About Permissible Damage Degree and Structural Seismic Safety

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SUMMARY:
Proposed article aims to improve seismic codes and harmonization of approaches and decisions relating to assign the seismic impact and acceptable performance of the building in case of such loading. Degree of structural damage associated with the probability of deaths, injury and suffering of the people, with performance and serviceability of buildings after design earthquakes, with economic damage tolerance. Thus, the permissible damage degree determines the value of the permissible risk level (PERIL). In fact PERIL is the hidden basis of any seismic code, independently of methodological approach, which uses, for instance, the physical and operational condition of the buildings or the coefficients of admissible damage, or the performance based design, etc. The dependence of the permissible damage degree to various new and existing buildings, which are differed in their functional assignment, responsibility, serviceability, residual service life, is offered. Recommendations to improve, to unify and to harmonize the approaches and solutions based on the seismic risk acceptability and permissibility are offered differently for developing and developed countries. Article is illustrated by example. Conditions of community resilient are given using the disaster magnitude scale DIMAK in new miracle and graphic forms.

Keywords: earthquakes, seismic damage, disaster magnitude, permissible risk, sustainable safety, resilient

1. INTRODUCTION. BACKGROUND

Some permissible risk level (PERIL) is laid in any building code, but it is not obvious. We have brought out the hidden PERIL from the different national codes, and it became clear that PERIL (i.e. possible EQ consequences) was not actually standardized. That is why, it was underlined that direct standardization of SR extracts this key & target parameter from a hidden scheme into an evident one.

2. PERFORMANCE OF BUILDINGS

As is well known, operative investigations into consequences of natural and technological disasters have long been using symbolic cards of three different colors: green, signifying that further operation of the building is allowed; yellow, meaning that the building can be operated subject to functional or temporal limitations, and red – when the condition of the building is so dangerous it call for urgent demolition. This mini-scale, sometimes known as American Red Tag (ART), served at the basis for the MART scale.

Civil engineers have probably always had the understanding that risk of loss and damage under extreme exposures should be evaluated on the basis of pre-designated condition of the building. It is this condition – the condition the building comes into during extreme exposure – that is considered acceptable. In mid-80s the author suggested to divide condition of a building into physical condition, dependent on structural reliability and the ultimate limit state (ULS), and operational condition, determined by the requirements for the building's capacity to be comfortable, functional, not harmful to property located within, to ensure fast and safe evacuation of people, not to harm human health and to maintain serviceability. The physical condition of the building is described by the degree of damage sustained, the operational condition – by the ability to satisfy certain design criteria. Thus, it is possible to manage risks both through physical and operational condition of a building, and therefore, it is advisable to carefully consider each of the two paths separately.

The performance requirements for buildings in design and emergency situations may vary. In some cases it is even possible to demolish the building in which there are no people and assume is to be quite acceptable.

Risk of adversity is also influenced by performance characteristics, including: the quantity of people (including the size of the maximal shift), work time duration, presence of potentially hazardous substances or processes, electricity and natural gas supply, people's readiness to evacuation, their awareness, level of training, etc. Consequences will be substantially different for a boarding-school dormitory with grilled windows at night, a hospital housing non-transportable patients, or a sports college in broad daylight, even if the buildings themselves and the emergency events are similar.

It is hardly possible to rank different risk factors according to their impact on the after-effects of emergencies. Yet it is an undeniably useful task, to correlate probable operational conditions of a building and the amount of damage sustained di (i= 0, 1, 2,3,4,5), and this has been done in the MART scale.

In discussing physical condition of a building, we should first of all note that building of different structural types show completely different behavior under extreme conditions and exposures. They are damaged in different ways and key elements responsible for the damage degree are also different. It is very important to provide necessary relationship between degrees of damage based on detailed description of damageability of different structural systems. Of particular importance are such descriptions at threshold/critical points, the crossing of which corresponds to a new level of serviceability. In particular, extremely important is the moment when a building becomes dangerous for human life and health, i.e. individual risk becomes unacceptable. This moment, for example, corresponds to the possibility of selling slab collapse (PERIL1) or the beginning of progressive collapse (PERIL2). It is to specify this moment that we improved the classification of building damage degrees by introducing degrees of damage 3A, corresponding to PERIL1, and 3B, corresponding to PERIL2.

