# Assessment of Seismic Risk of Areas with Diverse Site Development with Account of Influence of Local Factors and Ways of its Reduction

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**SUMMARY:**
Consistent and quantitative risk assessment tools for buildings and infrastructure in seismic active areas are urgently needed to ensure an efficient decision making process that facilitates the optimal allocation of available economical resources for the management of risks. To solve this problem on the example of Uzbekistan cities the types of buildings by structural features have been identified and classified. Analysis of the known factors, raising or lowering risk, has allowed reveal most significant parameters. These factors are taken into account with an indicative rating (by three-point scale) and an estimate of their weight by two-point scale. Risk factors for the cities are also endowed with weight functions and importance of the interval values of the groups. Presented technique allows in higher level to solve the problem of damage and risk of cities, critical facilities, as well as simulation scenarios of earthquakes.

*Keywords: earthquake risk, building vulnerability, damage grade, risk elements*

## 1. INTRODUCTION

The developments in earthquake engineering research during the last 2-3 decades provide, within acceptable limits, reliable design of new structures against earthquake loads. However, the existing older building stock still represents a significant risk in regard to the safety of people, mainly due to inadequate design, missing supervision during construction, insufficient quality of construction materials and inadequate ground investigation/interpretation. In such conditions we should focus on the integration of the most important factors, raising or lowering the risk, in a heterogeneous, in constructive terms, buildings. Consistent and quantitative risk assessment tools for buildings and infrastructure in seismic active areas are urgently needed to ensure an efficient decision making process that facilitates the optimal allocation of available economical resources for the management of risks.

## 2. BUILDINGS VULNERABILITY AND DAMAGE GRADE

The main provisions of seismic risk assessment methodology based on the one hand, the prediction of the expected parameters of seismic effects (intensity, repetition period of earthquakes, spectral characteristics of seismic motions, etc.), on the other - assessment of seismic vulnerability of buildings and people on the study territory. Seismic risk is often determined using a seismic modeling computer programs which uses the seismic hazard inputs and combines them with the known susceptibilities of structures and facilities, such as buildings, bridges, electrical power switching stations, etc. The result gives probabilities for economic damage or casualties. While the results can be used as a general measure of seismic risk for types of buildings, the actual seismic risk for any individual building may vary considerably and will depend upon its exact configuration and condition. Acquiring and analyzing the specific data for an individual building or facility is one of the most expensive and daunting aspects of seismic risk estimation. The only tool that we can manage to reduce the seismic risk in order to ensure sustainable urban development it is reduction of seismic vulnerability of buildings. Building codes are intended to help to manage seismic risk and are updated as more is learned about the effects of seismic ground motion on buildings. However, the changes generally do not immediately improve seismic risk in a community since existing buildings are rarely required to be upgraded to meet the revisions. In this paper authors have tried to show importance of the account of local conditions of the urbanized territories for more complete estimation of seismic risk and development of measures more effective and related to concrete territories for its mitigation.

Cities and towns in Central Asia built up with different structural types of buildings. Their analysis showed that the cities of Central Asia, characterized by diverse site development. There are about 30 types of structural systems with different levels of vulnerability to earthquakes. In this regard, the ranking was made of 24 types of structural systems of buildings, the most common in the Central Asian republics, according to their vulnerability to earthquakes, established indexes and functions of damageability, levels detected of so-called "natural earthquake resistance" of each type.

The importance of vulnerability assessments is also of high priority because the majority of structural types are not identified with the structural systems of other countries. Structural design and evaluation of buildings and other facilities with regard to their ability to withstand the effects of earthquakes requires special considerations that are not normally a part of such evaluations for other occupancy, service and environmental loads. Existing techniques of an estimation of seismic risk reflect rather general tendencies of consequences of earthquakes in the urbanized territory. Therefore, as has shown the analysis of estimations of risk, carried out by various methods, results of these calculations essentially differ for the same territory.

For more realistic assessment of seismic risk were established factors increasing or decreasing economical losses from natural disasters for cities and towns. The factors raising or lowering economic damage at natural disasters, including earthquakes, were considered by many authors engaged in an estimation of risk. Special development of work under the account of influence of these factors on size of damage have obtained in connection with necessity of definition of insurance division into districts of the territories, subject to natural and technogenic incidents. Only names of these factors by different authors changes in limits from 20 up to 50. Naturally the account of all these factors qualitatively raises reliability of the results obtained according to risk. As we consider concrete number of objects of vulnerability - civil buildings, so factors which are the most important for taking into account, are dated for a considered infrastructure.

