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Assessment of Seismic Resistance of Islamic Architecture Monuments on the Example of the Great Mosque of Aleppo taking into account the Seismic Zoning of the Territory of Syria

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Assessment of Seismic Resistance of Islamic Architecture Monuments on the Example of the Great Mosque of Aleppo taking into account the Seismic Zoning of the Territory of Syria

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Abstract. The analysis of the seismicity of the territory of Syria shows high seismic activity, which in turn can affect the further existence of architectural monuments, most of which are included in the list of UNESCO World Heritage Sites. The article presents the results of a study of the seismic resistance of monuments of Islamic architecture on the example of the Great Mosque in the city of Aleppo, taking into account the seismic features of this territory. Deformations are determined and a comparison of displacements in the mosque due to seismic impact is made.

1. Introduction

The territory of Syria is distinguished by the presence of numerous monuments of world architecture, among which various objects of Islamic architecture, erected in different historical periods, occupy a special place. These monuments are located in an area characterized by high seismic activity, which is significantly influenced by the presence of the nearby North Anatolian fault and neighbouring faults, which are the cause of numerous strong earthquakes that occur both in Syria in the past and present, and in other adjacent countries.

Seismic resistance of UNESCO World Heritage sites in Syria is of great importance. The situation is currently aggravated by the fact that hostilities were conducted in Syria, as a result of which many architectural monuments, including monuments of Islamic architecture, were seriously damaged. The preservation of these objects is a serious problem of national importance.

Researches on the seismic situation in the territory of Syria have been and are being carried out by many scientists and engineers in the works [1-8]. In the existing works the seismic situation in Syria is assessed, which is distinguished by a varied intensity and frequency composition. Based on the analysis of information about historical earthquakes in Syria, it was revealed that their epicenters are located mainly in the west along the Levant Fault, which runs from south to north [1-3]. The consequences of these earthquakes had a strong negative impact on the state of architectural monuments located throughout Syria [4-10]. In this regard, for an objective assessment of the seismic resistance of historical objects, one should take into account the proximity of the location of these objects to the Levant fault, the presence of nearby epicenters, taking into account the earthquakes that occurred in the past in this area (Fig. 1-2).

When assessing the seismic resistance of Islamic architectural monuments, in addition to the data on the seismicity of the area, great attention should be paid to the features of Islamic architecture, which is distinguished by lengthy structures of a regular shape with an inner courtyard space, the presence of a minaret in the form of a high-rise structure built into the structure plan, and so on. The article presents the results of a study of the seismic resistance of monuments of Islamic architecture on the example of the Great Mosque in Aleppo.

2. Methods

Aleppo is located in the northwest of Syria. Many different earthquakes have affected this city over a long period. Table 1 shows the values of peak ground acceleration (PGA) (Fig. 3-4) in fractions of (g) of Aleppo city [3, 11-16], and in table 2 seismicity with values of earthquake intensity (I) in points by the scale seismic intensity (SHSI-17) [17] corresponding to the return periods [18-20] of earthquakes T_{eq} = 100, 500, 1000 and 2000 years.

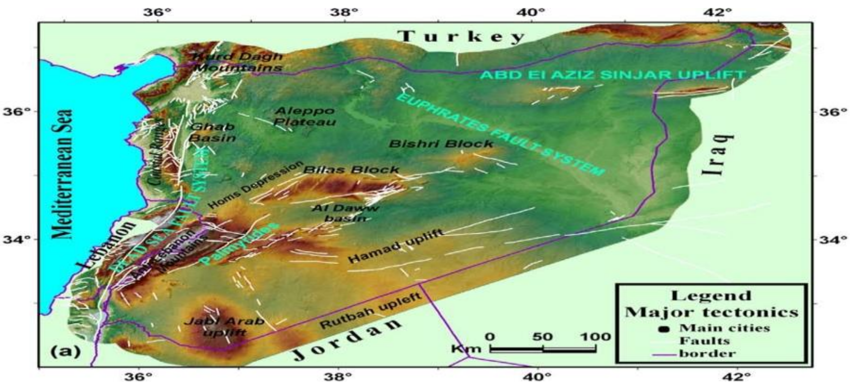

Figure 1. The main tectonic features of the territory of Syria.

