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Assessment of the Technical Condition of the Reinforced Dome Construction of the Kalyan Mosque under the Influence of Seismic Forces

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ABSTRACT: In the article was analyzed the technical condition of the dome construction of the Kalyan Mosque in Bukhara after reinforcing with metal profiles as a result of theoretical calculations. Using a special computer program, the dome structure was calculated separately from the accelerogram of the existing SA-482 model by the finite element method, and its stress-strain state was determined.

KEYWORDS: restoration, reconstruction, buttress, cable-stayed construction, accelerogram, connecting belt, isofield of displacements and stress.

I.INTRODUCTION

Uzbekistan is one of the richest countries in the world in terms of architectural monuments, which reflects the past, culture, science and development of our people, the spiritual and enlightenment of that time. Bukhara is a city of the unique architectural monuments of Central Asia. The famous monuments built by our ancestors have been preserved here for centuries. Most of these monuments were built during the Karakhanid period. During this period, Bukhara became a place in the East to realize the creative potential of architects invited from different countries. Bukhara is one of the ancient centers of Central Asia, and its historical heritage still attracts the attention of many researchers. Now, when it comes to the types of mosques, it is noteworthy that there are so many types of mosques in Islam as the main building of worship. These include Islamic festivals, such as Eid prayers, usually outside the city, Friday or Friday mosques, neighborhood and village mosques, as well as mosques and buildings near caravanserais, rabods, madrasas, and shrines enters. The mosque and musallas are designed for the entire population of the city to pray. Speaking of mosques, it should be noted that in medieval urban architecture, special attention was paid to the construction of mosques. At that time, there were mosques in Samarkand, Bukhara, Shakhrisabz, Tashkent, Herat, Mashhad and other cities, which were built in a very sophisticated and glorious way [1].

The Kalyan Mosque in present-day Bukhara was built in the 16th century and is part of the Poy Minor ensemble. In addition to the Kalyan Mosque, the ensemble includes the Kalyan Tower and the Mir Arab Madrasa. In the 11th century, there was a mosque on the site of the present-day Kalyan Mosque. Little is known about this in historical sources. The data of Narshahi, who lived and worked in the 12th century, were used by modern authors to describe the Kalyan Mosque. The authors look at the decorative bricks that have survived in the southeastern part of the mosque. It is believed to be a remnant from the 12th century. According to Narshahi’s written sources, the mosque, built in 1068, burned down and was rebuilt again. By order of Arslan Khan, the mosque and minaret were later built in the city center. When construction was almost complete, the minaret was demolished for unknown reasons and later 2/3 of the mosque was rebuilt. In 1121, the mosque was built completely. The minaret of the mosque was built in 1127. According to historical sources, the main mosque was built in the 11th century, and the northern mosque in the 12th century. In the 13th and 14th centuries, the mosque was rebuilt [2].

Thus, a long-term study concluded that three mosques had previously been built on the site of the current Kalyan Mosque. Kalyan Mosque is one of the largest mosques in Central Asia, measuring 127x78 m. The mosque is rectangular shape in the plan, with a main entrance to the east and a gallery of 208 columns and 288 small domes. The foundation at the base of the columns is made of brick by means of a mixture of gypsum and their dimensions are 1x1

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m in some places 0.7x0.7 m. The columns in the small domes are passed through a system of arches to the circular base of the dome. In the western part of the mosque is the main dome (Figure 1).

Figure 1. General view of the interior of the Kalyan Mosque

Strong earthquakes that have occurred in certain periods and the recent rise in groundwater levels have caused deformations in the mosque's structures. In addition, cases of erosion due to moisture in the lower part of the walls of the mosque were observed [3].

The mosque has been undergoing restoration and repair work for several years. The last repair was made in 2002. According to him, the south courtyard roof, north side pillars and the main dome have been renovated. The north pillars have been rebuilt from concrete. Reinforced concrete and metal structures were used in the reconstruction of the roof and main dome [4].

In assessing the technical condition of the Kalyan Mosque, archival materials of the Main Department of Scientific Production for the Preservation of Cultural Monuments under the Ministry of Culture of the Republic of Uzbekistan were used. The main reason for the demolition of the Kalyan mosque is the strong earthquakes that took place in Bukhara between 1818 and 1909. The mosque's structures were severely damaged during the earthquakes. The mosque was then left unattended for several years until it regained its appearance. Inside the mosque, the locks on the four backs of the main prism are cracked. Especially the southern rear lock part has moved and is in a state of emergency. Longitudinal and transverse cracks appeared in the walls of the mosque.