The analysis of the known factors, raising or lowering risk, has allowed to reveal the most significant, in our opinion, parameters. To known factors are referred: intensity of earthquakes; earthquakes of small and average intensity; repeatability of earthquakes, type of the ground condition; level of ground water; deficiency of seismic stability of prevailing buildings; flooring; quality of engineering - geological surveys and their account; quality of design, materials of bearing constructions, facilities and maintenance. By special technique the estimation of vulnerability of buildings was executed depending on their level of earthquake protection and seismic impact with definition of average value of an index of damageability for each constructive type using macroseismic scales MSK - 64 or EMS-98. Table 1 summarizes these factors with a rough rating (three-point scale) and an estimation of their weight by two-point scale.

These factors may be considered at the level of separate building and district of the city, town, region. Value of a rating of damageability of building or group of buildings $r_c$ as first approximation may be defined by the formula:

$$r_c = \sum_{i=1}^{N} \frac{F_i \text{ x } W}{N}, \qquad (1)$$

where: Fi - an expert estimation of i factor by 3-point scale ; W - weight of the factor by 2- point scale; N - number of factors.
The given value of rating of influence of the specified factors on vulnerability of constructive type of building can be determined by the formula:

$$r_r = r_i / r_{max} \text{, where } r_{max} = 57{,}0 \qquad (2)$$

Value of a rating, or its relative value, further will be taken into account at an estimation of parameter of vulnerability of buildings of the city as well as at calculation of economic losses and definition of rating of cities by degree of risk.

**Table 1.** Factors with a rough rating (three-point scale) and an estimation of their weight by two-point scale

| N | Name of the factor | Dimension | Interval values by groups | | | Weight of the factor |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | Seismicity | Intensity units MSK-64 | 7 | 8 | 9 and > | 2,0 |
| 2 | Repeatability of earthquakes | once in 100 years | < 0,01 | 0,1 | >1 | 2,0 |
| 3 | Earthquakes of small and average intensity | MSK-64 intensity unit | 4-5 | 5-6 | 6-7 | 1,5 |
| 4 | Type of a ground by seismic properties | Type | I | II | III | 1,5 |
| 5 | Type of ground by settling properties | Type | Non settling | I | II | 1,5 |
| 6 | Level of ground waters | M | < 3 | 4-6 | >6 | 1,5 |
| 7 | Deficiency of seismic stability of building (prevailing building) | MSK-64 units | 0-1 | 1 | 2-3 | 2,0 |
| 8 | Number of floors (buildings) | Floor | < 3 | 4-5 | >5 | 1,0 |
| 9 | Quality of engineering - geological researches and their account | - | High | Average | Low | 1,0 |
| 10 | Quality of design of object (building) | - | High | Average | Low | 0,5 |
| 11 | Quality of the building materials, bearing material | - | High | Average | Low | 1,5 |
| 12 | Quality of construction | - | High | Average | Low | 2,0 |
| 13 | Quality of operation | - | High | Average | Low | 1,0 |

Features of seismic hazard, for example on territory of Uzbekistan, are regulated by effective standards and rules of design КМК 2.01.03-96 "Construction in seismic areas”.

In design of new and reconstruction of existing buildings it is necessary to take into account parameters of seismic regime of territory of construction site:
a) expected intensity of earthquake in MSK intensity units and acceleration of motions at the basement (maximum and average);
b) return period of seismic impacts on the territory of Uzbekistan;
c) spectral content of seismic motions of basement.

Intensity and return period of earthquake motions for cities and settlements shall be accepted by obligatory Annexes 1 and 2 of Building Codes КМК 2.01.03-96.

The entire territory of Uzbekistan is divided into four seismic regions, which differ in the value of the spectral coefficient Wi. For each region there are identified characteristic samples of accelerograms of real earthquakes. Accounting of frequency of earthquakes of various intensities is presented in Table 2.

**Table 2**. Accounting of earthquakes return period

| Return period, years | Value of accounting coefficient of return period of earthquakes with intensity | |
|---|---|---|
| | 7 and 8 intensity units | 9 and more intensity units |
| ≤250 | 1,2 | 1,25 |
| 300-600 | 1,0 | 1,15 |
| 650-1000 | 0,8 | 1,0 |
| <1000 | - | 0,9 |

Seismicity of the construction site takes into account the coefficient $\alpha$. The value of coefficient is given in Table 3.

**Table 3.** The value of coefficient of seismicity of the construction site $\alpha$

| Seismic intensity of the construction site, intensity units by MSK-scale | 7 | 8 | 9 | > 9 | 9* |
|---|---|---|---|---|---|
| Coefficient $\alpha$ | 0,25 | 0,5 | 1,0 | 1,4 | 2 |
| Maximum acceleration, g | 0,1 | 0,2 | 0,4 | 0,6 | 0,8 |

There is a map of general seismic zoning of the territory of Uzbekistan OSR-78, according to which the distribution of area (thous. $km^2$) of various intensity zones is shown in Table 4.

