The work of the tent fence on the shearing strength in light metal structures

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Abstract. Over the past decades, the use of tent fences has increased significantly. Since the application of these materials is gaining great interest in use every year, sufficient experience in the design and research of tent fencing as part of structures has not yet been obtained. For structures with the use of tent fences, the research is aimed at studying the wind impact, and especially the joint work of the frame with the awning, their overall stiffness. Modern regulatory documents do not show a complete picture of the behavior of tent materials when they are included in the work of structural frames, so there is a need to analyze and study their behavior under the influence of wind load.

In this article, the work of the tent fence is considered, as well as a numerical study of the stress-strain state of light metal structures with a tent covering is performed.

Keywords: tent fence, rigidity of the metal frame, fictitious connection, elastic modulus, calculation method, modulus of rigidity.

1 Introduction

The purpose of this work is to develop a simplified method for calculating a light metal frame with tent fences (coverings).

The use of light metal structures [1], such as various tents and canopies, has become widespread relatively recently [2-4]. The presence of serious advantages, both in construction and operation, contributes to the rapid growth of popularity of this type of frame and tent structures. In fact, these structures are a variety of forms of awnings, tents, verandas and canopies [5-6], the key feature of which is their structure, which is based on the use of a strong frame and light coating [7-9]. Due to this structure, the construction is quick to assemble, easy, convenient and safe.

Frame and tent structures are [10-12] made of a metal frame covered with a PVC (polyvinyl chloride) fabric [13]. The frame provides strength and stability of the object [14], and also is able to withstand significant loads. The polyvinyl chloride canopy reliably protects against adverse climatic influences. A special protective coating makes the canvas waterproof, increases its resistance to rot, UV rays, and various contaminants. Modern technologies allow the product to be used in the atmospheric temperature range from -50 °C to +50 °C [5-6]. Prefabricated frame and tent structures are widely used as hangars for vehicles, agricultural structures, warehouses, trade pavilions, sports grounds.

The tent fencing stretched over the metal structure provides reliable protection from any adverse weather conditions: wind gusts, scorching sun, torrential rains, etc. [15-17].

The covering of frame and tent structures is made of frost-resistant and oil-resistant materials, meets all fire safety requirements [18-19], and does not collapse under the influence of UV rays. In
case of mechanical damage, cuts and breaks on the surface of the awning are easily eliminated, because the awning fabric is a multi-layer durable fabric made of synthetic fibers [20].

There are few works devoted to the analysis of loads acting on tent coverings. All types of tent fences are affected by the wind [21], and some are affected by the weight of snow. Therefore, the study of the work of the tent fence [22-26] is a very important task [27-32].

2 Methods

One of the main tasks related to the calculation of tent structures is the numerical description of the properties of fabric materials. According to the results of various experiments and tests, the ability of the fabric to resist longitudinal forces in the warp and weft directions is much greater than in other directions.

It turns out that the influence of shear stiffness in tent fabrics is insignificant.

Previously, in engineering calculations, taking into account various errors and deviations not taken into account in the calculations due to the imperfection of fabric materials, the influence of shifting forces of tent fences was ignored. This simplification was justified when calculating large structures, but when calculating small tents, it makes sense to take shear stiffness into account and take it into account.

In the article Dr.-Ing Robert Hartel reviewed the results of testing of flooring in a system of prefabricated structures based on scaffolding for the impact of horizontal loads in two mutually perpendicular directions.

As a result of cyclic loading, the "force-displacement" diagram is obtained. We also obtained averaged values of the stiffness of imaginary diagonal elements when considering the mechanical model of the structure.
The considered method of accounting for the shear stiffness of the flooring by replacing the actual flooring in the design scheme with an analog in the form of conditional connections with a diagonal lattice can be applied in structures with awning material. Based on the recommendations of the article, we considered a flat system of one cell of a frame-tent structure between two longitudinal frames with a step B and the height of the posts H. We consider only the case of the tent working in the direction along the crossbar (parallel to the plane of the longitudinal cell), considering the crossbar pivotally supported on the posts.

We consider a cross lattice of fictitious connections, since the tent can work for a shift in both directions. However, we take into account the connection that works only for tension with a horizontal load applied in a particular direction (flexible compressed connections lose stability and do not participate in the work). The task is to determine the elastic modulus E of a fictitious connection in order to set it in any software package that implements the finite element method.

For small rotation angles $\varphi$ (since the displacements off are also small compared to H, B), we can assume that:

$$\Delta l = l - l_0 = f \cos \alpha,$$

where $f$ – the relative displacement of the point A; $\cos \alpha = H/l_0$; $l_0 = \sqrt{H^2 + B^2}$ – initial geometric length of an unreformed fictitious connection.

