25 Years of EQ Preparedness in the Russian Federation

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SUMMURY:
Implementation of the preparedness program to probable EQ in the most seismically-prone regions of the Russian Federation is under consideration. This article describes a strengthening of existing buildings only. Strengthening is always preceded by seismic inventory and evaluation of buildings in urban area. Start point of such work was a governmental decree 21/11/1986, which appeared as a result of prognosis of destructive EQ with epicenter in Avachi gulf near Petropavlovsk-Kamchatsky. A lot of first projects that used traditional methods of buildings' retrofitting were impossible for implementation, because they were very time-taking and required a resettlement of habitants. That is why "non-stop building's service" methods and technology of strengthening were urgently elaborated. These methods of technologies for strengthening of masonry and large blocks residential buildings, kindergartens, schools and hospitals were tested by strong and damaging EQs are described. There are most significant ones: the method of superimposed stiffness and the strengthening of buildings by means of post-tensioned system. As a rule both methods are combined with the method of exterior frame. Besides, modern methods for retrofitting the buildings from prefabricated structural elements (large panels, large blocks and RC frames) are considered: the method of upper dampering storey; bandaging; by means of composite material incl. nanomodified materials; and seismic isolation devices.Long-term implementation into practice allowed to estimate the advantages and the field of rational application of the one or the other strengthening method, to learn and overcome technological difficulties, and improve the design models and to test the effectiveness of realized solutions.Current control and monitoring of strengthening efficiency is provided by means of accompanying of disaster scenario "DISCONT".

Keywords: disaster preparedness, non-stop building's service strengthening, new technologies, effectiveness control, disaster damage scenario

1. INTRODUCTION

At present, the problem of preventive preparedness of urbanized earthquake-prone areas for probable earthquakes is becoming more and more pressing. The growth of towns and cities, concentration of hazardous production processes, development of transport infrastructure, vulnerability of lifelines and facilities all result in an increase of seismic risks. Even the most advanced states belatedly come to realize that the loss of human lives and economic losses arising even from not so great seismic events can be highly extensive, i.e. absolutely unacceptable. If at the end of the 80's preventive seismic retrofitting of hospitals and schools in the USA was carried out only in California, then in the 90's this process took over the entire West Coast from Anchorage to Argentina, and starting from 1996 NHRP swept over the USA, as well as the areas of medium and low seismicity. A positive contribution to the expansion of this program was made by the 200th anniversary of the New Madrid earthquake: in the middle US states there are being actively developed scenarios of probable seismic disasters and the number of seismically retrofitted residential and school buildings is growing. That is why it is deemed interesting and useful to share the 25-year experience of preparing Russian towns and cities, located in earthquake-prone areas, for probable damaging and destructive earthquakes.

2. BACKGROUND

In the former Soviet Union, whose vast territory included a lot of earthquake-prone areas (Central Asian republics, the Caucasus, the Russian territories in the Far East and Siberia), the issues of seismology and earthquake engineering were treated quite seriously; however, the problems of integrated preventive preparation for destructive earthquakes were first voiced in the Resolution of the Council of Ministers of November 21, 1986. As a result, seismologists developed and the Government adopted a short-term forecast of earthquakes with an epicenter near the urbanized area of Avacha Bay, where the city of Petropavlovsk-Kamchatsky - the capital of Kamchatka – is located, as well as the towns of Elizovo and Vilyuchinsk.

The Soviet Union State Committee for Construction (Gosstroy) commissioned the development and subsequent implementation of preventive seismic safety program (PRESS) to the Far Eastern Research Institute of Construction (DalNIIS), which, in order to deal with the commission, established a branch in Kamchatka. After 2 years, this branch became RND CENTRE on Earthquake Engineering & Natural Disaster Reduction (CENDR). The program of preparation for earthquakes and a corresponding action plan, developed by CENDR, included the following problems and solutions:

A) Seismic inventory and evaluation of build environment.

B) Identification and evaluation of secondary hazardous seismogenic natural and technogenic processes.

