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Research Article

Assessment of seismic vulnerability of buildings and structures by using European standards

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Annotation: The issues of assessing the seismic vulnerability of existing buildings which are considered on the example of school buildings damaged during the earthquake in the Kashkadarya region (Uzbekistan, 2000-2002), by using European standards. It has been analyzed the condition of structural elements of schools, exposed to seismic effects. Making some attempts developing scientific and methodological approaches to integration into the international system for predicting risks and estimating damages from earthquakes.

Keywords: school buildings, seismic effects, seismic resistance estimate, seismic vulnerability, EMS 98 macroseismic scale, harmonization, European standards

1. Introduction

Currently, the world is working out various methods for assessing the territorial seismic hazard, predictive analysis of seismic risks, as well as seismic vulnerability, seismic resistance of buildings and structures, aimed for reducing the possible damages caused by earthquakes. The ultimate goal of these studies is to unify approaches and form an interregional and international forecasting system, minimize damage from earthquakes and optimize costs for anti-seismic measures. Moreover, buildings of various structural systems and schemes are considered, made of different materials, erected in different aims. In other words, the information processing system includes, whenever possible, all real objects of vital activity.

Noticed tasks are also relevant for the Republic of Uzbekistan and occupy a special place in the state scientific-technical policy of the country on earthquake-resistant construction, as more than 70% of its territory is subject to earthquakes of magnitude 7, 8, 9 and more. The country constantly pays close attention to the adoption of targeted measures for protecting the population and territories of the republic from seismic danger. So, according to the Resolution of the President of the Republic of Uzbekistan dated July 30, 2020 No. PP-4794 [1]:

the "Program for the improvement of the seismic safety system in the Republic of Uzbekistan" was approved;

The Academy of Sciences together with the Ministries of Emergency Situations and Construction, was entrusted with the development and introduction of the draft law "On ensuring the seismic safety of the population and territories of the Republic of Uzbekistan", as well as the "Concept for the development of the field of seismology, ensuring the seismic resistance of structures and seismic safety until 2030";

a decision was made to establish a research laboratory at the Turin Polytechnic University in Tashkent for the experimental study of buildings and structures, the main directions of research experiments were approved.

2. Methodology

At the end of the last century, the Institute of JSC "UzLITTI" (formerly TashZNIIEP, and now JSC "ToshuyjoyLITI") within the framework of the international UN project "RADIUS" to assess the seismic risk of buildings in Tashkent, for the first time, compiled a classification of almost every structural type of building which are built up in cities and villages Central Asia. They were ranked according to the degree of their vulnerability and damageability, including depending on the values of the spectral characteristics of earthquakes. The reliability of the data on the degree of damage to buildings in assessing the seismic risk of development in Tashkent was not in doubt. The estimated levels of earthquake intensity and damage to structural systems were in good agreement with the data accepted in the MSK-64 scale, and later in the European macroseismic scale EMS-98, practically for all considered structural types of buildings [2].

May be the macroseismic scale reliably estimate the intensity of an earthquake based on damageability data for modern buildings, that is, those built over the past 10-20 years, according to parameters that meet the requirements of design standards? To assess the reliability of the scale for new buildings, an engineering analysis of the consequences of earthquakes which occurred in the Central Asian region since 2000, including Kamashinsky, Uzbekistan (2000-2002), was carried out; Lugovsky, Kazakhstan (2003); Kantsky, Kyrgyzstan (2011); Tuyabuguz and Mardzhanbulak, Uzbekistan (2013). During the macroseismic survey of buildings using a well-known technique, the intensity of earthquakes in the area was established. In this area, the degree of damage to modern buildings on the MSK scale and their design seismic resistance were determined. And it turned out that the intensity of the earthquake is much lower than the design seismic resistance, and the damage received by the building corresponded to the limit, that is, corresponding to the calculated seismicity [3, 4, 5, etc.].

