Study of stress-strain state of structures and assessment of seismic safety of Ismoil Somoni Mausoleum in Bukhara

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Abstract. In this article, the state of deformation and stress of the constructions of the Ismail Somoni mausoleum in the city of Bukhara was calculated based on the impact of the accelerogram recorded as a result of engineering-seismological observations, and the seismic stability was evaluated.

1 Introduction

The era of the Somonites, which is recognized as an integral page in the history of our country, includes the 9th-10th centuries. In the second half of the 9th century, the Samanid dynasty appeared in Movarounnahr and Khorasan. Usually dynasties rise to prominence through some of their own major unrecognized activities. It was the same with the Somanites. Somonkhudot, who founded the dynasty, is originally the elder of the village of Soman and his descendants [1].

This historic monument, which is one of the rare examples of Somanid architecture in Central Asia, was built by Ismail Somani (Fig. 1).

If we talk about the personality of Ismail Somani, he is a major political figure who founded the state of Somani in Bukhara. Ismail Somoni was born in Bukhara in 848, in 874 he became the deputy of Somani in Bukhara, and from 888 he became governor of all Movarounnahr. Ismail Somani carried out the policy of strengthening the central authority and gathered scholars, writers, masters and craftsmen from different lands to Bukhara.

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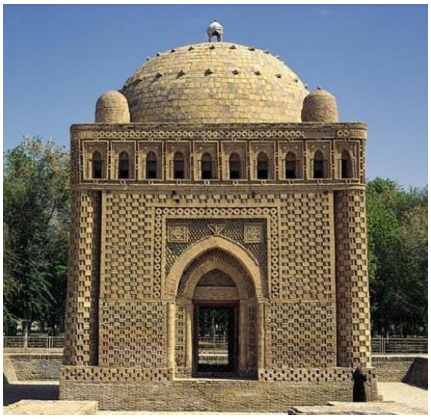

Fig. 1. Ismail Somani mausoleum in Bukhara

During the period when the architectural monument was built, local states independent from the Arab caliphate began to form in Central Asia. In Khurasan, the Tahiri state, and in Movarounnahr, the Somani state was established. Local states were united around a single center, and science flourished. In 874, Ismail was appointed viceroy of Bukhara. At that time, his brother Nasr was ruling in Movarounnahr. Relations between Nasr and Ismail broke down in 888, leading to war. After winning the war, Ishmael became the ruler of all Movarounnahr. In 893 he marched to Taroz and strengthened the northern borders. Ismail Somani Mausoleum was built in the old city of Bukhara between 864 and 868 during the advanced period of the Middle Ages. (Fig. 2).

Since the building served as a tomb, its interior was a one-room square shape with three steps (quadruple - four walls, octave - transition from wall to roof and dome - roof).[11].

Brick, stone and wood were used in its construction. As for the decoration of the mausoleum, the muted brick decoration is reminiscent of a fence with spikes or reeds, mat texture (Fig. 3).

Fig. 2. The current view of Ismail Samoni's mausoleum

Fig. 3. Decorations on the roof of the building

The thickness of the wall of the structure is 1.8 m, its dimensions are 10.80×10.70 m outside, 7.20×7.20 m inside. The roof of the building is covered with a dome. Its four corners are made in the form of columns, and four domes are placed around the dome. A total of 40 sun-shaped windows were designed at the top of the wall (Fig. 4).

Fig. 4. Yellow windows on the roof of the building

Fig. 5. Location of the arch system for sunlight and ventilation in the building

Each window is framed, and the cornice above the arch is bordered by a cornice of cornices. On both sides, small brick amulets are made. The interior of the building is inextricably linked with the exterior of the building, reminiscent of stylistic uniformity (Fig. 5).

The inner wall rested on overlapping arches - columns under the dome. The arches form the base of the 8-sided dome. Columns supporting the dome are made in the corners of the edges. During the archeological excavation (1927), it was found that there were 2 wooden sagans in the room. The mausoleum of Ismail Somoni is a grand architectural work in which the traditions of ancient Sughd architecture have been preserved in its structure.

The Ismail Somoni mausoleum is a unique work of world schools of architecture and construction. Architects and builders proudly mention this unique architectural monument, historians study its creation, and artists fondly reflect its images in various objects.

