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Tensioned Cladding Elements for Cable Roofs

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Abstract. **Pneumatic cladding element for the long span cable roofs was considered. The pneumatic cladding element is formed by the generally woven by the basket weave fabric from the Vectra (LCP) yarns, which is covered by the PoliTetraFluoroEthylene (PTFE) copolymer foil, and compliant contour, consisting from the several glued together layers of the mentioned covered fabric.**

The design procedure of the pneumatic cladding element was developed. 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 obtained.

It was shown, that the using of pneumatic cladding element instead of rigid ones, enables to decrease energy consumption on the transportation and assembling more than four times.

Keywords: **cable roof, tensioned fabric, internal pressure of the air, rational geometrical parameters**

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 at 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. Materials consumption for the rigid cladding elements changes within the limits from 25 to 300 kg/m^{2,} for the permanent structures and from 0.5 to 15 kg/m^{2,} for makeshift ones [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 is formed by the load-bearing cables, tensioned fabric and central pillar.

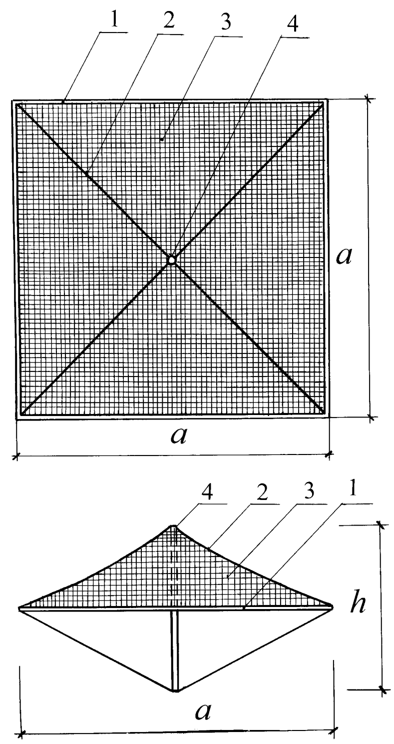

Fig.1. Prestressed element of cladding: 1– cables of the net; 2 – load-bearing cable; 3 – tensioned fabric; 4 – central pillar; *h* - height of prestressed cladding element; *a* – dimension of cladding element

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

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 dependences of pneumatic cladding element prestressing level and it height on the materials consumption must be determined for the purpose.

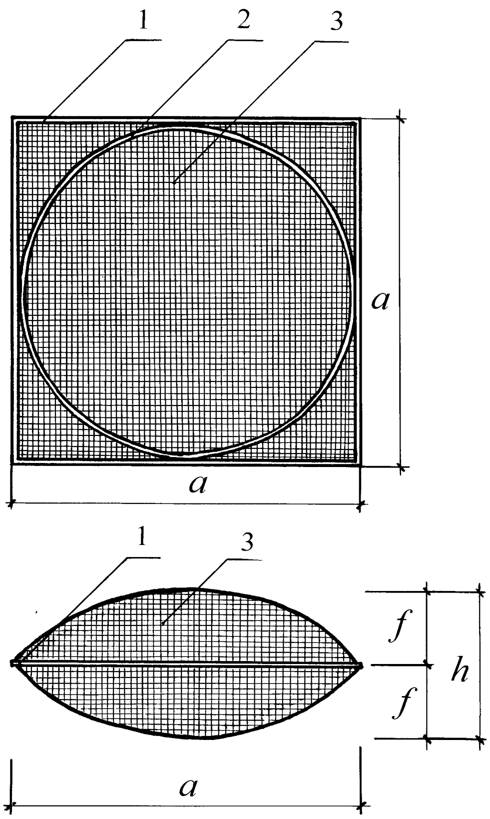

Fig. 2. Prestressed element of cladding:
1– cables of the net; 2 – compliant contour; 3 – covered fabric; *a* – dimension of cladding element; *h* – height of pneumatic cladding element; *f* – maximum deflection of the surface of pneumatic cladding element.

So, the aim of the paper is to evaluate the dependences 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.