C) Understanding of seismic risks and criteria of their acceptability.

D) Identification of the most effective ways of determining operational/short-term activities and development of a long-term program aimed at reducing seismic risks.

All the above-listed problems formed a risk analysis sub-program – PRANA.

E) Development and implementation of a risk management program – sub-program PRIMA.

It is clear that solving the above-identified problem “from scratch” would have been impossible, and the corresponding knowledge base had been formed in the previous decade. Within an article it is impossible and really not necessary to talk about the big long-term difficulties faced by the author when trying to introduce unfamiliar terminology and new concepts necessary for risk analysis. First of all, it was concerned with structural vulnerability, vulnerability of the population, proper understanding and use of the words “hazard”. Saying such things as “earthquake-prone area” and even more a “seismically hazardous building” in the 70’s and 80’s in the Soviet Union was simply unacceptable. However, thanks to the team of like-minded people and assistants, a well-structured, properly arranged and clear program called PRESS was developed by the author as a certain benchmark, which was later referenced and implemented in different earthquake-prone areas with due account for their specificity.

3. BASIC PROVISIONS

As basic provisions, let us turn to the concept of “vulnerability” as a key factor in seismic safety, the only parameter that can be and must be used to manage seismic risk (Klychko, 1993,1994b, 1996b, 2002b) . In the mid-70’s, the author gave the below-stated definition of to the term “vulnerability”.

Vulnerability of object of risk in relation to a certain damaging factor – the ability of this object to sustain its own damage or cause damage to another object under the influence of this damaging factor.

Since the risk of disasters is determined by the probability of both human and economic losses, one should distinguish 2 types of vulnerability.

Vulnerability of humans or the population under certain influence - the ability of humans to lose the quality of life due to this influence.

Vulnerability of built environment consists of structural vulnerability of buildings and the planning vulnerability of a human settlement, city /village. Vulnerability of a building (structure) is referred to as the proneness to lose its structural reliability and/or performance as a result of this influence. In the early 80’s, there appeared a need for classification of structural vulnerability of buildings and structures, and the author proposed a 10-degree scale of vulnerability levels: out of which 8-9 were working levels. Later, in the early 90’s, the European Seismological Commission in the process of drafting an improved scale MSK, later called the European macroseismic scale EMS-98, proposed a

scale of structural vulnerability, which had 6 classes of vulnerability arranged in the order of vulnerability reduction from class A to class F. The first version of the scale seems preferable, since such a classification of vulnerability may result in the user's suffering from contradictions and errors, because in the classes of vulnerability increasing from A to F the value of this vulnerability is actually decreasing.
In the new standard - ModEMS-10 (M. Klyachko, 2012), the lowest vulnerability class A, and the highest vulnerability class F, are divided into 2 sub-classes, resulting in the appearance of class A_1 or "0" (outstanding V) and class F_2 or "G" (guaranteed seismic stability). The appearance of sub-class A_1 was caused, for example, by a survey of the consequences of the earthquake in Bam (Iran 2002), and by the erection of such buildings, which are destroyed even in case of earthquakes with intensity VI. An example is a building with a steel skeleton filled with unbound brick walls and brick ceilings. Isolation of vulnerability class F_2 is explained by the need to design and build earthquake-resistant buildings in areas with initial seismicity of 10 points assigned as per the A OSR map for sites with generalized soil conditions.

