of Petropavlovsk-City, Kamchatka , Russia. At present the DISC has been carried out in the following variants:

- DISC-1 for the night-time, in winter, under seismic impacts of 8 and 9 MSK-intensity;
- DISC-2, which takes into account the secondary effects of tsunami, snow avalanches, soil instability, explosions and fires, hazardous chemical storages and facilities (ammonia and chlorine);
- DISC-3, which is elaborated for the several city's plots of local Civil Defence and takes into account the electric & heat power and water supply facilities and lifelines.

Due to DISC we can analize and understand the SR and then develop and realize the PRIMA in the Petropavlovsk-City. The current and target results of disaster preparedeness buildings are presented in table 3.

Table 3. Current results of possible disaster estimation (in terms of DIMAK)

Result of DISC Night, I=9	EQ - consequences								
					DIMAK Scale estimates				
	K	I	HL	S ($,mln)	Md	p	degree of disaster	Terms for disaster description	Score of disaster permisibility
Before PRIMA, 1990	3 000	14 000	100 000	8 000	5.63	0.8	3	major disaster	unacceptable
During PRESESS 1994	2 000	6 000	65 000	4 200	5.29	0.8	3	major disaster	unacceptable
Target results	200	1 500	9 000	1 200	4.29	0.67	2	disaster	semi-accept.
	50	200	5 000	1 000	3.95	0.5	2	disaster	permissible

CONCLUSIONS AND RESULTS

- The urban SR growth has been demonstrated in a conclusive way.
- The peculiarities of existent constructions have been studied and its decisive importance for EQ-disaster degree has been established.
- The modern approach to the EQ-disaster mitigation policy is presented as an integrated Programme of Preventive Seismic Safety (PRESS) which consists of the Programmes for the Risk Analysis (PRANA) and for the Risk Management (PRIMA), accompaning the urban sustainable development.
- The vulnerability of the SPUR is a sole factor by means of which we can and must manage the seismic risk to withstand the disasters and to ensure the safe and sustainable urban development.
- The DISC + DIMAK is a best integrated tool for vulnerability assessment and risk analysis, i.e. the basis of the EQ-disaster, prevention and mitigation policy. Thus the use of this tool by the city administration allow to aware risk and hold keys to strengthen the SESURB to withstand the EQs.
- The approaches, methodology, technique and manuals for certification and EQ-resistance assessment of the buildings and bridges were developed and tested by the long-standing practice.
- The technique of the EQ-disaster Scenarios (DISC), the corresponding mathematics apparatus MELESA and the Scale for Disaster Measuring "DIMAK" have been elaborated and implemented for vulnerability assessment and SR analysis on the SPUR of Petropavlovsk (Kamchatka, Russia), where the certification of buildings, Database, Bank of Experince and GIS have been created in advance.
- The criteria and conditions of disaster undesirability and permissibility, the levels of SR were determined and adopted; the limiting states under the EQ-load for the buildings and structures of

various main constructive types and functions were set.

- Damage Estimation Technique for the main constructive type of the residential buildings has been developed.
- The DISC elaborated for Petropavlovsk-City have permited to understand and aware the SR taking into account both the direct EQ-damage and the multidisasters under tsunami, landslides, snow avalaches, secondary industrial and military dangers as well as the EQ-consequences connected with the unpreparedness of lifelines, civil defence staff and population.
- The modern methods of seismic upgrading of bridges and standard projects for pneumoseismoprotection of reservoirs, water-towers and dams were implemented.
- Currently available methods and technology for preventive strenthening of the residential buildings without interruption of the service have been developed and implemented.
- SR awareness on Kamchatka leaded to the govermental decision to approve a PRIMA the renovated special Federal Programme "Seismoprotection", prepared by the KamCENDR and which is bieng realiz to withstand the predicted nearest violent EQ.

- The annualed control of effectiveness of disaster preparatory measures by means of repeated "DISC & DIMAK" shows how the current assessments of possible disaster come close to the result desired.
- The up-to-date knowledge and advanced technology are sufficient to really and successfully prevent and mitigate the EQ-disasters. Thus our knowledge and experience need to be translated into implementation of disaster mitigation policy; the developed and implemented tools for the SR analysis and standard Programme PRESS=PRANA+PRIMA may be disseminated to other SPUR.

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