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Theoretical and experimental studies

Strengthening the security of Syrian architectural monuments with the help of seismic isolation technologies in order to reduce the negative impact of earthquakes on the psyche of people

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Abstract: The article provides a definition of an earthquake and the causes of its occurrence, describes the types of seismic waves, which are divided into longitudinal and transverse. Three seismic intensity scales are compared, namely the modified Mercalli seismic scale, the 2017 seismic intensity scale, and the Japanese seismic scale. The following is a review of the negative impacts of earthquakes on the building, damage to various buildings in different countries as a result of an earthquake, the occurrence of such phenomena as landslides, soil liquefaction and rupture of the earth's crust, also as a result of an earthquake. The negative impact of earthquakes on the psyche and behavior of people, which causes panic, fear and seismophobia in humans, is considered. Further, it is proposed to use seismic isolation of buildings to reduce the negative impacts of earthquakes on people and buildings, using the example of the Great Mosque of Aleppo in Syria, which is an architectural monument and is included in the UNESCO World Heritage List. The description of the seismicity of the territory of Syria and the city of Aleppo is given, the High Damping Rubber Bearings (HDRB) proposed for use for seismic isolation of the mosque building are described. Formulas are given for calculating various parameters of such HDRB for their subsequent correct selection, depending on the forces acting on the building structures of the building. At the end, conclusions are drawn.

Keywords: seismicity, earthquake, earthquake resistance, base isolation system, Great Mosque of Aleppo in Syria, damage, panic, architectural monuments, building structures.

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Теоретические и экспериментальные исследования

Усиление безопасности памятников архитектуры Сирии с помощью технологий сейсмоизоляции с целью снижения негативного воздействия землетрясений на психику людей

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Аннотация: В статье дается определение землетрясения и причин его возникновения, описываются типы сейсмических волн, которые делятся на продольные и поперечные. Сравниваются три шкалы сейсмической интенсивности, а именно модифицированная сейсмическая шкала Меркалли, шкала сейсмической интенсивности 2017 года и японская сейсмическая шкала. Приводится обзор негативного воздействия землетрясений на здания, повреждения различных зданий в разных странах в результате землетрясений, возникновения таких явлений, как оползни, разжижение почвы и разрыв земной коры, также в результате землетрясений. Рассмотрено негативное влияние землетрясений на психику и поведение людей, которое вызывает у людей панику, страх и сейсмофобию. Далее предлагается использовать сейсмоизоляцию зданий для уменьшения негативного воздействия землетрясений на людей и здания, используя пример Великой мечети Алеппо в Сирии, которая является памятником архитектуры и включена в список Всемирного наследия ЮНЕСКО. Дано описание сейсмичности территории Сирии и города Алеппо, описаны резинометаллические опоры высокого демпфирования (HDRB), предлагаемые для использования для сейсмоизоляции здания мечети. Приведены формулы для расчета различных параметров таких HDRB для их последующего правильного выбора в зависимости от сил, действующих на строительные конструкции здания.

Ключевые слова: сейсмичность, землетрясение, сейсмостойкость, система изоляции основания, Великая мечеть Алеппо в Сирии, ущерб, паника, архитектурные памятники, строительные конструкции.

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Introduction

Panic, fear are a natural and protective reaction of people to danger during cataclysms, natural disasters and earthquakes. An earthquake causes all the above reactions in people and is also the cause of many destructions in buildings and structures and all infrastructure in the area where they occur.

To reduce fear and panic among people, and to save buildings and structures from damage or destruction as a result of earthquakes, it is advisable to perform their seismic isolation as one of the possible and effective ways to reduce seismic impacts on the building structures of buildings and structures, and on people in them, which leads to the preservation of their life and health.

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Earthquakes are subterranean shocks and vibrations of the Earth's surface, caused by natural causes, mainly tectonic processes, or artificial processes such as explosions, filling reservoirs, collapse of underground mine workings, etc. [1-6].

Every year on the globe there is over 300 thousand earthquakes, as a result of which dies about 10 thousand people.

The following processes cause seismic phenomena (earthquakes):

- tectonic, occurring in connection with tectonic movements of the earth's crust;
- volcanic (volcanic eruptions);
- denudation associated with karst ramparts, mountain collapses, bomb explosions in the ground, as well as with dynamic influences during production leadership of various works.

Tectonic movements of the earth's crust occur mainly slowly and are hardly noticeable within a person's life. Such slow displacements are called crane displacements. However, over many millions of years, displacements measured in hundreds and thousands of kilometers accumulate.

Volcanic and denudation processes are local in nature, while tectonic processes often cover vast territories.

Earthquake sources are the hypocenter and epicenter. Hypocenters are usually located at a depth of 10–700 km. The place above the focus of an earthquake on the surface of the earth is called the epicenter. Elastic oscillations of the earth's crust propagate in the form of waves from the hypocenter in all directions. These vibrations are of two types: P and S-waves propagating in deep rocks and surface acoustic L- and R-waves (figure 1 - 5).

The velocity of propagation of P-waves (compression waves) is 1.7 times greater than the velocity of S-waves (shear waves), so they are the first to be recorded by seismic stations.

The speed of longitudinal P-waves (compression waves) is equal to the speed of sound in the corresponding rock. If the wave frequencies are greater than 15 Hz, they are perceived by us as an underground rumble and rumble. Secondary transverse seismic waves S-waves (shear waves) cause oscillations of rock particles perpendicular to the direction of wave propagation. The third type of elastic waves is called long or surface seismic waves. It is this third type that causes the most severe destruction [1-2].