4. ABOUT SEISMIC INVENTORY AND CERTIFICATION OF BUILD ENVIRONMENT (BE)

Certification of build environment in earthquake-prone areas was for the first time in the world proposed in 1986 in the Soviet Union, where there was subsequently developed and approved by the State Construction Committee (Gosstroy) the first manual (M. Klyachko, 1987). Manuals developed in FEMA for similar purposes ("RAPID VISUAL SCREENING OF BUILDINGS FOR POTENTIAL SEISMIC HAZARDS: SUPPORTING DOCUMENTATION", "Seismic Evaluation of Existing Buildings: Supporting Documentation") were published in 1988 and 1989.
Improved certification manuals were republished in Russia in 1996, 2000 and 2010. These practical guidelines took into account the international project "Radius", within the framework of which in over 70 cities of the world, buildings were subjected to seismic inventory, and the result – seismic safety and building reliability certificates were presented in a form suitable for computer processing and use in urban planning.
Certification of build environment of an EQ prone area allowed to describe standard life facilities buildings, potentially dangerous and technically complex objects of risk (PORTOs), create a system of basic objects of safety analysis (BAOBAB), based on which regional catalogues of buildings-representatives are developed. Also, most importantly, there was created a database as per the so-called buildings-analogues without which it is virtually impossible to develop reliable disaster scenarios that we will discuss below. A progressive role in the practical implementation of these objectives was played by the project EERI in terms of developing the "World Encyclopedia of Vulnerability".
Central to the certification process is the evaluation of vulnerability of buildings and structures. It is only and primarily vulnerability that is a key feature of buildings' condition and the only parameter by which engineers can and should reduce the risk of seismic disasters.

5. ANALYSIS OF SEISMIC RISK IN URBANIZED AREAS

The next step after certification is risk-analysis of seismic risk. The purpose of seismic risk analysis is to understand the real situation in some earthquake-prone urbanized area associated with likely consequences of earthquakes for the life and health of residents of this area, their property, businesses, etc.
Risk analysis must result in specific quantitative (numerical) evaluations, and not in often used vague (blurred) categories such as "big", "small" risk. A person living in a world of risks in rural or urban area, using various types of transportation and living close to hazardous industrial facilities should be aware of all the risks and be able to compare them so as to consciously use his right to choose a safe location. The main tool of risk analysis are scenarios of probable disasters (DISK). A detailed development of this tool and its introduction into practical use started in the 80's and was described in

detail (M. Klyachko, 1995, 1996a, 2000a, 2004). In 1998 for the purpose of analyzing comprehensive natural & technogenic risk (seismic risk, first and foremost) there was developed in Russia the -GIS "extremum", and later in the USA there was developed the similar GIS HASUS. Since over the last 10 years development and introduction of DISK for completely different purposes has become somewhat of a fashion, it is important to emphasize typical mistakes which are made in this procedure. The fact is that in absolute majority of the cases DISK uses methodologies of evaluating probable losses and damage based on using a certain macroseismic scale. There is no problem with the fact that these scales are different, since they are well harmonized. The problem is that by setting the intensity we thus obtain the consequences by definition, which are, in fact, in a fairly wide range of probability. In order to reduce this range of probability, it is necessary to consider on the one hand not only a limited, but on the other hand a sufficiently large urbanized area, and also know well the seismic reaction of a large number of identical buildings (in terms of their shape, dimension and structural type), at the same time located in different soil conditions. In such cases when BE comprises a large number of identical, standard, traditional buildings, regional catalogues of buildings' vulnerability are extremely useful and even necessary. In such cases when there are few identical buildings, it is necessary to refer to buildings-analogues whose seismic behavior is well known from the lessons of the past EQ's. Only by complying with these basic methodological conditions it is possible to assert that this or that DISK constructed based on evaluations of structural vulnerability of buildings is performed in a satisfactory manner. It is necessary to dwell upon another condition, which it is crucially important to comply with. In order to be able to compare seismic risks not only on the global or interstate/regional level, but on the local level as well (considering, for example, two neighboring provinces), it is necessary to use identical methods of risk analysis. Otherwise many results will have no practical meaning whatsoever. In any case, such unification must be practiced within one country, whereas insurance companies are free to choose those methodologies, which they think the most appropriate. Since 2004 in Russia, as the next step toward seismic safety, there have been developed maps of seismic risk (M. Klyachko 2005, 2006), in particular individual risk, both for various constituent entities of Russia (regional level maps, scale 1:200000), and for cities (city and municipal level maps 1:10000–1:50000). All the said maps are developed based on a unified methodology adopted in the country, so that the values of risk in different regions of the country could be compared. Enhancement of this methodology will allow to centrally revise evaluations of risk in all 32 earthquake-prone urbanized regions of Russia without changing, for example, the ranging as per seismic risk. Proper performance of this very important phase allows to take into account comprehensive seismic risks in the programs of regional development of the country in terms of ensuring their sustainable safety.

