BUILDING STRUCTURES, BUILDING AND CONSTRUCTIONS

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CALCULATION OF THE SOFT ROOF OF AN ARCH CONSTRUCTION ON WIND LOADING UNDER THE DEFORMED SCHEME

Statement of the problem. The roof of the developed arch construction from constructional fabrics and the films, stabilized by means of wind ropes is considered. It is established that building regulations do not contain guidelines as to the calculation of a roof from the specified materials, and in an engineering method of calculation of similar awning constructions constructional fabrics and films are considered as not extensible that overestimates settlement efforts. The objective of the research is to develop a method of defining forces in a roof with use of the deformed settlement scheme which is most relevant to a tension of a roof in negative wind pressures.

Results. The method of static calculation of a soft roof of an arch construction with the account of its deformation is offered in negative wind loads. Dependencies for the definition of forces in a roof material are deduced on the basis of the *Laplace's equation* with the account of a preliminary tension of a material at the roof device. The formulas necessary for drawing up of the scheme of the appendix of loadings to an arch skeleton of a construction are resulted.

Conclusions. Application of the deformable settlement scheme at static calculation of a soft roof is adequate to its tension at influences of a wind and allows to define more precisely effort in a material and the scheme of the appendix of loading to a construction skeleton. It is established that settlement values of forces and loads in the use of the deformed scheme of a roof decrease.

Keywords: an arch construction, a soft roof, constructional fabrics, constructional films, wind loading, static calculation of a roof, deformed settlement scheme.

Introduction

In the developed arched multi-purpose structure for farms and private households [1], a roof can be made of constructional film-fabric materials which have to be replaced as the materials get wear and tear in the process of their operation. It was found that maintaining a roof of long-term films (e.g., sovelen, stabilized polyethylene) is the least costly with the durability of 4 to 7 years. In order to decrease wind effects, roofing materials should be laid with a degree of stretching, positioned in the ridge and base of the building and stabilized with wind ropes (e.g., artificial ones or plastic steel ropes) stretched every 2-3m of the roof.

The regulations [2] do not contain the guidelines for the calculations of construction fabrics and film roofings. In the engineering method of similar tent structures these materials are considered non-stretchable [3], which requires a great deal more calculation efforts. In fact at negative wind pressures (suction) determined according to the regulations [4], a roofing material will experience deformation (Fig. a, b) and two-axial stress. Therefore the aim of the study was to develop a method of calculating roofing on wind loads considering tensile deformation of the material which would be relevant to the operating conditions and enable the development of a scheme of applying loads to the carcass of the structure and their effects.

1. Statistical calculation of roofing using a deformation scheme

Being applied to stabilize rope roofings (Fig. d), a wind load is distributed between the ropes and longitudinal elements where they are secured in the ridge and base of the structure. The material of the roof undergoes stretching stresses in two mutually perpendicular planes (Fig. e) associated with the radii of the roof arch ρ_1, ρ_2 and external loads using the well-known Laplace equation (the pressure on the carcass generated by prior stretch of the roof material has not yet been taken into account):

$$W = W_1 + W_2 = \frac{S_1}{\rho_1} + \frac{S_2}{\rho_2}, \tag{1}$$

where W is a design wind load, Pa; W_1 is a wind load experienced by longitudinal elements of the roofing in the ridge and base of the structure, Pa; W_2 is wind load experienced by wind ropes, Pa; S_1 and ρ_1 is an effort (circular) respectively, N/cm, and the radius of the curve of the deformed roofing along the guide rail; S_2 and ρ_2 is an effort respectively, N/cm and the radius of the curve of the deformed roofing along the guide rail.

2. Identifying roofing deformations

W_1 and W_2 can be determined using the equality of curves in intersecting threads – film strips of 1 cm in width (Fig. e). Due to loads being uneven, there might be kinetic changes in the curve of the circular threads, however its overweighing arrow in the middle does not change much [5].