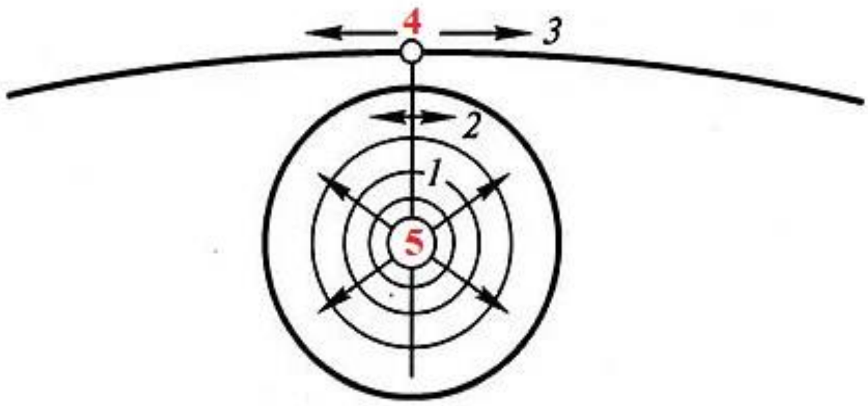

Figure 1 – Scheme of the propagation of seismic waves in the earth's crust and on the surface of the earth: 1–longitudinal seismic waves; 2 – transverse seismic waves; 3 – surface seismic waves; 4 – earthquake epicenter; 5 – earthquake hypocenter.

Рисунок 1 – Схема распространения сейсмических волн в земной коре и на поверхности земли: 1 –продольные сейсмические волны; 2 – поперечные сейсмические волны; 3 – поверхностные сейсмические волны; 4 – эпицентр землетрясения; 5 – гипоцентр землетрясения.

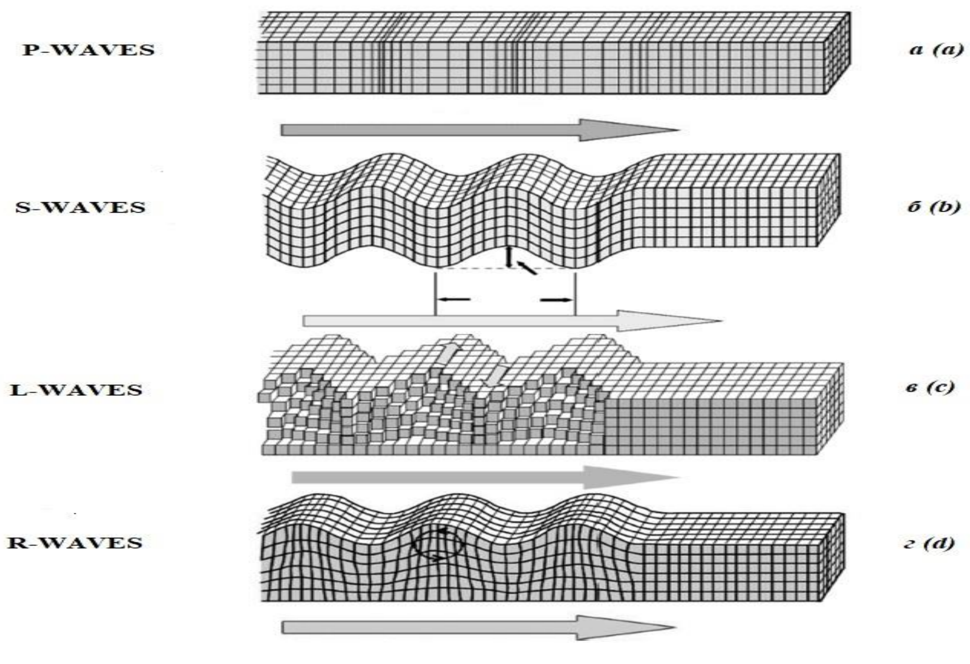

Figure 2 – Body and surface seismic waves:
a – Body Primary (compression) waves; *b* – Body Secondary (shear) waves;
c – Surface Love waves; *d* – Surface Rayleigh waves.

Рисунок 2 – Объемные и поверхностные сейсмические волны:
а – Первичные волны тела (сжатия); б – Вторичные волны тела (сдвига);
в – Поверхностные волны Лява; *г* – Поверхностные волны Рэлея.

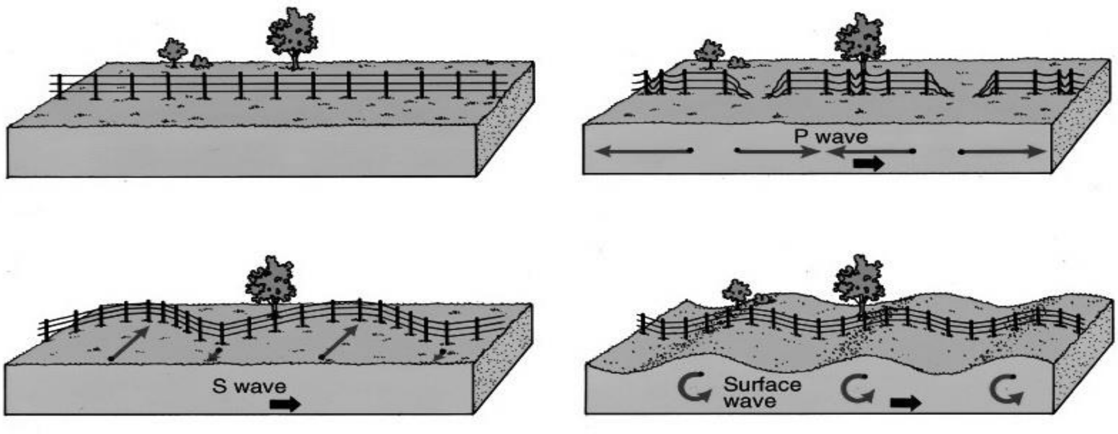

Figure 3 –Movement of Body (P- and S-) waves and Surface (L- and R-) waves of earthquake.