From this engineering analysis of the consequences of the behavior of modern buildings, even with not very strong earthquakes, it follows the main conclusion: in practice, the seismic resistance of buildings of a modern, little-studied building may be lower than the seismic resistance level declared in the project by 1-2 points. This means that the seismic risk of modern buildings can be significant in the event of earthquakes of the design intensity [4]. This conclusion requires a more detailed theoretical and experimental substantiation. At the same time, a very important direction is the formation of scientifically grounded methodological approaches to assessing seismic vulnerability and seismic risk, the development of organizational and technical measures to reduce damage from the consequences of probable earthquakes, further improvement and development of domestic building codes and seismic scales, their harmonization with the norms and standards of developed countries. To a certain extent, such work began during the last revision [6] of the KMK 2.01.03-96 “Construction in seismic regions” that had been operating for 24 years, but there is still a very difficult painstaking work in this direction.

The purpose of this study is to develop scientifically basic methodological approaches to assessing seismic vulnerability and seismic risk, organizational and technical measures to reduce damage from the consequences of probable earthquakes in the territory of the Republic of Uzbekistan in accordance to European norms and standards using modern European analytical programs and techniques. The implementation of such studies will serve as the basis for the creation of a unified system of predictive risk analysis, ensuring effective integration into the international system for assessing territorial seismic danger, harmonization of the domestic regulatory and methodological framework for earthquake-resistant construction with international standards.

Currently, one of the most promising international programs in this direction is the program "Analysis of seismic risks and the degree of damage from earthquakes" EDAC (Earthquake Damage Analysis Center) [7] of the Weimar University Bauhaus (Germany). Activities under this program are held in Germany, Greece, Italy, Switzerland, Turkey, Iran, Pakistan, Peru, Venezuela and other countries. Its main task is to unify and create a unified approach to assessing seismic risks and damage from earthquakes. The unified European macroseismic scale EMS-98 [8], adapted to the conditions of Germany, was adopted as a basis for assessing the intensity of seismic impacts and seismic vulnerability.

At present, when assessing seismic danger in various territories of Europe, EMS-98 performs to a certain extent the role of a standard, and taking into account the great interest in it and on the part of many non-European states, we can already speak of this scale as an international scale, widely used throughout the world [9]. The increased interest of scientists and specialists to our country and other ICC countries, especially Russia, to EMS-98 is also due to the fact that in our country the normative macroseismic scale has been used for more than half a century and requires urgent revision taking into account international experience.

3. Results

Since 2001, in cooperation with EDAC, UzLITITI and TACI, the noticed program above, included a pilot project on civilian objects in Kamashi district of Kashkadarya region, affected by earthquakes in 2000-2002 [7]. In total, within the framework of the project, 83 public buildings with various defects and damages were examined. Of the total number of objects located in the Kamashinsky district, 58 schools were included as the most typical in the research program.

In the process of implementing the project, one of the main tasks was to streamline and systematize objects that are very different from each other. For this, the surveyed objects were classified and divided into 9 types and are shown in the table.

TABLE Differentiation of structures (buildings) affected by the Kamashinsky **earthquake by vulnerability classes**

Types	Design features of the object	Comparative analysis	Vulnerability class					
				E	C	I	E	
1	Single-storey, consisting of one rectangular block, with pakhsa walls, wooden beams	By EMS-98	○					
		By the condition after seismic impact	├┈○					
		By the condition after strengthening and recovery		●				
2	The same, with walls made of natural stone, floors made of wooden beams	By EMS-98	○					
		By the condition after seismic impact	○┈	┈┤				
		By the condition after strengthening and recovery	├	●○┈	┈┤			
3	The same, with walls made of fired bricks, floors made of wooden beams	By EMS-98		├	○┈	┈┤		
		By the condition after seismic impact	├	○┈	┈	┈┤		
		By the condition after strengthening and recovery		├	●┈	┈┤		
4	The same, with walls made of fired bricks, floors made of reinforced concrete slabs	By EMS-98		├	○┈	┈┤		
		By the condition after seismic impact		├	○┈	┈┤		
		By the condition after strengthening and recovery			├	●┈	┈┤	
5	Two-storey, consisting of one rectangular block, with walls made of fired bricks, floors made of reinforced concrete slabs	By EMS-98		├	○┈	┈┤		
		By the condition after seismic impact		├	○┈	┈┤		
		By the condition after strengthening and recovery			├	●┈	┈┤	