**Table 4.** The distribution of area (thous. $km^2$) of varying intensity zones on the maps OSR-78

| Title of the map | Intensity, MSK-scale units | | | |
|---|---|---|---|---|
| | 6 | 7 | 8 | 9 |
| OSR-78 | 71,0 | 168,6 | 50,2 | 8,2 |

Use of materials of the seismological information over Uzbekistan will allow solve the following tasks of the present research:

- Development and analysis of maps of seismic hazard, damage and risk;
- Assessment of seismic hazard of mass types of residential and public buildings of our cities;
- Modeling of scenario of earthquakes consequences.

Parameters of urban environment that are most important, which determine the ranking of cities according to the degree of seismic risk are presented in the table 5.

**Table 5.** An estimation of factors of definition of risk of cities

| N | Name of the factor | Dimension | Interval values on groups | | | W |
|---|---|---|---|---|---|---|
| 1 | Density of building | $m^2$ / ha | Low | Average | High | 0,5 |
| 2 | Population density | per/$km^2$ | <100 | 101-1000 | >1000 | 1 |
| 3 | Population | person | <2000 | 2001-5000 | >5000 | 1 |
| 4 | Percent of individual building | % | <5 | 5,1¸15 | >15 | 1 |
| 5 | Percent of the urbanized territory with soft soils | % | <5 | 5,1¸20 | >20 | 0,5 |
| 6 | Percent of the urbanized territory with high ability of ground to liquefaction | % | <5 | 5,1-10 | >10 | 0,8 |
| 7 | Area of urbanized territories | $km^2$ | <50 | 50-100 | >100 | 0,06 |
| 8 | Area of residential buildings | Thousand $m^2$ | <1000 | 101-10000 | >10000 | 0,14 |

Gradation of the cities is the important component of an estimation of risk as enables to open the reasons of the increased or lowered level of seismic risk and acceptance of measures on its reduction.

Weight factors of each factor can be specified on the basis of expert estimations of the experts working in the field of an estimation of seismic risk.

Methods for seismic risk assessment should reflect the particular manifestation of seismic hazard areas, as well as the vulnerability of buildings and structures, the most common in this particular area. In general, seismic risks are the harm or losses that are likely to result from exposure to seismic hazards.

Without considering the ability of seismic risk assessment of direct damage, we note that the seismic risk is defined as the probability of social and economic losses associated with earthquakes on a given area during a certain period of time. The developed method allows to estimate mainly definition of economic losses from earthquakes at the level of individual buildings, site development or urban area (region, city, town, city type, etc.). Assessment of damage or seismic risk may consist of two parts: passive and active. The passive part includes development of maps of the distribution of damage and losses on the territory under consideration. The active part of the risk assessment provides preventive measures to improve safety as a newly built-up as existing development.

The technique is focused mainly on civilian buildings and facilities, including residential and public buildings of mass construction, but with minor adjustments and additions can be applied to virtually any structures, including elements of the life support system of cities.

To estimate losses from earthquakes and to identify effective interventions to reduce this damage, in addition to information about seismicity of the region, it is necessary presence of background information about the characteristics of seismic hazards, existing buildings, infrastructure and population distribution, the availability of appropriate mathematical models, etc.

For example, a block of data elements of the risk of study area should include:
- inventory of buildings and facilities: data on the number of residents living or working in the building, type of material of bearing structures, height, geometrical parameters, geographical location of the object, year of construction and other information;
- classification of buildings by structural types and functional purpose;
- information about the vulnerability and damageability of different structural types buildings;
- diagrams of damage in the form of economic loss as a percentage of the estimated (replacement) value of $1m^2$ of the total area of building or $1m^3$ or buildings, depending on the degree of damage to the building.

Knowing the amount of buildings by constructive type, damageability and economic losses graphs, caused by seismic effects, depending on the level of earthquake protection, it is possible to calculate the economic and material losses for each type of building. In the deterministic scenario earthquake economic losses would be the upper level of risk when the probability of an earthquake $P = 1$. In the presence of probabilistic seismic hazard parameters evaluation of seismic risk will be probabilistic in nature.

It should be pointed out that in calculation of risk may be added also damage caused by the presence of the previously discussed risk factors and take into account the results of preventive anti-seismic measures, leading to a decrease in direct losses. It is also possible to optimize the overall risk to the value of investments in anti-seismic strengthening of buildings.

