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PNEUMATIC CLADDING ELEMENT FOR CABLE STRUCTURES

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Abstract: Pneumatic cladding element on the base of Vectra fabric, coated by the PTFE foil, was considered. Approach for the designing of pneumatic cladding element was developed. The dependences of pneumatic cladding element prestressing level and it height on the materials consumption were evaluated. Rational from the point of view of materials consumption height of cladding element and internal pressure of the air were determined.
Keywords: Cable net, covered fabric, materials consumption.

1. INTRODUCTION

Cable roofs are characterized by the decreased materials consumption because nearly all it main load bearing units are tensioned. Cable roofs can be divided into the groups depending on the type of cladding. It can be rigid elements working in bending. Reinforced concrete slabs, profiled metal sheets, several types of composite units that are the examples of rigid elements for cable roofs cladding. Such elements mainly are used for the permanent structures and are characterized by the comparably big materials consumption [1].

Tensioned fabric is other type of cladding for cable roofs and membrane structures, where high strength materials can be used in the full scale. Decreased materials consumption and dead weight in combination with the increased mobility are the most significant advantages of tensioned fabric as the cladding element material.

Probability of wave development at some parts of structure after design vertical load application is a serious problem for tensioned fabric claddings. Other parts of cladding can be over-strengthened in this case.

Development of cladding element with the increased compliance and enough strength is probable way to fix the problem together with the cladding's prestressing. Combination of rigid and compliant elements also is possible [2]. Prestressed cladding element (Fig.1) is formed by the load-bearing cables, tensioned fabric and central pillar.

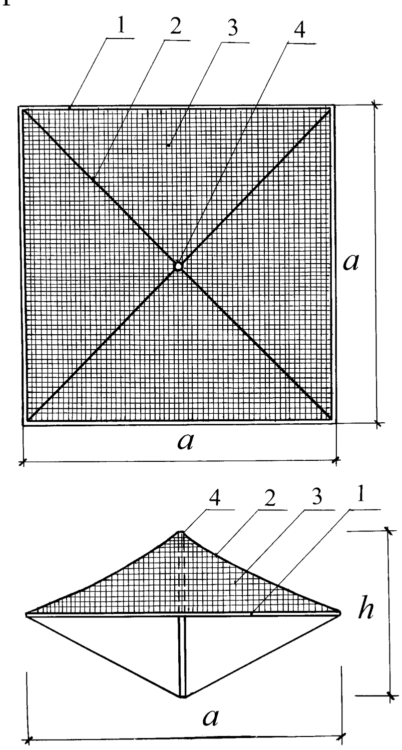

Fig.1. Prestressed element of cladding: 1– cables of the net; 2 – load-bearing cable; 3 – tensioned fabric; 4 – central pillar; *h* - height of prestressed cladding element; *a* – dimension of cladding element

But pneumatic cladding elements, where all the units are tensioned, cause the bigger interest (Fig.2) due to the absence of compressed units.

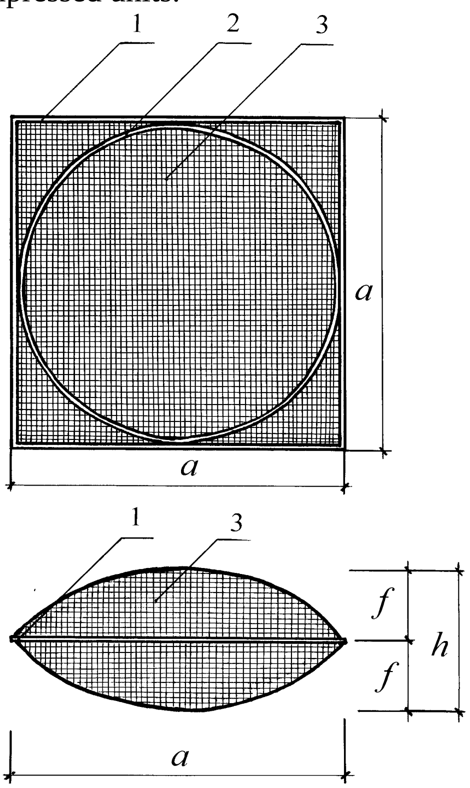

Fig. 2. Pneumatic element of cladding:
1– cables of the net; 2 – compliant contour; 3 – covered fabric; *a* – dimension of cladding element; *h* – height of pneumatic cladding element; *f* – maximum deflection of the surface of pneumatic cladding element.