The south side of the main mosque was also badly damaged. Here you can see that the roof part is separated from the main mosque. The side rooms were completely destroyed. The dome structure and the drum structure on which it is based were also damaged. Almost the entire upper part of the dome collapsed. Longitudinal cracks appeared in the remaining parts and in the drum. The small mosques to the north and south of the mosque complex also suffered heavy losses due to the earthquake and other factors. It can be seen that the above deformations also occurred in these.

Due to the earthquake, the domed porches connecting the four components of the mosque complex were completely destroyed. Today, some of their column foundations have been preserved. In 1967, the Institute of Reconstruction developed a project to repair the Kalyan Mosque in Bukhara, but for some reason the mosque complex remained unrepaired. However, restoration and restoration work has been carried out in different years. An example of this is the restored condition of the roof and dome of the Kalyan Mosque (Figure 2) .

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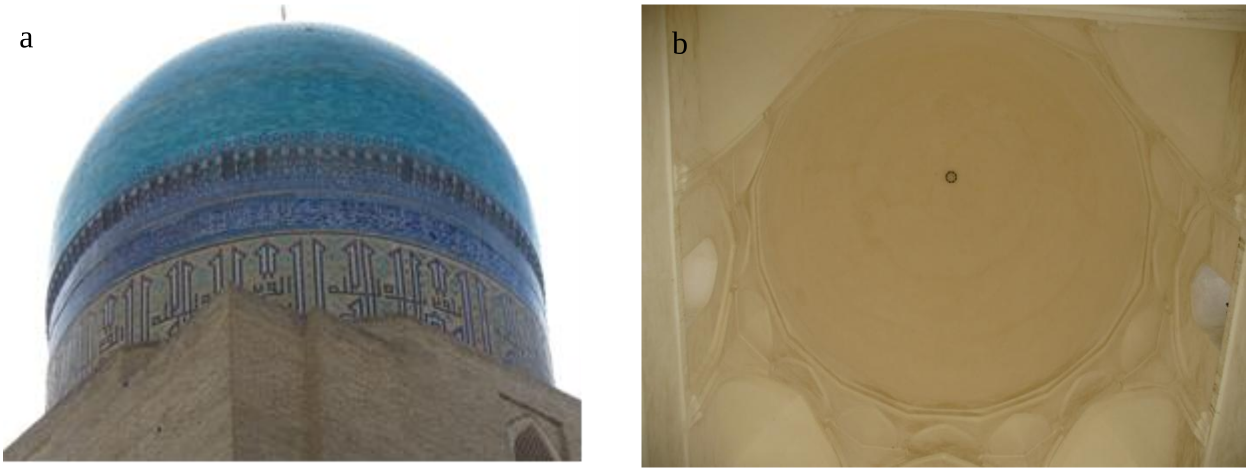

Figure 2. The dome of the main mosque building (a) and view from the inside (b)

The main material of the entire mosque complex is burnt brick, the dimensions of which are 0.22x0.22x0.05 m. These bricks were assembled using a mixture of gypsum [5]. One of the main structures of the mosque is the dome structure, which was damaged during the earthquake and was quite damaged. During the repair, it was reinforced with a cable-stayed construction using steel profiles, which was not entirely based on engineering calculations. The brick buttress diaphragms located on the inner side of the dome under the dome are attached to the connecting belt using rolled channels and are attached to the drum wall using bolts and nuts using a steel rope. Due to the fact that most of the republic's territory is located in seismic zones, a theoretical study of the influence of this strengthening structure on the structure of the drum during an earthquake is important and relevant. One of the main solutions to this is to perform computational work using Lira Soft based on the finite element method available in construction practice [6]. The geometric dimensions of the drum structure and the strengthening steel profiles in it are shown below (Figures 3, 4, 5).