6. SEISMIC RETROFITTING

As mentioned earlier, the basic engineering method of increasing seismic safety of SPUR is preventive seismic retrofitting of BE. Many countries still lack seismic standards in relation to existing buildings. That is why it was important to establish criteria for seismic safety of old buildings. In fact, there may be several such criteria, and selection of a suitable one depends not only on the economic opportunities of a country or province, not only on social and, for instance, housing policy and the program of development of a certain SPUR, but also on such target factors as, for example, the final performance level of a retrofitted building. It is understandable that in old buildings with reduced residual service life and operating time demand for their usability can be reduced. However, in any case, the minimum and the most commonly used criterion of sufficiency of seismic retrofitting is the requirement of ensuring the safety of human life and health. These approaches and differentiation of various physical (in terms of structural reliability) and operational conditions of buildings (in terms of requirements for usability) have been developed by the author since 1984 and used in the standards for certification and seismic retrofitting of buildings. As mentioned earlier, seismic retrofitting of housing stock of any SPUR requires using methods of seismic retrofitting radically different from those usually used to recover from damaging EQ's. One of the reasons is the lack of temporarily allocated public housing and the impossibility of resettlement of large numbers of tenants with their property. That is why since 1987, simultaneously with the development of necessary standards and requirements, CENDR began an active search for already known and development of new non0-stop operation technologies of seismic retrofitting of masonry and large-block residential houses, kindergartens, schools, hospitals, ambulance stations and fire stations. Today it is safe to say that the already tested and widely introduced methods of seismic retrofitting such as PTS (Post-tensioned System) and SIS (Superimposed Stiffness) have turned out to be effective from all points of view. First of all, they do not require relocation of tenants and do not restrict normal operation of buildings. These methods have proven to be very effective in terms of labor intensity (4-storey residential building for 36 apartments is retrofitted within 1-2 weeks) and cost (100-150 USD/sq.m.). And the most important manifestation of their effectiveness consisted in excellent results of seismic retrofitting. i.e. a real increase in seismic resistance, which was proven during the analysis of damage to buildings after strong EQ's in 1993 and a damaging EQ in 1997 in Petropavlovsk - Kamchatsky. It was confirmed that the use of these methods actually reduces structural vulnerability of seismically retrofitted buildings by two classes. In 1996 CENDR developed special guidelines approved by the Ministry of Construction of Russia, whereas in 2001 - albums of standard technical solutions implementing these methods.

In recent years, this important area of preventive seismic retrofitting has gained new development. First of all, the field of application of seismic retrofitting has expanded, i.e. it has become required for reinforced concrete frame buildings, and even for pre-cast large-panel buildings, whose high seismic resistance has not previously been challenged. Among reinforced concrete frame & pre-cast buildings there have been more and more often identified vulnerable buildings with a flexible floor, with improperly reinforced elements, certain buildings having frames without girders and joints, without diaphragms or ties, prone to progressive collapse, etc. As regards pre-cast large-panel buildings, their insufficient seismic resistance is primarily stipulated by high degrees of wear due to the absence of normal operation, as well as current and major repairs for 10-20 years. One of the peculiarities of seismic retrofitting of reinforced concrete frame buildings is that it is virtually impossible to perform their seismic retrofitting without disrupting their normal operation. The most effective method of seismic retrofitting of such buildings is installation of additional diaphragms or bracers, whereas the most challenging and complicated thing in their design is computer-based modeling of various seismic retrofitting options, which often requires high engineering skills.

7. NEW TECHNOLOGIES AND MATERIALS

In recent years, rapid development of materials science has brought to the construction market a large number of new materials and technologies. Focusing on the problem of seismic retrofitting, let us mention some of these new products.

