IMPORTANT FEATURES OF THE METHODOLOGY FOR ASSESSING THE MAXIMUM SEISMIC RISK OF LARGE TERRITORIES

(BASED ON THE EXAMPLE OF ARMENIA)

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Abstract. *The features of the developed methodology for assessing the main components of the maximum seismic risk of a large area. Risk assessment is carried out on the basis of data on seismic hazard, vulnerability of buildings and structures, population size, as well as some secondary consequences of an earthquake. The methodology uses the current regulatory seismic hazard map, the zones of which are accepted as cells for risk assessment. Using the developed methodology, risk maps of buildings, population and infrastructure were compiled.*
It is recommended that the leading place is given to statistical data on the consequences of large earthquakes and the results of their analysis.

Key words: *seismic hazard, vulnerability, risk.*

Introduction

There are few methods for assessing the risk of a large territory, especially the territory of a state. In practice, the seismic risk of a specific object (settlement area, critical structure, small urbanized area, etc.) is more often assessed, for which numerous methods have been developed and used. For this purpose, the territory of the facility is divided into cells, in most cases in the form of squares with a side of tens or hundreds of meters, seismic scenarios are selected (earthquake, acceleration attenuation model), calculations of the behavior of buildings and structures in the cells are carried out, and different types of losses are assessed. When developing a methodology for assessing the risk of a large area, it is imperative to use the principles and approaches of the developed methods for specific objects, especially for urban areas. In this work, we widely used both well-known methods for assessing the risk of cities, and the methods we developed for assessing the risk of the territory of cities in Armenia [1,2,5,6]. For certain purposes, for example, to understand the level of risk of the territory of a state or its individual regions, an assessment of the possible consequences in any area during expected earthquakes of maximum magnitude is required. The need for a risk assessment taking into account the maximum seismic hazard of the entire territory according to the regulatory map of general seismic zoning is also important. Such a seismic risk can be conventionally called **the maximum seismic risk** of the territory**.** Each large territory has features of seismic hazard and risk, which are important when developing the methodology. In our opinion, it is advisable to develop a methodology for territories with complex hazard structures, where the development is represented by seismically vulnerable buildings and structures. Taking this into account, we have chosen the territory of the Republic of Armenia. **The purpose of** this work is to present the main features of the methodology we have developed for assessing the maximum seismic risk. The methodology evaluates the following components: buildings, population (human losses) and infrastructure. When developing the methodology, an important place was given to the reasons for the high vulnerability of buildings and structures, with which human losses are closely associated. The reasons for the high vulnerability of buildings are numerous, of which the most important are the following, which significantly affect the level of risk: a) underestimation of the level of seismic hazard; b) poor quality of design and construction; c) the factor of “aging” and violation of the rules of operation of buildings and structures; d) high level of urbanization. To ensure uniformity of hazard values throughout the territory of Armenia, the acceleration values of seismic zones on the 2020 map were converted to a point on the EMS-98 scale.

Main results and their discussion

Features of the developed methodology. The logical diagram of the developed methodology is as follows**:** reasonable division of the territory into cells for risk assessment; assessment of the vulnerability of the main types of buildings, taking into account factors influencing vulnerability and assessment of the maximum risk of damage to buildings in each cell; assessment of human losses in populated areas of each cell due to severe damage to buildings (degrees 4 and 5 according to EMS-98); generalization of the results of damage to buildings and the number of probable victims by cell; risk assessment of the infrastructure of the entire territory; mapping the main components of maximum risk for the entire territory.

According to this scheme and sequence, the main content of this article is presented.

Cells for seismic risk assessment. As cells for risk assessment, it is proposed to take seismic zones with different levels of seismic hazard according to the current regulatory map of general seismic zoning (GSZ) [2]. It is advisable to divide some Cells that occupy large territories into smaller parts based on its size, homogeneity of data for risk assessment, etc. Such division of the territory of the Republic allows us to reasonably take into account the modern seismic hazard and the design seismicity of existing buildings and structures.

Seismic hazard of the cell territory. Practice shows that seismic hazard (level, size and location of zones) changed over time, mostly grew. Unfortunately, buildings and structures were designed based on low estimates. It is advisable to present the seismic hazard in terms of intensity according to the EMS-98 macro-seismic scale. For example, the seismic hazard of the territory of Armenia in 1937 was estimated at 6-8 points, and in 2017 – 8, 9 and 9 points or more [2]. As an example, Figure 1 shows compiled map of understatement values (underestimation) seismic level dangers in relation to the 2017 hazard map of Armenia.