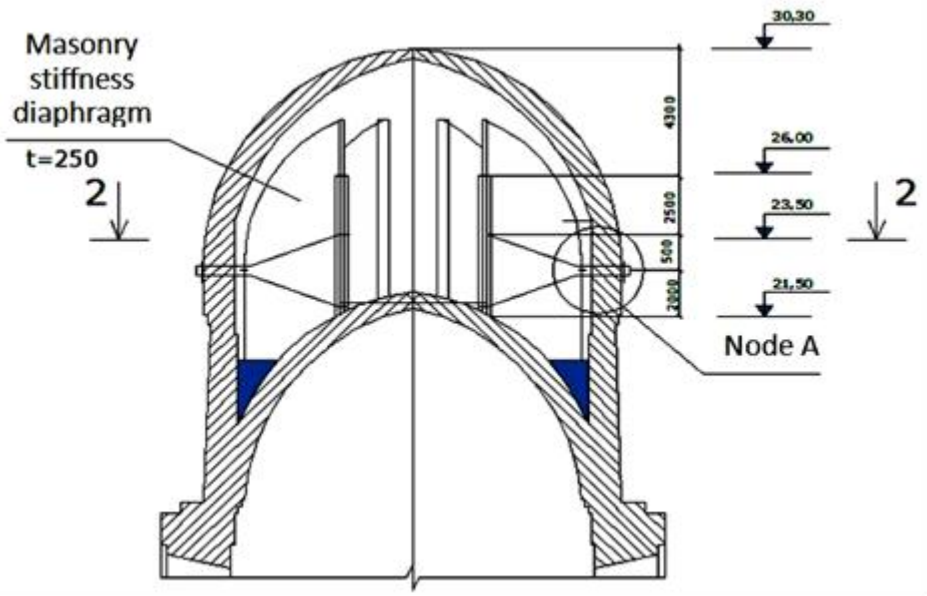

Figure 3. The section of the dome construction of the main mosque (1-1)

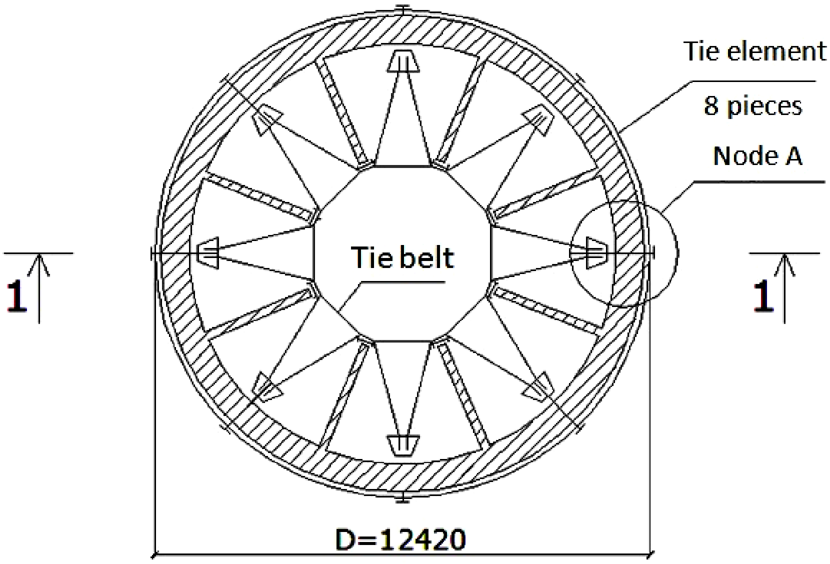

Figure 4. Drum construction plan (2-2)

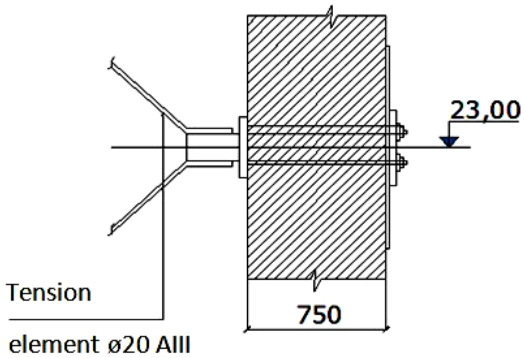

Figure 5. View of the wall of the drum construction with tensioning elements (Node A)

Before calculating the dome construction using the Lira Soft program, three-dimensional calculation scheme is drawn (Figures 6, 7).

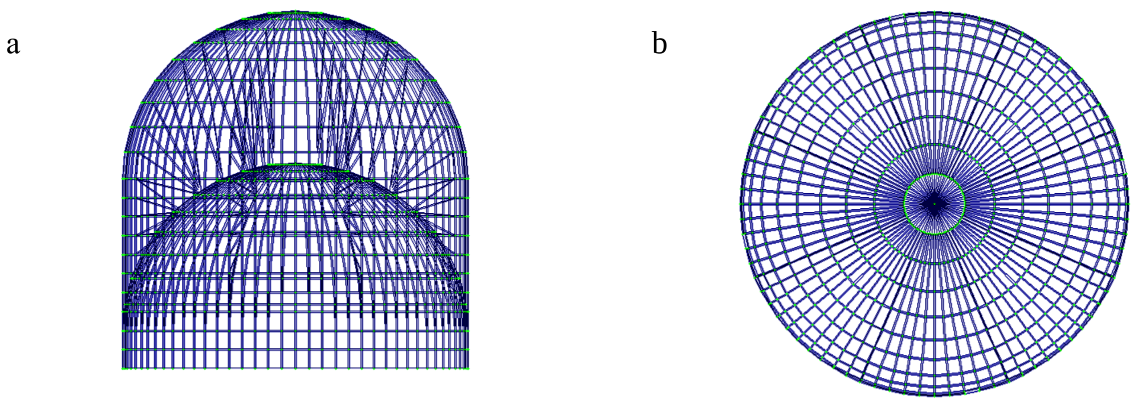

Figure 6. View from side (a) and under the dome (b) before strengthening the dome structure