Рисунок 3 – Движение объемных (P- и S-) волн и поверхностных (L- и R-) волн землетрясения.

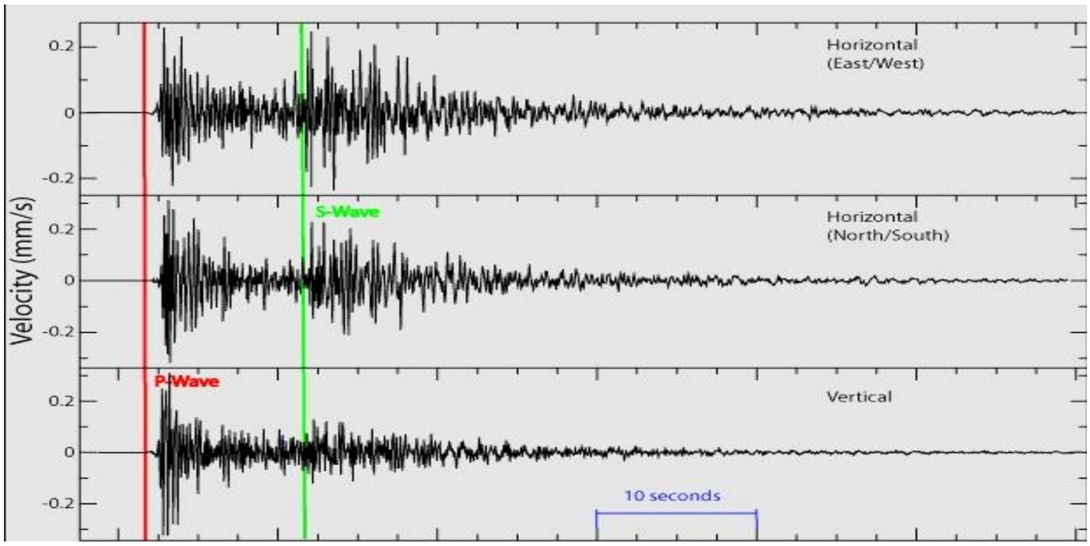

Figure 4 – An example of seismic P- and S-waves on seismograph readings.

Рисунок 4 – Пример сейсмических P- и S-волн на показаниях сейсмографа.

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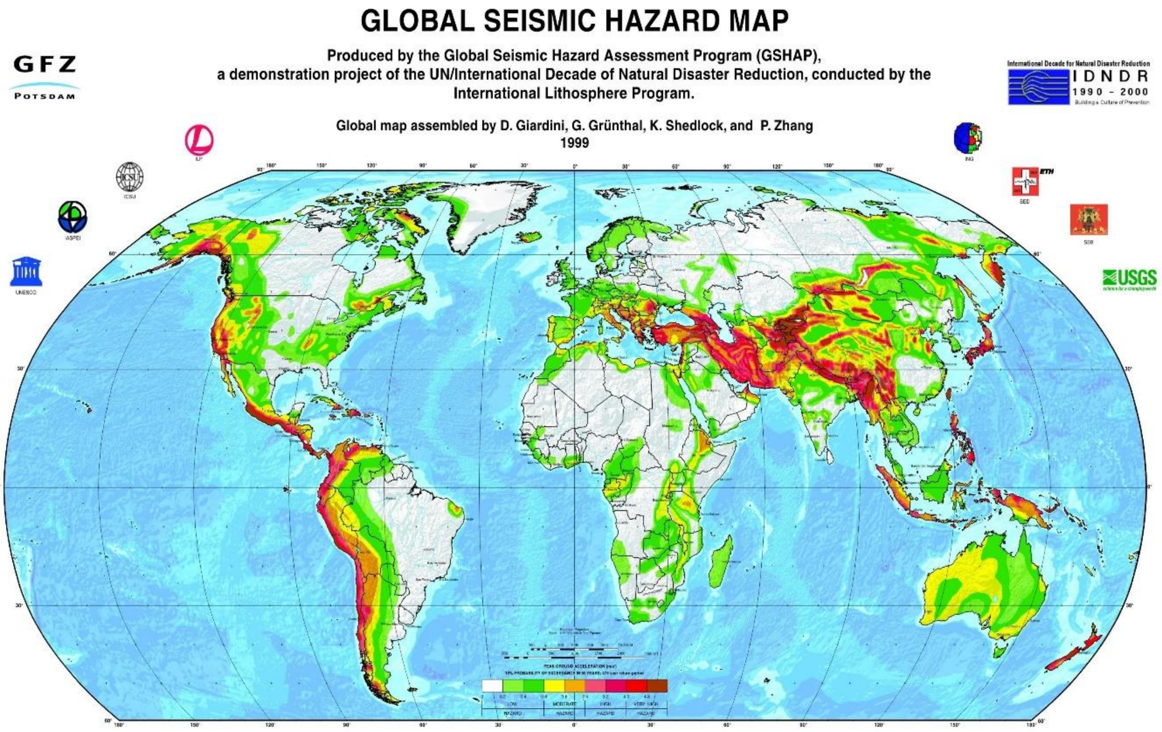

Figure 5 – Seismic map of the world as of 1999.

Рисунок 5 – Сейсмическая карта мира по состоянию на 1999 год.