As a result, a rational list of generalized categories of building serviceability conditions can be given: a fully functional (serviceable), usable, or normal condition, slightly limitedly usable condition, and very limitedly usable condition, unusable / invalid condition, pre-crash usable condition.

3. DESIGN SITUATIONS

Now let's turn to stresses and exposures, which in turn lead us to consideration of design situations. Here structural analyst can be given free rein – it is only necessary to fully understand the probability of this or that design situation. Let's start with rating of seismic hazard, dividing it according to the intensity of possible event (6, 7, 8, 9 or 10 points) and its recurrent period: very frequent (< 25 years). Then, scale and probability of the expected design situation affects the decision on whether to take this event into account in calculations, or ignore it. General Seismic Zones Maps of Russia (OSR97) include A Maps with event return periods of 500, 1000, 2500, 5000 years with different provision. This concerns not only seismic loads, but also creation of corresponding special (seismic) combinations of loads. Shall we add seismic and wind loads, like they do, say, in the US? And if yes, with what weight? The right answer seems to be: yes, we shall, but only in cases when wind loads are big enough. In Russia such combination of loads can be reasonably recommended for the region of Petropavlovsk-Kamchatsky at the Pacific Coast and Novorossiysk at the Black Sea. Similar approach can be recommended for combination of seismic and snow: for a number of regions of Russia, where winter period is considerably long, it might be better to adopt a higher snow load coefficient than the currently used 0, 5. Such statutory changes shall be based on natural meteorological surveys and use the probability of the combination of loads in question for buildings of different purpose and life expectancy as the working criterion. It is worth noting here, that such approach is suitable for calculation of buildings intended to be exposed to hurricanes and tornados, which have their own specifics (wind shadow creating torsion components of the impact, influence of open / broken out doors and windows, etc.).

4. PERMISIBLE DAMAGES COEFFICIENT AND SEISMIC RISK

Seismic regulations currently in effect in Russia and CIS, the coefficient of reduction K_1 is taken as the coefficient of permissible damages, ranging from 1 (for high accountability buildings) to 0.12 (for temporary building with low economic accountability). First of all, it should be noted that while extreme values of K_1 are adopted based on accountability/purpose of the building, all intermediate ranking is determined by structural type of the building in question, i.e. the approaches adopted and used simultaneously are illogical and not unified. These regulations imply self-contradictory/impossible statement that with the values of K_1 (and, in consequence, of nominal seismic load) showing such variation, a building of any structure guarantees safety of people within in case of a 7 – 9 point earthquake! It should be noted that K_1 has been inaptly named. There can not be permissible damages for buildings of different structural types. It is just that buildings of different structures and materials have different elastic reaction ranges, different plastic response properties, i.e., when making calculations for this buildings according to linear spectral theory, it is necessary to apply different force impacts to different buildings, in order to obtain comparable limit states. Badly chosen, inexact, incorrect terminology results in misunderstanding and engineering mistakes. This is why, if we prioritize “seismic risk” in the context of seismic safety, we have to “drag it out” of the seismic regulations, where it is now hidden deep within. Besides, the risk of human losses and the risk of financial damage, these two not always interrelated defining parameters of seismic safety are always in one way or another related to the damage generation properties of BE. Conceptually new, clear and exact regulations, based on seismic risk evaluation and control, which were considered by the Scientific and Technical Council of the Russian Federation State Committee for Construction, Architectural and Housing Policy in April 1998 and discussed in press 10 years ago, are still badly needed by a wide range of users: building designers, insurance companies, CD officers, etc. As for the assignment of K_1 coefficient for seismic strengthening of existing buildings, it appears reasonable to recommend a value of 0.2, which meets the criterion of seismic safety of the building with respect to ensuring life and health of its tenants in case of an earthquake. At the same time, modern seismic regulations mainly take into account resistance to a single earth shock and do not provide for safety of the building in case of aftershocks, while the majority of recent earthquakes were followed by powerful aftershocks. Aftershocks usually have little impact on the number of human losses, yet they are a significant factor of “finishing off” buildings, increasing structural damage and, therefore, the number of homeless. A highly illustrative example of consequences of an aftershock was provided by the earthquake in Christchurch, NZ. The situation when a large amount of residential property is left unused in the affected urbanized area, also constitutes an unacceptable seismic risk, especially in colder countries; yet, this is not accounted for in seismic regulations currently in effect, which should be changed.

