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CREATION OF ENERGY SAVING AND REINFORCEMENT SOLUTION OF BIBIKHONIM JOM'E MOSQUE CONSTRUCTION IN SAMARKAND CITY

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Abstract. Based on an analysis of published works, engineering surveys of detailed latching damage and deformation; as well as static calculations to assess the impact of the stress strain state; field observations and calculations of dynamic characteristics of seismic impact of Bibikhonim mosque in Samarkand.

Keywords. Deformation, dynamic, construction, Bibikhonim mosque, seismic, earthquake resistant, tension

Introduction

Today, the interest in architectural monuments and the attention given to them shows that the place and importance of architectural monuments on the world scale is incomparable. They have a great meaning in themselves. The peoples of the world have paid great attention to national historical monuments since time immemorial. Everyone is amazed when it comes to Egyptian tombs, medical temples, Muslim mosques and madrassas, ancient Roman and Greek historical monuments, the Great Wall of China, and the Taj Mahal palace in India.

The past, history, and national spirituality of an entire people are hidden in the architectural monuments.

It's no secret that the territory now called Uzbekistan, that is, one of the cradles of our world civilization, is now recognized by the whole world.

The achievement of independence of our country opened a wide way for our monuments to attract the attention of the world community. After gaining independence, the whole world learned that there are such great historical monuments in our country. Nowadays, tourists from all over the world come to visit our monuments. The most gratifying thing is that most of our historical monuments have been taken over by UNESCO. Almost all the monuments in the city of Samarkand, including the "Bibikhonim" complex, were recognized as the heritage of this international organization. This indicates that the interest of the entire world community in the historical monuments of our country is increasing more and more.

Architectural monuments in Uzbekistan are unique works of art created by human hands, which contain the history, culture, art, scientific achievements, ethics and philosophy of the people, and the traditions of the people and embodied national values.

The huge, magnificent buildings - historical monuments that have risen in the ancient cities of our republic, such as Samarkand, Bukhara, Khorezm, Shahrisabz, Tashkent, Kokan - are a clear proof of our opinion. One of our historical monuments is the building of the "Bibikhonim" public mosque, which is part of the "Bibikhonim" complex in Samarkand. It was one of the largest and rarest monuments of the XIV-XV centuries.

On the way from Registan Square to Shakhi Zinda, on Tashkent Street, there is a wonderful historical architectural monument - Bibikhonim Mosque. The construction of the mosque is attributed to the name of Amir Temur's beloved wife - Bibikhonim, in written sources and folk tales. One of the legends says: "Bibikhonim, who accompanied Amir Temur on a military campaign, decides to prepare a wonderful gift for her husband's triumphant return." He wants to build an unprecedentedly large and magnificent mosque in the capital. The best architects were invited to the advisory board. They want to dissuade Bibikhonim from this idea, thinking that such a construction will cost a lot of money. However, relying on the countless treasures and dedication of Amir Temur, they started the construction.

The mosque was built in Samarkand in 1399-1404 during the reign of Amir Temur. The mosque consists of several buildings and forms a large complex with the Bibikhonim madrasah.

The Bibikhonim congregational mosque occupies an entire dakha of the city. The length of the rectangular complex surrounded by a brick wall is 167 m, and the width is 109 m. In each corner of the complex, there were towers with a cross section in the shape of a truncated cone. Only one of them, the north-western minaret outside the outer wall, has been preserved. The height of the tower is 18.2 m. In the eastern part of the complex is the entrance gate, opposite to it in the west is the main mosque building and in the northern and southern parts are smaller mosques.

Methods

Methods of modeling and calculation of heat processes in construction. Methodological bases of visual study of the current state of barrier constructions. Methods of experimental tests on thermal physics of experimental, practical construction. And other scientific, technical and technological methods related to the ventilation system. In addition, methods of determining the deformation of the structure in natural conditions. Methods of determining physical and mechanical properties of construction materials and soil. Methods of determining the state of stress and deformation by determining the weight of the structure, calculating the static force. Methods of determining dynamic characteristics using highly sensitive seismometric instruments in natural conditions. Methods of calculating earthquake resistance using the found dynamic characteristics.

Results

The mosque was built in Samarkand in 1399-1404 during the reign of Amir Temur. The mosque consists of several buildings and forms a large complex with the madrasa of Bibikhonim.

The Bibikhonim congregational mosque occupies an entire dakha of the city. The length of the rectangular complex surrounded by a brick wall is 167 m, and the width is 109 m. In each corner of the complex, there were towers with a cross section in the shape of a truncated cone.

Only one of them, the north-western minaret outside the outer wall, has been preserved. The height of the tower is 18.2 m. In the eastern part of the complex is the entrance gate, opposite to it in the west is the main mosque building and in the northern and southern parts are small mosques. According to the position of the mosque, the road leads to the mehrab, which is decorated in the lattice of the room. This altar is common to all Muslim mosques, and it is built in such a way that the worshiper faces Mecca while facing it. Earlier, the square building was combined with multi-pillared porches. A porch with many stone pillars leading to the courtyard, a gate and a large mosque connecting two small mosques around the courtyard. This multi-column porch is an architectural method unique to Central Asia. Because the region of Central Asia is an earthquake region, earthquakes have been happening here. Therefore, earthquake resistant marble columns were rarely used. More than 400 marble columns were destroyed and buried in the Bibikhonim mosque. Only some of them were found during archaeological excavations. It is possible to see that the found pillars are decorated with carved patterns. Column bases and small bowls were also found. The distance between the columns is 3.6 m, and the brick arches supporting the domes rest on the columns. The total length of the column was 4.8 m from the base and 7.1 m from the base to the dome lock. The porch floor is covered with marble tiles. The top diameter of the column is 45 cm and the diameter of the base is 50 cm. The base of the columns is equipped with a brick foundation, the sides are 1.4x1.8x m. The size of the courtyard of the mosque is 63x76 m, and it is bordered on four sides by a row of one-story arches and porches of the main buildings. Marble slabs are laid on the ground. In the middle of the courtyard there is a step-like slab, its height is 60 cm. It was removed in 1875 in order not to be buried if the dome collapses. According to the inscriptions, the tablet was made in the middle of the 15th century according to the decree of Mirza Ulug'bek. In the inscription there is a place where it is said: "...Sultani Azim Oli Himmatli Hakhan Ulug'bek Quragon". A book of the Koran is poured on the tablet and made for reading.