The intensity of an earthquake can be estimated by the size of cracks in the soil, by the behavior of people in buildings and by the reaction of structures, that is, by the degree of damage to structures. There are several seismic scales in the world. Japan uses the JMA 7-point seismic scale, Europe uses the 12-point European Macroseismic Scale (EMS-98), USA use the 12-point Modified Mercalli scale (MM), and Russia uses the 12-point Seismic Intensity Scale-17 (SHSI-17). When it is necessary to convert the intensity in one scale to the intensity in another scale, you can use table 1, which compares the three seismic scales (JMA, MM and SHSI-17). For example, if an earthquake with an intensity of 3 points on the SHSI-17 scale occurred, then on the MM scale this earthquake will also be estimated at 3 points, and on the JMA scale - already at 1.8 points [5, 7].

Table 1 – Comparison of the main seismic scales.

Таблица 1 – Сравнение основных сейсмических шкал.

Modified Mercalli intensity scale (MM), in points	Seismic Intensity Scale-17 (SHSI-17), in points	Japan Meteorological Agency seismic intensity scale (JMA), in points	Effects on people
0,6	≈1,0	≈0,0	≈ Imperceptible to most people
1,9	≈2,0	≈1,1	≈ Perceptible to some people in the upper stories of multi-story buildings
3,0	≈3,0	≈1,8	≈ Perceptible to most people indoors. Awakens light sleepers
4,2	≈4,0	≈2,4	≈ Perceptible to everyone indoors. Frightens some people
5,6	≈5,0	≈3,1	
6,4	≈6,0	≈3,8	≈ Frightens most people. Some seek escape. Awakens most sleepers
6,6	≈6,5	≈4,0	
7,0	≈7,0	≈4,3	≈ Most people try to escape from danger by running outside. Some people find it difficult to move
8,4	≈8,0	≈5,0	≈Many people are considerably frightened and find it difficult to move
9,5	≈9,0	≈5,7	≈ Difficult to keep standing
10,2	≈10,0	≈6,2	≈ Impossible to stand; cannot move without crawling
11,0	≈11,0	≈6,9	≈ Thrown off by the shaking and impossible to move at will.
12,0	≈12,0	≈ 7	

Impact of earthquakes on buildings and structures

The study of the consequences of earthquakes showed that buildings of various designs in case of exceeding the calculated seismic impacts, they can receive various damages. In frame buildings, the frame nodes are predominantly destroyed. Severe damage is especially received by the bases of the uprights and the joints of the crossbars with the uprights of the frame, if the dimensions of the latter are insufficient and if they do not have reinforcements in the form of haunches. In large-block and large-panel buildings, there are cases of mutual displacement of panels, opening of vertical joints, deflection of panels, and even their collapse [6, 8-12]. It should be noted that earthquakes also cause the formation of various vertical, diagonal and cruciform cracks in the masonry, and in some cases lead to the complete destruction of buildings or structures (figures 6-12).

Figure 6 – Damaged house on the island of Crete in Greece as a result of the Arkalochori earthquake in 2021.

Рисунок 6 – Поврежденный дом на острове Крит в Греции в результате землетрясения в Аркалохори в 2021 году.

Figure 7 – Damaged old masonry building built in 1875, during the earthquake in South Napa, California, in 2014.

Рисунок 7 – Каменное здание, построенное в 1875 году и поврежденное во время землетрясения в Южной Напе, Калифорния, в 2014 году.

Figure 8 – Damaged Benedictine Hall turret at Saint Gregory University in Shawnee, Oklahoma USA, in the 2011 earthquake.
Рисунок 8 –Башня Бенедиктинского зала Университета Святого Грегори в Шони, штат Оклахома, США, поврежденная во время землетрясения 2011 года.

Figure 9 – Partially collapsed old Inmaculada Concepcion church built in 1841, after the 2020 earthquake on the island of Guayanilla, Puerto Rico.

Рисунок 9 – Частично разрушенная после землетрясения 2020 года на острове Гуаянилья, Пуэрто-Рико церковь Инмакулада Консепсьон, построенная в 1841 году.

Figure 10 – Collapsed building as a result of the 2017 earthquake in Mexico City, Mexico.

Рисунок 10 – Здание, обрушившееся в результате землетрясения 2017 года в Мехико, Мексика.

Figure 11 – Damaged Greek Orthodox church on the island of Crete in Greece as a result of the Arkalochori earthquake in 2021.

Рисунок 11 – Греческая православная церковь на острове Крит в Греции, поврежденная в результате землетрясения в Аркалохори в 2021 году.

Figure 12 – Damaged dome of Catholic temple “Sanctuary of Our Lady of the Angels” as a result of the 2017 earthquake in Mexico City, Mexico.

Рисунок 12 – Купол католического храма “Святилище Богоматери Ангелов”, поврежденный в результате землетрясения 2017 года в Мехико, Мексика.

Strong earthquakes closer to the epicenter leave many traces, such as screes of loose soil, landslides and cracks on the surface of the earth (figures 13-15).

Figure 13 – Liquefaction of sand base as a result of a longitudinal seismic wave in Kobe, Japan.

Рисунок 13 – Разжижение песчаного грунта в результате продольной сейсмической волны в Кобе, Япония.

Figure 14 – Landslides and slope buckling under residential buildings from the 1994 Northridge, California, USA earthquake.

Рисунок 14 – Оползни и потеря устойчивости склона под жилыми зданиями в результате землетрясения в Нортридже, Калифорния, США в 1994 г.

Figure 15 – Rupture of the earth's crust due to a series of earthquakes (along Garlock Fault) in Ridgecrest, California, USA in 2019.

Рисунок 15 – Разрыв земной коры в результате серии землетрясений (вдоль разлома Гарлок) в Риджкресте, Калифорния, США, в 2019 году.

The impact of earthquakes on people and their psyche

As stated at the beginning of this article an earthquake is a dangerous natural disaster for living beings, in particular for people, which occurs suddenly. Despite its short impact on a building or people, often no more than 30 seconds, its devastating consequences are much worse than the consequences of other natural disasters [9-10].