The mausoleum of Ismail Somoni shows how advanced and developed the art of architecture and construction techniques were in Bukhara in the 9th century. From that period, high-quality baked bricks and alabaster mixtures were used in construction.

Before the restoration of this rare monument, mathematical knowledge, especially geometry, was very well developed in Bukhara.

It is no coincidence that Professor M. Bulatov wrote his doctoral thesis based on the study of the geometric rules and laws used in its construction. There are still many unexplored aspects of the structure, laws, rules, construction methods [3].

The mausoleum of Ismail Somoni is a centralized structure, the main volume of which is made up of a slightly curved cube and a spatial dome with its four walls rising. The structure connecting the wall squares and the dome is one of the unique aspects of the building. All facades of the mausoleum are made in the same way. The walls are decorated from inside and outside with high-quality baked bricks, and carving methods were also used in the construction.

The decorative brick skin gave the building a sense of lightness. The entrance door spans are built in the form of an arrow-shaped arch. These solutions, especially the pointed arch and domed roof constructions, were widely used not only in the architecture of Bukhara, but also in the architecture of the entire Central Asia.

There are many positive aspects of using vaulted ceilings, one of which is that at that time, there were almost no products and structures like reinforced concrete, which had good bending parts of long-lasting structures. For this reason, the roof covering was built in such a way that any structure built according to its shape worked mainly for compression. As a result, the spans of the buildings were restored in the form of pointed arches, and the roofs were made of brick in the form of domes (Fig. 6).

On the other hand, in dry and hot climates, where a lot of solar radiation falls on the ground, the dome solution is considered effective. Sunlight falls directly on only one part of

the domed roof and heats that part a lot. At the same time, radiation does not directly fall on the remaining parts of the dome and the roof does not heat up much. The third aspect of the dome covering is that the heat from such a surface quickly leaves and the roof cools down quickly. And when the wind blows, this process is even more intense.

The architectural monument of Ismail Somani has been well preserved for more than nine centuries. It is considered a masterpiece of world architecture.

Fig. 6. Interior view of the arch system and dome of the building

It cannot be denied that several tectonic solutions were developed in this structure as a whole. The confident use of the foundations of residential and cultural architecture in this building shows the high development of the Bukhara school of architecture at that time (Fig. 7).

In the middle of the dome of the building, a drum structure covered with a dome is installed for light penetration and hot air escape, and arched spans are placed on its sides. The outer corners of the walls of the building are skillfully made of carved columns, and the arches of the walls and entrance doors are made of decorative, polished bricks. If you get to know the interior of the domed building in depth, you will be sure that the art of creating it started from ancient times and has become a tradition. The architectural analysis of the monument testifies to its genetic connection with Iranian, Mesopotamian architecture.

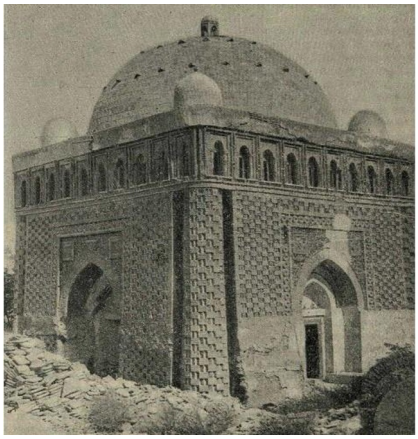

Fig. 7. General view of the building before the renovation

So, the volume - celestial and constructive structure of Ismail Somoni's mausoleum determined the development of domed buildings built after it. Architectural motifs, beautiful

muted decorative elements, extremely beautiful and exquisite artistic expressions testify to the flourishing of the art of bricklaying in that period. The mausoleum's bricks were selected with a high artistic taste, which made it the basis for its place among the world's great architectural masterpieces.

The mausoleum is dome-shaped, built in the tyFigal "Chor" style of Movarounnahr and Khurasan architecture. The unique feature of the architectural monument is that it is one of the first tombs in the history of architecture and art of Central Asia. From the design of the Ismail Somoni mausoleum to its dimensional structure, it is created on the basis of a geometrical order, which distinguishes it from other mausoleums. The mausoleum was considered a hut where Samani emirs were buried. Nowadays, the surroundings of the architectural structure have been turned into a garden (Fig. 8).