Types	Design features of the object	Comparative analysis	Vulnerability class					
				E	C	I	E	
	One-storey with a "P" or "L" layout - shaped in plan, with walls made of fired bricks, floors made of	By EMS-98		○				

├┈○

6	reinforced concrete slabs	By the condition after seismic impact						
		By the condition after strengthening and recovery	├┄	●				
7	The same with pakhsa walls, wooden beams	By EMS-98		○				
		By the condition after seismic impact	├┄	○				
		By the condition after strengthening and recovery	├┄	●				
8	The same, with walls made of fired bricks, floors made of reinforced concrete slabs	By EMS-98		├─	○	┄┤		
		By the condition after seismic impact		├─	○	┄┤		
		By the condition after strengthening and recovery			├─	●	┄┤	
9	Two-storey with "P" -shaped layout in plan, with walls made of pakhsa, floors made of reinforced concrete slabs	By EMS-98		○				
		By the condition after seismic impact	├┄	○				
		By the condition after strengthening and recovery		●				

Analysis of survey results showed (Fig. 1) that most buildings (28%) belong to the 5th type, 19% - to the first, 16% - to the fourth, 14% - to the seventh. The rest of the building types are less than 9%. For all 58 objects, a detailed analysis was carried out and an assessment of their technical condition after the earthquake was given. As a result, it was found that 7.5% of buildings belong to buildings with the 1st type of damage, 7% of buildings - to the 7th type, 1-1.5% of buildings to the 2nd. Buildings of the 5th, 8th and 9th damage types were to be demolished.

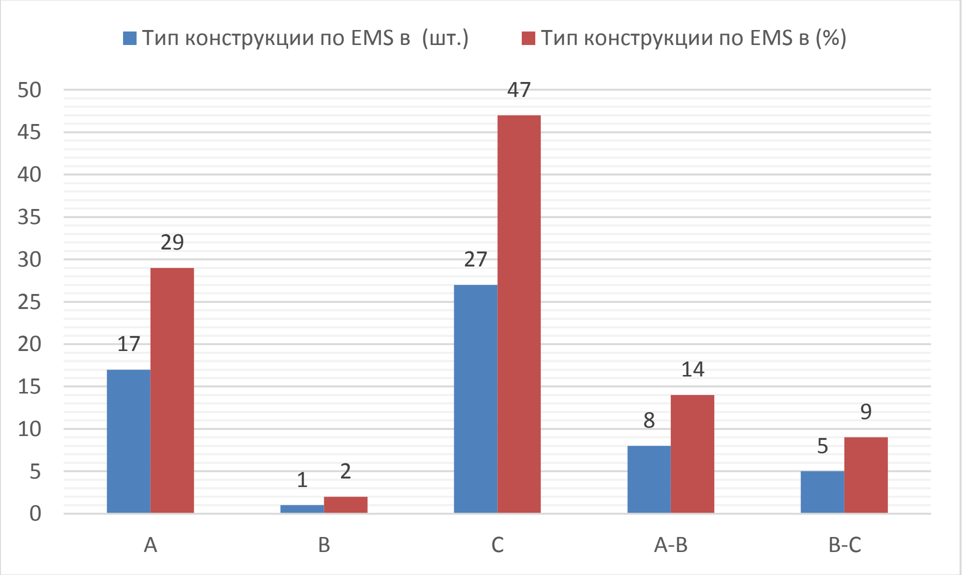


Figure: 1: Percentage distribution of vulnerability of schools and kindergartens in Kamashi according to EMS

The next task was to identify and type the damaged buildings according to European standards. For this, in accordance with the EMS-98 scale [8], all buildings were classified according to the degree and type of damage sustained by the earthquake. Of the total number of 17 buildings (29%), according to the degree of damage, they are classified as "A", 1 (2%) - "B", 27 (47%) - up to "C", and 8 (10%) - to the intermediate degree " AB "and 5 (9%) -" BC "(Pl 4 (Fig. 1)).