Returning to the issue of seismic retrofitting of pre-cast large-panel buildings, it is necessary to recall methods of seismic retrofitting of prefabricated RC buildings by means of polymeric slurries developed by TbilZNIIEP over 40 years ago, which, with participation of TashZNIIEP, were put into the practice of renovating buildings turned defective and/or damaged as a result EQ's and other emergencies. Reliability and effectiveness of these methods were confirmed by the consequences of the EQ in Gazli on March 20, 1984. Pre-cast large-panel buildings in Gazli, renovated and seismically retrofitted in 1981-84 by means of polymeric slurries, were originally built without seismic retrofitting and suffered serious damage during two EQ's in 1976 with the intensity of 8 and 9 points respectively; however, they bore quite well an EQ with the intensity of 9 points on March 20, 1984, suffering only minor, easy to fix damage. Yet, this method was not widely used due to technological restrictions when performing the works and relatively high cost of polymer-cement slurries. Labor intensity of this method was also quite high, since it was necessary to install special dowels in pre-cast elements to be connected. Recently, there have been developed such polymer-cement compositions and technologies, which ensure connection of the to-be-connected reinforced concrete elements on the molecular level along the lines of their joints, thus the corresponding modern technology of renovation – seismic retrofitting consists of step-by-step procedure of applying polymer-cement materials along the joints of the to-be-connected elements in the form of horizontal and/or vertical stripes 25-30 cm wide. In this case, not only high shear and tensile strength of connections is ensured, but also structural continuity, water tightness, high resistance to aggressive media and longevity under ambient temperatures within the range of -20ºC up to +40ºC. Such renovation – seismic retrofitting is easy to perform and fully controllable, whereas its cost is around 40-50 USD per sq.m. of residential area of a pre-cast large-panel building. Using for the presently considered cluster of seismic retrofitting methods the term "bandaging", it is also necessary to mention the use of carbonaceous materials, whose effectiveness for seismic retrofitting has been fully proven by dynamic (including seismic explosion) tests at an experimental test site near the town of Vyborg in Russia. Taking into account the fact that the cost of these still expensive materials has been steadily going down, it is safe to say that their use will become expedient and efficient in the near future. B. Rapid development of nanotechnologies allows to obtain new building materials with such unique properties and their combinations, which until now seemed impossible.

One of such examples is the relatively well-tested, nanostructured light-weight concreted as per TC 5789-035-23380399-2008, which, being light-weight, can also be high-strength and water-tight (hydrotechnic up to W20). The concrete has high workability and castability. In terms of using it for seismic retrofitting of buildings and in earthquake engineering in general, this nanostructured concrete (NSC) can be used very effectively. For instance, the SIS method the combination of NSC properties "light+strong+very hard" allows to considerably enhance the efficiency of placed reinforced concrete diaphragms. A similar effect is achieved when using this concrete in shear walls of frame buildings. One of the most attractive properties of this NSC is its tensile strength characteristics, in which case there is no brittle failure that concrete is prone to, since there is quite a long "even area" on the sigma-epsilon diagram; thus, it is safe to say that this concrete is extremely valuable for earthquake engineering, because it possesses long ductility.

8. CONCLUSIONS

The above-presented analytical review of the 25 years of development of approaches, methods and technologies, as well as the results of their implementation in the practice of seismic retrofitting of existing buildings in Russia, provides the ever-important and necessary transfer of knowledge and experience. Lessons of recent EQ's in Italy, China, Haiti, Chile, Japan and New Zealand have reaffirmed the importance of preventive seismic retrofitting to ensure sustainable safety of SPUR, and the annual meeting of EERI in April 2012, dedicated to the 200th anniversary of the New Madrid EQ and the general program of preparation in the central states of the USA for a probable EQ, have shown the interest of specialists in the exchange of practical experience in implementing programs similar to NSHP. The author hopes to continue discussions on the topics dwelt upon in the article, which Prof. Haresh Shah called the "last mile".

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