5. EVALUATION AND CRITERIA OF DISASTER ADMISSIBILITY AND RESILIENCE

Any intention to reduce any risks or any attempt to improve security are pointless, and financial investments and other efforts to this end are baseless and can not be effective, as long as there are no initial and final (target) risk factors.

In order to evaluate, compare and combat disasters, we must be able to measure these disasters.
For this purpose, the scale of disasters DIMAK was developed in 1989.

To develop this part we have to define built environment of the selected seismic prone urban area (SPUR), i.e. to divide it on the edifices of certain construction types (M. Klyachko, 1987) and to distribute a population within SPUR (to settle people in the buildings of certain construction types). Then, we can develop a night working disaster scenarios (DISK) which gives following: amount of fatalities (killed people) – K, amount of injured people - I, direct economic damage – S ($, billion), homeless people – HL (M. Klyachko, 2004).

Accordance wave DIMAK scale:

Disaster magnitude:

$$M_d = \sqrt{\lg^2(K + 0.03I) + \lg^2(3S)} \tag{5.1}$$

Index of relative social vulnerability:

$$p = \frac{\lg(K + 0.03I)}{\lg(3S)} \tag{5.2}$$

To provide permissibility of multi-disaster and PERIL we recommend following expressions:
Md ≤ 4,5; p < 0,75 (for developing countries)
Md ≤ 3; p < 0,5 (for developed countries)

To withstand the disasters the SPUR has to reach sufficient economic capacity.

Determination of degree of violation of the SPUR sustainable development by means of calculation of relative disaster magnitude:

$$d_m = \frac{L}{S_d} \tag{5.3}$$

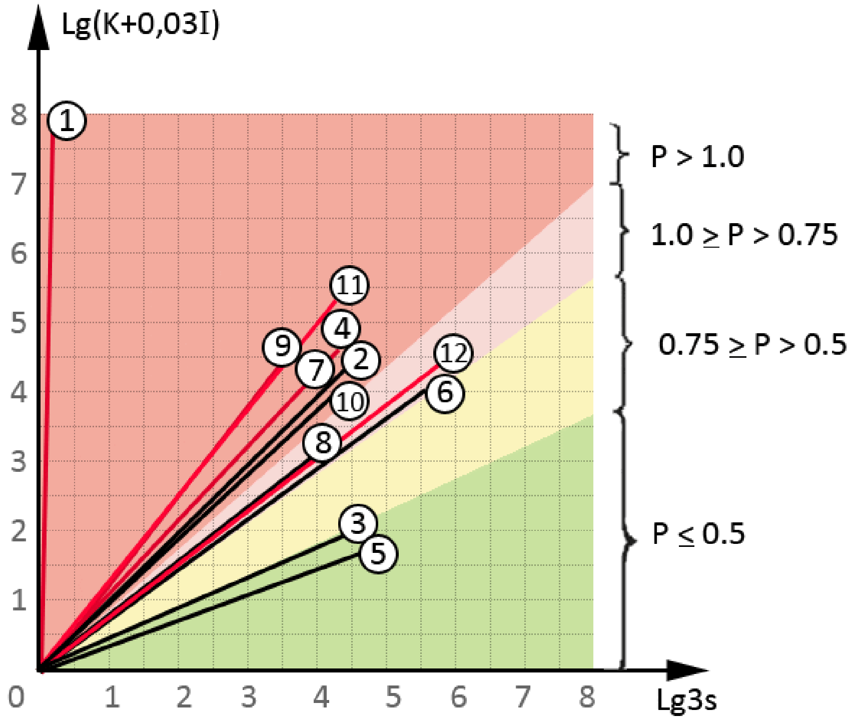
where L – generalized economic losses,

$$L = \left(\frac{K}{3} + S\right)10^{-3} \text{ (\$, billion)} \tag{5.4}$$

S_d – index of relative economic stability,

$$S_d = \frac{GNP}{100} \tag{5.5}$$

where 100 – GNP of Iran ($, billion, in 1990).
S_d – most important criterion of community resilience.