During the study of the objects, a comparative analysis of their technical condition was carried out and the identification of damage was carried out with the EMS-98 scale, the corresponding conclusions were drawn based on the results of their detailed study.

At the same time, an analysis of the applied anti-seismic measures used in the strengthening and restoration of damaged buildings was carried out. Identified 18 types of amplifications. Methods and possible errors in the design of the device of antiseismic measures, in the choice of materials, etc. have been critically studied. All these factors directly or indirectly, to a certain extent, influenced the seismic resistance of buildings and their vulnerability after their strengthening and restoration.

In addition to a comparative analysis of the technical condition of buildings during their identification according to EMS-98 and the conclusions obtained from the results of their detailed examination, a comparative analysis of their current technical condition (as an independent component) was carried out after strengthening (restoration) and liquidation of the consequences of an earthquake (table)

At the next stage of research, the task of calculating, analyzing the technical condition of the buildings under consideration, taking into account and using materials and data from the survey of buildings as after seismic impacts, as well as after the implementation of reinforcement and restoration, was set [10].

For this, the analytical program BLM of the EDAC center was used. This program was developed in 2002 by K. Kaufman based on Microsoft Visual Basic 6.0 [10]. The program is designed to analyze and assess the technical condition of buildings with different types of masonry, based on their actual condition under seismic impacts of varying intensity.

The program allows you to determine the most vulnerable parts of a building, sections, units and structures of buildings with a high degree of accuracy and reliability under these external influences. According to the given drawings, characteristics of materials, soil conditions and other indicators, the program determines critical points, mass distribution, places of occurrence of bending and torque moments, places of stress concentration and other factors. In the case of using such a program, the calculation results are displayed directly in the form of a three-dimensional graphic image of an object with a color-spectral representation of the most problematic areas.

Using this program, we made an experimental calculation of the building of the school. Safarov in the Kamashinsky district. An important task at this stage was the correct preparation and introduction into the program of the initial data, which would include the soil conditions, the characteristics of real materials revealed during the survey, the geometric characteristics of the building, other parameters and graphic materials. School building them. Safarova is a one-storey building, built of adobe bricks, consists of 4 separate blocks with "W" - shaped layout. All blocks have expansion joints between each other.

When entering the initial data into the BLM program, at the first stage, the program generates a three-dimensional image of the object in a static state as the initial calculation scheme. The indicators of individual parts of the building (openings, nodes, walls, etc.) are shown here in detail. The initial calculation data included the real indicators of the objects of study obtained in natural conditions, including the characteristics of wall materials, foundations, floors, foundations, soil conditions, etc.

The calculation for the program is divided into 3 levels:

Level 1 - assessment (formation and analysis) of the structural parameters of the building;

Level 2 - assessment and analysis of the potential stress-strain state of individual structures, assemblies and parts, as well as the building as a whole, with the detection of stresses, bending and torques at a certain load level;

Level 3 - assessment and analysis of all indicators of the stress-strain state of a building in a three-dimensional image with color spectral characteristics.

After the completion of the three-level calculation, a general conclusion is made about the indicators and results of all levels.

In accordance with the European seismic standards - Eurocode 8 EN 1998-1: 2004 [12], seismic vibrations at a given point on the surface are represented by the elastic spectrum of the response of ground acceleration (Se, m / s2). Of the five soil types (A, B, C, D, E) considered by European standards, the soil conditions of the Kamashinsky district fall under types B and C, for which the corresponding parameters of the elastic response spectrum were taken according to the data in Fig. 2

