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DETERMINATION OF SEISMIC HAZARD AND ITS CONTRIBUTION TO SEISMIC RISK OF NUCLEAR FACILITY

Seismic safety of nuclear facilities has been under account since beginning the 70s of last century. The seismic protection is realised in practice by special seismic safety management and by seismic safety engineering. Their real forms are codified in national building laws and in developed countries with medium and high seismicity. The ground of seismic safety of nuclear facilities in the determination of seismic hazard of site in which the nuclear facility is located, distinguishing and getting control over unacceptable risks that are connected with vulnerabilities of site, buildings, technologies and technical equipment. The present paper deals with the seismic hazard, seismic risk and seismic safety.

Key words: *nuclear facility; earthquake; seismic hazard; contribution of seismic risk to integral risk; safety*

Introduction into the problem

From the history it is known that sites, domains and sometimes the whole countries after strong earthquake and extreme tsunami often interrupted their development for a long time (e.g. Portugal after Lisbon earthquake in 1755). Return period for extreme earthquakes occurring at boundaries of large plates is several thousand years, and therefore, we have not data and experiences. The size of damages caused by earthquakes on humans and on human system assets is determined not only the magnitude but also number and quality of assets affected by earthquake and also focal dimension. The huge focal dimensions are typical just for great submarine earthquakes accompanied by tsunamis, e.g. 1755 (Lisbon), 2004 (Aceh) a 2011 (Sendai).

The strong earthquakes in Salvador and in the NW India (more than 50 000 victims) in the year 2001, and those in Turkey on Aug. 17, 1999 and on the November 12,1999 (about 20 000 victims, damages more than 30 billion USD), in Taiwan on September 21, 1999 (accompanied by the change of terrain morphology), in Aceh (Indonesia) on December 26, 2004 (about 320 000 victims), Haiti on January 17, 2010 (more than 100 000 victims; country has not been started renovation yet), Sendai on March 11, 2011 (about 18 000 victims, about 10 000 missing, more than 5000 injured, economic losses more 700 billion USD) force us, who work in the professional domain or in the state administration to answer the following basic questions: May such natural disaster occur in our country?; How is our country protected in the case of impact of such strong earthquake?; Are prepared specialist teams and means for early and adequate intervention?

The origin of strong earthquake in collision zone near Indonesia (Aceh 2004), where the subduction reaches 7 – 9 cm per year was predicted in 2003 by Soloviev and Ismail-Zadeh, but warning system protecting from tsunami was only installed in the Pacific part. The strong submarine earthquake with large focal dimension on December 26, 2004 at 06h59m of local time induced large tsunami. The Pacific warning centre distinguished tsunami origin after 8 minutes and after 15 minutes informed that investigated Pacific coast was not threaten, but it had not capability to distinguish the threat for Indian coast. Tsunami reached: Aceh coast after 31 minutes; Thailand coast after about 1 hour; India coast after 2.5 hours; Malevide coast after 3.5 hours; Africa and Madagascar after 7.25 hours etc. The appropriate Pacific tsunami centre warned the Thailand government that had no capability to alert inhabitants because no warning system for emergency caution in the country. This experience shows the importance of emergency preparedness in each country, territory and object.

The great submarine earthquake originated eastward from town Sendai on Japan island Honshu on March 11, 2011 at 14h46m23s (5h46m UTC, 6h46m central European time). Its parameters: magnitude 8.9; Kawasaki magnitude 9; JMA 7; duration about 6 minutes; focal depth 24 km; ground acceleration 2.99g. It had 7 foreshocks (4 with magnitude greater than 6); aftershocks have been occurred yet (maximal one had magnitude 7.8). It affected mass distribution in the Earth’s crust, diverted the Earth’s axis and shortened day on 1.8 ms. The active fault length was about 500 km (from Iwate to Ibaraki) and active fault width about 200 km. These properties caused that tsunami had an

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extreme size. The warning system protected from tsunami reacted and informed the whole coast but tsunami wave amplitude was higher than: the height of normal protected walls (4.5 m) on coast; and then the height of special higher protected walls at industrial complexes (including the Fuku-shima – Daichi nuclear power plant). A lot of technological accidents started, including 3 units of mentioned Nuclear power plants.

At present there are several professional disciplines dealing with earthquake problems´ investigation and solving. The most important are: the seismology, i.e. the science dealing with earthquake investigation; and the seismic engineering, i.e. the discipline the aim of which is to construct infrastructures, buildings and equipment's resistant to earthquake and similar phenomena impacts, and by this way to protect human lives and health and human property. Earthquakes also enable the Earth's interior research (Earth's crust, mantle, external core, internal core and its parts). In literature there is often used general term seismicity; it is used in many different meanings.