Then the relative longitudinal strain of the fictitious connection corresponding to the displacement of $f$ will be determined by the formula:

$$\varepsilon = \frac{\Delta l}{l} = \frac{f \cos \alpha}{l} = \frac{\sigma}{E} = \frac{N}{EA}.$$  

The force that occurs in a fictitious connection from the load $F$:

$$N = \frac{F}{\cos \alpha}.$$  

The linear modulus of elasticity is equal to:

$$c = \frac{EA}{l} = \frac{Nl}{\Delta l} = \frac{N}{\Delta l} = \frac{F}{f \cdot \cos^2 \alpha}.$$  

Thus, the elastic modulus of a fictitious connection is determined by the formula:

$$E = \frac{F \cdot l}{f \cdot \cos^2 \alpha \cdot A}.$$  

Thus, a formula was obtained for determining the modulus of rigidity of a fictitious connection:

$$EA = \frac{F \cdot l}{f \cdot \cos^2 \alpha}.$$
Based on the analytical method proposed above for taking into account the shear stiffness of the tent fence under the influence of a horizontal load, the work of the tent fence was modeled in the nonlinear formulation of the problem shown in figure 4.

Then, based on the obtained Eq. (6), the tent was replaced with a fictitious connection, and then the results obtained in the simulation of the tent and in the simulation of the fictitious connection were compared, and equal displacements were obtained. Thus, we can conclude that the proposed method of accounting for the shear stiffness of the awning when it is working on horizontal loads is effective. However, for the parameters for a fictitious connection, it is necessary that its modulus of elasticity depended on the modulus of elasticity of the used tent, therefore, to determine the general formula the variations of elastic modulus were considered: 1) from the angle $\alpha$; 2) from the length $l$. To do this, the calculations in LIRA-SAPR were carried out, after which the following conclusions were made:

1. The inverse linear dependence of the elastic modulus of a fictitious connection on the cosine of the angle of inclination of the connection itself is observed;
2. An almost linear dependence of the elastic modulus of a fictitious connection on its length is observed.

Figure 5. Graphs of the dependence of the elastic modulus of a fictitious connection on the cosine of the angle of inclination of the connection: a) at $F = 5$ kN; b) at $F = 10$ kN.
Figure 6. Graphs of the dependence of the elastic modulus of a fictitious connection on the length of the fictitious connection: a) at $F = 5$ kN; b) at $F = 10$ kN.

However, for more accurate calculations, it is necessary that both parameters (the length of the fictitious connection $l$ and the angle of inclination $\alpha$) are included in the generalized formula. Based on the above conclusions, the following formula was obtained:

$$E = K \cdot E_{\text{tent}} \cdot l / \cos^2 \alpha.$$  (7)

For more accurate calculations, you need to perform linear interpolation and get a more accurate coefficient $K$, some of which can be selected from the table. 1:

| $\alpha$ | $F, kN$ | 2.5  | 5   | 7.5 | 10  |
|---------|---------|------|-----|-----|-----|
| 30      | 0.015   | 0.014| 0.014| 0.014|     |
| 37      | 0.015   | 0.014| 0.013| 0.013|     |
| 45      | 0.013   | 0.012| 0.012| 0.012|     |
| 60      | 0.008   | 0.007| 0.007| 0.007|     |

Table 1. Numerical values of the equalizing coefficient $T$.

3 Results and discussion

To confirm the obtained method, the design of the pavilion with a span of 10 m with a tent cover and a fictitious connection was considered. In this example we used a tent cover with an elastic modulus of 300 MPa. The results of the movements were almost identical.

Figure 7. Calculation scheme a) with a tent, b) with fictitious connections.

To identify the proportion of tent inclusion in real structures, we considered the simultaneous operation of schemes with existing flexible connections (figure 8) and schemes with a tent cover,
which was replaced with fictitious connections according to the obtained method (figure 9). As a result of the calculation, the incoming share of the tent was 19%.

4 Conclusions
Using the obtained method, a qualitative task for calculating tent structures was implemented, on the basis of which the following conclusions and recommendations were made:

1) A general formula for determining the elastic modulus of a fictitious connection was proposed:

\[ E = K \cdot \frac{E_{\text{tent}} \cdot l}{\cos^2 \alpha} \]

2) For structures small in plan, it is advisable to use flexible connections, and when taking into account the shear stiffness of the tent fence in the longitudinal direction, it is entirely possible to increase the rigidity of the structure by 19%.

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