It is located 60-50 cm below, as it was found through archaeological excavations. Today, this building has become the center of attention of enlighteners and scholars of the Islamic world, as well as a tourist destination.

As for the attention paid to the mausoleum by the Uzbek government, in 1997, on the occasion of the 2500th anniversary of the city of Bukhara, among all the monuments in Bukhara, the Ismail Somoni mausoleum was renovated.

Fig. 8. General view of the garden around the building

The building was included in the list of UNESCO World Monuments. In 1993, the historical center of Bukhara was included in the "List of World Cultural Heritage".

2 Materials and methods

An earthquake is a vibration of the earth's surface, and the energy released from its center is understood as the occurrence of deformations on the earth's surface as an oscillating movement in large areas [4]. Earthquake intensity is a measure of its impact on objects, and the unit of measurement is a score based on the degree of damage to buildings and structures. Taking these into account, earthquake intensity can be expressed in the form of kinematic magnitude acceleration.

Currently, there are wide opportunities to use existing engineering programs for calculating architectural monuments under the influence of seismic forces and evaluating their strength.[10] Accordingly, since the main load-bearing structures of monuments are massive, their calculation model is reconstructed as complex three-dimensional elements and requires calculation through real accelerograms as seismic forces.

An earthquake accelerogram records one-dimensional accelerations over time as a graph or numbers in the (N-S) north-south, (W-E) west-east, and (V) vertical directions.

Analog accelerogram (AA) is an accelerogram of earthquakes that have occurred and is used in the design of earthquake-resistant buildings and structures.

When calculating buildings and structures under the influence of seismic forces by direct dynamic methods, an earthquake accelerogram with indicators corresponding to the seismicity of the construction area is needed. The accelerogram can be recalibrated using special software, and it takes a lot of time and effort to get the right results. In order to overcome the above difficulties, it is recommended to use synthesized accelerograms that reflect the characteristics of several seismic regions [8].

Below, Figtures 9 and 10 show accelerograms of the horizontal X, Y and Z axes of the recorded and amplified accelerogram as a result of microseismic vibrations of the ground based on the results of engineering-seismological observations of an earthquake that is likely to recur in 50 years in the territory of Bukhara city. In the accelerogram, the value of the maximum acceleration in the X and Y directions is PGM=0.25g and in the direction of the Z axis PGM=0.175g. The time step of the accelerogram is 0.01 s and the duration of the earthquake is T=10.06 c.

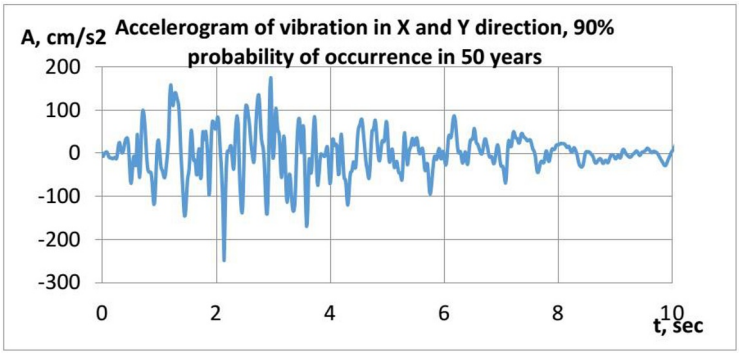

Fig. 9. X and Y ground vibration accelerogram with 90% probability of occurrence in 50 years for the city of Bukhara

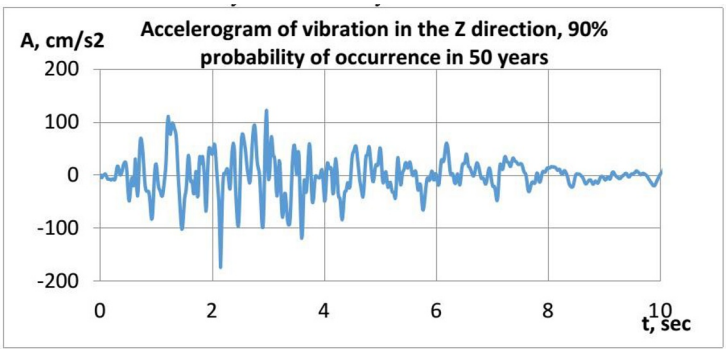

Fig. 10. Z direction ground vibration accelerogram with 90% probability of occurrence in 50 years for the city of Bukhara