1. Murrain, Europe, 1337-1352; Md=7.8; p=0;
2. Spitak, USSR, 07.12.88; Md=6.45; p=0.94;
3. Loma Prieta, USA, 17.01.89, Md=4.80; p=0.42;
4. Manjil, Iran, 21.06.90, Md=6.3; p=1.06;
5. Northridge, USA, 17.01.94; Md=4.93; p=0.38;
6. Kobe, Japan, 17.01.95; Md=6.67; p=0.68;
7. Turkey, 17.08.99; Md=5.75; p=1.06;
8. Taiwan, 21.10.99, 04.10.94; Md=5.15; p=0.83;
9. Phuj, India, 27.01.01, Md=5.64; p=1.17;
10. Terror attack, USA, 11.09.01; Md=5.52; p=0.9;
11. Haiti, 12.01.10, Md=6.88; p=1.24;
12. Takohu, Japan 11.03.11, Md=7.29; p=0.77.

Figure 1. Disaster planetary

As 4th criterion of disaster admissibility in addition to Disaster magnitude, Index of relative social vulnerability and Index of relative economic stability we have adopted individual seismic risk – Ri, which is a probability of human losses in the certain place during 1 year.

Complex estimations of all-known disasters are shown at "disaster planetary" (Fig.1) in graphic form (where each point is corresponded to some Md and p).

As an example of "vulnerability-structural damage-EQ intensity" dependencies can use Table 5.1 which is taken out of modernized EMS-98 (9th CCEE, Ottawa, 2007).

Table 5.1. Relation of Damage Grades to Intensity Degree for building of different vulnerability class

Intensity	VULC	Expert LER	Grade of damage (d)				
			1	2	3	4	5
VI	A	no ERD	◑	◔	◷		
	B	no ERD	◑	◔			
	C	~7	◔	◷			
	D	~8	◔				
	E	~9	◔				
	F	Excellent	◷				
	G	Special					
VII	A	no ERD		◑	◷		
	B	no ERD		◑			
	C	~7	◑	◔			
	D	~8	◑	◷			
	E	~9	◔	◷			
	F	Excellent	◔				
	G	Special	◷				
VIII	A	no ERD			◑	◷	
	B	no ERD		◑	◔	◷	
	C	~7	◔	◑	◔		
	D	~8	◑	◑	◷		
	E	~9	◑	◔			
	F	Excellent	◑	◷			
	G	Special	◔	◷			
IX	A	no ERD				◑	◔
	B	no ERD				◑	◷
	C	~7				◔	
	D	~8		◑	◑	◷	
	E	~9		◑	◔		
	F	Excellent		◑	◷		
	G	Special		◔			
X	A/B	no ERD					◑
	C					◑	◔
	D			◑	◑	◑	◷
	E				◑	◔	
	F	Excellent			◑	◷	
	G	Special		◔	◔		

◑ - many (≤60%) ◔ - few (<20%) ◷ - very few (≤**7%**)

6. CONCLUSION

The dependence of the permissible damage degree to various buildings, which are differed in there functional assignment, responsibility, serviceability, residual service life, is under consideration. Both human losses and economic damage stipulated by structural vulnerability which is given in advance by desirable – performance of building environment, i.e. by permissible damage degree and serviceability. In this article nature of vulnerability is explained and disaster permissibility criteria are given. Recommendations to improve, to unify approaches and solutions based on the risk-analyses, which is provided by means of DISK development, are under consideration. To meet conditions of resilient community we can use and the disaster magnitude scale DIMAK (criterion #1, 2, 3), the individual risk estimation (criterion #4) and take into account lessons learned from recent EQ disasters. For countries of various economic capacities (developed and developing countries) different conditions of resilience community are advised. Doing so, we can see on the example of Tohoku EQ that index of relative economic stability (Sd) is most important criterion shown the resilience capacity, i.e. survivability of built environment plus vitality of population.

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