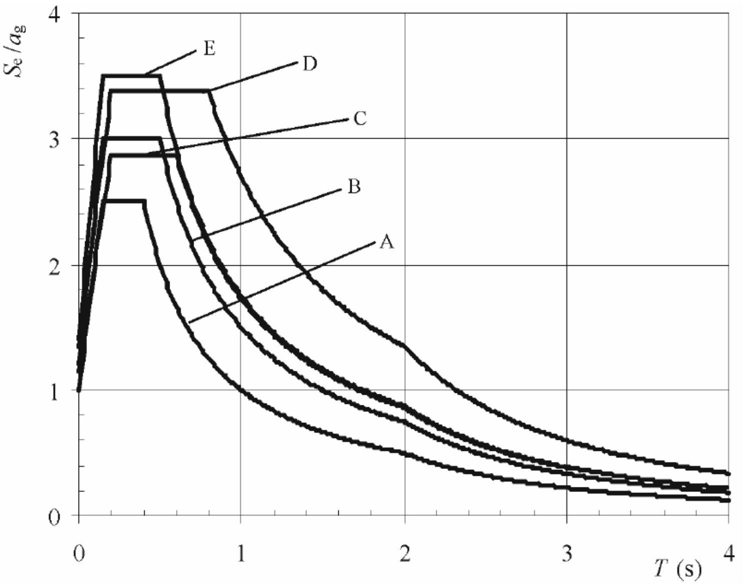


Figure: 2: Recommended type 1 elastic response spectra for soil classes A to E [8]

In the course of the calculation, a step-by-step loading of the building with seismic load along the axes was provided. In this case, the level of damage was determined by us using the spectral scale of German DIN standards [13] from 0 to SG1, then to SG2, and so on. The damage level from 0 to SG5 was determined by the level of accelerations and the spectrum of deformations (Fig. 3). This approach allowed us to gradually trace the level of permissible seismic load for the objects under study.

As a result, a complete characterization of buildings was obtained by comparing their individual structures and units with the level of seismic load, including their three-dimensional image with a color spectral representation of the most vulnerable and problem areas. Including the acceptability of the depth of foundations, dimensions of openings and walls, their percentage, wall stiffness and distribution of centers of mass, etc.

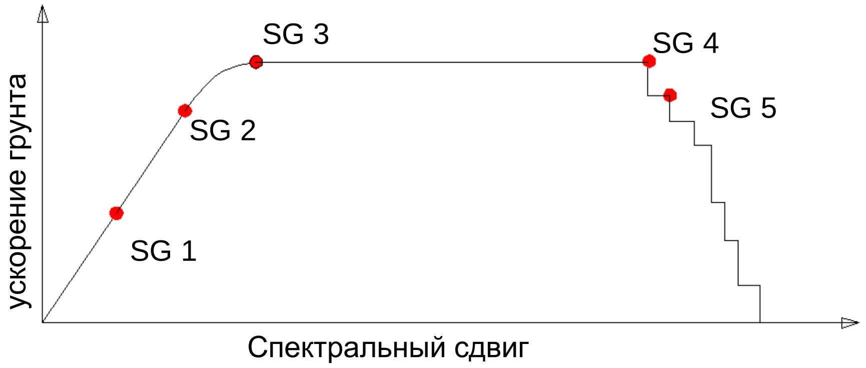


Figure: 3: Damage level - SG versus acceleration rate and strain spectrum

As a result, it was found that in the building of the school. Safarov, the depth of the foundations, the width of the walls between the openings and the stiffness of the walls for all four blocks turned out to be critical, and in some places absolutely unacceptable for a given level of seismic load. At the same time, in this design scheme, the height of the openings, their percentage in the walls and the distribution of the centers of mass are recognized as quite acceptable. The calculations also showed the degree of damage to buildings depending on the value of the calculated ground acceleration ag in the longitudinal and transverse directions. So, the degree of damage to the 2nd block of the building of the school. Safarov under the action of the seismic force along the X axis (transverse direction), as expected, was greater than along the Y axis (Fig. 4). Significant damage corresponding to level 3, the building receives already at a value of ag = 0.53 m / s2, and in the longitudinal direction, this level of damage is achieved at ag = 1.16 m / s2. The value of the calculated acceleration of the soil with complete destruction of the block (damage level 5) in the longitudinal direction is twice as high as in the transverse direction (ag = 1.67 m / s2 and ag = 0.83 m / s2, respectively).