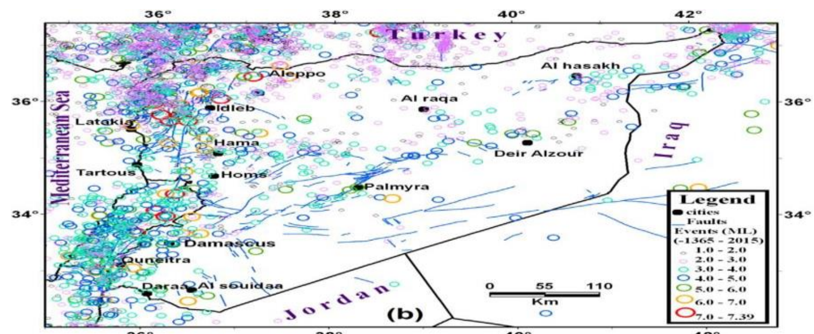

Figure 2. Map of historical earthquakes of the territory for the period from 1365 BC. to 2015 AD.

Table 1. Peak Ground Acceleration (PGA) values in fractions of (g) for Aleppo, Syria.

City name	PGA, peak ground acceleration for earthquake return period T_{eq}≈100 years	PGA, peak ground acceleration for earthquake return period T_{eq}≈500 years	PGA, peak ground acceleration for earthquake return period T_{eq}≈1000 years	PGA, peak ground acceleration for earthquake return period T_{eq}≈2000 years
Aleppo	0,051	0,0516	0,1885	0,4691

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According to Appendix B and formula (1) GOST R 57546 –2017 [17] and using information on historical earthquakes, the values of the intensity of earthquakes (I) were calculated. As a result, table 2 was compile:

$$I = 2.50\, lg(PGA) + 1.89 \pm 0.6 \quad , \tag{1}$$

Where I - is the intensity of the earthquake in points according to ShSI-17 [17];

PGA - peak ground acceleration, cm/s^2.

In addition, if you know the value of earthquake intensity (I) in points, then using formula (1) you can get formula (2) for calculating peak ground acceleration (PGA):

$$PGA = 10^{\frac{I-1.89\pm 0.6}{2.50}} \quad , \tag{2}$$

Table 2. Seismicity of the territory of Aleppo, Syria with the values of intensity (I) in points.

City name	I (100), the intensity of earthquakes in points for the earthquake return period T_{eq}≈100 years	I (500), the intensity of earthquakes in points for the earthquake return period T_{eq}≈500 years	I (1000), the intensity of earthquakes in points for the earthquake return period T_{eq}≈1000 years	I (2000), the intensity of earthquakes in points for the earthquake return period T_{eq}≈2000 years
Aleppo	VII	VII	VIII	IX

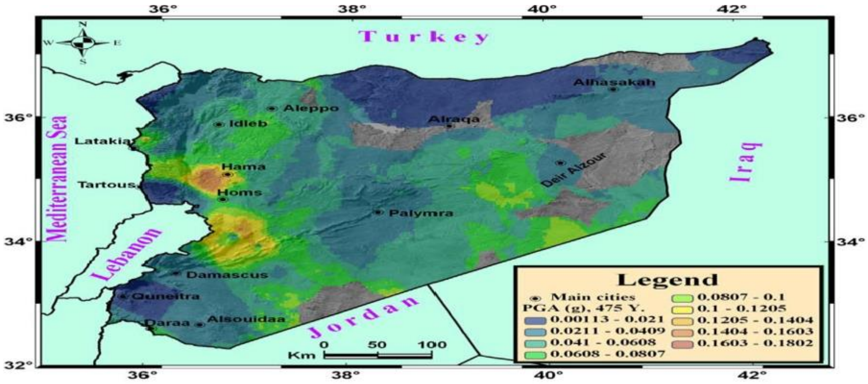

Figure 3. Seismic hazard map of Syria with PGA values in fractions of (g) for the earthquake return period of 475 (≈ 500) years.