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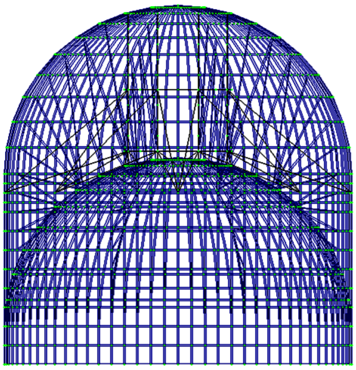
a



b

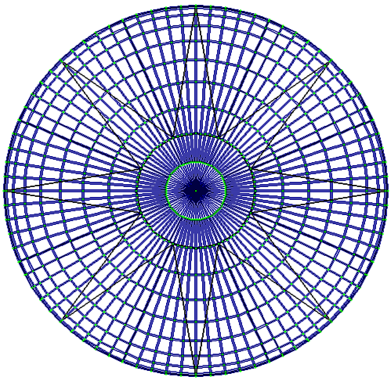


Figure 7. View from the side (a) and under the dome (b) after strengthening the dome structure using the cable-stayed construction

When the calculating of the dome of the structure of the main Kalyan mosque, a synthesized accelerogram of the SA-482 model was used, which reflects the strong earthquakes using the Lira Soft program based on the finite element method? This accelerogram is reflects the effects of the low frequency earthquake was occurred in 1977 in Bucharest, a high frequency earthquake was occurred in 1976 in Gazli and mid frequency earthquake was occurred in 1940 in El Centro. The duration of this accelerogram is 4.3 s and consists of 0.005 s steps. The multiplication factor is 9.81. Some of the accelerogram values are given in the form of numbers below.

SA-482 # 0 0.006408 0.012816 0.0188235 0.0252315 0.03165395 0.0380475 0.0444555 0.0508635 0.0572515 0.0636795 0.069687 0.076095 0.082503 0.088911 0.095319 0.101727 0.108135 0.114543 0.0004005 0.1269585 .... 0.38448 0.3864825 0.388485 0.390087 0.3920895 0.393291 0.394893 0.3960945 0.3968955 0.398097 0.398898 0.3992985 0.399699 0.4000995 0.4000995 0.4000995 0.399699 0.3992985 0.398898 0.398097 0.3968955 0.3960945 0.3944925 0.393291 0.3912885 0.3896865 0.387684 ………………………0.104931 0.008811 -0.092115 -0.16821 -0.1926405 -0.1525905 -0.055269 0.067284 0.1654065 0.190638 0.12015 -0.020826 -0.1557945 -0.1870335 -0.0668835 0.1245555 0.18423 -0.0140175.

In the calculation, it was assumed that seismic waves act in the transverse direction. In cases where the dome structure is not reinforced and reinforced, stress states are reflected in the isofield below (Figures 8-14).

