Determination of Forces in the Meridional Rods of the Mesh Dome

M Abu-Khasan¹, V Egorov, D Charnik¹, E Nikonova¹
¹Emperor Alexander I St. Petersburg State Transport University

E-mail: pgups1967@mail.ru

Abstract. Currently, the construction of residential domed houses in Russia is gaining popularity. It is possible to use dome structures for the formation and reconstruction of an expressive urban environment, as pavilions, awnings, cover public spaces. The use of domes in urban development solves the problem of maintaining the landscape in optimal condition, improves its aesthetic and functional properties.

This paper discusses a technique for determining the forces in the rods of a mesh dome to simplify the search for these forces, and a study of design solutions for wooden mesh shells using the example of a dome for a pool. Also, the developed model is tied to the terrain, which makes it possible to solve part of the practical problem.

The main design parameters for the method and the algorithm for working with it are given, in the general case, taking into account different values of the coefficients of the design models.

1. Introduction

The essence of the method for determining the forces in the rods is reduced to constructing diagrams of the forces M and N in the elements of the dome – with a rigidly supported contour (by analogy with the method described for the dome – shell) [1-2].

The dome is divided into annular zones bounded by points 1 to 4 (Fig. 1). In each zone, the maximum value of the forces in the rods is determined and a general plot of the forces for half of the meridional section of the dome is constructed (from the edge to the center) [3-4]. For a symmetric load, point 2 is stationary, for an asymmetric load, it is mobile, and the distance to it from the center is regulated by the discreteness and rigidity of the shell [5-6]. This method allows you to simplify the search for maximum forces in the dome, without going into the difference in approaches to calculating the meridional and radial edges [7-8].
2. Theoretical part
In general, the value of the longitudinal forces $N$ and bending moments $M$ for symmetric and asymmetric loads are determined by the formulas [9-10]:

$$
\begin{align*}
N^j_i &= \chi_{21} N^j_{zh,i} + \chi_{22} N^j_{sh,i}, \\
M^j_i &= \chi_{21} M^j_{zh,i} + \chi_{22} M^j_{sh,i},
\end{align*}
$$

where $\chi_{21}$ and $\chi_{22}$ are coefficients that take into account the stiffness of the support ring, their value is equal to:

$$
\begin{align*}
\chi_{21} &= \frac{\chi_2 - \chi_2 \left( \frac{\omega}{k_{reb}} = \infty \right)}{1 - \chi_2 \left( \frac{\omega}{k_{reb}} = \infty \right)}, \\
\chi_{22} &= \frac{\chi_2 - 1}{\chi_2 \left( \frac{\omega}{k_{reb}} = \infty \right) - 1}.
\end{align*}
$$

The value of the coefficient $\chi_2$ is given in the table below.

**Table 1.** The value of the coefficient $\chi_2$

| $\frac{\omega}{k_{reb}}$ | symmetric | $k_{reb}, cm$ | asymmetric |
|---------------------------|------------|---------------|------------|
| $\infty$                  | 13.4       | 50.0          | 100.0      | 3.38       | 2.36       |
| 218.0                     | 1.11       | 1.94          | 2.64       | 1.13       | 1.43       | 2.04       |
| 54.50                     | 1.02       | 1.12          | 1.91       | 1.02       | 1.07       | 1.51       |
| 13.63                     | 1.00       | 1.03          | 1.20       | 1.00       | 1.00       | 1.01       |
| 3.41                      | 1.00       | 1.00          | 1.00       | 1.00       | 1.00       | 1.00       |
| 0.85                      | 1.00       | 1.00          | 1.00       | 1.00       | 1.00       | 1.00       |
| 0.00                      | 1.00       | 1.00          | 1.00       | 1.00       | 1.00       | 1.00       |
\[ \omega = \frac{R r_{reb} E}{FE_k} \]

The value of the forces in the dome rods under symmetric load is determined by the formulas [11-12].

| Force          | Dome point | 1       | 2       | 3       | 4       |
|----------------|------------|---------|---------|---------|---------|
| \( N_{zh}, t \) | \( \frac{l}{100\sqrt{3}} \left( N_x + \sqrt{3}N_{xy} \right) \delta \sqrt{\theta} \) |         |         |         |         |
| \( N_{sh}, t \) | \( \begin{cases} \left( N_{zh} \alpha_2, b y r_i \geq 0.6r \right) \\ \left( N_{sh}, b y r_i < 0.6l \right) \end{cases} \) |         |         |         |         |
| \( M_{zh,op}, \text{kg} \cdot \text{m} \) | \( \frac{-1}{\sqrt{30}} \frac{ql^3 \alpha_4}{12} \) | \( \frac{-ql^3}{24\sqrt{30}} \left( \alpha_3 - 1 \right) \) |         |         |         |
| \( M_{zh,pr}, \text{kg} \cdot \text{m} \) | - | \( \frac{1}{\sqrt{30}} \frac{ql^3 \alpha_3}{24\sqrt{\theta}} \) | At point 2 (\( r_i = r - l \)): \( M_2 = \frac{\alpha_5 ql^3}{\sqrt{30}} \) |         |         |
| \( M_{sh}, \text{kg} \cdot \text{m} \) | 0 | | At point 3 (\( r_i = \alpha_6 l \)): \( M_3 = 0 \) |         |         |
| \( M_{sh}, \text{kg} \cdot \text{m} \) | | At point 4 (\( r_i = 0 \)): \( M_4 = 0 \) |         |         |         |