The total height of the Bibikhanim mosque is 45.6 m. The height of the Peshtok before repair was 33.15 m, and the span of the entrance arch of the Peshtok was 17.64 m. The width of the passage from Peshtok is 5.85 m, and the distance to the triangular arch lock is 12.6 m in height. The thickness of the arch on the facade of Peshtoq is 9.95 m. The inner room of the mosque is square in plan, the sides are equal to 14.6x14.6 m. The internal walls are mihrabs on three sides, and these are the mehrab on the western wall, the depth of which is 2.5 m, the depth of the mihrab where the imam sits is 0.95 m, the passage on the north and south sides is equal to 0.81-0.85 mg. There are three main reasons for placing mihrab inside mosques. The first of these increased the size of the room; the second reduced the size of the wall, and finally the third gave the building an architectural beauty. The facade of the mosque is covered with marble tiles and the plinth with mysterious colorful patterns. Above the first geometric volume, where the base of the dome begins, there is a square around it, and it is accessed by spiral stairs from inside the minarets and by stairs at both ends of the mihrab. The other sides of the large building of the Bibikhanim Mosque are covered with the same colorful brick tile technology as the central facade. Ceramic bricks are laid on the bottom, and glazed bricks are stacked upright. The geometric pattern repeated in a certain order on the facades is proportionately combined with the help of armor. The writings are mainly taken from the Koran. "... Allah, Allahu Akbar" and similar addresses. A little darker than the one used to decorate the interior of the mosque, beautiful painted patterns were applied to the plaster. The main material of the whole complex is brick, the size of which is 27x27x6.5 cm. These bricks were typed using ganch mixture. Brick and stone powder is added to pure ganch to make the ganch mixture strong and crack-resistant. The mixture gained its strength in one year. The mixture is cooked at 130-150 degrees. Fine ganch powder hardens faster than large ganch, so craftsmen also used fine ganch. Sometimes ash and coal dust are added to it. The wall of the mosque is reduced to 12 rows of bricks along its height. The wall thickness is different in different parts of the building. The minimum wall thickness in the main building is 3.8 m, the average thickness is 4.5-5 m. In small mosques, it varies from 1.8 m to 2.3 m. The mixture between the bricks is composed of a ganch mixture with the addition of sand and crushed brick powder. In architectural monuments, the mixture on the wall made up 30% of the entire wall volume. In the Bibikhanim mosque, the seam between two bricks changed from 1.2 to 2 cm and decreased towards the top of the building. They considered this change to be one of the measures against earthquakes.

The geometric formation of the arch structure of the main entrance of the mosque is as follows:

As mentioned above, all the arch constructions used in the mosque have the same geometrical construction, that is, a part of it is built from the point O_1 in the center of the arch to 45^o in a radius equal to half of the arch proline. The second part is formed from O_2 points formed by intersecting the upper radius with the lower part of the diagonal line delimiting the first part. The radius forming the arc from this point is equal to its proline. (Figure 1).

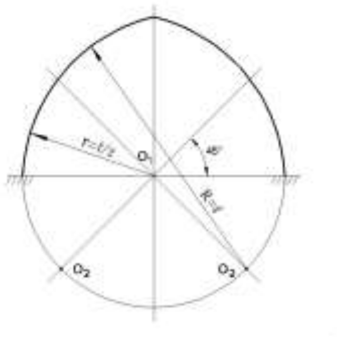


Figure 1. Geometric formation of the arch construction

Since the geometric dimensions of the arch constructions in the mosque are different, we take the calculation scheme, i.e., the arch profile, as ℓ. Its height comes from the geometric design of the system. We load the system with a force "q" evenly distributed over the entire length and carry out the calculations using the force method. (Figure 2).

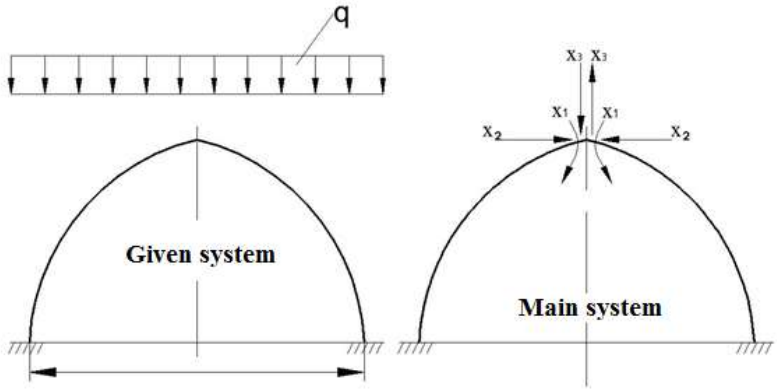


Figure 2. The given and main systems of the arch structure for option I

The degree of static uncertainty of the system:

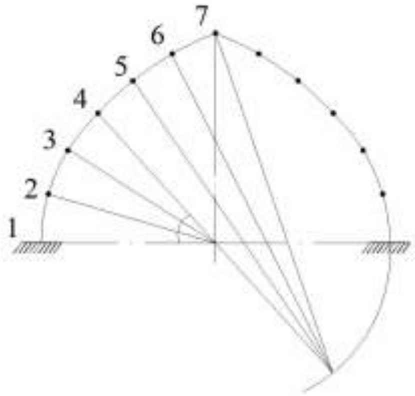
$$n = C_T - 3 = 6 - 3 = 3$$

Therefore, the system is three times uncertain, therefore the number of the canonical equation is also three, the system itself is symmetric and the external force applied to it is also symmetrical, the unsymmetrical unknown in the main system is x_3=0 and the canonical equation is also simplified.

We select the main system by cutting the arch from the lock. Taking into account the above simplifications, the general form of the canonical equation is as follows:

$$\begin{cases}\delta_{11}x_1 + \delta_{12}x_2 + \Delta_{1p} = 0 \\ \delta_{11}x_1 + \delta_{22}x_2 + \Delta_{2p} = 0\end{cases}$$

We select 7 characteristic points on the left wing of the arch to carry out calculations. We combine the points with a straight line to form an arc-shaped frame. The first of the points is located on its support, and the 7th point is located on the arch lock (Figure 3). **Figure 3. Division of the main system of the arch construction into points**



Ensuring that the distance between the points, i.e., the lengths of the sections, is the same, makes the calculations more accurate. The angle $\boldsymbol{\alpha}$ can be used to divide the first part of the arch into equal intervals. In the second part, it is required to find the angle $\boldsymbol{\beta}$ in the figure. For this, we determine the coordinates of points 4 and 7:

$x_4 = \ell / 2 * \cos 45^0 = 70{,}71 * 10^{-2}\ell$;

$y_4 = \ell / 2 * \sin 45^0 = 70{,}71 * 10^{-2}\ell$.

We determine the coordinates of the 7th point from the equation of the circle drawn at the radius ℓ with respect to the second center of the arc:

$x^2 + y^2 = R^2 \Rightarrow y = \sqrt{R^2 - x^2}$: $\{x = -35{,}355 * 10^{-2}\ \ell\}$

$y_7 = \sqrt{R^2 - x^2} = \sqrt{\ell^2 - (-35{,}355 * 10^{-2}\ell)} = 93{,}542 * 10^{-2}\ell$

0_1 in relation to $y_7 = 93{,}542 * 10^{-2}\ell - 35{,}355 * 10^{-2}\ell = 58{,}187 * 10^{-2}\ell$.

We determine the distance between points 4 and 7 using the formula for finding the distance between two points:

$x_4 = -70{,}71 * 10^{-2}\ell$: $x_7 = -35{,}355 * 10^{-2}\ell$

$y_4 = 70{,}71 * 10^{-2}\ell$: $y_7 = 93{,}542 * 10^{-2}\ell$

$\ell = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$:

$\ell_{47} = \sqrt{(-70{,}71 * 10^{-2}\ell + 35{,}355 * 10^{-2}\ell)^2 + (70{,}71 * 10^{-2}\ell - 93{,}542 * 10^{-2}\ell)^2} = 42{,}086 * 10^{-2}\ell$

$4,7,0_2$ we determine the angle β using a triangle.