The construction of earthquake-resistant structures of buildings and structures can protect people from the destructive effects of strong earthquakes, but cannot protect them from severe mental trauma resulting from the impact of strong earthquakes when they are in buildings.

An analysis of the behavior and reactions of people in buildings during an earthquake showed that in with strong earthquakes of 7 points and higher, people panic, which poses a certain risk to their lives in such situations.

International seismic scales such as MSK-64[5], the Mercalli scale [6], the new SHSI-17 scale [7] indicate the natural reaction of people who are in buildings during an earthquake. They use people's reactions, such as fear, panic and anxiety, as a yardstick for assessing the intensity of earthquakes. The Mercalli Scale indicates that there is a sense of general terror and flight from home for people who are in a building during a magnitude 7 earthquake.
There is such a thing as the so-called "crowd effect", which means that with a large crowd of people in the halls, when an earthquake occurs, their panic can multiply [13-14].

The author of the work [13] gives an example that when analyzing the mental state of law enforcement personnel during the Spitak earthquake that occurred on the territory of the Armenian SSR in 1988, medical scientists recorded seismophobia in all examined patients, i.e. a feeling of fear of repeated shocks. The severity and severity of fear was inversely proportional to the mental stability of a person. Seismophobia was the cause of panic among the personnel who arrived for reinforcement, which led to the loss of efficiency of the above staff [13-16, 17-21].

Building structures and their influence on people's reaction to earthquakes and optimization of people's evacuation time.

Building structures during earthquakes have a strong influence on people's behavior. The vibration parameters of building structures differ on different floors [13-17].
In works [14-17] it was pointed out and justified that the reaction of people during an earthquake should be assessed only on the first floor of the building [18], since the higher the floor, the greater the intensity of the earthquake. If the earthquake strength on the first floor is 7 points, then on the second floor and above it will be 8 points.
If we compare the reaction of people in buildings and in open areas, the authors [13-16] conclude that people in buildings experience a seismic effect by almost 1 point more than those in open areas.
During strong earthquakes, people have a natural reaction to the threat and the desire to leave the building and go to a safe open space. The set of rules for construction in seismic areas dictates to the designer the time for evacuating people from the building [4, 17] and this means that the reaction of people is predetermined even when designing an earthquake-resistant building.
Clause 3.4 of the Code of Practice for Building in Seismic Areas [4] requires that escape routes pass through a long series of intermediate spaces such as corridors, lobbies, stairwells, etc. Because of this rule, escape routes in earthquake-resistant buildings where there are halls , for example, cinemas, theaters, mosques, etc., are long. The time required for the evacuation

of people from the auditoriums ($t_{additional}$) according to fire regulations varies from 1.5 to 4.5 minutes [13].

An important role in the duration of the evacuation of people is played by the number of floors in the building [13]. The higher the floor, the more time citizens need to evacuate the building. In public buildings, the time for the evacuation of citizens from the upper floors to the lower ones along the staircase is determined by the formula 1:

$$t_{calc} = \frac{L}{V} \tag{1}$$

where: L is the length of the path (evacuation) along the flight of stairs, V is the speed of people in m/min.

Engineering seismological classification of the degree of human reaction (E) during an earthquake can be found in the work of scientists from the Institute of Physics of the Earth named after. O. Yu. Schmidt [13, 19]:

- (E = 0) - there are no reactions at all: a person does not notice anything, does not feel anything, does not react to anything;
- (E = 1) - the presence of weak sensations: a person experiences a barely noticeable bewilderment, behavior does not change, in the case of sleep, he wakes up calmly, but does not thirty understands and is unaware of the reason;
- (E = 2) - the presence of a strong sensation (anxiety): a person can pay attention, clearly feels, is able to estimate the duration, direction, and some phases of oscillation, in case of sleep - wakes up feeling that he was awakened;
- (E = 3) - fright: a person is frightened, but retains the ability to assess the duration, direction, and some phases of oscillations, tends to leave the building;
- (E = 4) - a strong fright: a person in this case is very frightened, shows a desire to run out of the building, and runs out;
- (E = 5) - panic: a person falls into a state of panic, screams in hysterics, may lose balance, may jump out of a window;
- (E = 6) - the strongest panic: a person cannot stand on his own without support, he reacts very badly to everything that surrounds him;
- (E = 7) - complete shutdown: in this case, the person falls into a state of stupor and loses consciousness.

Earthquakes that occur in the same construction area with the same soil conditions form a different level of seismic effects in the structures of buildings and constructions with different design solutions. The highest level of seismic impact is formed in buildings and constructions, in which the value of the period of the fundamental tone of vibrations coincides with the value of the period of soil vibrations. And vice versa, the seismic impact will be minimal in the structures of buildings and constructions, in which the period of the fundamental tone of vibrations differs significantly from the period of soil vibrations.

Therefore, in order to reduce seismic effects on people, on the building structures of buildings and constructions, it is advisable to use seismic isolation, which allows you to change the dynamic scheme of the object and thereby reduce seismic effects in it and their negative nature on people and building structures.

Significance of architectural monuments of cultural and religious significance in Syria in the culture and life of Muslim society

Architectural monuments of cultural and religious significance are of great importance in the culture and life of Muslim society. The main place of worship for Muslims is the mosque. Mosques have played and are playing a very important role in their lives, because in them they pray and listen to sermons. There are ancient mosques everywhere where there were Muslims. For example, in Spain, which was once conquered by the Arabs, there are many ancient mosques. In all Arab countries, including Syria, there are many ancient and modern mosques.

In Syria, the Great Mosque in Aleppo (figure 16) is one of the largest and oldest Muslim sites of religious significance in this country [2, 3, 22-24] and is located in the old part of the city of Aleppo.