DESIGN OF PNEUMATIC CLADDING ELEMENT

Coated fabric on the base of Vectra (LCP) yarns and PTFE coating are considered as the main structural materials [1].

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

- development of the design scheme of pneumatic cladding element;
- determination of loads, acting on the pneumatic cladding element;
- previous evaluation of the pneumatic cladding elements units cross-sections;
- analyze of the prestressed 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 Figure 3.

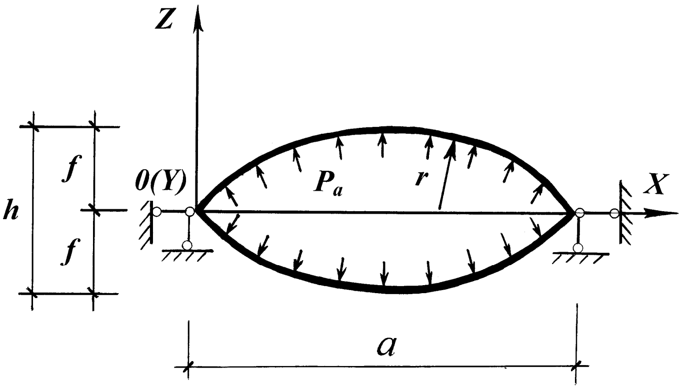

Fig. 3. Design scheme of pneumatic cladding element: p_a – internal pressure of the air; *r* – radius of pneumatic cladding element surface; other designations as in Fig.2.

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 modelled 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.
- 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 [4-7].

Previous evaluation of the covered fabric cross-sections was conducted on the base of internal forces, acting in the covered fabric in warp and weft directions. The values of internal forces were determined by the equations (1) and (2) and must not exceed the tensile strength of coated fabric in warp and weft directions.

$$N_1 = r \cdot \left(0.5 p_a + w \cdot \beta_1\right) \le N_0, \qquad (1)$$

$$N_2 = r \cdot \left(0.5 p_a + w \cdot \beta_2\right) \le N_y. \qquad (2)$$

N_1 and N_2 - internal forces, which act in covered fabric in warp and weft directions; N_o and N_y - tensile strength of covered fabric in warp and weft directions; *r* – radius of pneumatic cladding element surface; p_a – internal pressure of the air; w – negative wind pressure; β_1 and β_2 -factors, which depend from the dimensions of pneumatic cladding element.

The values of internal forces, which act in covered fabric in warp and weft directions, mainly depend from the internal pressure of the air.

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.

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.

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, accidental snow load which is equal to 0.2 kPa or negative wind pressure, which is equal to 0.2 kPa. Internal pressure of the air changes within the limits from 0.10 to 0.20 MPa.

Pneumatic cladding element is a unit of cladding of saddle-shaped cable roof. The cable roof was 50x50 m in plan with the rational geometrical characteristics: the initial deflection of contour cables was 8.6 m, the initial deflection of suspension and stressing cables 20 m and the step in plan of the latter ones was 1.414 m [10]. The displacements of cable net of saddle – shaped roof were not taked into account.

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 Figure 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.

It is interesting to compare the dependences obtained for the pneumatic cladding element and for prestressed cladding element [2]. The dependences of the materials consumption of the prestressed cladding element on the level of prestressing of tensioned fabric and height of prestressed cladding element are shown in Fig.5. The dimension of prestressed cladding element is equal to 2.5 m.

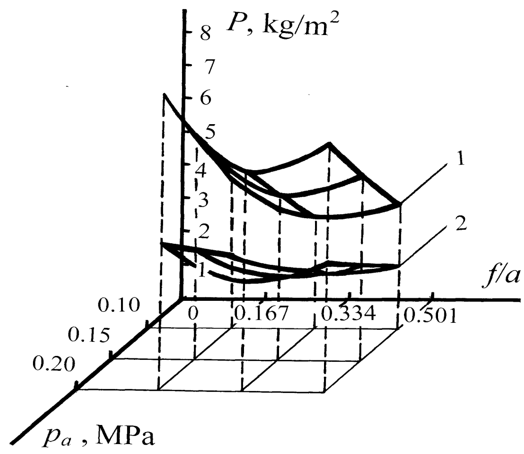

Fig. 4. The dependences of the internal pressure of the air p_a and relations of maximum deflection of the surface of pneumatic cladding element to it dimension *f/a* on the materials consumption *P*: 1 - the dimension of pneumatic cladding element is equal to 2.50 m; 2 - the dimension of pneumatic cladding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