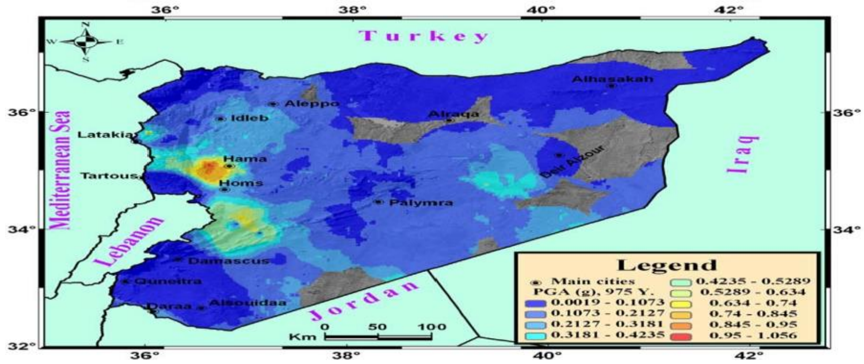

Figure 4. Map of the seismic hazard of Syria with PGA values in fractions of (g) for the earthquake return period of 975 (≈ 1000) years.

The Great Mosque of Aleppo is considered one of the oldest buildings of Muslim religious significance in the area. It was built in 715. The plan of the building is rectangular with a rectangular courtyard measuring approximately 105x78 m. Various past earthquakes and hostilities that began in

2011 damaged this building (Fig. 5-6). The mosque is included in the UNESCO World Heritage List [1-3].

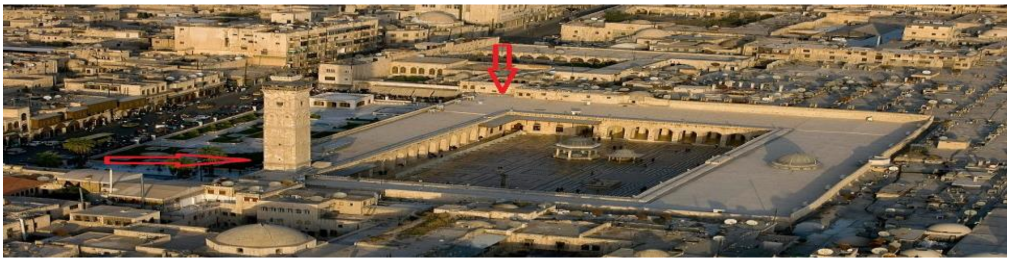

Figure 5. Condition of the Great Mosque of Aleppo before the destruction.

Figure 6. Condition of the Great Mosque of Aleppo after the destruction. The arrows show the places of the main destruction

Using the seismic information described above, the seismic resistance of the Great Mosque in Aleppo, Syria was assessed. The assessment of the seismic resistance of the building (Fig. 7-8) was carried out in the LIRA-SAPR 2017 software package, in which it is possible to obtain all the necessary parameters of the system, for example, loads in elements, displacements, vibration periods, visualization of vibration modes.

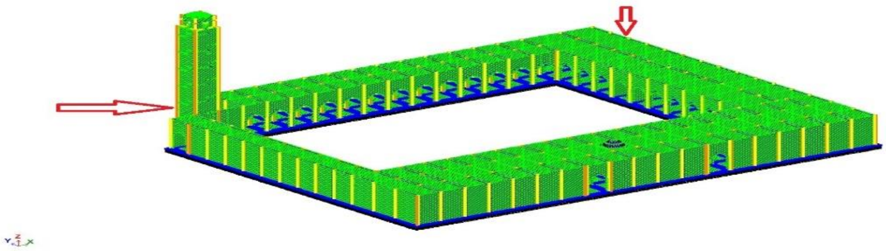

Figure 7. design model of the Great Mosque of Aleppo (condition before destruction).