1. Seismic engineering

Seismic engineering used for nuclear and other critical facilities building and operating is the advanced risk engineering discipline that is based on philosophy system of systems safety, i.e. the target is security of system of systems and security of vicinity of system of systems at critical conditions at system of systems [6]. The system of systems is a set of overlapping systems. The goal of all managerial and engineering activities is the co-existence of overlapping systems because their targets are time from time conflicting. Their assumptions are: each technological system is open system of systems and is threatened by all hazards to which also belongs failures of linkages and couplings being inside and outside this system of systems; establish synergic relations among the risks, vulnerability and safety; consider interdependences caused by cross-sectional risks; model the process of decision-making the public administration with regard to risks and uncertainties (to perform support decision-making systems); specify legal conditions and protected measures; improve activities of institutions (institutional changes); improve safety systems by new equipment and by independent redundant systems (especially in domains of power and cooling); improve activity of inspections and other check mechanisms; ensure preparedness for extreme events (special resistant control room for response; technical sources, forces and means for special needs of response to extreme events – fire fighters, security guards, technical services, cyber safeguard etc. that are prepared and trained for putting under control critical situation induced by extreme events; finance and material resources for putting under control critical situation induced by extreme events; special methodical procedures for response to extreme events of different kinds; specially trained personal ensuring the first response); improve capability to cope with extreme external and internal events (e.g. special facility – catcher for corium purchase); ensure sources, forces and means for response to extreme events including the support from public administration; educate systematically population; and form (generate) permanently professional background for decision-making by research and science support.

With regard to lessons learned from other technological accidents arranged under the term "organising accident" there is necessary to improve the role of top management and to force it to apply management that is proactive, coming out sophisticated grounds, strategic, tailored to real conditions and understandable to all subjects to which is addressed. The top management must recognise that the safety is not something in advance given, but that it must be created by conscious, directed and linked system measures and interventions, which from the theory viewpoint means to carry out management of safety in public interest and benefit.

2. Seismic hazard

The seismic hazard of a site or locality is the size of earthquake (expressed by the earthquake intensity or by peak ground acceleration of seismic waves – PGA) that may be expected at given locality in a specified time interval with a stipulated credibility, usually 0.95. When we define it, we assume that the origin of earthquakes is a steady uniform process going on in space and time (i.e. in this moment we do not consider the influences leading to the change of processes within the Earth as a consequence of internal and external forces or even by human interventions).

For determination of seismic hazard value there are used the statistical models (algorithms) [2, 3, and 5]. At the theoretical model application there is assumed that: observed seismic activity trend will be preserved in the future; homogeneous distribution of earthquake foci exists in the each zone; random occurrence of earthquakes in space and time exists; independence in the earthquake occurrence in individual focal provinces exists; and same attenuation exists in the region under account.

The hazard curves are calculated for the annual probabilities of non-exceedance of 0.95, 0.85, mean, median and 0.05 in the dependence on local geological conditions [16].

The example of results of extreme theory application, which is used in Central Europe [16], is in Figure 1. In the shown hazard calculation based on the theory of extreme values is used the formula.

3. Getting over seismic risk

The seismic risk expresses a possibility what it might be happen. It is related to a given site, facility, construction or equipment. It presents a set of phenomena that take place at impact of earthquake with size and characterisation corresponding to seismic hazard on the credibility level of 0.95 in a given time interval. It depends on the seismic hazard of locality and on the seismic vulnerability of site, facility, individual constructions and their equipment at the earthquake impact.

The basic requirement of human society is that seismic risk must be acceptable, that is determined by legal rules. It is also true that the seismic risk acceptance changes in time, that is valid for any risk, e.g. consider the change of nuclear power plants acceptance after accidents in Three Mile Island, Chernobyl and in Fukushima.

Quantitatively, the acceptable seismic risk means the set of phenomena that are tolerable at the earthquake impact. The seismic risk depends on the seismic hazard and the seismic vulnerability. The seismic vulnerability of facilities, constructions and equipment follows from earthquake size and earthquake ground motion characteristics (maximum amplitude of acceleration, maximum ground motion duration, and design spectrum). Taking into account the construction characteristics we can determine with a given probability places in which can occur damages of defined extent at earthquake impact.