The step of the numbered accelerogram of the earthquake in the X and Y direction is 0.01 s and the measured points are 1006. In the accelerogram, the duration of the earthquake is 10.06 s. (Table 1)

Table 1. Numbered accelerogram

A, cm/s2					
0	-10,26675	-12,73287	3,13821	-28,06752	2,4512
-6,79945	10,50885	-10,31278	8,12975	-28,59883	4,51225
-2,91589	-10,382	-3,11543	14,8478	-27,88813	6,10094

-0,87408	-10,65944	7,6181	21,96212	-25,91017	7,58989
0,32685	-11,46016	18,19471	28,25813	-22,87122	9,68359
1,87581	-12,17498	24,60862	32,99034	-19,28957	12,88235
3,20597	-12,22266	24,8671	.....	-15,72722	16,6823
3,78898	-11,3495	19,90296	-17,65816	-12,58465	19,43296
2,39764	-10,08052	12,57611	-19,83244	-9,70501	21,20136
-1,03577	-9,37254	5,88072	-22,14356	-6,74982	……
-5,24415	-10,05656	1,73183	-24,47337	-3,51514	
-8,55219	-11,78509	0,83189	-26,57287	-0,33183	

Mechanical and strength indicators of architectural monuments N.S. It is fully presented in the works of Grajdankina and several scientists [5-6].

Baked ceramic bricks have been used in historical monuments since the 9th-10th centuries.[9] Until then, historical monuments were restored from raw bricks. The process of making ceramic bricks required a lot of time and labor. They were mainly due to the complexity of the composition and the complexity of the preparation process, as well as the need for manual labor to bring the clay to the same shape. Until now, the composition and production technology of Muslim bricks have not been fully studied. In the architectural monuments built in the 9th-10th centuries, Muslim bricks with a ceramic square shape were used in the restoration of massive walls, the size of which is 23 x 23 x 3 cm; 12 x 12 x 3 cm; It is 60 x 63 x 6.5 cm. In addition, bricks measuring 21 x 21 x 2.5 cm and 24 x 24 x 4 cm were used in the X-XI centuries. In the 12th - 16th centuries, bricks with side dimensions of 24÷28 cm and thickness of 4.5, 5÷7 cm were used.

As a result of research, the water absorption rate of solid wall ceramic bricks is from 18 to 30%, depending on their porosity. The compressive strength of bricks was 50-300 kg/cm2 (5-30 MPa). The frost resistance of bricks was higher than 50 cycles. Physical and mechanical parameters of ceramic bricks used in architectural monuments correspond to 8.0÷11.5 MPa [5-6]. The compressive strength of the construction mixture is 2.0÷6.0 MPa. The average strength of bricks when mixed with mortar is 0.05÷0.15 MPa.

The structures of the Somonites mausoleum have been restored in different years, and now they have been completely restored to their original condition. Most of the land area of our republic is located in the seismically active area, and the analysis of statistical data in recent years shows that the seismic activity on the earth has increased significantly. Taking into account the above, the calculation of the seismic effects that can be expected in the mausoleum structure and the preliminary determination of damages, as well as the research of the seismic strength using the available numerical methods and the assessment of the seismic strength are considered urgent issues [5-6].

3 Discussion of experimental results

Calculations were carried out using the finite element method in the Lira software package by calculating real accelerograms under impact, and the state of deformation and stress in structures was determined. During the calculation, in order to evaluate the category of brick constructions in mausoleum constructions based on their category, a three-dimensional computational model was modeled, deformation-stress states under the influence of real accelerograms were determined and their mutual values were compared [7].

A three-dimensional view of the mausoleum structure is presented below (Fig. 11).