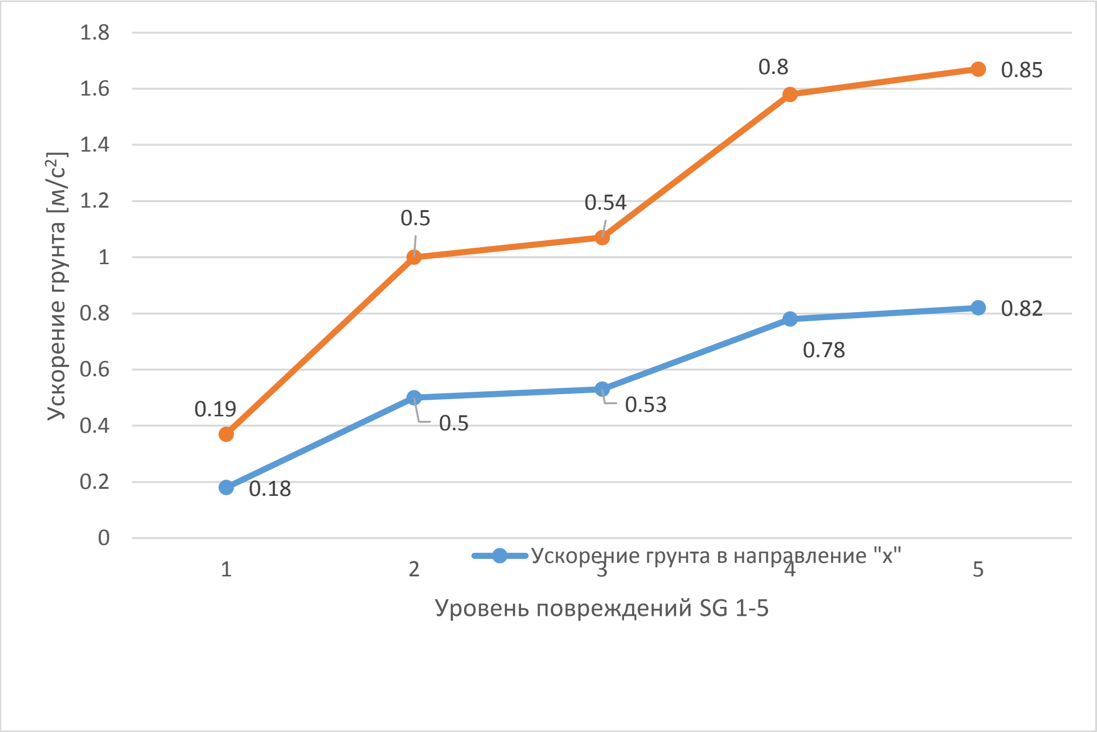
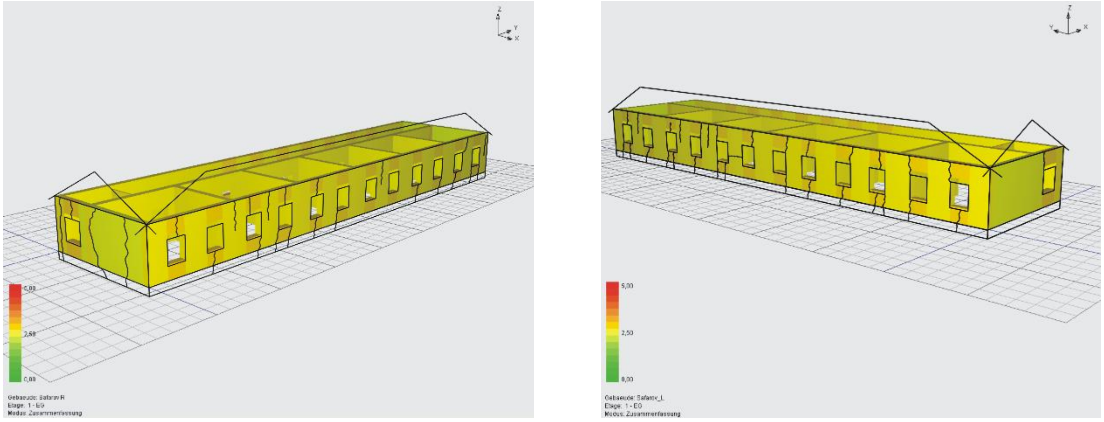


Figure: 4: Change in ground acceleration of block 2 depending on the degree of damage.

