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VULNERABILITY OF STRUCTURES FROM THE ASPECT OF SEISMIC SAFETY AND RISK IN ARCHITECTONIC DESIGNING*

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Abstract. *It is natural the people should be most interested in the behavior of buildings during earthquakes, as they spend the most of their time in them. The times when the buildings were designed and constructed for unknown customers have passed. Apart from the static stability, which must not be endangered, care must be taken of functional and esthetic features. The buildings are long-lasting and expensive human property, more so in the seismic areas, so by their quality they must guarantee safety to their users. Regarding high seismicity and frequency of earthquakes on the territory of our country, safety of social resources and human lives must be harmonized with the development degree and future needs of the society and the users. Through seismic safety and reduction of risks, we protect ourselves from collapse and damage of the structures, from injuries and human casualties, and from direct and indirect, economic and functional, social and other damage. For these reasons building in seismically active areas is a complex task. Complete protection from the earthquake action is not possible, and for this reason the level of seismic risk represents an acceptable vulnerability for the corresponding period and probability of excitation. Structures are protected from collapse and seismic damage if the appropriate regulations are applied. Seismic division in micro-regions represents a good approach to defining an uniform criterion of protection of structures and protection of equipment in them.*

Key words: *vulnerability, risk, earthquake, seismic safety, designing.*

1. INTRODUCTION

Taking protective measures in spatial and town planning and designing is considerably more efficient and rational when good structural concept is chosen and construction is of good quality. Earthquakes as natural forces act for a short time but they destroy the vital

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structures of human settlements and disrupt normal life for long periods of time. That is why planning of settlements, and large cities in particular, is a complex task even in non-seismic conditions and is particularly complicated in seismically active areas, regarding the unpredictability of earthquakes on the Earth's surface.

The basic philosophy of designing of seismically resistant structures is to prevent human injuries, ensure survival of vital functions and keeping the damage on the property as low as possible. When designing structures, it is necessary to ensure their functionality, rationality and safety for all possible loads, and so for earthquake actions. When determining the earthquake load, there is a high uncertainty of the data which are most often defined in statistical sense of their probability of occurrence. In the similar manner, the strength of the structure can be defined in a statistical sense but the absolute reliability cannot be achieved. Yet, with the increase of resistance of a structure to the earthquake action, a sufficiently small collapse probability can be achieved, i.e., sufficiently high safety. On the other hand, the increase of safety renders the structure more costly, so it is a question what degree of safety is acceptable. The issue is not only technical in nature, but also the socio-economic and there is no solution for it. The ultimate degree of safety comprises protection against: a) technical and b) social effects of collapse [4].

We can build structures of various safety degrees. The adopted degree depends a lot on the quantity of available finances, because the cost increases with the increase of the safety. The methods of determining safety must yield solutions which satisfy both technical and social aspects. The engineering structures collapse due to failure or due to functional deficiencies. In addition, there is, as it has already been said, the social dimension. It requires introduction of an additional safety degree to what is required by technical considerations. This additional degree protects the owner, user or general public from the effects of collapse. It is generally known that full protection from the action of earthquake is neither economically justifiable nor possible. For buildings with a lot of people, a higher level of safety is required. The same holds for the structures whose function is vital during and after earthquakes such as, hospitals, power plants, fire fighting services, water supply facilities, etc. Everything said so far relates to protection of an engineering building as such. However, often the constructed hospitals, factory halls and similar structure, withstand earthquakes quite well, but the equipment and devices in them get damaged because they are not secured with the same degree of safety risk to the intensity of earthquake as the structure building itself.

2. VULNERABILITY OF STRUCTURES AND EQUIPMENT

Vulnerability of structures depends on its own dynamical characteristic and the character and level of the excitation. The interdependence of the occurrence of the earthquake and its action on the entire human activity expressed by the probabilistic approach is given through the seismic risk. Thus the level of seismic risk is an acceptable vulnerability of a structure for the appropriate time period, level and probability of excitation. Taking of efficient protection measures from the catastrophic earthquake can be solved through the town planning only if they are treated as a part of the complex of technical, economic, functional, esthetic and other criteria. Having in view concrete seismic conditions of the area being urbanized, application of principles of aseismic building in town planning and designing to a great extent results in reduction of earthquake consequences and decreases sesmic risk in seismically active areas [6].