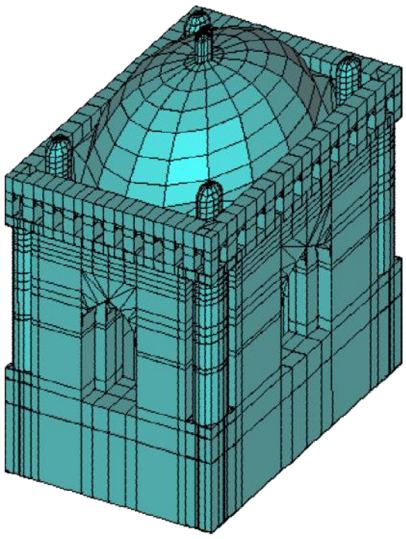

Fig. 11. View of the mausoleum building calculation model

In the calculations of the constructions of the Samonite mausoleum using the finite element method using the Lira program, microseismic effects for the city of Bukhara were calculated in the form of an accelerogram to the seismic effects that may occur in 50 years as a result of engineering-seismological measurements of the area, and the state of deformation and stress of brick structures was studied. The duration of this accelerogram is 10.06 s with a step of 0.01 s. Multiplier coefficient was adopted in accordance with the intensity of 7 points on the scale of earthquakes. Some of the accelerogram values are presented above in graphical and numerical form.

During the calculation, assuming that seismic waves act in the longitudinal, transverse and vertical directions, displacements of the three-dimensional model in the longitudinal and vertical directions, as well as the isopoles of the equivalent stresses in the extension, were constructed (Figures 12-15).