The preferable shape of the surface of pneumatic cladding element is a spherical one [3]. The pneumatic cladding element is formed by the tensioned fabric, and compliant contour, consisting from the several glued together layers of the mentioned fabric. The pneumatic cladding element is prestressed by the internal pressure of the air. The compliant contour is joined directly with the cables of saddle-shaped roof. Correct choice of pneumatic cladding elements height and internal pressure of the air enables to minimize materials consumption. But the dependence of pneumatic cladding element prestressing level and it height on the materials consumption must be determined for the purpose.

So, the aim of the paper is to evaluate the dependence of pneumatic cladding element prestressing level and it height on the materials consumption. Rational from the point of view of materials consumption height of cladding element and internal pressure of the air must be determined. Approach for prestressed cladding element designing also should be developed.

2. CHOICE OF MATERIALS FOR PNEUMATIC CLADDING ELEMENT

Tensioned fabric is the most important unit of pneumatic cladding element. In general, tensioned fabrics can be coated or uncoated. Uncoated fabrics have short service lives and it applications is limited by the temporary membrane and cable structures. Coating of fabrics gives the following benefits:

- protecting the yarns against different sources of damages (UV, abrasion, atmosphere);
- proofing the membrane against rainwater and atmospheric moisture;
- stabilizing what might otherwise be unstable fabric geometry;
- providing material to permit heat-sealed seams.

Coated fabrics can be divided into the following groups depending on the type of coatings [1]:

- PVC coatings;
- PTFE coatings;
- Silicone coatings.

PTFE coatings cause the biggest interest due to the row of advantages. Since PTFE upper limit of continuous service temperature is +260 ºC it can be used in hot climatic zones. The lower limit of the continuous service temperature is -200 ºC. Temperature variations have no influence on the lifespan. PTFE has a low thermal conductivity (0.25-0.50 W/Km) and good insulating properties. PTFE is under normal conditions inflammable, and is resistant against the strongest corrosive substances. PTFE is not soluble in most common solvents. Because of its hydrophobic properties, PTFE is an excellent protection for the textile reinforcement of the membrane. PTFE is totally resistant to UV and IR-radiation. PTFE membranes show no ageing or increased brittleness due to UV/IR radiation [4-7].

Vectra (LCP) yarns take intermediate position between polyester and glass ones. Modulus of elasticity and strength in tension of Vectra (LCP) fibers are equal to 65000 and 2850 MPa, respectively. Elongation at break and density are equal to 3.3% and 1.4 g/cm^3 [4]. It means that Vectra (LCP) yarns can be used as components of tensioned fabrics for tensioned structures. Practical absence of creep allows us to consider Vectra (LCP) yarns as a material for prestressed structures [4]. So, coated fabric on the base of Vectra (LCP) yarns and PTFE coating will be considered next. Strength in tension of PTFE is more then 10 times less than of Vectra (LCP) fibers. It means that mechanical properties of considered coated fabric are determined by the properties of the Vectra (LCP) fibers.

3. DESIGN OF PNEUMATIC CLADDING ELEMENT

3.1. General approach

The design procedure of the pneumatic cladding element can be divided into the following stages:

- development of the design scheme;
- determination of loads, acting on the pneumatic cladding element;
- previous evaluation of the pneumatic cladding elements units cross-sections;
- analyze of the pneumatic cladding element by the program „ANSYS” and correction of previously determined cross-sections of units.

The design scheme of pneumatic cladding element is shown in the Fig. 3.

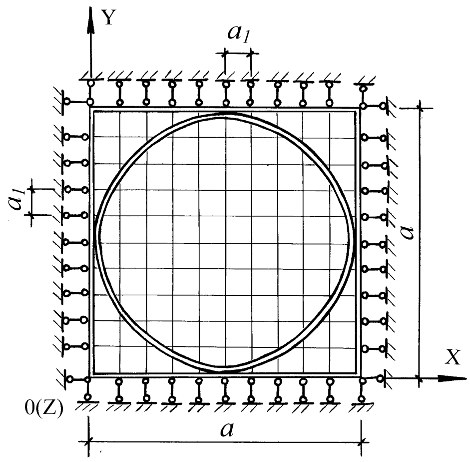

Fig. 3. Design scheme of pneumatic cladding element: a – dimension of pneumatic cladding element, a_1 – distance between the conditional yarns in warp and weft directions

Following assumption are taked into account during formation of design scheme.

- Design vertical load is applied as the pointwise forces to the nodes of the design scheme.
- The displacements of support points of prestressed cladding element are neglected.
- Tensioned coated fabric is considered as totality of yarns in warp and weft directions modeled by the universal nonlinear spatial cable finite element LINK 10 with specific bilinear stiffness matrix, which defines that the element works in tension only without bending stiffness [1].

The modulus of elasticity and tensile strength of yarns in warp and weft directions are determined basing on the properties of separate fiber.