The face of a triangle is based on Heron's formula

$$S = \sqrt{P(P-a) * (P-b) * (P-c)} = \left\{P = \frac{a+b+c}{2}\right\} = \left\{\frac{\ell + \ell + 42{,}086 * 10^{-2}\ell}{2}\right\} =$$

$$\{121{,}043 * 10^{-2}\ell\} = \sqrt{121{,}043 * 10^{-2}\ell * 121{,}043 * 10^{-2}\ell * 121{,}043 * 10^{-2}\ell * 78{,}957 * 10^{-2}\ell} = 2057{,}182 * 10^{-2}\ell;$$

Face relative to the angle at the 4th point of the triangle

$$S = \frac{1}{2}\ell * 42{,}086 * 10^{-2}\ell * Sin\,\gamma \Rightarrow Sin\,\gamma = \frac{2S}{4208{,}6 * 10^{-4}\ell^2} = \frac{2 * 2057{,}182 * 10^{-4}\ell^2}{4208{,}6 * 10^{-4}\ell^2} = 0{,}9776$$

From this $\gamma = arc\sin(0{,}9776) = 77^0 51^1$

β corner esa $\beta = 180^0 - 2\gamma = 180^0 - 2 * 77^0 51^1 = 24^0 18^1$

To divide the triangle into 3 equal parts of 4-7 sides, we divide the β triangle into 3.

$$\beta^1 = \frac{\beta}{3} = \frac{24^0 18^1}{3} = 8^0 6^1$$

We determine the coordinates of all points on the left wing of the arch in relation to 0_1

$x_1 = -50 * 10^{-2}\ell$

$x_2 = -50 * 10^{-2}\ell * \cos 15^0 = -48{,}295 * 10^{-2}\ell$
$x_3 = -50 * 10^{-2}\ell * \cos 30^0 = -43{,}3 * 10^{-2}\ell$
$x_4 = -50 * 10^{-2}\ell * \cos 45^0 = -38{,}355 * 10^{-2}\ell$
$x_5 = -\ell * \cos 53^0 6^1 + 35{,}355 * 10^{-2}\ell = -24{,}685 * 10^{-2}\ell$
$x_6 = -\ell * \cos 61^0 12^1 + 35{,}355 * 10^{-2}\ell = -12{,}825 * 10^{-2}\ell$
$x_7 = -\ell * \cos 69^0 18^1 + 35{,}355 * 10^{-2}\ell = 0.$

$y_1 = 0$
$y_2 = 50 * 10^{-2}\ell * sin15^0 = 12{,}94 * 10^{-2}\ell$
$y_3 = 50 * 10^{-2}\ell * sin30^0 = 25 * 10^{-2}\ell$
$y_4 = 50 * 10^{-2}\ell * sin45^0 = 35{,}355 * 10^{-2}\ell$
$y_5 = \ell * sin53^0 6^1 - 35{,}355 * 10^{-2}\ell = 44{,}615 * 10^{-2}\ell$
$y_6 = \ell * sin61^0 12^1 - 35{,}355 * 10^{-2}\ell = 52{,}275 * 10^{-2}\ell$
$y_7 = \ell * sin69^0 18^1 - 35{,}355 * 10^{-2}\ell = 58{,}187 * 10^{-2}\ell.$

Using the coordinates of the points, we determine the lengths of the plots. we take $\ell = 100\ell^1$ to simplify calculations. we return again to ℓ with the result obtained.

$\ell_{12} = \sqrt{(50\ell^1 - 48{,}295\ell^1)^2 + (0 - 12{,}94\ell^1)^2} = 13{,}052\ell^1 = 13{,}052 * 10^{-2}\ell$
$\ell_{23} = \sqrt{(48{,}295\ell^1 - 42{,}3\ell^1)^2 + (12{,}94 - 25\ell^1)^2} = 13{,}052\ell^1 = 13{,}052 * 10^{-2}\ell$
$\ell_{34} = \sqrt{(43{,}3\ell^1 - 35{,}355\ell^1)^2 + (25 - 35{,}355\ell^1)^2} = 13{,}052\ell^1 = 13{,}052 * 10^{-2}\ell$
$\ell_{45} = \sqrt{(35{,}355\ell^1 - 24{,}685\ell^1)^2 + (35{,}355 - 44{,}615\ell^1)^2} = 14{,}12\ell^1 = 14{,}12 * 10^{-2}\ell$
$\ell_{56} = \sqrt{(24{,}685\ell^1 - 12{,}825\ell^1)^2 + (44{,}615\ell^1 - 52{,}275\ell^1)^2} = 14{,}12\ell^1 = 14{,}12 * 10^{-2}\ell$
$\ell_{67} = \sqrt{(12{,}825\ell^1 - 0)^2 + (52{,}275\ell^1 - 58{,}187\ell^1)^2} = 14{,}12\ell^1 = 14{,}12 * 10^{-2}\ell$

Using the coordinates of the points and the distances between them, we determine their trigonometric values.

$Sin\ \alpha_1 = \frac{12{,}940\ell}{13{,}092\ell} = 0{,}9914;\ \ Cos\ \alpha_1 = \frac{1{,}705\ell}{13{,}052\ell} = 0{,}1306$
$Sin\ \alpha_2 = \frac{12{,}060\ell}{13{,}092\ell} = 0{,}9240;\ \ Cos\ \alpha_2 = \frac{4{,}995\ell}{13{,}052\ell} = 0{,}3827$
$Sin\ \alpha_3 = \frac{10{,}355\ell}{13{,}092\ell} = 0{,}7934;\ \ Cos\ \alpha_3 = \frac{7{,}945\ell}{13{,}052\ell} = 0{,}6087$
$Sin\ \alpha_4 = \frac{9{,}260\ell}{14{,}120\ell} = 0{,}6558;\ \ Cos\ \alpha_4 = \frac{10{,}670\ell}{14{,}120\ell} = 0{,}7557$
$Sin\ \alpha_5 = \frac{7{,}660\ell}{14{,}120\ell} = 0{,}9425;\ \ Cos\ \alpha_5 = \frac{11{,}860\ell}{14{,}120\ell} = 0{,}8399$
$Sin\ \alpha_6 = \frac{9{,}912\ell}{14{,}120\ell} = 0{,}4187;\ \ Cos\ \alpha_6 = \frac{12{,}825\ell}{14{,}120\ell} = 0{,}9085$
$Sin\ \alpha_7 = 0{,}1797;\ \ Cos\ \alpha_7 = 0{,}9831$

Almost all information was found to solve the system by force method. We construct bending moment diagrams from the unit and external loads to the selected basic system. We distribute the force **q** to the arch points so that the curves of the bending moment created from the external load are straight in each section. We determine the displacements of the constructed unit and external load curves using the Mohr formula using the Vereshgen and Simpson Kornaukhov methods.

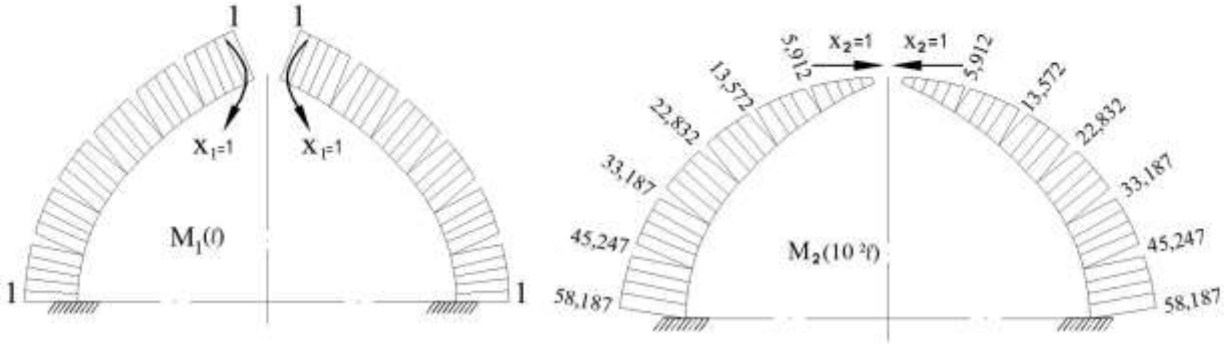


Figure 4. Epures formed from unit forces

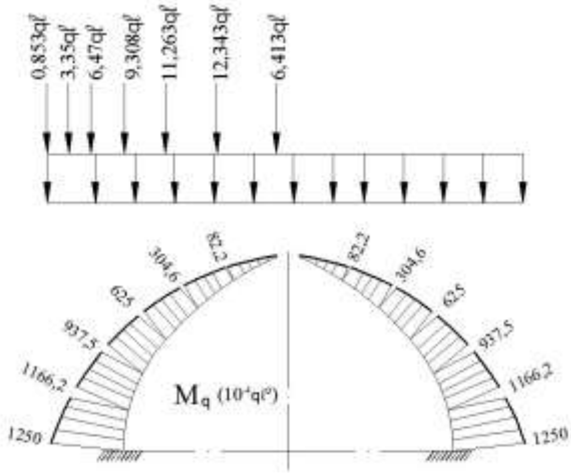


Figure 5. Epure formed by external force

We determine the extensions of the canonical equations from the epures. to simplify calculations, we take $\ell^1 = 100\ell$, and in the obtained result, we return to the real value.