In practice the seismic risk is determined on the basis of assessment of response of constructions, systems and components of facility to earthquake with defined parameters. For its assessment it is necessary in each case: to create the tree of failures and events that lead to accident of critical facility or of its most vulnerable and most risk technological part at earthquake occurrence, i.e. they lead to defect or to loose of functional capability of relevant components at earthquake occurrence; and to determine the probability of occurrence of individual scenario leading to technological accident.

For designer the seismic risk is defined by the response spectra form and by the strong ground motion duration or by the accelerograms´ set. Data for seismic risk assessment are: safe shutdown earthquake (SSE); design basis earthquake (DBE); ground motion accelerogram; duration of maximum phase of acceleration; floor accelerograms; ground response spectrum; floor response spectra.

The assessment of seismic safety of technological facilities to which belong nuclear installations, chemical facility, storage of hazardous and toxic substances, military facilities of different types etc. must consider: facility (technological or civil) represents the system consisted of elements (components) and links (linkages) and flows (of energy, information, substance etc.) among them. There is possible to subdivide a set of

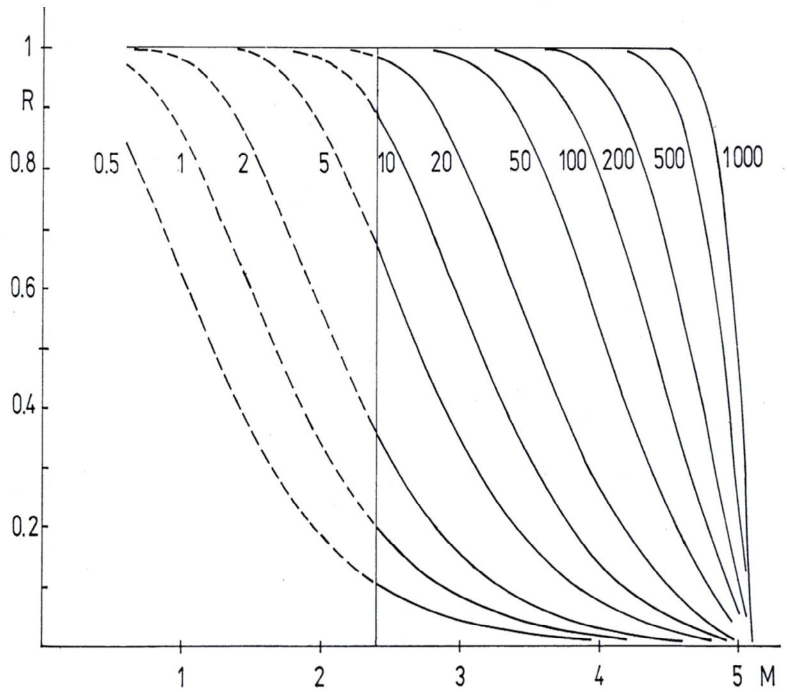

Fig. 1. Seismic hazard for site in Central Europe determined by help of extreme theory

sub-systems (at some level autonomous), that are created either by nature or by human kind and that are mutually affected. They have basic characteristics, properties and different mechanisms that affect possible development scenario of construction response to seismic waves at the earthquake impact; and human factor.

Determination of seismic risk of individual facility or its construction or its equipment is performed either directly (computation, test in laboratory) or indirectly (by analogy). At constructions and their equipment it is necessary to consider the quality and physical properties of materials, ways and quality of mounting and the effects of ageing on material and mounting the structures. The engineering assessment is based on the knowledge and experience of expert who by site walkdown determines if the seismic risk is greater than acceptable value or tolerable one. The deterministic assessment of safety of equipment (or selected systems and components) is codified in legal rules of many countries and it is usually very conservative. The probabilistic assessment has two steps: determination of possible variants of behaviour of components and systems at the earthquake impact having the size corresponding to site seismic hazard; and determination of probabilistic curves for occurrence of defects of facility, i.e. its constructions, systems and components that are safety related, ⇒ aggregation of results obtained for individual variants - median or median + σ. For risk determination there are used methods based on process's models [17]. One of the most used methods is the seismic PSA [25].

Conclusion

The seismic protection is realised in practice by special seismic safety management and by seismic safety engineering. Their real forms are codified in national building laws and in developed countries with medium and high seismicity also in special legislative. In-depth forms of both disciplines are processed in nuclear engineering, and therefore, further main attention is concentrated to this domain. Seismic safety management is advanced risk management that is based on negotiation with seismic risk in the profit of public interest; i.e. it also includes the precaution principles. The same holds for seismic safety engineering that realises targets of seismic safety management and is based on trade-off with seismic risk in the profit of public interest; i.e. it also includes the precaution principles, i.e. it uses specific safety systems and specific operating procedures for effective coping with seismic risk if it is realised.