3.2. Evaluation of mechanical properties of coated fabric

The modulus of elasticity and tensile strength of coated fabric on the base of Vectra (LCP) yarns and PTFE coating were evaluated basing on the assumption, that the properties are mainly determined by the characteristics of the base fabric.

Modulus of elasticity of tensioned fabric and the tensile strengths in warp and weft directions were considered as the main mechanical properties. Modulus of elasticity of tensioned fabric in warp and weft directions was evaluated by the following equations [8]:

$$E_{f,o} = E_1 \cos^4 \beta_{o,} \quad (1)$$

$$E_{f,y} = E_1 \cos^4 \beta_y , \quad (2)$$

Where

$$\cos \beta_o = 1 - 0{,}001 a_o ,$$

$$\cos \beta_y = 1 - 0{,}001 a_y .$$

Here $E_{f,o}$; $E_{f,y}$ - modules of elasticity of cladding element in warp and weft directions respectively; E_1- modulus of elasticity of separate yarn, β_o, β_y – angles of yarns inclinations in warp and weft directions respectively, a_o, a_y- shrinkage of fabric in warp and weft directions respectively.

The tensile strength of coated fabric was determined [8] for the basket weave case.
Quasi instantaneous tensile strength of fabric in warp and weft directions (kN/m) was determined using the recommendations [9] depending on the breaking force of fabric in both directions.

$$\tilde{N}_{f,o} = 0.5 K_o n_o P_o , \quad (3)$$

$$\tilde{N}_{f,y} = 0.5 K_y n_y P_y , \quad (4)$$

where

$$P_x = P_y = \eta_0 m_0 p_0 (1 + \frac{\nu}{\eta_0} \cos \beta_c \sin \beta_c),$$

$$tg\beta_c = 0.67 \pi d_1 t_1 .$$

$\tilde{N}_{f,o}$ и $\tilde{N}_{f,y}$ – tensile strength of fabric in warp and weft directions (kN/m); P_o and P_y – breaking force of yarns in warp and weft directions; K_o and K_y – coefficients of yarn strength using in warp and weft directions; n_o, n_y – amount of yarns in warp and weft directions at 1 meter; ν – friction coefficient of fiber; η_0 – coefficient taking into account inhomogeneity of fiber loading in the yarn; m_0 – amount of fibers in the cross-section of the yarn; p_0 – breaking force of fiber; β_c – lay angle of a yarn; d_1 – external diameter of the yarn; t_1 – number of twists at one millimeter of the yarns length .

4. EVALUATION OF RATIONAL PARAMETERS FOR PNEUMATIC CLADDING ELEMENT

The interaction between the materials consumption of the pneumatic cladding element, from one side, and internal pressure of the air and height of cladding element, from other, were obtained by the numerical experiment. Using a computer program “ANSYS” the numerical experiment was carried out. The numerical experiment was combined with the determination of tension forces, acting in the units of pneumatic cladding element under the main load combination. The main load combination includes dead weight of cladding element and accidental snow load which is equal to 0.2 kPa. Internal pressure of the air changes within the limits from 0.10 to 0.20 MPa [3].
The dimensions of considered pneumatic cladding element were equal to1.25, 2.50 and 5.00 m. The relations of maximum deflection of the surface of pneumatic cladding element to it dimension changes within the limits from 0.167 to 0.501. The height of pneumatic cladding element is equal to double maximum deflection of it surface. The materials consumption was determined as the dead weight of pneumatic cladding element, related to the covered area.
The dependences of the materials consumption of the pneumatic cladding element on the internal pressure of the air and relations of maximum deflection of the surface of pneumatic cladding element to it dimension are shown in Fig.4.
The material consumption of pneumatic cladding element changes within the limits from 0.833 to 1.894 kg/m^2, from 1.668 to 4.404 kg/m^2 and from 3.334 to 8.820 kg/m^2

for the elements with the dimensions 1.25, 2.50 and 5.00m, correspondingly.

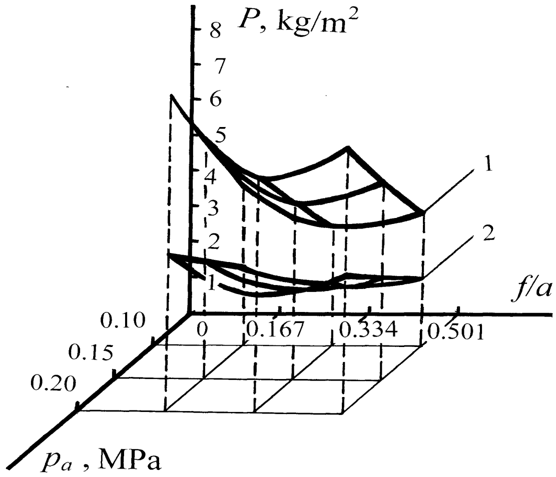

Fig. 4. The dependences of the internal pressure of the air p_a and relations of maximum deflection of the surface of pneumatic cladding element to it dimension *f/a* on the materials consumption *P*: 1 - the dimension of pneumatic cladding element is equal to 1.25 m; 2 - the dimension of pneumatic cladding element is equal to 2.50 m.