$$\delta_{11} = \frac{M_1 * M_1^1}{EJ} = 2\left[3\frac{1*1*14{,}12\ell}{EJ} + 3\frac{1*1*13{,}052\ell}{EJ}\right] = \frac{163{,}032\ell}{EJ} = \frac{163{,}032*10^{-2}}{EJ}$$

$$\delta_{12} = \delta_{21} = \frac{M_1 * M_2}{EJ} = 2\begin{bmatrix} \frac{1*14{,}12\ell*2{,}956\ell}{EJ} + \frac{9{,}742\ell*14{,}12\ell*1}{EJ} + \\ \frac{18{,}202\ell*14{,}12\ell}{EJ} + \frac{28{,}01\ell*13{,}052\ell}{EJ} + \\ \frac{39{,}217\ell*13{,}052\ell}{EJ} + \frac{51{,}71\ell*13{,}052\ell}{EJ} \end{bmatrix} = \frac{3977{,}53\ell^2}{EJ} = \frac{3977*10^{-4}\ell^2}{EJ}$$

$$\delta_{22} = \frac{M_2 * M_2^1}{EJ} = 2\begin{bmatrix} \frac{5{,}912\ell*5{,}912\ell^1}{3EJ} + \\ \frac{14{,}12\ell}{6EJ}(34{,}952\ell^2 + 379{,}626\ell^2 + 184{,}199\ell^2) + \\ \frac{14{,}12\ell}{6EJ}(184{,}199\ell^2 + 1325{,}231\ell^2 + 521{,}300\ell^2) + \\ \frac{13{,}052\ell}{6EJ}(521{,}300\ell^2 + 3138{,}24\ell^2 + 1101{,}377\ell^2) + \\ \frac{13{,}052\ell}{6EJ}(1101{,}377\ell^2 + 6151{,}892\ell^2 + 2047{,}291\ell^2) + \\ \frac{13{,}052\ell}{6EJ}(2047{,}291\ell^2 + 10698{,}592\ell^2 + 3385{,}727\ell^2) \end{bmatrix} = \frac{144065{,}37*10^{-6}\ell^3}{EJ}$$

$$\Delta_{1p}=\frac{M_1M_p}{EJ}=2\left[\begin{array}{c}\frac{1*14{,}12\ell*41{,}12q\ell^2}{EJ}+\frac{1*14{,}12\ell*193{,}47q\ell^2}{EJ}+\\ \frac{1*14{,}12\ell*464{,}855q\ell^2}{EJ}+\frac{1*13{,}052\ell*781{,}275q\ell^2}{EJ}+\\ \frac{1*13{,}052\ell*1091{,}892q\ell^2}{EJ}+\frac{1*13{,}052\ell*1208{,}126q\ell^2}{EJ}\end{array}\right]=\frac{99142{,}348q\ell^3}{EJ}=\frac{99142{,}348*10^{-6}q\ell^3}{EJ};$$

$$\Delta_{2p}=\frac{M_2M_p}{EJ}=2\left[\begin{array}{c}\frac{5{,}912\ell*14{,}12\ell*82{,}247q\ell^2}{3EJ}+\\ \frac{14{,}12\ell}{6EJ}(486{,}244q\ell^3+7539{,}139q\ell^3+4135{,}293q\ell^3)+\\ \frac{14{,}12\ell}{6EJ}(4135{,}293q\ell^3+33849{,}162q\ell^3+14270{,}388q\ell^3)+\\ \frac{13{,}052\ell}{6EJ}(14270{,}388q\ell^3+87534{,}051q\ell^3+31113{,}874q\ell^3)+\\ \frac{13{,}052\ell}{6EJ}(31113{,}874q\ell^3+165008{,}19q\ell^3+52769{,}404q\ell^3)+\\ \frac{13{,}052\ell}{6EJ}(52769{,}404q\ell^3+249922{,}6q\ell^3+72733{,}75q\ell^3)\end{array}\right]=\frac{3602219{,}4q\ell^4}{EJ}=\frac{3602219{,}4*10^{-8}q\ell^4}{EJ};$$

We put the findings into the system of canonical equations, multiply them by **EJ** and solve the system.

$$\{163{,}032*10^{-2}*\ell*X_1+3977*10^{-4}\ell^2X_2+99142{,}348*10^{-6}q\ell^3=0$$
$$\{3977*10^{-4}\ell^2X_1+144065{,}37*10^{-6}\ell^3X_2+3602219{,}4*10^{-8}q\ell^4=0$$

Remove the system $X_1=5{,}863*10^{-4}q\ell^2{:}\,X_2=-29{,}165*10^{-2}q\ell$ we get the values. Based on the findings, we perform calculations in the form of a table to find the values of the bending moment stress.

Table-1.

T/r	$M_1(1)$	M_1X_1 $(10^{-4}q\ell^2)$	M_2 (ℓ)	M_2X_2 $(10^{-4}q\ell^2)$	M_q $(10^{-4}q\ell^2)$	M $(10^{-4}q\ell^2)$	M $(q\ell^2)$
1	-1	-5,863	-58,187	1464,276	-1250	208,413	0,021
2	-1	-5,863	-45,247	1138,641	-1166,252	-33,447	-0,003
3	-1	-5,863	-33,187	835,151	-937,532	-108,244	-0,011
4	-1	-5,863	-22,832	574,567	-625,017	-56,313	-0,007
5	-1	-5,863	-13,572	341,539	-304,963	30,983	0,003
6	-1	-5,863	-5,912	148,775	-82,247	60,665	0,006
7	-1	-5,863	0	0	0	-5,863	-0,001
6'	-1	-5,863	-5,912	148,775	-82,247	60,665	0,006
5'	-1	-5,863	-13,572	341,539	-304,963	30,983	0,003
4'	-1	-5,863	-22,832	574,567	-625,017	-56,313	-0,007
3'	-1	-5,863	-33,187	835,151	-937,532	-108,244	-0,011
2'	-1	-5,863	-45,247	1138,641	-1166,252	-33,447	-0,003
1'	-1	-5,863	-58,187	1464,276	-1250	208,413	0,021

To obtain the final result in the table, the values of the unknowns found were multiplied by the values of the unit curves and the observed values at these points were found. The resulting value of the bending moment was obtained by adding the observed values to the stress value generated by the external load.

Using the last cell of the table, we construct the bending moment diagram for the arch. (Figure 6).