The architecture of the mosque belongs to the Islamic period of the Umayyad Dynasty and was built in 715. The plan (figure 17) of the Great Mosque is rectangular with a rectangular courtyard measuring 105x78m. Surrounded by galleries with square and rectangular columns. The columns are built of limestone and lined with marble. In the courtyard there is a column and two fountains for the ablution of believers before prayer. This courtyard is famous for its multicolored stone pavement of intricate geometric patterns. In the north-western corner rises a square minaret about 45 m high, measuring 4.7 x 4.7 m in plan. The minaret was built in 1095 and stands on a stone foundation. The mosque was damaged as a result of past earthquakes and hostilities. It is included in the UNESCO World Heritage List.

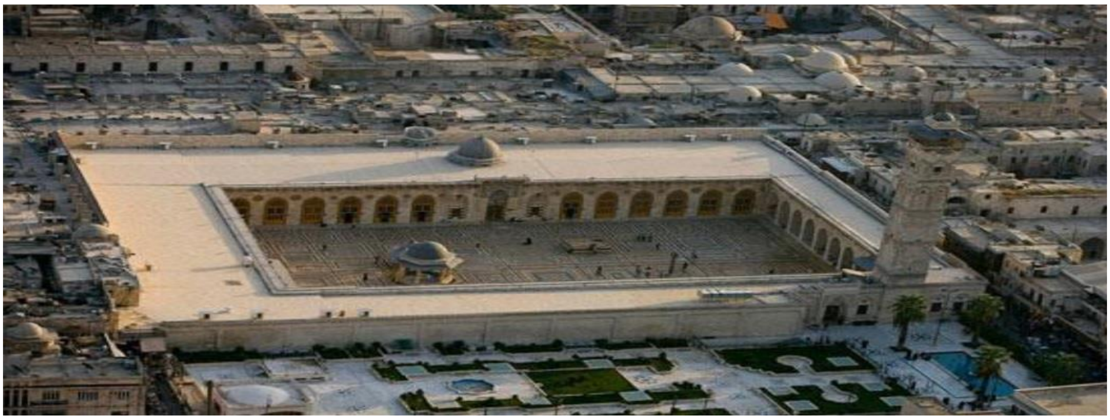

Figure 16 –The Great Mosque in Aleppo, Syria.

Рисунок 16 – Большая мечеть в Алеппо, Сирия.

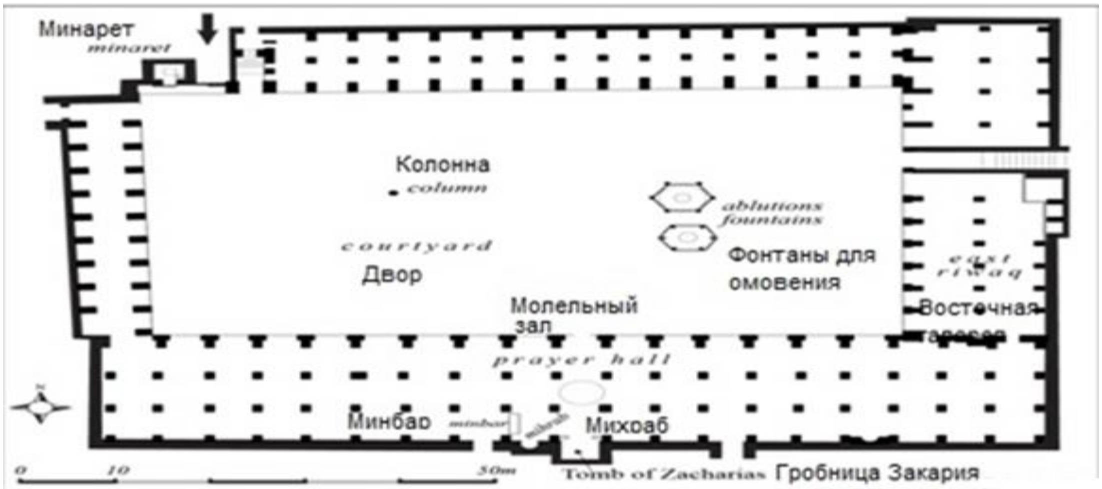

Figure 17 – The Plan of the Great Mosque in Aleppo, Syria.

Рисунок 17 – План Большой мечети в Алеппо, Сирия.

Buildings and constructions of religious significance, such as Muslim mosques, are primarily public buildings, and a place where a large number of people gather during prayer. If an earthquake occurs at this time, people's reactions such as panic, fear, stampede, etc. will inevitably follow.

If a person prays, then at that time he is concentrated on this action. The shocks and vibrations from an earthquake lead to different reactions in different people from panic and fear to trance or mental illness, depending on the innate, psycho-physiological qualities and type of the human nervous system. After all, melancholic, sanguine, phlegmatic and choleric people can react to this in different ways. Therefore, there is a need to protect people and building structures of buildings and structures by reducing the seismic impact using traditional or non-traditional methods of seismic protection

Seismic protection of the Great Mosque in Aleppo

An analysis of the seismic situation in Syria and the city of Aleppo [2-3,22-24] in particular showed that the territory of this country and this city is subject to seismic effects of different intensity and Peak Ground Acceleration (PGA), (tables 2-3).

Table 2 – Seismicity of the territory of the city and province of Aleppo, Syria in points according to the scale of seismic intensity SHSI-17.

Таблица 2 – Сейсмичность территории города и провинции Алеппо, Сирия в баллах по шкале сейсмической интенсивности ШСИ-17.