We make the assumption that the radius of the curve ρ_1 as the roofing is deformed for all the points of the thread remains unchanged. According to the calculations, ρ_1 changes linearly as the curve increases (Fig. c)

$$\rho_1 = \rho_O - kf_1, \tag{2}$$

where ρ_0 is the radius of a non-deformed roofing, cm; f_1 is a curve of the roofing (Fig. b), k is a coefficient of 3.5 for the span of the structure of 6 m and 4 for the spans of 7.5 and 9 m.

According to (1) and (2), as the radius of the curve decreases, circular stretching efforts S_1 in a roofing material should also decrease. For the developed size schemes of a multi-purpose arch structure, a change ρ_1 can also be approximated using the following ratio (an average error for spans in Fig. a $\leq$ 3 %):

$$\rho_1 = \rho_o \sqrt[3]{\frac{2{,}8h}{a}\frac{f_1}{\Delta l}}, \tag{3}$$

where a is the distance between the points where the roofing material is secured – the chord (Fig. b); h is an arrow of the segment; Δl is lengthening of the roofing material during deformation.

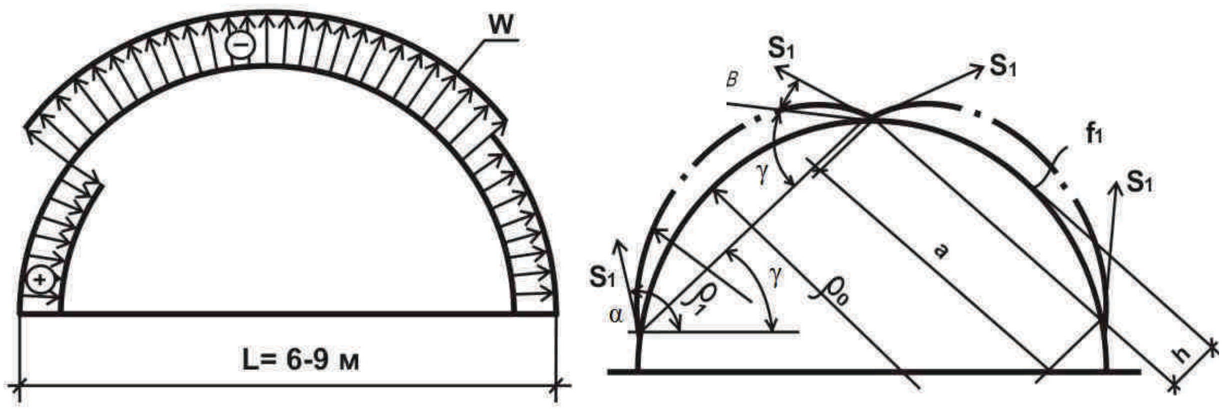

Fig. Statistical calculation of a soft roof of the structure:

a) a diagram of wind loads applied to the structure; b) scheme of the deformation of the roof;