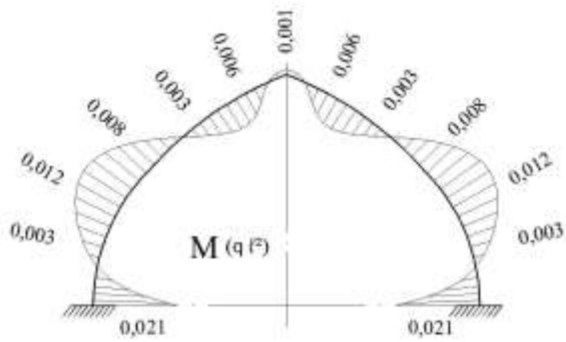


Figure 6. Bending moment curve generated by external force

We calculate the shear and longitudinal force values for the arch using the following formulas:

$$Q = Q^0 Cos\alpha - HSin\alpha;$$

$$N = -[Q^0 Sin\alpha + HCos\alpha]$$

We keep accounts in the form of a table:

Table-2.

T/r	sinα	cosα	Q^0 $(10^{-2}q\ell)$	Q^0 cosα $(10^{-2}q\ell)$	X_2 sinα $(10^{-2}q\ell)$	Q $(q\ell)$	Q^0 sinα $(10^{-2}q\ell)$	X_2 cosα $(10^{-2}q\ell)$	N $(10^{-2}q\ell)$
1	0,9914	0,1306	50	6,53	24,948	-18,418	49,57	3,287	52,857
2	0,9240	0,3827	48,295	18,483	23,252	-4,769	44,625	9,631	54,256
3	0,7934	0,6087	43,300	26,357	19,966	6,391	34,354	15,318	49,672
4	0,6558	0,7557	35,355	26,718	16,503	10,215	23,186	19,017	42,203
5	0,5425	0,8399	24,685	20,733	13,652	7,081	13,392	21,136	34,528
6	0,4187	0,9083	12,825	11,649	10,536	1,083	5,37	22,857	28,227
7	0,1797	0,9837	0	0	4,522	-4,522	0	24,755	24,755
$7'$	-0,1797	0,9837	0	0	4,522	-4,522	0	24,755	24,755
$6'$	-0,4187	0,9083	-12,825	-11,649	10,536	-1,083	5,37	22,857	28,227
$5'$	-0,5425	0,8399	-24,685	-20,733	13,652	-7,081	13,392	21,136	34,528
$4'$	-0,6558	0,7557	-35,355	-26,718	16,503	-10,215	23,186	19,017	42,203
$3'$	-0,7934	0,6087	-43.300	-26,357	19,966	-6,391	34,354	15,318	49,672
$2'$	-0,9240	0,9240	-0,3827	-48,295	18,483	-23,252	-4,769	44,625	54,256
$1'$	-0,9914	0,1306	-50	-6,53	24,948	18,418	49,57	3,287	52,857

Using the table, we construct transverse and longitudinal force diagrams (Fig. 7).

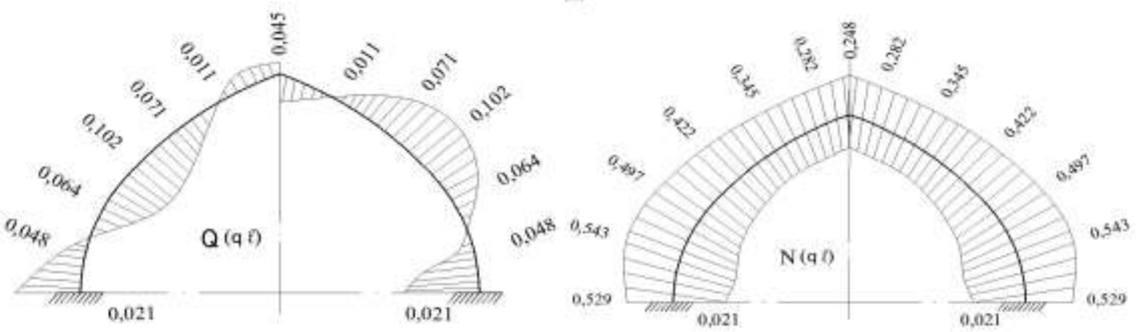


Figure 7. Transverse and longitudinal force diagrams

The considered calculation option represents the stresses of the mosque arch in its initial condition under the influence of static forces, and due to the changes as a result of different technological influences with the passage of time, it cannot completely determine the later condition of the arch. It can be seen that as a result of technological effects, a disruption has occurred at the $3'$ point of the arch, and this disruption completely changed the working conditions of the structure. As a result of the disconnection, the arch became two independent consolidated structures, that is, the system became a construction fixed on two sides. (Figure 8).

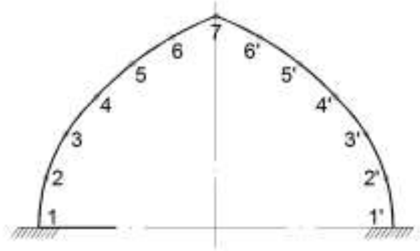
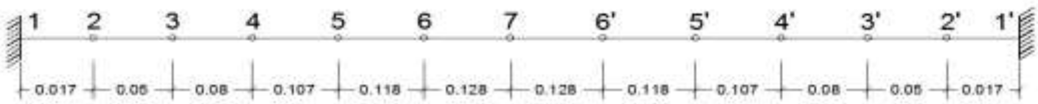


Figure 8. The given system of the arch construction for the second option

Determining the internal stresses for this system is easier to solve than the previous system, that is, the internal stress curves for the system can be constructed using the cutting method. For this purpose, the tension is calculated from the free end of the system alternately to the supports.

We calculate the tension based on the projection of the arch axis on the base.



We calculate the bending moment values for the second option arch structure:

$$M_7 = q\frac{x_7^2}{2} = q\frac{(0{,}433)^2}{2} = -0{,}093q\ell^2$$

$$M_1 = q\frac{x_1^2}{2} = q\frac{(0{,}933\ell)^2}{2} = -0{,}4352q\ell^2$$

$$M_2 = q\frac{x_2^2}{2} = q\frac{(0{,}91595\ell)^2}{2} = -0{,}419q\ell^2$$

$$M_3 = q\frac{x_3^2}{2} = q\frac{(0{,}866\ell)^2}{2} = -0{,}3749q\ell^2$$

$$M_4 = q\frac{x_4^2}{2} = q\frac{(0{,}78655\ell)^2}{2} = -0{,}3093q\ell^2$$

$$M_5 = q\frac{x_5^2}{2} = q\frac{(0{,}67985\ell)^2}{2} = -0{,}231q\ell^2$$

$$M_6 = q\frac{x_6^2}{2} = q\frac{(0{,}56125\ell)^2}{2} = -0{,}157q\ell^2$$

$$M_{6'} = q\frac{x_{6'}^2}{2} = q\frac{(0{,}30475\ell)^2}{2} = -0{,}046q\ell^2$$

$$M_{5'} = q\frac{x_{5'}^2}{2} = q\frac{(0{,}18615\ell)^2}{2} = -0{,}017q\ell^2$$

$$M_{4'} = q\frac{x_{4'}^2}{2} = q\frac{(0{,}079\ell)^2}{2} = -0{,}003q\ell^2$$

$$M_{3'} = 0$$

$$M_{2'} = q\frac{x_{2'}^2}{2} = q\frac{(0{,}067\ell)^2}{2} = -0{,}000144q\ell^2$$

$$M_{1'} = q\frac{x_{1'}^2}{2} = q\frac{(0{,}017\ell)^2}{2} = -0{,}002q\ell^2$$

We calculate the transverse forces from the following formula.

$$Q = Q^0 * Cos\alpha - H * Sin\alpha$$

Since the forces acting on the arch are vertical and the arch itself is statically clear, the horizontal reaction force H is equal to 0. H=0.