where \( r_i \) – the distance from the center of the dome to the center of gravity of the rod in the horizontal projection [13-14]. The lower index "pr" or "op" indicates the location of the section in the rod for which the calculation is carried out – "span" and "reference", respectively [15-16]. When calculating the forces \( N_{zh}, N_{sh}, \) the thickness of the equivalent shell «\( \delta \)» can have any value, since it is compensated for when calculating the forces in the rods [17-18].

The value of the coefficient \( \theta \) (taking into account the impact of runs).

\[ \theta = 1 + \frac{E_{\text{prog}} I_{\text{prog}}}{E_{\text{reb}} I_{\text{reb}}} \left( 1 - \frac{a}{l} \right) \]

where \( E_{\text{prog}}, I_{\text{prog}} \) is the modulus of elasticity and the moment of inertia of the runs; \( a \) – Is the step of the runs. Note that the dimension \( q \) is in kg / m².

The value of the coefficients [19-20].

Coefficient \( a_i \) (taking into account the edge effect, "m" and "k_{reb}")
Figure 2. The value of the coefficient $\alpha_1$

The value of the coefficient $\alpha_2$ (taking into account the distance from the center)

\[
\alpha_2 = \frac{1}{20}(\alpha_1 - 1)\left(\frac{5r_i}{r} - 3\right) + \frac{1}{10}
\]

Coefficient $\alpha_3$ (accounting for "m" and "$k_{reb}$")

Figure 3. The value of the coefficient $\alpha_3$ as a function of the "$k_{reb}$".

Figure 4. The value of the coefficient $\alpha_4$ as a function of the "$k_{reb}$".
Figure 5. The value of the coefficient $\alpha_5$

Figure 6. The value of the coefficient $\alpha_6$

With a concentrated load, we have the following formulas for calculating:

\[
\begin{align*}
N &= -F \alpha_{10} \alpha_{11} \alpha_{12} \alpha_{13} \theta^{-1}; \\
M &= \frac{M_{\text{min}} - M_{\text{max}}}{l} r_i + M_{\text{max}}, \text{by } r_i \leq l; \\
M &= \frac{M_{\text{min}}(r_i - \tau)}{l - \tau}, \text{by } r_i > l; \\
M_{\text{max}} &= 10^{-4} FR \alpha_{15} \alpha_{16} \alpha_{17} \theta^{-1}; \\
M_{\text{min}} &= -M_{\text{max}} \alpha_{19}.
\end{align*}
\]

Dimension of the obtained values: N·t; M·t·m.

The value of the coefficients
$$\begin{align*}
\alpha_{10} &= \frac{1}{192k_{reb}}; \\
\alpha_{11} &= 8\Omega; \Omega = \frac{b}{h}; \\
\alpha_{13} &= 1 + \frac{r_i - r}{r}(\alpha_{14} - 1); \\
\alpha_{15} &= \frac{k_{reb}^{0.24}m^{0.54}}{25m^{0.67}}; \\
\alpha_{16} &= 1.1m^{0.35}; \\
\alpha_{17} &= (0.228 - 0.912\Omega)m + 1; \\
\alpha_{19} &= \frac{1.18}{\sqrt{k_{reb}}}\alpha_{20}.
\end{align*}$$

**Figure 7.** The value of the coefficient $\alpha_{12}$

**Figure 8.** The value of the coefficient $\alpha_{14}$
3. Results and discussion
Thus, when calculating and determining the forces in the dome elements, it is necessary to calculate the maximum values of the forces in the rods, simplifying the search for these forces, without going into the difference in approaches to calculating the types of edges.

4. Conclusions
As a result, the following results were obtained:
1. The characteristic of the structure of the load-bearing element of the mesh shell is given and the factors affecting its operation are determined. The characteristic is given for a frame made of reinforced wood, taking into account the influence of various loads and moments of forces.
2. The finite element method in mesh shells is considered in relation to the problem in the paper. The main calculated parameters of the method are given.
3. An algorithm for constructing computational models for determining the forces in the meridional rods of a mesh dome is presented. The steps for taking the coefficients into account in the model calculation are highlighted separately.