Defining of global seismic risk and levels of acceptable risk, as one of the basic parameters in production of town and spatial plans is related to socio-economic potential of investment in this kind of protection. Classification of structures according to their importance and the period of their depreciation are the parameters necessary for evaluation of seismic risk. For this reason a special attention must be paid to the structures of special importance of whose functioning depends operation of other technical and technological system, whose disruptions can cause catastrophic effects on the environment, that is, cause large material damage to a wider community. With this in view one should analyze designing of infrastructural networks (hospitals; electric, water supply and sewage networks; steam and gas mains; fuel reservoirs etc), irrespective of whether they are under or above ground. By reducing the potential for their damage during the earthquake action, one improves the conditions for efficient assistance to the injured, i.e. reduces the number of possible casualties and accidents after an earthquake, and the potential for fire breaking out and explosions. Therefore, when planning and designing traffic routes it is desirable to provide parallel links, i.e. unimpeded traffic, access to collapsed structures and help in post-earthquake critical moments. Pursuant to the regulations of technical norms for construction of high-rise structures in seismic areas, these structures are designed so that the highest intensity earthquakes can damage the bearing structure, but it must not collapse. This part of the regulations protecting the structure of the buildings is in most part observed, and for this reason the structures withstand the earthquakes well, but the equipment in them gets damaged or destroyed, because it is not secured to withstand the same level of seismic intensity of an earthquake as the structure of the building. The provisions of the Regulations providing for the protection of elements or equipment in the buildings are mostly not observed.

3. Seismic Hazard and Seismic Risk

Seismic risk is defined as an expected degree of loss caused by the effects of future earthquakes: by collapse or damage to the structures, injuries or loss of human life, direct and indirect economic, functional, social and other damage. Seismic hazard is defined as part of natural hazard and represents potential of occurrence of earthquakes of corresponding characteristics (intensity, velocity, soil oscillation acceleration, etc.) in a certain period and on a certain location [5]. The results of seismic hazard and seismic risk differ in qualitative terms. The seismic hazard defines the probability of occurrence of earthquakes, that is, expresses prediction of future earthquakes, and by that, because it can be directly applied, contributes the reduction of seismic risk.

The result of seismic risk is related to the effects caused by the earthquake, that is, represent the function of interdependence of an earthquake as a natural phenomenon and human activities. The best practical method for presentation of earthquake parameters, for the certain geographic region is a map of seismic hazard where the effects of an earthquake are presented in the form most convenient for the designing engineer.

For the analysis of seismic risk, it is possible to define several mathematical models depending what we wish to analyze, and one of the acceptable models is presented in

Fig.1 [5]. Apart from the level of seismic loading based on the seismicity of the location, for the purpose of defining the seismic risk, it is necessary to establish the relations between:

a) service period (economically justifiable service life) of the structure;
b) adopted level of risk;
c) return periods corresponding to the defined level of risk and service period.