$$Q_7^0 = q * 0{,}433\ell = 0{,}433q\ell$$

$Q_1^0 = q * 0{,}933\ell = 0{,}933q\ell$
$Q_2^0 = q * 0{,}91595\ell = 0{,}91595q\ell$
$Q_3^0 = q * 0{,}866\ell = 0{,}866q\ell$
$Q_4^0 = q * 0{,}78655\ell = 0{,}78655q\ell$
$Q_5^0 = q * 0{,}67985\ell = 0{,}67985q\ell$
$Q_6^0 = q * 0{,}56125\ell = 0{,}56125q\ell$

$Q_{6'}^0 = q * 0{,}30475\ell = 0{,}30475q\ell$
$Q_{5'}^0 = q * 0{,}18615\ell = 0{,}18615q\ell$
$Q_{4'}^0 = q * 0{,}079\ell = 0{,}079q\ell$
$Q_{3'}^0 = 0$
$Q_{1'}^0 = -q * 0{,}067\ell = -0{,}067q\ell$
$Q_{2'}^0 = -q * 0{,}017\ell = -0{,}017q\ell$

$$Q = Q^0 * Cos\alpha$$

$$Q_7 = 0{,}433q\ell * 0{,}9831 = 0{,}42568q\ell$$

$Q_1 = 0{,}933q\ell * 0{,}1306 = 0{,}12q\ell$
$Q_2 = 0{,}91595q\ell * 0{,}3827 = 0{,}35q\ell$
$Q_3 = 0{,}866q\ell * 0{,}6087 = 0{,}52q\ell$
$Q_4 = 0{,}78655q\ell * 0{,}7557 = 0{,}59q\ell$
$Q_5 = 0{,}67985q\ell * 0{,}8399 = 0{,}57q\ell$
$Q_6 = 0{,}56125q\ell * 0{,}9083 = 0{,}509q\ell$

$Q_{6'} = 0{,}30475q\ell * 0{,}9083 = 0{,}27q\ell$
$Q_{5'} = 0{,}18615q\ell * 0{,}8399 = 0{,}1563q\ell$
$Q_{4'} = 0{,}079q\ell * 0{,}7557 = 0{,}059q\ell$
$Q_{3'} = 0$
$Q_{1'} = -0{,}067q\ell * 0{,}1306 = -0{,}00875q\ell$
$Q_{2'} = -0{,}017q\ell * 0{,}3827 = -0{,}0065q\ell$

As a result of the obtained calculations, we will build the curve of bending moment and cutting force (fig. 9).

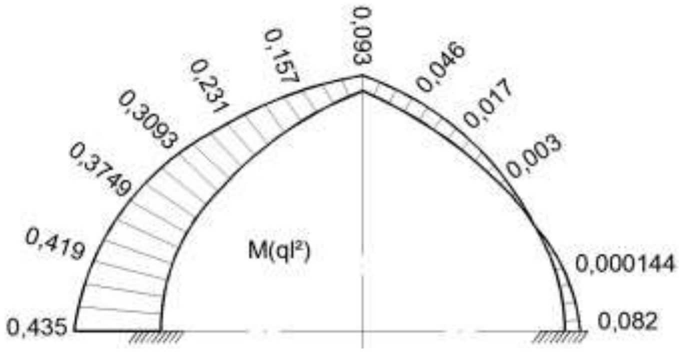


Figure-9. Bending moment and shear force curve

We determine the longitudinal force curve for the arch from the following expression.

$$N = -[Q^0 Sin\alpha - H * Cos\alpha] = -Q^0 * Sin\alpha$$

$$N_7 = -0{,}433q\ell * 0{,}1797 = -0{,}0778q\ell$$

$N_1 = -0{,}933q\ell * 0{,}9914 = -0{,}92q\ell$
$N_2 = -0{,}91595q\ell * 0{,}9240 = -0{,}84q\ell$
$N_3 = -0{,}866q\ell * 0{,}7934 = -0{,}687q\ell$
$N_4 = -0{,}78655q\ell * 0{,}6558 = -0{,}515q\ell$
$N_5 = -0{,}67985q\ell * 0{,}5425 = -0{,}3688q\ell$
$N_6 = -0{,}56125q\ell * 0{,}4187 = -0{,}234q\ell$

$N_{6'} = -0{,}30475q\ell * 0{,}4187 = -0{,}12759q\ell$
$N_{5'} = -0{,}18615q\ell * 0{,}5425 = -0{,}10q\ell$
$N_{4'} = -0{,}079q\ell * 0{,}6558 = -0{,}051q\ell$
$N_{3'} = 0$
$N_{1'} = 0{,}067q\ell * 0{,}9914 = 0{,}066q\ell$
$N_{2'} = 0{,}017q\ell * 0{,}9240 = 0{,}015q\ell$

Based on the results, we will build a longitudinal force curve (fig. 10).

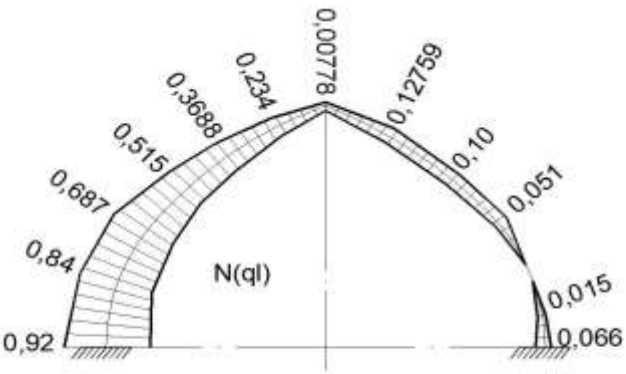


Figure 10. Longitudinal force graph

Before the repair work carried out in the 80s, the gable arch was strengthened. The strengthening project will be carried out by specialists of the "Tashkent Institute of Renovation". According to the project, a reinforced concrete frame will be built on the upper part of the arch, and the arch will be hung on this frame by steel wires. In this case, the calculation scheme for the arch will be as follows.

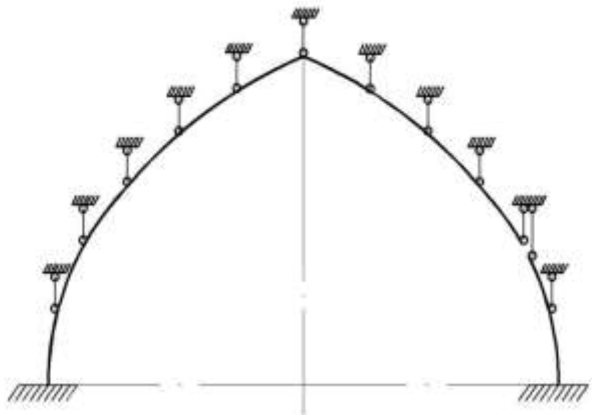


Figure 11. The given system of the arch construction for the third option

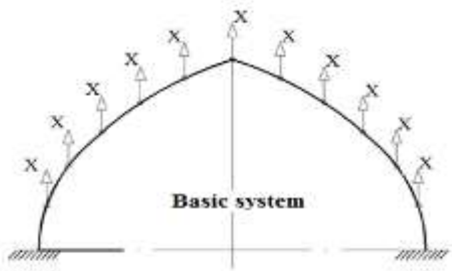
It can be seen from the calculation scheme that the construction consists of two separate constructions with static uncertainties equal to 10 and 2. For these systems, the force method can be used to determine the internal stresses. The canonical equations of the force method are as follows.