The surface 1 in Figure 4 and 2 in Figure 5 should be compared. The materials consumption changes within the limits from 0.368 to 0.633 kg/m^2 in the case, when the displacements of cable net were neglected (see surface 2 in Figure 5). It is from 4.53 to 6.96 times less in comparison with the pneumatic cladding element. The significant difference can be explained by the differences in the levels of prestressing for the pneumatic and prestressed cladding elements. Internal pressure of the air for pneumatic cladding element changes within the limits from 0.10 to 0.20 MPa, but probably this level can be decreased.

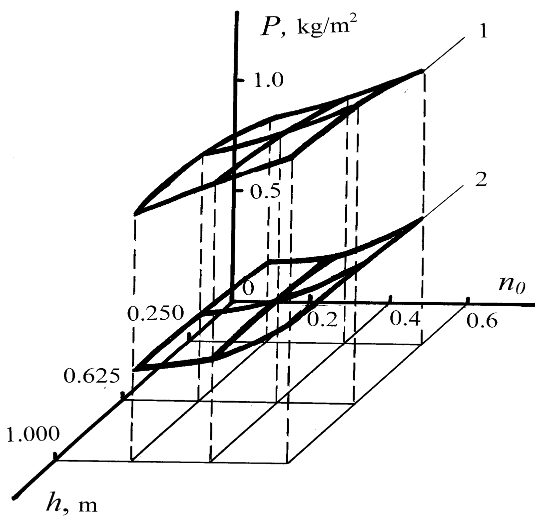

Fig. 5. The dependences of the height *h* of prestressed cladding element and level of it prestressing n_0 on the materials consumption *P*: 1 - the displacements of cable net of saddle – shaped roof were taken into account; 2 - the displacements of cable net of saddle – shaped roof were not taken into account

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

$$P = b_0 + b_1 \frac{f}{a} + b_2 p_a + \\ + b_{12} \frac{f}{a} p_a + b_{11} \left(\frac{f}{a} \right)^2 + b_{22} p_a{}^2. \quad (3)$$

The coefficients of equation (3) were determined applying the method of experimental design and are given in the table 1.

TABLE 1
Coefficients of the equation (3)

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

The coefficients of the equation (3) 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 (4) and then corrected by the inspection.

$$\begin{cases} \dfrac{\partial P}{\partial \dfrac{f}{a}} = b_1 + b_{12} p_a + 2b_{11} \dfrac{f}{a} = 0, \\ \dfrac{\partial P}{\partial p_a} = b_2 + b_{12} \dfrac{f}{a} + 2b_{22} p_a = 0. \end{cases} \quad (4)$$

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 Figure 6.

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.

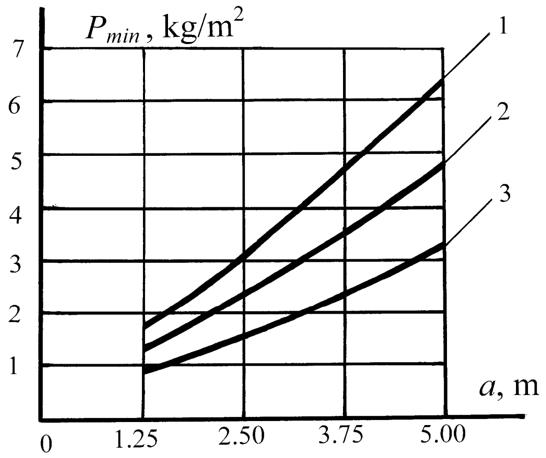

Fig.6. The dependences of the minimum materials consumption P_{min} on the dimensions of the pneumatic cladding element a: 1 – internal pressure of the air is equal to 0.20 MPa; 2 – internal pressure of the air is equal to 0.15 MPa; 3 – internal pressure of the air is equal to 0.10 MPa.