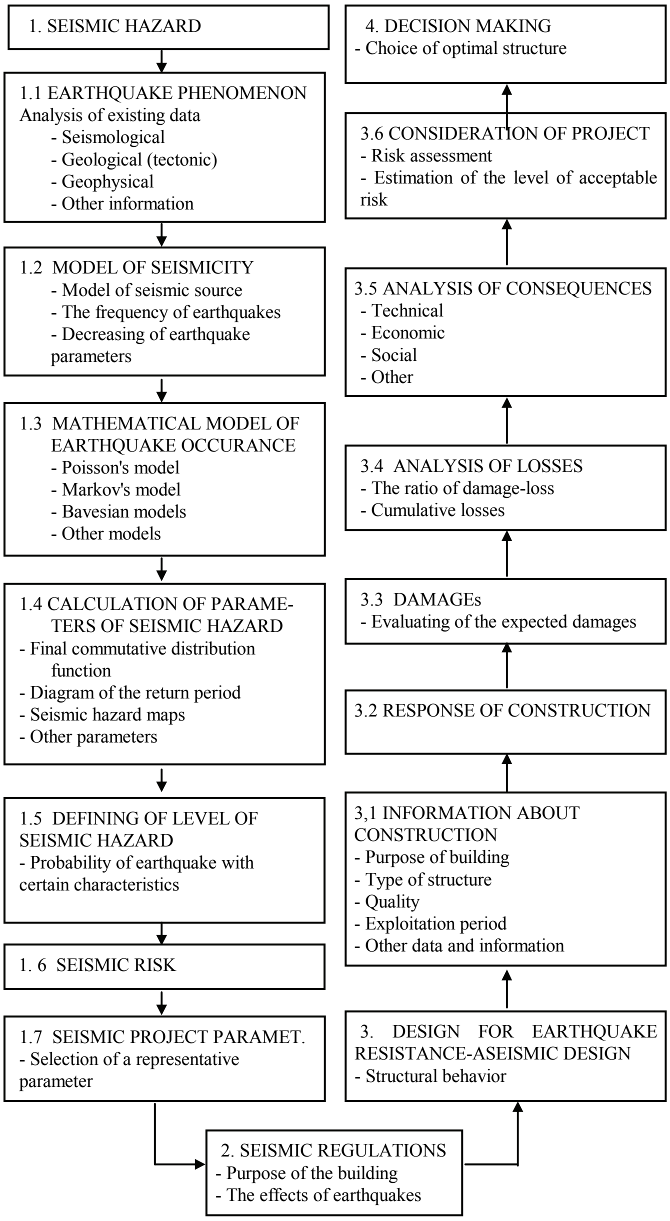

Fig. 1 Dependence of parameters of potential focus

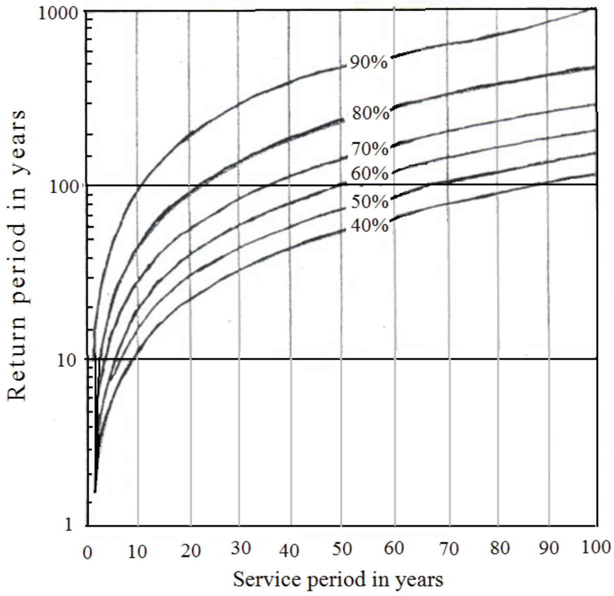

Fig. 2 Dependence of the return period on the service period of the facility and an acceptable level of seismic risk

In Fig.2 is presented the dependence of the return period on the service period of the structure and the level of acceptable seismic risk. The goal of the analysis of behavior of the structures during exposure to seismic action is conduct statistic prediction of potential damage of the structure. Potential damage and losses are the result of excessive reaction (response) of the structure, so the reaction calculations are of great importance. The loss is the result of the damage and it consists of two categories: determinate and indeterminate. Determinate losses are those defined by spending investment capital, while the indeterminate losses are mostly composed of injuries or loss of human life, for which reason no adequate quantification is possible. Very often, the interests of the investor and people using the structures do not coincide, in terms of safety of structures to earthquake action. The risk in this view is neglected and the earthquake is treated as a force major which needs not occur in the time in which the persons responsible for construction of the structure would be accountable for neglecting of the corresponding regulations.

4. View of the Regulations of Construction in Seismic Areas

Many urbanized and industrial areas, as well as other structures of capital value are located in high seismicity areas, but they were built without taking into account the earthquake effects. For the purpose of regulation and detailed urban planning, and for aseismic designing and building, it is most likely that seismic division in regions and micro-regions are a good approach to defining a uniform criterion. Spatial planning is a very complex activity. The plans of spatial planning must be based on the fundamentals of social and economic development, as well as on the data on economic and technical components of space. In laws regulating spatial planning, it should be proscribed that one of the basic documents for production of a spatial plan must be an appropriate seismologic map. In the procedure of issuing civil engineering permits, one must control whether the technical documents are produced in agreement with the various public interest. Protection of the interest is regulated by the special regulations which specify the organs or organizations which are monitoring application of those regulations. In practice, the control of regulations of building in seismic areas is not performed by a controller, but he possibly checks whether the technical documents comprise mentions of application of these regulations. For those reason, in the recent years there is a case in conversion of some residential or other space into office or when adding floors onto existing buildings, that the Regulation provisions are violated [7], [1].

The protection of equipment in structures must be paid due attention as provided for in the mentioned Regulations [3]. According to the article 35, the effects of seismic forces on the structural elements are calculated according to the expression:

$$S = K_S K_e G_e \,, \tag{1}$$

where:

K_s = (0.025-0.10) - is the coefficient of seismic intensity,

K_e = (2.5-10.0) – is the coefficient according to the article 36,

G_e – is the weight of the structural element for which the seismic force is calculated.