$$\delta_{11}X_1 + \delta_{12}X_2 + \delta_{13}X_3 + \delta_{14}X_4 + \delta_{15}X_5 + \delta_{16}X_6 + \delta_{17}X_7 + \delta_{18}X_8 + \delta_{19}X_9 + \delta_{110}X_{10} + \Delta_{1q} = 0$$
$$\delta_{21}X_1 + \delta_{22}X_2 + \delta_{23}X_3 + \delta_{24}X_4 + \delta_{25}X_5 + \delta_{26}X_6 + \delta_{27}X_7 + \delta_{28}X_8 + \delta_{29}X_9 + \delta_{210}X_{10} + \Delta_{2q} = 0$$
$$\delta_{31}X_1 + \delta_{32}X_2 + \delta_{33}X_3 + \delta_{34}X_4 + \delta_{35}X_5 + \delta_{36}X_6 + \delta_{37}X_7 + \delta_{38}X_8 + \delta_{39}X_9 + \delta_{310}X_{10} + \Delta_{3q} = 0$$
$$\delta_{41}X_1 + \delta_{42}X_2 + \delta_{43}X_3 + \delta_{44}X_4 + \delta_{45}X_5 + \delta_{46}X_6 + \delta_{47}X_7 + \delta_{48}X_8 + \delta_{49}X_9 + \delta_{410}X_{10} + \Delta_{4q} = 0$$
$$\delta_{51}X_1 + \delta_{52}X_2 + \delta_{53}X_3 + \delta_{54}X_4 + \delta_{55}X_5 + \delta_{56}X_6 + \delta_{57}X_7 + \delta_{58}X_8 + \delta_{59}X_9 + \delta_{510}X_{10} + \Delta_{5q} = 0$$

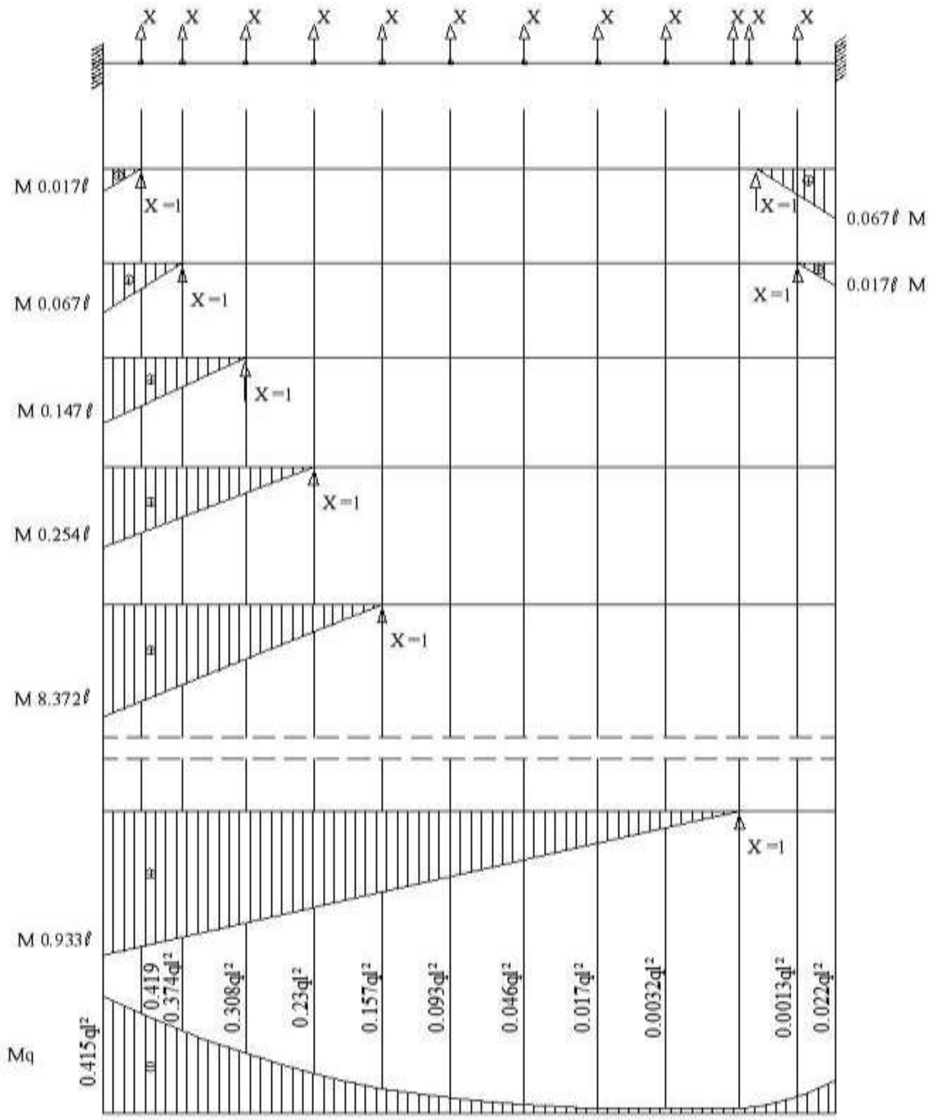
....

$$\delta_{101}X_1 + \delta_{102}X_2 + \delta_{103}X_3 + \delta_{104}X_4 + \delta_{105}X_5 + \delta_{106}X_6 + \delta_{107}X_7 + \delta_{108}X_8 + \delta_{109}X_9 + \delta_{1010}X_{10} + \Delta_{10q} = 0$$
$$\delta_{1111}X_{11} + \delta_{1112}X_{12} + \Delta_{11q} = 0$$
$$\delta_{1211}X_{11} + \delta_{1212}X_{12} + \Delta_{12q} = 0$$

The main system selected for system calculation is as follows (Fig. 12).



We carry out calculations in the order of strength method. Since the unknowns are mutually parallel and consist of a straight line between them, unit curves can be expressed in one straight line.



We calculate the coefficients and degrees of freedom of the canonical equation by multiplying the constructed curves.

$$\delta_{11} = \frac{\overline{M}_1\overline{M}_1}{EJ} = \frac{0{,}017\ell * 0{,}017\ell}{2EJ} * \frac{2}{3}0{,}017\ell = \frac{0{,}0000016\ell^3}{EJ}$$

$$\delta_{12} = \delta_{21} = \frac{\overline{M}_1\overline{M}_2}{EJ} = \frac{0{,}017\ell}{6EJ} * (0{,}00114\ell^2 + 0{,}00199\ell^2) = \frac{0{,}0000088\ell^3}{EJ}$$

$$\delta_{13} = \delta_{31} = \frac{\overline{M}_1\overline{M}_3}{EJ} = \frac{0{,}017\ell}{6EJ} * (0{,}0025\ell^2 + 0{,}0047\ell^2) = \frac{0{,}0000204\ell^3}{EJ}$$

$$\delta_{14} = \delta_{41} = \frac{\overline{M}_1\overline{M}_4}{EJ} = \frac{0{,}017\ell}{6EJ} * (0{,}0043\ell^2 + 0{,}0083\ell^2) = \frac{0{,}0000358\ell^3}{EJ}$$

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$$\delta_{1010} = \frac{\overline{M}_{10}\overline{M}_{10}}{EJ} = \frac{0{,}933\ell}{6EJ} * (0{,}871\ell^2 + 0{,}871\ell^2) = \frac{0{,}271\ell^3}{EJ}$$

$$\Delta_{1q} = \frac{\overline{M}_1\overline{M}_q}{EJ} = \frac{0{,}017\ell}{6EJ} * (-0{,}0074\ell^2 - 0{,}016\ell^2) = -\frac{0{,}000062\ell^3}{EJ}$$

$$\Delta_{2q} = \frac{\overline{M}_2\overline{M}_q}{EJ} = \frac{0{,}067\ell}{6EJ} * (-0{,}029\ell^2 - 0{,}0542\ell^2) = -\frac{0{,}000929\ell^3}{EJ}$$