The proposed method of estimation of seismic risk assessment does not affect the risk of secondary and indirect costs, as these studies are beyond the scope of this paper.

The presented concept for the assessment of seismic risk and economic damage makes it possible to carry out in advance the protection of vulnerable urban areas, to differentiate the valuation of each region, depending on the features of the territory and the values of the damage. For the cities in Uzbekistan have been developed measures to reduce damage from earthquakes, covering the following areas: risk assessment and action plan, physical protection of buildings of new construction and existing buildings, protection of lifelines and non-structural elements of building structures, management of risk. The developed activities focused on protecting the most common and vulnerable targets: homes and public buildings. This direction was taken due to the fact that over 90% of earthquake damaged buildings, and therefore suffered people were in civilian buildings: homes, schools, kindergartens, hospitals and medical institutions.

These elements of risk used in the development of preventive measures. Procedure for review of steps to reduce the risks shown in the table 6 below:

**Table 6**. Scheme of risk mitigation measures

| I Risk assessment and planning | II Physical protection | | | | III Response development, risk management | |
|---|---|---|---|---|---|---|
| | A Existing buildings | B New buildings | C infrastructure, lifelines | D Non structural elements | Response skills | Provision of response |

Actions in each direction should be realized in three levels:
- Small level;
- Middle;
- High level.

Small level of action is implemented on an individual or family level.

Middle level of action is typical for separate or group of organizations, or quarter (mahalla), district.
High levels of action related to the public, government level, urban or regional bodies scale.

For each level recorded their activities. The solution of all identified problems at different levels may work out common problem of society in this direction.

The technique of problem solving to reduce risk is a dynamic model, both in time and with the name of the problems that you can always upgrade or adopt new measures that have arisen at the next stage. Measures as they are implemented in case of necessity, may be updated, modified, clarified, etc.
These charts, plans can and should be realized at each of the three principal directions of seismic risk reduction. Coordinating and leading role assigned to the Ministry for Emergency Situations of the Republic of Uzbekistan.

Established enforcement of actions outlined in this case, by physical protection of buildings and structures of existing development. It should be taken into account operating laws and regulations.
Established all concerned ministries, departments, organizations with the designation of the type of their functional activity in this matter.

Analytical report is compiled with the assistance of experts in this course of action outlining the condition of resolving the problem, assessing the situation and recommends actions for each level of action, set the level of resolution of the problem and its importance in reducing the risk of action in this direction, and also determined the order (priority), execution activities of each level.

Similar steps are provided for each of the three courses of action on ways to reduce the seismic risk and to reduce damage from earthquakes.

Thus, complex measures designed to reduce damage from earthquakes, which must be implemented prior to the event, i.e. before the earthquake. This feature of the preparatory measures is different from existing ones, which tend to define the actions of organizations following the earthquake.Activities at each level and each course of action communicated to the society of concrete actions and steps indicating the type of event and determine the degree of elaboration of this problem in the country, the degree of importance and priority setting, establishing the degree is characterized by such terms as "high" (H), "medium" ( M), and "low" (L).

For each type of directions of the estimated state of the problem in the country, enforcement of measures by applicable laws and regulations documents. Determined by the range of stakeholders who are responsible or involved in activities with the definition of their role and specific actions.

The developed activities are not claiming to be their absolute fullness of time, as the situation changes, they may be corrected.

The scientific significance of the work is as follows:

- The first buildings with different structural types of bearing elements (30 types) are classified by the degree of vulnerability to the definition of the coefficient of damage;
- Systematic factors affecting the level of damage to structures and buildings in general;
- Classified as risk factors for damage to buildings from the definition of the rating and estimation of their weight;
- Revealed the relative level of "natural" types of seismic design of buildings;
- Limits are designed to ensure seismic safety of existing buildings, depending on their category of responsibility and the vulnerability of structures;
- Methods have been developed taking into account manifestations of seismic hazard in Uzbekistan in the assessment of seismic risk cities;
- Prepare proposals for risk assessment of cities (public space);
- Developed guidelines for assessing the direct economic damage from the destruction of buildings;
- Identify the main parameters for the ranking of cities according to risk;
- List of activities designed to reduce the seismic risk of apartment houses and public buildings, including individual buildings, for a given seismic hazard.

## 3. CONCLUSION

The studies produced a tool that allows to adjust the level of seismic safety of existing buildings as well as newly constructed buildings and facilities by:
- Seismic risk assessment of towns and villages according to local conditions;
- The choice of measures to reduce damage from earthquakes within the allowable acceptable risk.

Using the results of the study may be significantly raised the level of earthquake safety of the cities, reducing overall costs by 10-15% compared to the existing level of expenses.

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