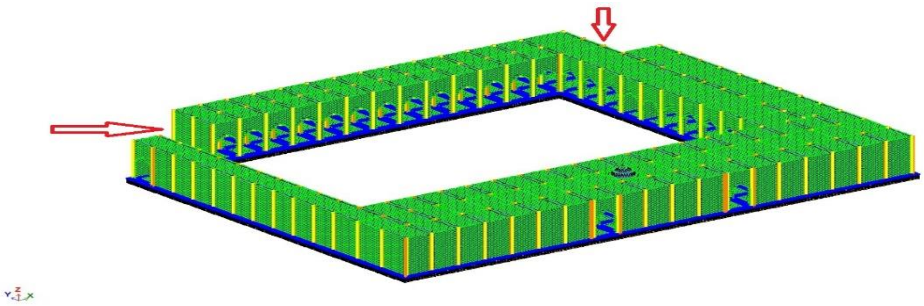

Figure 8. design model of the Great Mosque of Aleppo (condition after destruction). The arrows show the places of the main destruction.

The calculation was carried out in two stages, using the normative data presented in the Russian SP [14, 21], the purpose of the first stage of the calculation study was to determine the deformation by the earthquake of the design basis earthquake level which according to the Eurocode corresponds to serviceability limit state (SLS). To calculate the design basis earthquake in the LIRA-SAPR 2017 program, the following basic earthquake characteristics were set: type of structure, type of soil, ground acceleration for a 7-point earthquake and direction of impact perpendicular to the longitudinal axis of the structure, because in this direction the structure has minimum rigidity, which in turn means that this direction is the most dangerous in terms of horizontal impact. The masses and loads were converted in the LIRA-SAPR 2017 program from static to dynamic, including seismic. For this, all static loads were set and loads were collected on the design model, guided by SP 20.13330.2011 "Loads and Impacts" [21].

At the second stage of the computational study, a study was carried out on the action of seismic load of the level of the maximum design earthquake, which according to the Eurocode corresponds to the ultimate limit state (ULS), according to the given accelerograms with different vibration frequencies: high-frequency earthquake (T = 0.1-0.3 s); medium-frequency earthquake (T = 0.4-0.7 s) and low-frequency earthquake (T = 1.0-1.7 s).

3.Results

Some of the results of the calculations performed in the study are presented in table 3, where, in order to assess the seismic resistance of the building structures of the Great Mosque of Aleppo, a comparison of displacements in the level of the mosque cover was made. The results show the maximum displacements in the mosque along X in millimeters before and after destruction, and along Y before and after destruction for different periods of the earthquake (T, s).

Table 3. Maximum displacements along X and Y in the Great Mosque of Aleppo, for different periods of the earthquake (T,s).

Earthquake periods (T,s)	Maximum displacements along X, (X_{max},mm), Before destruction	Maximum displacements along X, (X_{max},mm), After destruction	Maximum displacements along Y, (Y_{max},mm), Before destruction	Maximum displacements along Y, (Y_{max},mm), After destruction
High frequency earthquake (T = 0.1 - 0.3s)	1,4	0,0854	1,62	0,113
Medium frequency earthquake (T = 0.4 - 0.7s)	26,9	7,82	28,4	10
Low frequency earthquake (T = 1.0 -1.7 s)	85,4	4,06	118	5,39

4.Conclusions

1.To carry out an objective assessment of the seismic resistance of objects of Arab architecture, including Islamic monuments of architecture, it is necessary to preliminarily assess the seismicity of the regions in which they are located, taking into account the frequency composition of a possible earthquake, the intensity of seismic impacts, and also taking into account the analysis of historical information about earthquakes of past years;

2.The analysis of the seismic resistance assessment of the considered building of the Great Mosque in the city of Aleppo shows that the maximum efforts have different values depending on the nature of the seismic impact and are the basis for further researches on the anti-seismic strengthening of architectural monuments in Syria.

5. References

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