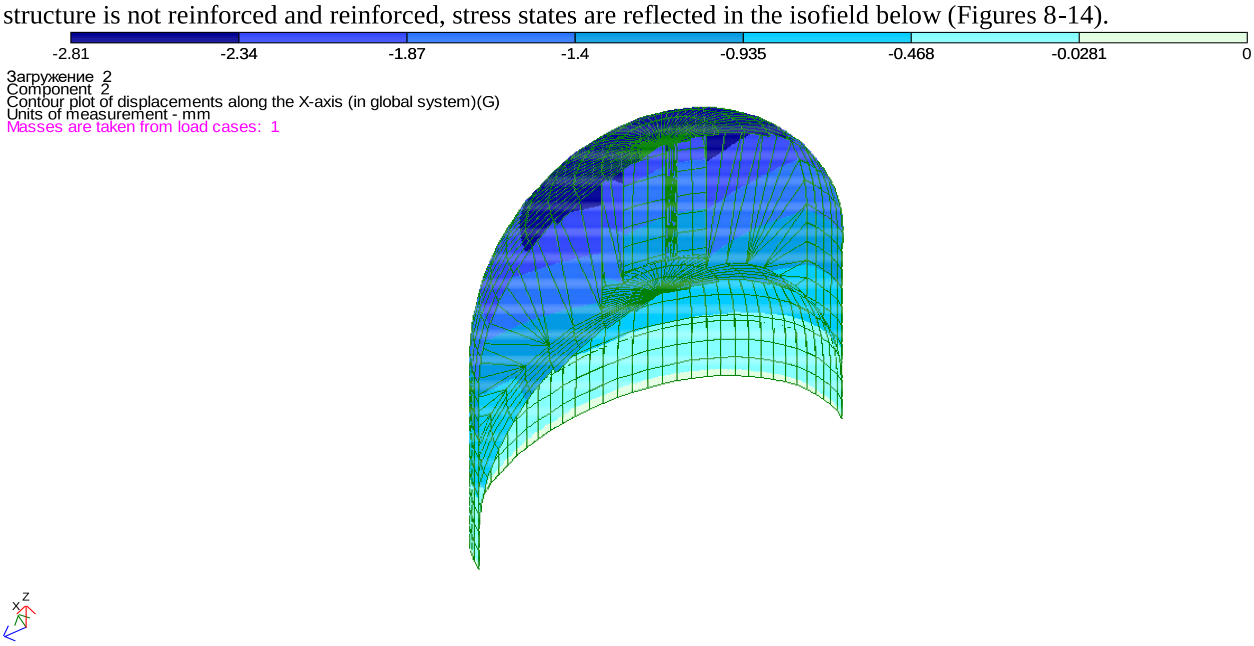


Figure 8. Isofield of displacement on the horizontal direction before strengthening of the dome

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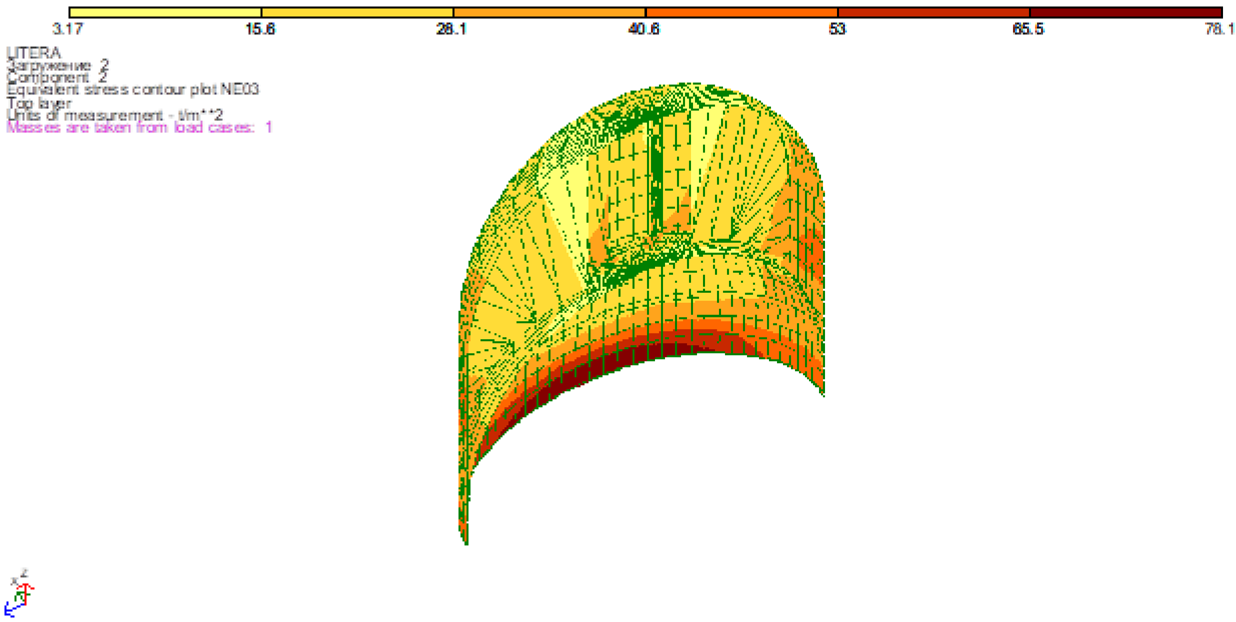

Figure 9. Isofield of tensile equivalent stress at the walls before strengthening of the dome