It is necessary to note, that earthquake is especially danger for technological facilities, even though these are now especially protected against external hazards to which earthquake belongs. The reason is simple, the earthquake can cause: collapse of structures; rupture of pipings; damage of relevant equipment; damage of cables; disturbing cyber nets etc., what can lead to failure of: power supply; water supply; and unacceptable changes in technological process, what can cause further events, e.g. release of hazardous materials, fire, explosion (in nuclear power plant also loss of coolant accident) the impact of which can be much more dangerous than primary earthquake impacts. Therefore, the IAEA recommends to apply seismic PSA (probabilistic safety assessment) and to consider its results for seismic nuclear power plant upgrade. Such seismic assessment must consider broader problems, minimally failures due to seismic ground motion, random failures, human errors and test of maintenance outages [27].

The state safety management system ensuring the disaster protection (including the protection against earthquakes) in the EU and its Member States [28] must: guarantee the protection of human lives and health, property, environment and technical infrastructure; consider all relevant disasters with possible occurrence on its territory and against relevant disasters it carries out the prevention and preparedness with regard to their impacts; i.e. it must also consider failures of system linkages and couplings; form the professional base, managerial structure, efficient forces, means, substances and sources to ensure protection of human lives and health, property, environment and of the state; and form the professional base, managerial structure, efficient forces, means, substances and sources to ensure renovation after disaster and after crisis.

The strategy of seismic risk management [29] is based on the knowledge of real seismic hazard and on the use of preventive measures (technological and organisational) that mitigate the earthquake impact when a strong earthquake comes into existence. To be able to reduce a seismic risk we call for: the determination of real seismic hazard; the satisfaction of demands of legal rules in force; the use of technical measures that can mitigate earthquake effects; and the set of organisational means for the case when strong earthquake will come into existence. In depth details the seismic management safety demands are given for nuclear facilities.

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ПОНЯТИЕ СЕЙСМИЧЕСКОЙ ОПАСНОСТИ И ЕГО ВКЛАД В СЕЙСМИЧЕСКИЙ РИСК ЯДЕРНЫХ ОБЪЕКТОВ

Д. Прохазкова

С 70-х годов прошлого столетия понятию сейсмической безопасности ядерных объектов уделяется повышенное внимание. Сейсмическая защита на практике реализовывается с помощью специального сейсмически-безопасного управления и инжиниринга. Их настоящий вид прописан в национальном законодательстве развитых странах со средней и высокой сейсмичностью. Понятие сейсмической безопасности основывается на расчете сейсмического риска территории, на которой расположен ядерный объект, определение и получение контроля над неприемлемыми рисками, связанными с уязвимостями местонахождения объекта, его строениями, технологиями и техническим оснащением. В данной статье рассматриваются вопросы сейсмической опасности, сейсмического риска и сейсмической безопасности.

Ключевые слова: ядерные объекты; землетрясение; сейсмическая опасность; вклад сейсмического риска в интегральный риск; безопасность

ПОНЯТТЯ СЕЙСМІЧНОЇ НЕБЕЗПЕКИ ТА ЙОГО ВКЛАД У СЕЙСМІЧНИЙ РИЗИК ЯДЕРНИХ ОБ'ЄКТІВ

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Із 70-х років минулого століття поняттю сейсмічної безпеки ядерних об'єктів приділяється підвищена увага. Сейсмічний захист на практиці реалізовується за допомогою спеціального сейсмічно-безпечного керування та інжинірингу. Їх сучасний вид прописано у національному законодавстві розвинутих країнах із середньою та високою сейсмічністю. Поняття сейсмічної безпеки ядерних об'єктів базується на визначенні сейсмічного ризику території, на якій знаходиться ядерний об'єкт, визначенні та отриманні контролю над неприйнятними ризиками, що пов'язані з вразливостями місцезнаходження об'єкту, його будівлями, технологіями та технічним оснащенням. местонахождения объекта, его строениями, технологиями и техническим оснащением. У даній статті розглядаються питання сейсмічної небезпеки, сейсмічного ризику та сейсмічної безпеки.

Ключові слова: ядерні об'єкти; землетрус; сейсмічна небезпека; вклад сейсмічного ризику в інтегральний ризик; безпека.

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