After obtaining the calculated results, they are compared with the actual data obtained for the surveyed buildings. It was necessary to find out to what extent the “theoretical damage” to the building, identified using the BLM program, corresponds to the actual one obtained as a result of a real earthquake. For this, again, using the BLM program, graphic diagrams of a building with full-scale damage are created and with color-spectral images of the most problematic areas at a certain level of damage (for example, with SG 3). A similar analysis was made for each of the four blocks of the school. Safarov, who showed that the calculated spectral display of the most vulnerable and problematic areas of a building during an earthquake coincides by more than 70% with its real damage. For example, the red color of the spectrum above the window blocks (Fig. 5) coincided with the largest full-scale fractures in this place at the same seismic load level.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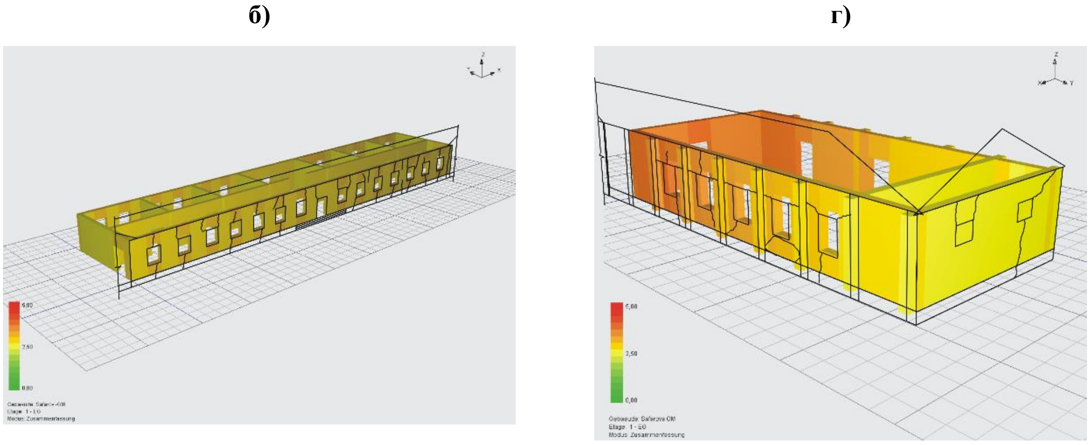

Fig. 5. Full-scale damage to blocks of the school. Safarov and color spectral images of the most problematic areas at the level of damage SG 3 (calculated and actual state of the blocks): a - block 1; b - block 2; c - block 3; d - block 4

This analysis confirms the correctness, reliability and objectivity of the BLM program, its ability to accurately determine the degree of vulnerability of buildings and damage during an earthquake, depending on the terrain, soil and soil types, structures and materials used. The main part of public buildings for social purposes, which suffered from the Kamashinsky earthquake, were strengthened, restored and brought in line with the current building codes KMK 2.01.03-96 "Construction in seismic regions". In general, the strengthening of these buildings was carried out mainly structurally using well-known, proven in practice methods and technologies of anti-seismic strengthening [10], without calculations. Due to the large amount of work, there was practically no time to optimize the technical solutions of anti-seismic measures. As our calculations showed, the applied anti-seismic measures ensured a sufficiently high seismic resistance of the objects.

At the same time, it should be noted that in such situations, the use of the BLM program would make it possible to select and apply more optimal schemes and amplification methods in accordance with the identified problem areas, to optimize the consumption of materials, especially metal.

Based on the results of surveys and calculations, recommendations were developed for strengthening the structures of buildings and structures that were subjected to an earthquake. For each object included in the program, standard technical data sheets have been developed with full characteristics of their condition and the degree of resistance to seismic loads in accordance with European standards.

4. Conclusion

The research results are essentially an attempt in the development of scientific and methodological foundations for assessing the seismic vulnerability of buildings, the effective integration of the country's territory into the international system for assessing the territorial seismic hazard, predictive risk analysis, potential damage from an earthquake, which provides significant advantages and benefits in minimizing it, eliminating the consequences earthquakes, their insurance and forecasting.

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