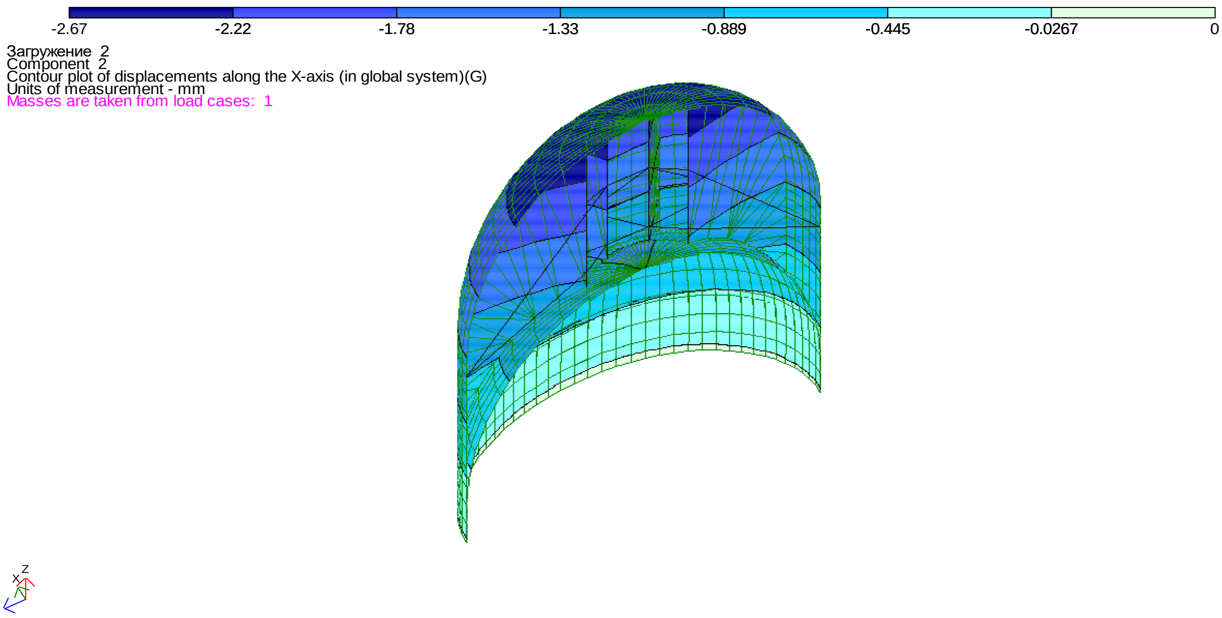

Figure 10. Isofield of displacement on the horizontal direction after strengthening of the dome

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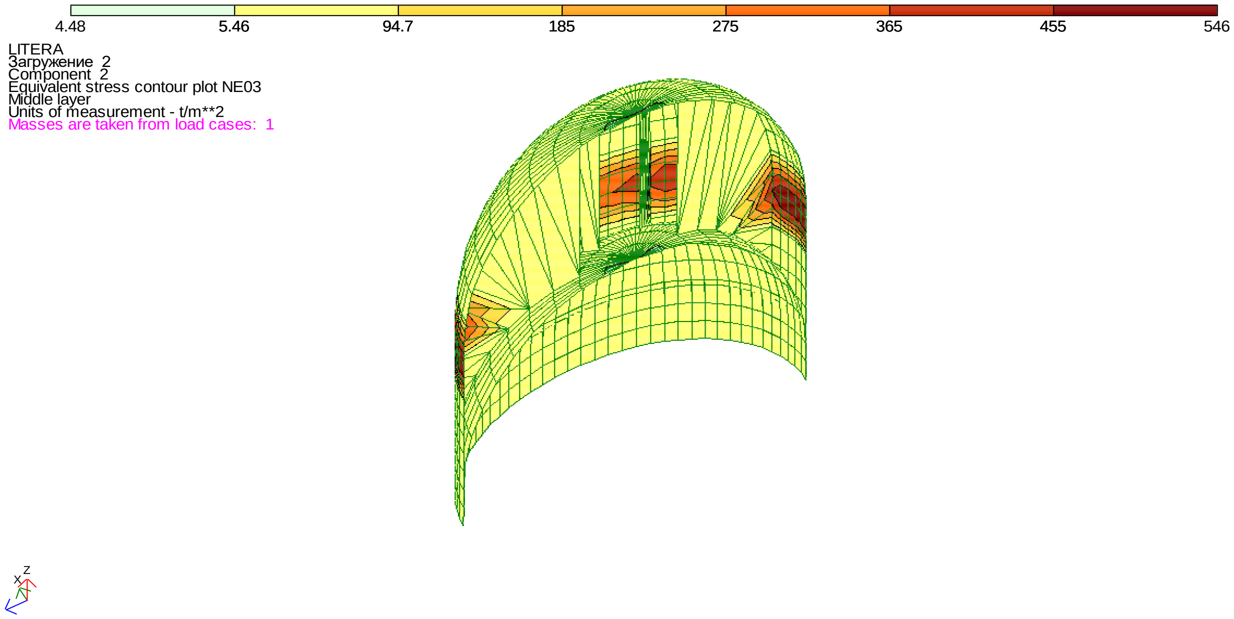

Figure 11. Isofield of tensile equivalent stress at the walls after strengthening of the dome