The dependences, which are shown in Fig. 4, were determined in the form of second power polynomial functions:

$$P = b_0 + b_1 \frac{f}{a} + b_2 p_a + b_{12} \frac{f}{a} p_a + b_{11} \left(\frac{f}{a} \right)^2 + b_{22} p_a{}^2. \quad (5)$$

The coefficients of equation (5) were determined applying the method of experimental design (Table 2).

Coef.	Values of coefficients for the dimensions of pneumatic cladding elements, m		
	1.25	2.50	5.00
b_0	0.9675	1.8932	3.8214
b_1	5.5603	5.4960	5.4448
b_2	11.1694	22.6689	44.2445
b_{12}	3.8212	3.8332	3.9532
b_{11}	6.6721	3.3015	1.6397
b_{22}	0.2000	1.2000	2.1333

Table 2. Coefficients of the equation (5)

The coefficients of the equation (5) were determined for the case when the units of the internal pressure of the air and materials consumption are MPa and kg/m^2, respectively. Rational from the point of view of materials consumption values of internal pressure of the air and relations of maximum deflection of the surface of pneumatic cladding element to it dimension were determined by the system of equations (6) and then corrected by the inspection.

$$\begin{cases} \dfrac{\partial P}{\partial \dfrac{f}{a}} = b_1 + b_{12} p_a + 2b_{11} \dfrac{f}{a} = 0, \\ \dfrac{\partial P}{\partial p_a} = b_2 + b_{12} \dfrac{f}{a} + 2b_{22} p_a = 0. \end{cases} \quad (6)$$

The dependences of the minimum materials consumption on the dimensions of the pneumatic cladding element for different values of the internal pressure of the air are shown in Fig.5.

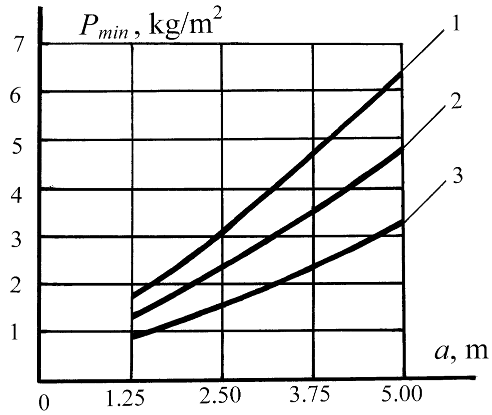

Fig. 5. The dependences of the minimum materials consumption P_{min} on the dimensions of the pneumatic cladding element *a*: 1 – internal pressure of the air is equal to 0.20 MPa; 2 – internal pressure of the air is equal to 0.15 MPa; 3 – internal pressure of the air is equal to 0.10 MPa.

It was shown, that the rational, from the point of view of materials consumption, relations of maximum deflection of the surface of pneumatic cladding element to it dimension are within the limits from 0.32 to 0.4 for 1.25x1.25, 2.50x2.50 and 5.00x5.00 m cladding elements.

5. CONCLUSIONS

Pneumatic cladding element on the base of Vectra fabric, coated by the PTFE foil, was considered. Approach for the designing of pneumatic cladding element for cable roof was suggested. Mechanical properties of prestressed fabric were evaluated, basing on the properties of separate yarn.

The dependences of the internal pressure of the air and relations of maximum deflection of the surface to it dimension on the materials consumption were evaluated for the pneumatic cladding elements. It was shown, that the material consumption of pneumatic cladding elements changes within the limits from 0.833 to 1.894 kg/m^2, from 1.668 to 4.404 kg/m^2 and from 3.334 to 8.820 kg/m^2 for the elements with the dimensions 1.25, 2.50 and 5.00m, correspondingly.

The dependences of the minimum materials consumption on the dimensions of the pneumatic cladding elements were evaluated. It was shown, that the rational, from the point of view of materials consumption, relations of maximum deflection of the surface of pneumatic cladding element to it dimension are within the limits from 0.32 to 0.4 for 1.25x1.25, 2.50x2.50 and 5.00x5.00 m cladding elements.

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