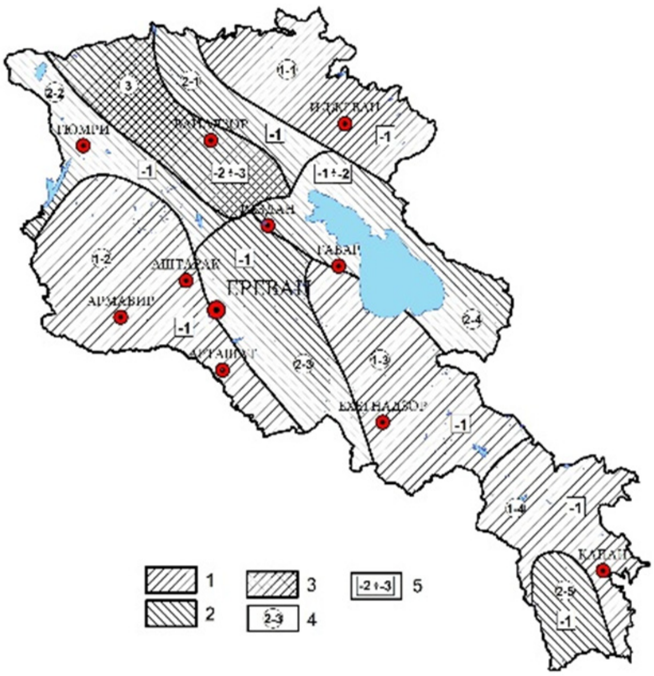

Figure 1. *Regulatory seismic hazard map of the territory of the Republic of Armenia for 2020 [2] indicating the average value of “underestimation” of the level of seismic intensity according to GSZ maps for 1957-1989. Seismic hazard in horizontal ground accelerations (intensity in points): 1 – 0.30g (8 points); 2 – 0.40g (9 points); 3 – 0.50g (more than 9, up to 10 points). 4 – numbers of sectors and subsectors, for risk calculation; 5 – values of underestimation of intensity in points in the selected sectors and subsectors.*

Seismic vulnerability of buildings. When assessing the vulnerability of buildings and structures located in cells, along with data on their structural types, special attention must be paid to all the main reasons that reduce their seismic vulnerability, outlined in the introduction. When assessing the seismic vulnerability of transport lines and life support lines, the level of danger of both the entire territory and individual cells was taken into account. It is difficult to assess the vulnerability of buildings and structures built with violations of construction technology and the use of materials that do not meet standards. If poor design, careless operation, etc. are added to these, the vulnerability assessment becomes even more difficult. Therefore, as a real solution to the problem, we propose to provide statistical data on their damage due to strong earthquakes as a basis for assessing the seismic vulnerability of different types of buildings and structures. For example, for the territory of Armenia it is advisable to use data on the consequences of the 1988 Spitak earthquake, which is considered one of the most comprehensive and detailed earthquakes in the world [1.5]. For this purpose, the number of population and buildings, their number of storeys and structural type, the number of 1-3 storey buildings, the seismic vulnerability of all other buildings, etc. were taken into account.

Estimation of human losses. It is recommended to use the following estimated data to determine the number of victims: a) in one destroyed apartment of an multiapartment building – 1.5 people during the day and 3.0 people at night; b) in destroyed 1-3 storey stone houses – during the day 0.3% of the total number of inhabitants of these houses, and at night – 1%. The number of seriously wounded who must be hospitalized is proposed to be determined based on the number of victims. To do this, the number of victims is multiplied by a factor of 1.5 [1.5]. For other buildings, presenting such data is difficult, because they require an individual approach.

Seismic vulnerability assessment of infrastructure (transport highways and other life support lines) is mainly damaged due to strong ground shaking and the activation of such geological phenomena as faults, seismo-gravity formations (landslides, rockfalls, liquefaction and subsidence of the soil), etc. It is advisable to assess the risk of infrastructure throughout the entire territory and, if possible, by cell. For this purpose, it is better to compare infrastructure maps with maps of standard seismic hazard and hazardous geological phenomena [3,4,5]. The impact on the infrastructure of seismic-gravity formations and surface faults is especially significant (Figure 2). When developing a methodology for assessing the maximum risk of the territory of Armenia, much attention was paid to the following infrastructure lines: railways and highways, high pressure gas supply lines, water supply lines, high voltage power supply lines, telecommunication lines (telephone trunk lines, fiber optic cables for the Internet). When assessing their vulnerability, it is more effective to use statistical data on the geotechnical consequences of strong earthquakes, preferably in a given area. According to statistical data, earthquakes are more often infrastructure lines receive noticeable damage at an intensity starting from 8 units, and dangerous geological phenomena appear and cause serious damage to tenches mainly at an intensity 9 points or more [1].

Table 3. Estimated data on damage to the infrastructure of Armenia with an earthquake intensity of 8-10 points, obtained on the basis of a generalization of geotechnical data on the Spitak earthquake of 1988 [1,5].

N	Life support lines	Damage level at earthquake intensity		
		8 points	9 points	10 points
1.	Water supply	weak	average	strong
2.	High voltage lines power supply	weak	average	strong
3.	Pipelines gas supply high pressure	weak	strong	strong
4.	Cable lines telecommunications	weak	strong	strong
5.	Railway	weak	weak	average
6.	Roads	weak	weak	average

Maps of the main components of maximum seismic risk

As an example, below is a map of the maximum seismic risk **of residential buildings, population and infrastructure** territory of Armenia (Figures 2,3,4).

Table 4. Some basic data on cells and seismic risk assessment results (fragment).