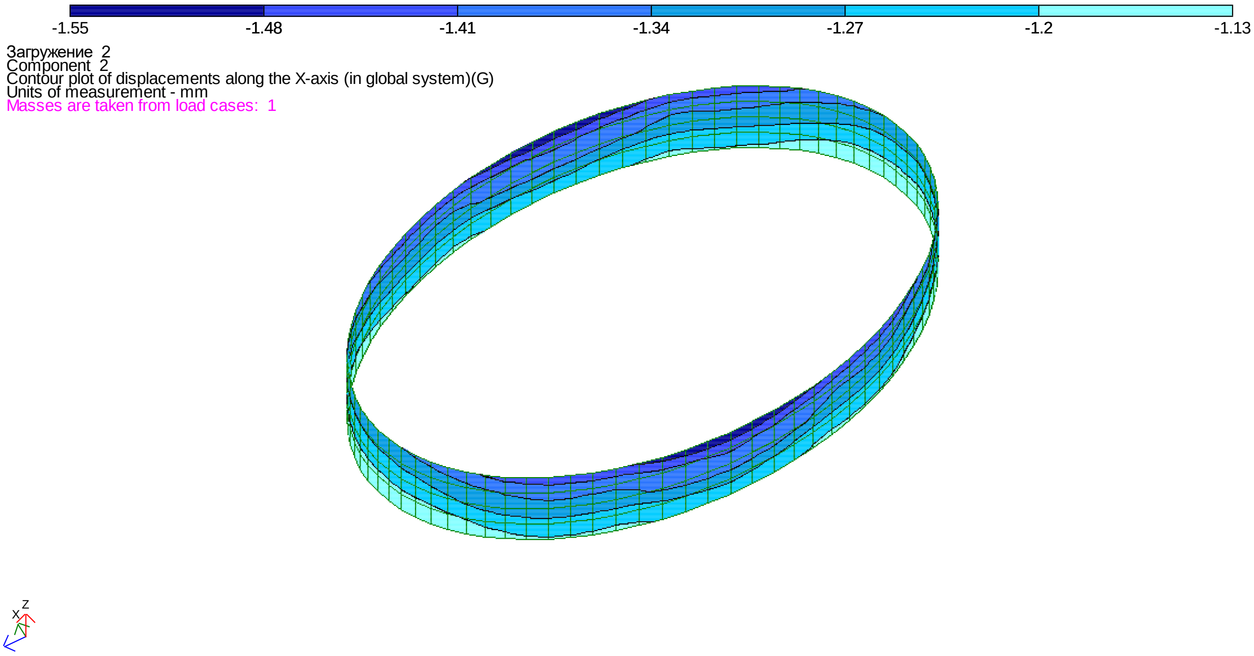

Figure 12. Isofield of horizontal displacement of plate-like traction element

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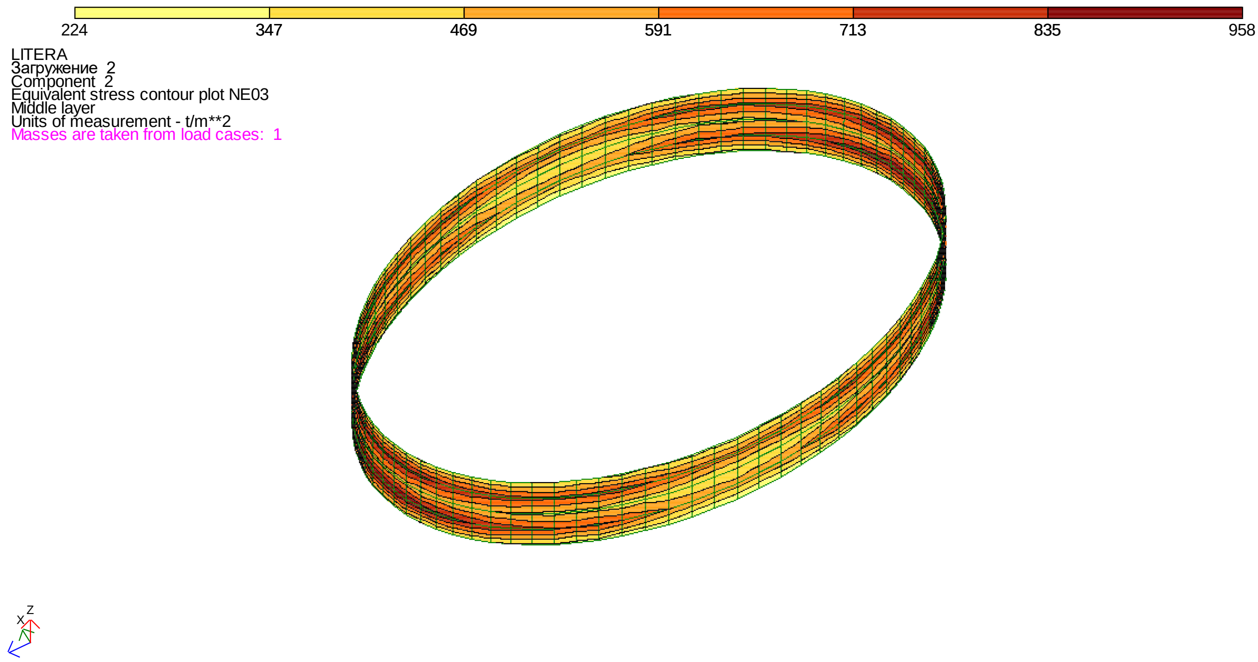