Locality name	$I_{(100)}$, Intensity (in points) for earthquake return period Teq≈100 years	$I_{(500)}$, Intensity (in points) for earthquake return period Teq≈500 years	$I_{(1000)}$, Intensity (in points) for earthquake return period Teq≈1000 years	$I_{(2000)}$, Intensity (in points) for earthquake return period Teq≈2000 years
Aleppo	VII	VII	VIII	IX

Table 3 – Peak Ground Acceleration (PGA) values in fractions of (g) for the city and province of Aleppo, Syria.

Таблица 3 – Значения пикового ускорения грунта (PGA) в долях (g) для Алеппо, Сирия.

Locality name	PGA, (g) peak ground acceleration for earthquake return period Teq≈100 years	PGA, (g) peak ground acceleration for earthquake return period Teq≈500 years	PGA, (g) peak ground acceleration for earthquake return period Teq≈1000 years	PGA, (g) peak ground acceleration for earthquake return period Teq≈2000 years
Aleppo	0,051	0,0516	0,1885	0,4691

It is proposed to protect people and building structures of buildings and constructions from the negative consequences of earthquakes [25-28] to use an unconventional method of seismic protection in the form of seismic isolation of the entire building of the mosque to reduce seismic impact.

For seismic isolation of the Great Mosque in Aleppo, it is proposed to use a High Damping Rubber Bearing (HDRB) with a high ability to dissipate energy, designed for maximum movement of equal ±200 mm. The rubber compound used in the production of the HDRB support has a dynamic shear modulus (G_{din})=0.4 MPa (figures 18-19).

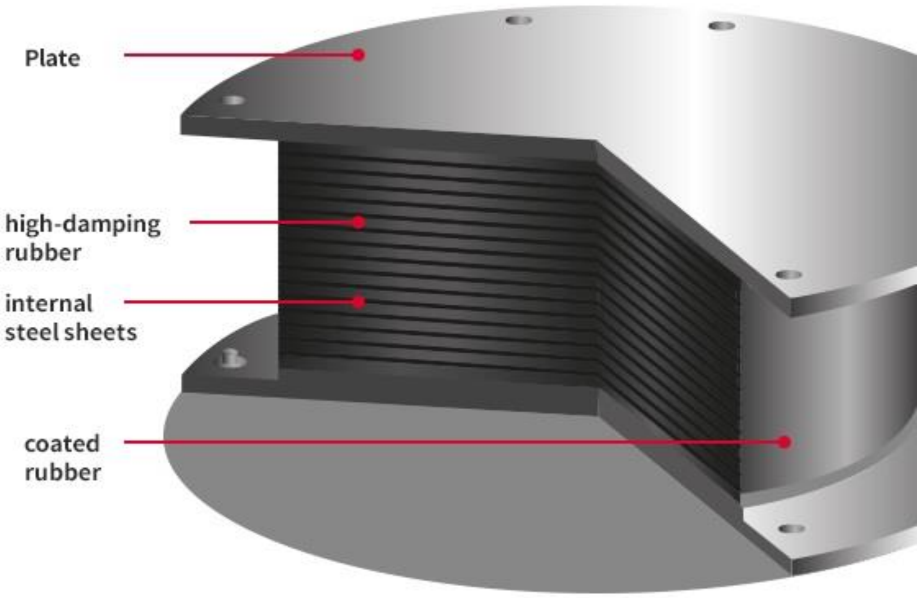

Figure 18 – High Damping Rubber Bearing (HDRB) in section.

Рисунок 18 – Сейсмоизолирующая резинометаллическая опора с высокой способностью к диссипации энергии в разрезе.

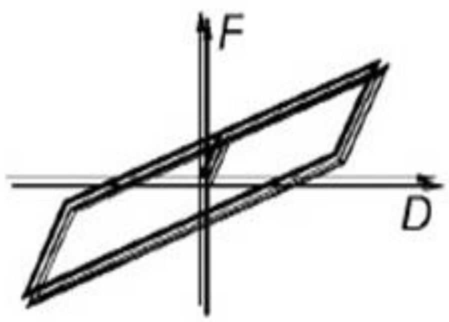

Figure 19 – Idealized “force - displacement” (F–D) relationship for a High Damping Rubber Bearing (HDRB).

Рисунок 19 – Идеализированное соотношение “усилие – перемещение” (F–D) для резинометаллических опор высокого демпфирования (HDRB).

The total thickness of rubber (T_r) provides the low horizontal stiffness (K_h) needed to lengthen the fundamental natural period of the system [2-3,9], whereas the close spacing of

the intermediate steel shim plates provides a large vertical stiffness and critical load capacity for a given shear modulus (G) and bonded rubber area (A_b). However, steel shim plates do not affect the horizontal stiffness of the bearing.
It is possible to calculate the horizontal stiffness factor (K_h) of the elastomeric bearing by the formula 2:

$$K_h = \frac{GA_b}{T_r} \tag{2}$$

The modulus of compression (E_c) for a single solid round rubber layer, assuming that the rubber is incompressible, given by the formula 3:

$$E_c = 6GS^2 \tag{3}$$

Shape factor, which can be calculated by the formula 4:

$$S = \frac{A_1}{A_2} \tag{4}$$

Where:
S- shape factor, which is a dimensionless geometric parameter defined for a single rubber layer;
A_1- loaded area;
A_2- seismic isolation surface area.
The vertical stiffness factor (K_v) can be calculated using formula 5:

$$K_v = \frac{E_c \cdot A_b}{T_r} = \frac{6GS^2A_b}{T_r} \tag{5}$$

The vertical and horizontal stiffness of the elastomeric bearing are related. For example, for circular bearings can be calculated using formula 6:

$$\frac{K_v}{K_h} = 6S^2 \tag{6}$$

The shape factor for a circular bearing with a diameter d_g is given by the formula 7 and made of rubber layers of thickness T_r:

$$S = \frac{(\frac{\pi d_g^2}{4})}{\pi d_g T_r} = \frac{d_g}{4T_r} \tag{7}$$

The shape factor for a square bearing of sides $a \cdot a$ is given by the formula 8 and made of rubber layers of thickness T_r:

$$S = \frac{a \cdot a}{2T_r(a + a)} = \frac{a}{4T_r} \tag{8}$$

The shape factor for a rectangular bearing of sides $a \cdot b$ is given by the formula 9 and made of rubber layers of thickness T_r:

$$S = \frac{a \cdot b}{2T_r(a + b)} \quad (9)$$

And, finally, a design model (figure 20) was built corresponding to the state of the mosque after seismic isolation and the calculation was performed in the LIRA-SAPR 2016 software package, in which it is possible to obtain all the necessary system parameters, for example, loads in elements, displacements, vibration periods, visualization of vibration modes [25-36].

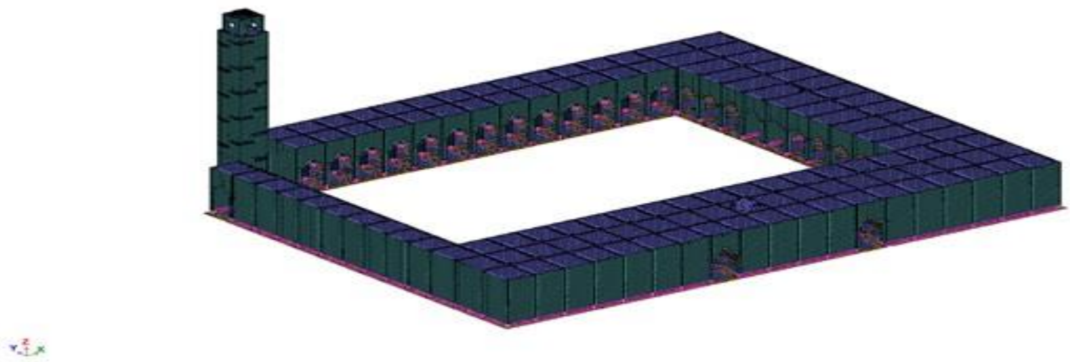

Figure 20 – Design model of the Great Mosque in Aleppo with High Damping Rubber Bearing (HDRB), installed under the building.

Рисунок 20 – Проектная модель Большой мечети в Алеппо с резинометаллическими опорами высокого демпфирования (HDRB), установленными под зданием.

The assessment and calculation of the seismic resistance of the building showed the effectiveness of seismic isolation in this case (figure 21). More about this may be written in future articles.

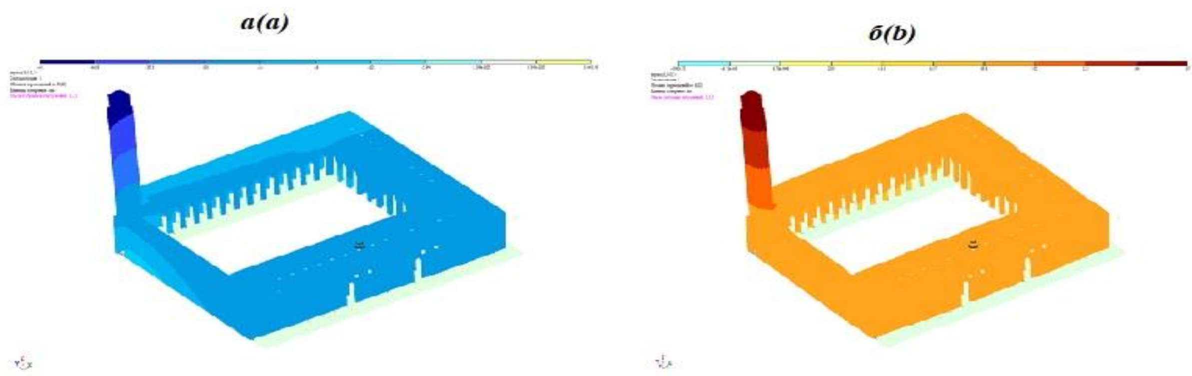

Figure 21 –Displacement mosaics along X and Y after seismic isolation of the building of the Great Mosque in Aleppo:
a – displacement mosaic along X; *b* – displacement mosaic along Y.

Рисунок 21 – Мозаики перемещений вдоль X и Y после сейсмоизоляции здания Большой мечети в Алеппо:
а – мозаика перемещений вдоль X; b – мозаика перемещений вдоль Y.

It turned out that High Damping Rubber Bearings (HDRB), have the best characteristics such as very high damping capacity, with an equivalent damping factor of more than 15 % for a large earthquake, and good recoverability without additional dampers, in other words ability to recover to its original position after seismic impact.

All of the above made it possible to reduce the impact of the earthquake on building structures, which would lead to a decrease in negative reactions of people in buildings and structures, such as fear and seismophobia, leading to panic.

Conclusions

To reduce the negative impact of earthquakes on people, on buildings and structures and on the environment, the following measures should be taken:

- construction of buildings and structures, taking into account and based on the normative maps of seismic zoning;
- increasing the seismic resistance of existing buildings and structures using non-traditional methods of seismic strengthening, such as seismic isolation;
- as a successful and effective example of increasing the seismic resistance of buildings, we can cite the proposed use of seismic isolation of the Great Mosque building in Aleppo, which is one of the significant architectural monuments of Syria;
- pay special attention to seismic hazard forecast;
- effective organization of rescue services, medical assistance and firefighters;
- creation of emergency supplies of tents, medicines, clothing, heating appliances, food, drinking water, etc.;
- educating people and teaching them the rules of behavior in seismic hazard conditions in order to avoid panic and increase the survival rate.

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