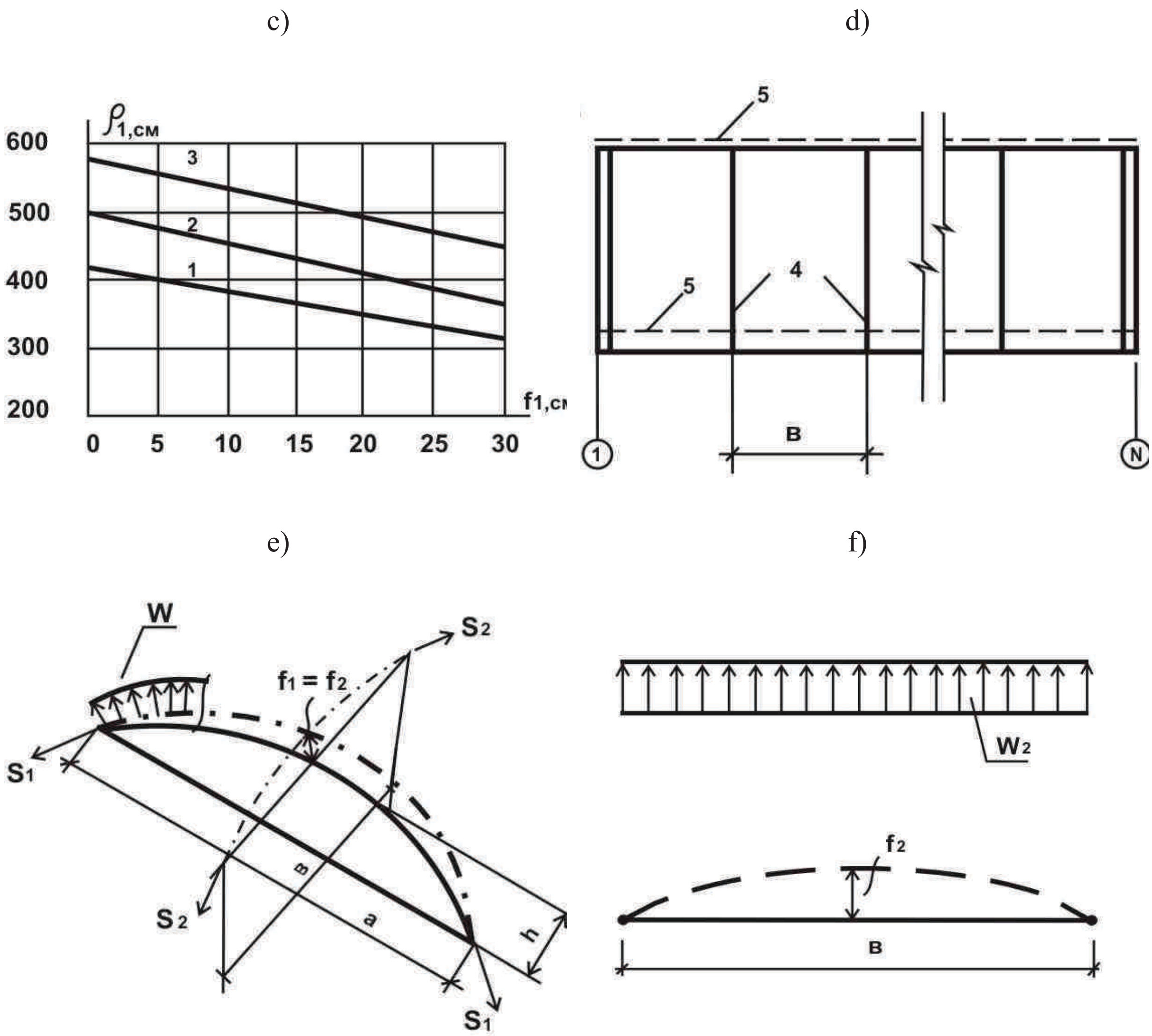

Fig. (ending) Statistical calculation of a soft roof of the structure:

c) change of the radius of the roof arch during its deformation;

d) scheme of the position of wind channels and elements of securing the roof;

e) scheme of the deformation and efforts in the roof;

f) calculation scheme of a thread between wind ropes;

span of the structure: 1 is 6 m; 2 is 7.5 m; 3 is 9 m;

4 is a wind rope; 5 are elements of securing the roof in the ridge and base of the structure

Considering that

$$S_1 / \delta = \sigma,$$

where δ is the thickness of the material, σ are normal strains, based on Hooke's law we determine how long the roofing material of 1m in width is under wind loads:

$$\Delta l = \frac{S_1 l_O}{E\delta} = \frac{W_1 \rho_1 l_O}{E\delta}, \qquad (4)$$

where l_0 is the distance between the securing elements of the roofing material in the ridge and base of the structure:

$$l_0 = a + \frac{8h^2}{3a};$$

where E is a coefficient of elasticity.