The equipment must be in an adequate way fixed to the floor or walls to retain its functionality during and after the earthquake. Anchoring of equipment in buildings, whose displacements or toppling over can endanger human lives and cause damage, is calculated according to the article 35, with K_e=10.0, to prevent the equipment from toppling over. The calculation of anchoring of precious equipment, whose function is necessary in buildings, is done by the method of dynamic analysis of structure-equipment [2]. In order not to have a large part of necessary equipment as damaged and unserviceable after an earthquake, in a relatively undamaged structure, it is necessary to secure both the structure and equipment with the same degree of safety. Some American research and experience in the earthquakes indicate that due to the effects of amplification on some parts of the equipment, the acceleration was more than 1,0·g (g- gravitational acceleration), in horizontal and vertical direction. Hospitals, as the most important institutions for human health care must be prepared to provide help at any time, and especially after catastrophic disasters such as earthquakes. In those moments, it is important that the equipment of the hospital is not damaged and ready to use, and that medical personnel is unharmed and ready to commit to their primary task – helping people. Medical equipment is mostly expensive, and necessary, so these are the main reasons to take care to adequately protect it. The protection methods are varied and relatively simple and cheap. The medical equipment is composed of both complex necessary devices for life support to simple by costly auxiliary equipment. If the entire equipment is not preventively protected in an adequate manner, the image after an earthquake can be terrifying: the sights of toppled over and broken equipment lying around on the floor, broken glass and spilled liquids which can be poisonous, injured inpatients and medical staff. Equipment may appear fine after earthquakes, but due to the internal failures or damage of auxiliary devices may be rendered useless. The same principles of design of the structure hold for the design of equipment protection. However, none of the calculation methods guarantee that the equipment will remain serviceable after an earthquake.

5. Conclusion

The existing regulations for designing and building in seismic areas and their rigorous application would contribute to a higher degree of protection from earthquake action. Defining of seismic risk must have adequate treatment in the spatial and town planning and architectonic designing and construction. The effects of taking preventive and protective measures in the design phase are more efficient and rational than the measures which would be taken to remove the earthquake effects and damage. Taking these measures means significant increase of costs in construction so they need to be harmonized with of the principles of urban planning, such as technical, economic, sociologic, functional and others.

Having in mind that human life is invaluable, the equipment in important structures and particularly in hospitals should be paid more attention than now. When it comes to a life-important equipment facilitating the unlimited and necessary operation of the system, it is necessary to provide its reliability with no compromises, both during and after the action of earthquakes. With the same degree of seismic safety, it is necessary to secure both the equipment existing and future buildings which are important for the life and health of people.

Construction of seismically resistant buildings is primarily achieved through the following measures: by the choice of the location favorable in respect to the seismic influences, by adequate formation the building and adequate constructive disposition, choice of suitable building material, designing structure to seismic action and high quality of building. In practice, often at the time of investment, the interests of investor do not coincide with the public interest regarding the safety of the structure to earthquake action, rather the investors are interested to cut the costs as much as possible. It is known that building in seismic areas requires higher investment. The risk is usually neglected in this case, the earthquake is treated as a force major which needs not occur in the time in which the persons responsible for construction of the structure would be accountable for neglecting of the corresponding regulations. It is necessary that in the procedure of issuing a building permit, the supervisor deliver the investor the already elaborated conditions for construction in seismic areas.

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POVREDLJIVOST OBJEKATA SA ASPEKTA SEIZMIČKE SIGURNOSTI I RIZIKA U ARHITEKTONSKOM PROJEKTOVANJU

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Prirodno je što su ljudi najviše zainteresovani za ponašanje zgrada za vreme zemljotresa, jer u njima provode najveći deo svog vremena. Prošlo je vreme usmerene izgradnje kada se projektovalo i gradilo za nepoznatog korisnika. Pored statičke stabilnosti koja ne sme biti ugrožena, mora se voditi računa i o funkcionalnoj i o estetskoj stabilnosti. Zgrade su dugotrajna i skupa ljudska dobra, još skuplja u seizmičkim područjima, pa moraju svojim kvalitativnim svojstvima garantovati bezbednost njihovim korisnicima. Obzirom na visoku seizmičnost i učestanost pojave zemljotresa na teritoriji naše zemlje, osiguranje društvenih dobara i ljudskih života mora se uskladiti sa stepenom razvoja i budućim potrebama društva i korisnika. Seizmičkom sigurnošću i smanjenjem rizika u velikoj meri se štitimo od rušenja i oštećenja objekata, povreda i gubitaka ljudskih života, direktnih i indirektnih, ekonomskih funkcionalnih, socijalnih i drugih šteta. Zato gradnja u seizmički aktivnim područjima predstavlja složen zadatak. Potpuna zaštita od dejstva zemljotresa nije moguća, zato nivo seizmičkog rizika predstavlja prihvatljivu povredljivost objekata za odgovarajući period i verovatnoću pobude. Poštovanjem odgovarajućih propisa na najoptimalniji način štitimo objekte od rušenja i seizmičkih razaranja. Seizmička mikrorejonizacija predstavlja dobar prilaz definisanju ujednačenog kriterijuma zaštite objekata kao i zaštite opreme u njima.

Ključne reči: *povredljivost, rizik, zemljotres, seizmička sigurnost, projektovanje*