Risk assessment cells				Population by data for (2015)		Number of residential buildings cities (2015)		Approximate number of residen-tial buil-dings in villages, (2015)	The number of seriously damaged is many kvar shooting range buildings and/apartments of cities	Percentage of damaged buildings/ apartments from the total number quality	Number of casualties in cells (**day** /night)		
Number on the map (Fig.1)	Plo spa-ring (1000 k m^2)	Seismic level chemical danger tee according to 2020 standards. (in points) Oh)	Underestimation is dangerous you in 1957-1989 (in points)	If quality city who in the population nia	Raft number, people/ km^2 By cells	Many Apartment **building** /apartments	Residential buildings and mansions (1-3 floor)				Victims to the city duh	Victims in villages	Total count casualties and percentage of total population
1-1	3.2	8	1	50000	short	**562** / 12664	8101	18000	**51**/ 1850	**9.1%** /14.6%	**2775/** 5550	**360** / 720	**3135**/ 5550 **6.3%/11.1** %

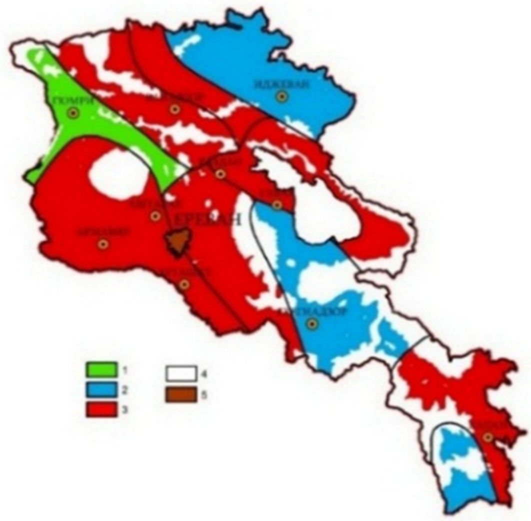

Figure 2. *Map of the maximum seismic risk of residential buildings on the territory of Armenia. The risk level is determined* based on the percentage of severely damaged apartments (4 and 5 degrees) of their total number*: 1 – Below average* (number of severely damaged apartments up to 10%)*; 2 – Average* average (7-15%)*; 3 – High* (more than 16%)*; 4 – There is no ris; 5 –Intense risk* (in UNISDR terminology, high risk associated with exposure to large crowds of people and areas, which can lead to disasters).

Figure 3*. Map of the maximum seismic risk of the population (human losses) of the territory of Armenia. Risk level: 1 – Below average* (irretrievable losses at night up to 15%)*; 2 – Average* (16-20%)*; 3 – High* (more than 20%)*; 4 – There was no risk; 5 – Intense risk.*

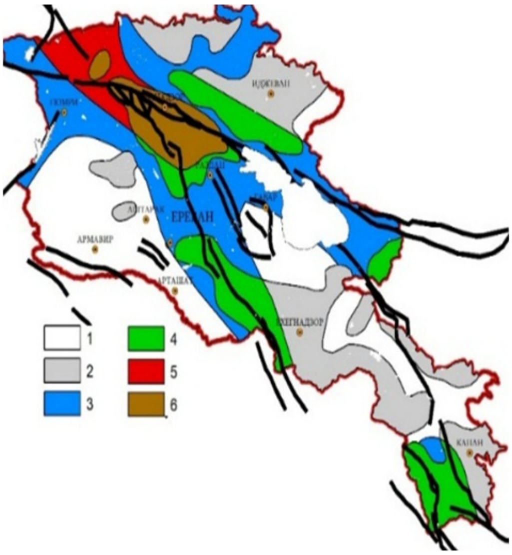

Figure 4*. Map of the maximum seismic risk of the infrastructure of the territory of Armenia. Risk zones: 1 – Low (with a seismic intensity of 8 units-0.3g, with virtually no seismo-gravity formations /SGF/); 2 – Below average (8 units and with widespread SGF); 3 – Medium (9 units-0.40g, without widespread SGF); 4 – Above average (9 units and with wide distribution of SGF); 5 – High (9-10 units-0.4-0.5g and without widespread SGF); 6 – Highest (9-10 points and with widespread SGF).*

Conclusions

1. The main features of the developed methodology for assessing the maximum seismic risk of a large territory are presented, which is based on data on seismic hazard in the form of a regulatory map of seismic zones, the vulnerability of buildings and infrastructure lines, the number, distribution and vulnerability of the population in populated areas. For this purpose, the territory is divided into cells corresponding to seismic zones (or their individual fragments) of the standard probabilistic map of general seismic zoning.
2. To quantify the main components of risk, assessment data on the vulnerability of buildings, infrastructure and the population are proposed, obtained mainly as a result of the analysis of statistical data on the consequences of devastating earthquakes in the world, especially the Spitak earthquake of 1988. It is important that these assessment data take into account a number of local conditions (geological, seismic, development features, structural types and seismic vulnerability of buildings and structures, vulnerability of the population, etc.), which allows for a more reliable risk assessment.
3. As a result of testing (application) of the developed methodology, maps of the three main components of the maximum seismic risk in Armenia were compiled as an example: buildings, population and infrastructure.

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