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$$\Delta_{10q} = \frac{\overline{M}_{10}\overline{M}_q}{EJ} = \frac{0{,}933\ell}{6EJ} * (-0{,}405\ell^2 - 0{,}203q\ell^2) = -\frac{0{,}0945\ell^3}{EJ}$$

Putting the calculated values into the canonical equation, we solve them using a special program on an electronic calculator and get the following results:

$X_1 = 0{,}114276694q\ell$ $\quad X_7 = -0{,}834630813q\ell$
$X_2 = 0{,}078758723q\ell$ $\quad X_8 = 0{,}901095966q\ell$
$X_3 = 0{,}040351688q\ell$ $\quad X_9 = -0{,}360663629q\ell$
$X_4 = 0{,}303181666q\ell$ $\quad X_{10} = 0{,}174662726q\ell$
$X_5 = -0{,}3607633295q\ell$ $\quad X_{11} = 0{,}0002095q\ell$
$X_6 = 0{,}953717385q\ell$ $\quad X_{12} = 0{,}13q\ell$

We carry out the rest of the calculations based on the table and build a bending moment diagram based on the obtained results.

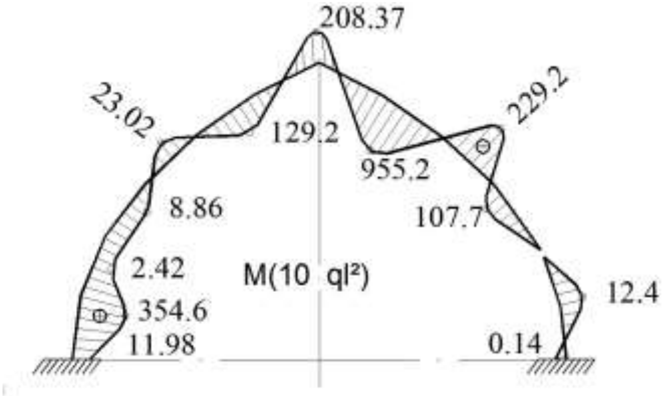

Figure 13. Bending moment plot

We construct transverse force stresses for the arch using the bending moment diagram. We make calculations based on the following formula.

$$Q = \left(\pm Q_0 \pm \frac{M^{ong} - M^{chap}}{\ell}\right) Cos\alpha$$

here: Q_0- value of transverse force derived from external force.

$$Q_{01} = \left(\frac{q * 0{,}13\ell}{2} + \frac{(0{,}03546939 - 0{,}00119864)q\ell^2}{0{,}13\ell}\right) Cos\alpha_1 = 0{,}04229q\ell$$

$$Q_{10} = \left(-\frac{q * 0{,}13\ell}{2} + \frac{(0{,}03546939 - 0{,}00119864)q\ell^2}{0{,}13\ell}\right) Cos\alpha_1 = 0{,}025q\ell$$

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$$Q_{1312} = \left(\frac{q * 0{,}13\ell}{2} + \frac{(0{,}00124 - 0{,}000014)q\ell^2}{0{,}13\ell}\right) Cos\alpha_1 = 0{,}0097425q\ell$$

Based on the obtained results, we will build a cutting force diagram

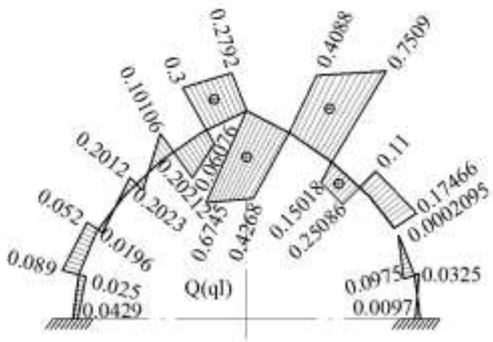

Figure 15. Longitudinal force graph

Conclusion

In conclusion, we compare the graphs built from the calculation results with each other. We compare the diagrams with the diagrams of bending moment **M** and longitudinal force **N** according to three options. We do not compare the cross-sectional force curves **Q** because its effect is negligible since the arch structure acts in compression.

At point 1, the value of the bending moment M is increased by 21 times in the II option compared to the I option, and decreased by 17.5 times in the III option.

The value of longitudinal force N increased by 1.7 times in option II compared to option I, and decreased by 1.46 times in option III.

At point 2, the value of the bending moment M is increased by 139.6 times in the II option compared to the I option, and by 11.82 times in the III option.

The value of longitudinal force N increased by 1.54 times in option II compared to option I, and decreased by 1.26 times in option III.

At point 3, the value of the bending moment M is increased by 34 times in the second option compared to the first option, and decreased by 45 times in the third option.

The value of longitudinal force N increased by 1.38 times in the II option compared to the I option, and by 1.34 times in the III option.

At point 4, the value of the bending moment M is increased by 44 times in the II option compared to the I option, and decreased by 7.9 times in the III option.

The value of longitudinal force N increased by 1.2 times in the II option compared to the I option, and by 1.8 times in the III option.

At point 5, the value of the bending moment M is increased by 77 times in option II compared to option I, and decreased by 1.3 times in option III.

The value of longitudinal force N increased by 1.06 times in the II option compared to the I option, and by 7.32 times in the III option.

At point 6, the value of the bending moment M is increased by 26 times in the II option compared to the I option, and by 2.1 times in the III option.

The value of longitudinal force N increased by 1.2 times in option II compared to option I, and by 8.96 times in option III.

At point 7, the value of the bending moment M is increased by 93 times in the II option compared to the I option, and by 20,837 times in the III option.

The value of longitudinal force N was reduced by 3.1 times in option II compared to option I, and increased by 10.1 times in option III.

Value of bending moment m at 7'-point option ii increased 93 times compared to option I, and in option III it increased 20,837 times.

The value of the longitudinal force N was reduced by 3.1 times in the II option compared to the I option, and increased by 23,522 times in the III option.

Value of bending moment m at 6'-point option ii increased 7.6 times compared to option I, and in option III it increased 15.92 times.

The value of longitudinal force N was reduced by 2.21 times in option II compared to option I, and increased by 20.6 times in option III.

Value of bending moment m in point 5' is increased 5.6 times in option II compared to option I, and 7.64 times in option III.

The value of the longitudinal force N was reduced by 3.45 times in the II option compared to the I option, and increased by 16.8 times in the III option.

Value of bending moment m in point 4' in compared to option I, option II decreased by 2.3 times, and in option III, it increased by 1.53 times.

The value of longitudinal force N was reduced by 8.27 times in option II compared to option I, and increased by 4.2 times in option III.

Value of bending moment m at 3'-point is 0 in option II and 0 in option III compared to option I.

The value of the longitudinal force N has increased by 0 times in the II option, and by 3.57 times in the III option compared to the I option.

Value of bending moment m at point 2 in option II decreased by 20.83 times compared to option I, and in option III it decreased by 2.41 times.

The value of the longitudinal force N is reduced by 36 times in the II option compared to the I option, and by 1.1 times in the III option.

The value of the bending moment m at the 1'-point is 10.5 times decreased in option II compared to option I, and in option III it decreases by 1500 times.

The value of the longitudinal force N was reduced by 8.8 times in the II option compared to the I option, and by 1.07 times in the III option.

Based on the results of calculating the static forces of arch structures used in architectural monuments, the current state of arch structures was determined. According to this, the values of M, N graphs have decreased significantly compared to before the repair.

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