According to (4)

$$\rho_1 = \frac{\Delta l E\delta}{W_1 l_O}. \qquad (5)$$

Equating the right parts (3) and (5), we get

$$\frac{\Delta l^2 E\delta}{W_1 l_O} = \rho_O \sqrt[3]{\frac{2,8h}{a}} f_1. \qquad (6)$$

Based on the ratio of the elements of the circle, it was found that in the segment (Fig. b) an increase in the arch will be proportional to an increase in the curve (at $f_1 \le 30$ cm):

$$\Delta l = \frac{3 f_1}{\sqrt[3]{\frac{a^2}{h^2}}}. \qquad (7)$$

From (6) and (7) we determine

$$f_1 = \frac{0,16\rho_O W_1 l_O a}{E\delta h}. \qquad (8)$$

A maximum curve of the thread between wind ropes at $W_2 = W - W_1$ (Fig. e)

$$f_2 = \frac{M}{H}, \tag{9}$$

where H is an arch of the thread распор нити; M is a bending moment of the beam:

$$M = \frac{(W - W_1)db^2}{8},$$

where d is the width of a 1cm-strip of the material; b is the distance between wind ropes.

In threads with small arrows (curves) an arch H is not much different from the largest effort S_2 and can be defined as an arch of a string [6-8].

Then for a thread of the width d = 1cm

$$S_2 = H = \sqrt[3]{\frac{((W - W_1)d)^2 b^2 EF}{24}}, \tag{10}$$

where F is the area of the longitudinal section of the thread.

Following the transformation

$$f_2 = 0.36b\sqrt[3]{\frac{(W - W_1)b}{E\delta}}. \tag{11}$$

3. Determining efforts in the roof

Equating the right parts (8) and (11) and following the calculations we get

$$W_1^3 + kW_1 - kW = 0, \tag{12}$$

where

$$k = \frac{11,4b^4h^3E^2\delta^2}{a^3 l_O^3 \rho_O^3}.$$

From (12)

$$W_1 = \sqrt[3]{\frac{kW}{2} + \sqrt{D}} + \sqrt[3]{\frac{kW}{2} - \sqrt{D}}, \tag{13}$$

where D is a discriminant of the cubic equation:

$$D = \left(\frac{kW}{2}\right)^2 + \left(\frac{k}{3}\right)^3.$$

As the calculations indicate, the discriminant of the cubic equation is small and can thus be neglected.

Then

$$W_1 = 2\sqrt[3]{\frac{kW}{2}}. \quad (14)$$

A maximum circular linear effort considering prior stretch of the roofing material $W_{П}$

$$S_{1\max} = (W_1 — W_{П}\frac{W_1}{W})\rho_1 + S_{П} = (W_1 — W_{П}\frac{W_1}{W})\rho_1 + W_{П}\rho_o, \quad (15)$$

where $W_{П}$ and ρ_1 are distributed in (16) and (2) respectively:

$$W_{П} = \frac{S_{П}}{\rho_O} \approx \frac{0{,}15R}{\rho_O}, \quad (16)$$

where $S_{П}$ is effort in the material following a prior stretch, N/cm; R is a design resistance of a width unit of the material roofing, N/cm; ρ_0 is the radius of the arch of a non-deformed roofing, cm.

The directions of the circular efforts (Fig. b) can be determined according to the following expressions:

$$\alpha \approx \gamma + \arccos\frac{a}{2\rho_1}; \quad \beta \approx \arcsin\frac{a}{2\rho_1} - \gamma. \quad (17)$$

The intensity of the circular linear efforts change from $S_{1\max}$ in the middle of the distance between wind ropes to $S_{П}$ at the point of bearing of the roofing material on wind ropes.

Maximum linear efforts along the gudie rail, N/cm are

$$S_{2\max} = \sqrt[3]{\frac{(W_2 - W_{П}\frac{W_2}{W})^2 d^2 b^2 EF}{24}} + W_{П}\rho_O. \quad (18)$$

Conclusions

1. The method of the statistical calculation of a soft roof of an arch structure on wind loads considering deformation of the roofing material.

The ratios for determining the efforts in the roofing materials are obtained based on the Laplace's equation considering prior stretch of the material in the process of laying the roof. The formulas are presented for making a scheme of loads on the arch carcass of the structure.

2. The use of the deformed calculation scheme in a statistical calculation of a soft roof is adequate to its strain state under the effect of wind and allows for a more accurate calculation of the effort in the material and a scheme of the load on the carcass of the structure.

It was found that the use of the suggested method of the statistical calculation allows for about 20 % smaller efforts in a soft roof.

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