Figure 13. Isofield of tensile equivalent stress of plate-like traction element

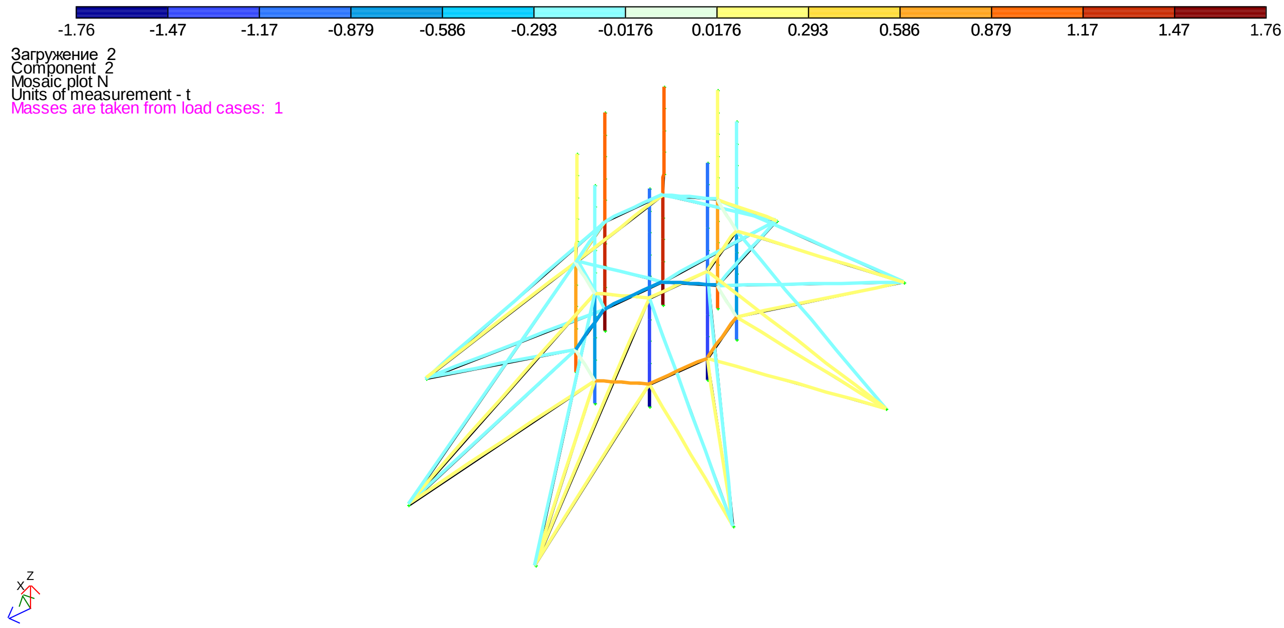

Figure 14. Longitudinal force mosaic of the steel bar elements, reinforced the dome construction

The obtained numerical results show that the horizontal displacement decreased from 2.81 mm to 2.67 mm after strengthening the dome structure.

The maximum value of the equivalent tensile stress in the walls of the dome structure varied before reinforcement is 65.5 H/cm^2 in the range of 78.1 H/cm^2, but increased from 5.46 H/cm^2 to 94.7 H/cm^2 after its strengthening. This value is due to the stress of the reinforcing elements under the influence of dynamic forces.

The horizontal displacement of the plate tension element was 1.55 mm, and the maximum equivalent tensile stress value was 958 H/cm^2.

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The maximum value of the longitudinal forces in the elements of the reinforcing bar was 17600 H, which did not exceed the allowable stress value. As a result of the calculations and analysis of archival materials, the following conclusions can be drawn:

1. The average equivalent value of the tensile stress in the walls after strengthening the design of the dome using steel profiles reduced by 11 times, but as a result of the load of strengthening bar elements on the areas where the traction area is located increased by 1.2 times;

2. Shear stress at the result of the horizontal displacements of the dome walls reduced the value by 1.05 times;

3. Since the calculations failed to take into account the existing cracks in the walls in the calculation scheme of the dome structure, the effectiveness of the strengthening elements was determined by comparing the dome structure with the initial stress-strain state using strengthening elements.

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