5. References
[1] Abu-Khasan M, Egorov V, Rozantseva N, Kuprava L 2018 Load carrying wood and metal structures of trusses of covering of long spanned rail depot IOP Conference Series: Materials Science and Engineering 463(4) 042075 DOI: 10.1088/1757-899X/463/4/042075
[2] Veselov V, Abu-Khasan M, Egorov V 2020 Innovative design of wooden beams in the far North IOP conference series: materials science and engineering DOI: 10.1088/1757-899X/753/2/0220242
[3] Abu-Khasan M, Rozantseva N, Egorov V, Kuprava L 2020 Prefabricated Dome Structures with Walls Made of Soil Composites and Urea-Formaldehyde Foam Insulation (UFFI) as a Way to Solve Transport Infrastructure Problems in Permafrost Regions IOP conference series: materials science and engineering 022022 DOI: 10.1088/1757-899X/753/2/022022
[4] Temnev V, Abu-Khasan M, Charnik D, Kuprava L, Egorov V 2020 The mesh of shells of a bionic type to be operated in extreme habitats IOP conference series: materials science and engineering 022023 DOI: 10.1088/1757-899X/753/2/022023
[5] Egorov V, Kravchenko A, Abu-Khasan M 2020 The Application of Evolutional Algorithm Optimization of Sprengel Systems of Transport Buildings and Structures for Northern Districts IOP conference series: materials science and engineering 022020 DOI: 10.1088/1757-899X/753/2/022020
[6] Egorov V, Abu-Khasan M, Shikova V 2020 The systems of reservation of bearing structures coatings of transport buildings and constructions for northern areas IOP conference series: materials science and engineering 022021 DOI: 10.1088/1757-899X/753/2/022021
[7] Abu-Khasan M, Egorov V 2020 The Influence of Different Types of Reinforcement on the Deformation Characteristics of Clay Soil in the Conditions of Seasonal Freezing and Thawing IOP conference series: materials science and engineering 022041 DOI: 10.1088/1757-899X/753/4/022083
[8] Chernykh A K, Gorschkoza E E, Dergachev A I, Abu-Khasan M S Use of Integrated Accounting Methods for Calculation of the Profile Volume of Embankments IOP Conference Series: Earth and Environmental Science DOI: 10.1088 / 1755-1315 / 456 / 062008
[9] Vilkov V B, Dergachev A I, Chernykh A K, Abu-Khasan M S 2020 On the Concept of Solving a Fuzzy Cooperative Game with Side Payments 2020 International Multi-Conference on Industrial Engineering and Modern Technologies FarEastCon 2020 9271558 DOI: 10.1109/FarEastCon50210.2020.9271558
[10] Egorov V, Belyy G Nonlinear properties of hybrid construction of coatings of buildings and structures E3S Web of Conferences 217 01001 DOI: 10.1051/e3sconf/202021701001
[11] Rusanova E, Abu-Khasan M, Sakharova A 2019 The control waste of communal services IOP Conference Series: 2019 Earth and Environmental Science 272(2) 022109 DOI: 10.1088/1755-1315/272/2/022109

[12] Abu-Khasan M, Solovyov V, Solovyov D 2018 High-strength Concrete with new organic mineral complex admixture 2018-MATEC Web of Conferences 193 03019 DOI: 10.1051/matecconf/201819303019

[13] Rusanova E, Abu-Khasan M, Egorov V 2020 Influence of wooden cross ties on the surrounding medium at operation of transport objects in cold regions IOP conference series: materials science and engineering 022042 DOI: 10.1088/1757-899X/753/2/022042

[14] Rusanova E, Abu-Khasan M, Egorov V 2020 The complex evaluation of geo eco-protective technologies taking into account the influence of negative temperatures IOP conference series: materials science and engineering 022042 DOI: 10.1088/1757-899X/753/2/022042

[15] Dergachev A, Dergachev S, Perepechenov A, Abu-Khasan M 2019 Fundamentals of Algorithmization of Functional and Computational Problems 2019 International Multi-Conference on Industrial Engineering and Modern Technologies FarEastCon 2019 8933942 DOI: 10.1109/FarEastCon.2019.8933942

[16] Sakharova A S, Svatovskaya L B, Baidarashvili M M, Petriaev A V 2017 Detoxication of the heavy metal ions in water resources by means of mineral. Bearing Capacity of Roads, Railways and Airfields Proceedings of the 10th International Conference on the Bearing Capacity of Roads, Railways and Airfields, BCRRA 2017 pp 2187-2190 DOI: 10.1201/9781315100333-309

[17] Sakharova A, Svatovskaya L, Baidarashvili M, Petriaev A 2016 Sustainable Development in Transport Construction through the Use of the Geoecoprotective Technologies Procedia Engineering 143 pp 1401-1408 DOI: 10.1016/j.proeng.2016.06.165

[18] Sakharova A S, Svatovskaya L B, Baidarashvily M M, Petriaev A V 2014 Building wastes and cement clinker using in the geocoprotective technologies in transport construction Computer Methods and Recent Advances in Geomechanics - Proceedings of the 14th Int. Conference of International Association for Computer Methods and Recent Advances in Geomechanics IACMAG 2014 pp 619-622 DOI: 10.1201/b17435-106

[19] Shershneva M, Sakharova A, Kozlov I Geoecoprotective screens for road construction and operation in cold regions Lecture Notes in Civil Engineering 50 pp 347-356 DOI: 10.1007/978-981-15-0454-9_36

[20] Shershneva M, Puzanova Y, Sakharova A Geoecoprotective technologies from heavy metal ions pollution for transport construction in permafrost regions Lecture Notes in Civil Engineering 50 pp 329-338 DOI: 10.1007/978-981-15-0454-9_34