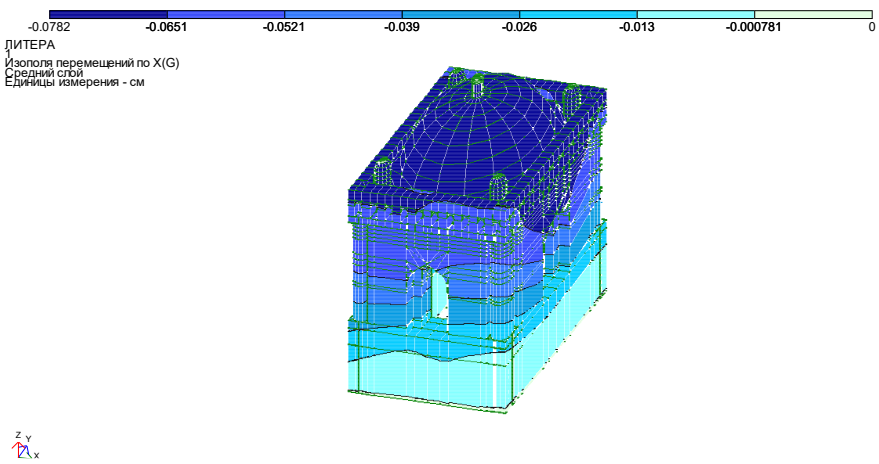

Fig. 12. The isopole of displacements in the X direction of the structure

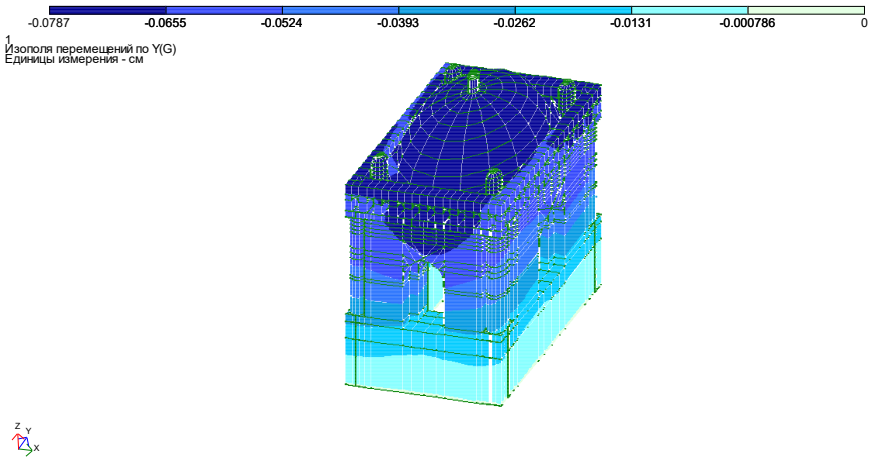

Fig. 13. The isopole of displacements in the Y direction of the structure

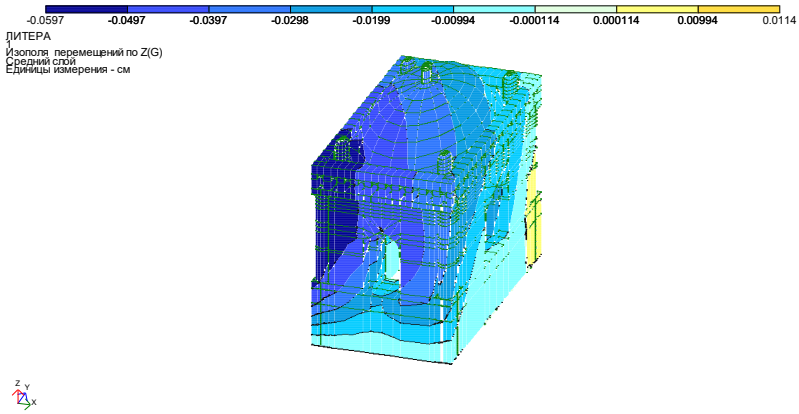

Fig. 14. The isopole of displacements of the structure in the Z direction

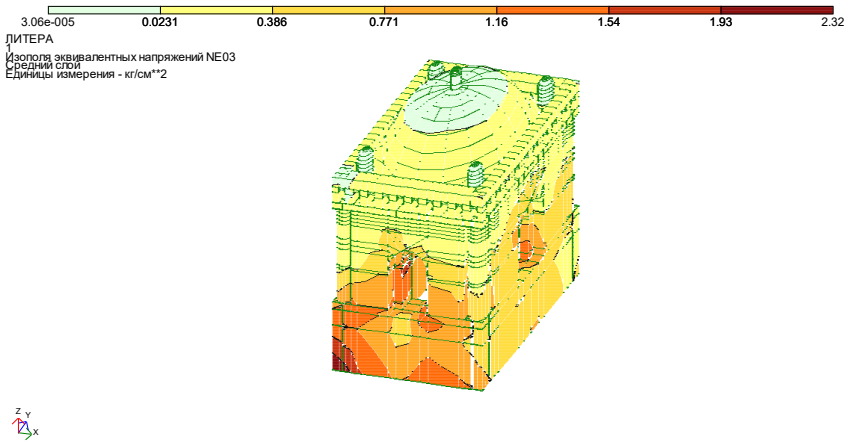

Fig. 15. Equivalent tensile stress isopole arising in building structures

4 Summary

The following conclusions can be made as a result of comparing the isopolyes reflecting the deformation-stress states of the constructions of the mausoleum structure under the influence of seismic forces according to the obtained numerical calculation:

It was found that the strength of the bricks in terms of jointing is lower than the standard value in the roof structure near the arch structure of the building under the influence of seismic forces of 7 points intensity.

The displacements of the structure in the longitudinal X direction under the influence of real seismic forces were 0.000782 m, the displacement in the transverse U direction was 0.000787 m, and the displacement in the vertical Z direction was 0.000597 m.

According to the calculation results, it can be estimated that the reason for the small value of the displacements in the corresponding directions is the massiveness of the structure's walls.

Stresses in brick walls in the supporting parts of the roof and arch structures of the building under the influence of seismic forces of intensity 7

It was 2.32 kgs/cm^2. According to clause 3.5.4 of QMQ 2.01.03-19 "Construction in seismic areas" regulatory document, according to the ability of the wall structure to resist seismic effects, the limit value set for class II skin is $180\,kPa > R_t^B \geq 120kPa$ (1.2 kgk/cm^2) was found to be greater than;

In the full assessment of the seismic stability of the constructions of the Somonites' mausoleum, in addition to the above numerical calculation results, it is necessary to fully evaluate the necessary calculation parameters based on the results of the test laboratory, and to develop new structural solutions for the purpose of comprehensive strengthening of the structures.

Nowadays, there are significant cracks in the structures of buildings, and complex engineering studies are required to eliminate them. It requires the use of modern latest engineering equipment to assess the technical condition of infrastructure structures and ensure their seismic strength.

In the evaluation of the technical condition of the constructions of the facility, it was evaluated based on the results of the scientific and research work carried out until now, on the basis of archival materials and the results of the collected engineering works.

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