Materials consumption of the pneumatic cladding element is comparable with the materials consumption for the existing makeshift structures. Using of pneumatic cladding elements for the permanent structures is a question for the discussion. But materials consumption can be decreased more then 4 times in the case. Correspondingly decreases energy consumption on transportation and assembling. So, using of pneumatic cladding elements instead of rigid ones enables to decrease pressure on the environment.

CONCLUSIONS

Pneumatic cladding element on the base of Vectra fabric, coated by the PTFE foil, was considered. So, using of pneumatic cladding elements instead of rigid ones enables to decrease more than four times energy consumption on transportation and assembling. 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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Dmitrijs Serdjuks, Kārlis Rocens, Raimonds Ozoliņš. Stieptie norobežojošie elementi vanšu pārkrājumam
Darbā apskatīts vanšu pārklājuma pneimatiskais norobežojošais elements. Pneimatiskais elements veidots no Vektrana groza pinuma audekla ar politetraftoretilēna pārklājumu. Elementa pakļāvīgais atbalsta kontūrs veidots no vairākiem kopā salīmētiem Vektrana audekla slāņiem.
Pneimatiskā norobežojošā elementa aprēķins satur sekojošus posmus:
- pneimatiskā norobežojošā elementa aprēķina shēmas izvēle;
- slodžu aprēķins;
- apakšelementu šķērsgriezumu novērtēšana;
- pneimatiskā norobežojošā elementa aprēķins, izmantojot datora programmu *ANSYS* ar apakšelementu šķērsgriezumu korekciju.

Iegūta sakarība starp pneimatiskā norobežojošā elementa materiālu patēriņu, gaisa pārspiedienu un pneimatiskā elementa malas attiecību pret tā virsmas izlieci. Gaisa pārspiediens mainās robežās no 0.10 līdz 0.20 MPa. Pneimatiskā norobežojošā elementa malas attiecība pret to virsmas izlieci mainās robežās no 0.167 līdz 0.501. Pneimatiskā norobežojošā elementa materiālu patēriņš mainās robežās no 0.833 līdz 0.894 kg/m^2, no 1.668 līdz 4.404 kg/m^2 un no 3.334 līdz 8.820 kg/m^2 elementiem ar malas izmēriem 1.25, 2.50 un 5.00 m.
Darbā parādīts, ka pneimatiskā norobežojošā elementa pielietošana dos iespēju vairāk kā četras reizes samazināt materiālu patēriņu, salīdzinot ar stingiem norobežojošiem elementiem.

Дмитрий Сердюк, Карлис Роценс, Раймондс Озолиньш. Растянутые ограждающие элементы для вантовых покрытий
Пневматический ограждаущий элемент для большепролетных вантовых покрытий рассмотрен в данной работе. Пневматический ограждаущий элемент формируется вектрановой тканью полотняного переплетения, покрытой ПолиТетраФторЭтиленовой пленкой, и податливым опорным контуром, образованным несколькими склеенными вместе слоями вышеупомянутой ткани.
Расчет пневматического ограждающего элемента включает следующие этапы:
- принятие расчетной схемы пневматического ограждающего элемента;
- расчет нагрузок, действующих на пневматический ограждающий элемент;
- предварительный расчет поперечных сечений суб-элементов;
- расчет пневматического ограждающего элемента с помощью прогаммы „*ANSYS"* и коррекция первоначально принятых сечений суб-элементов.

Получена зависимость расхода материала пневматического ограждающего элемента от избыточного давления воздуха и отношения стороны элемента к выгибу его поверхности. Величина избыточного давления воздуха менялась в пределах от 0.10 до 0.20 МПа. Отношение стороны элемента к выгибу его поверхности менялось в пределах от 0.167 до 0.501. Расход материалов пневматического ограждающего элемента менялся от 0.833 до 1.894 кг/м^2 и от 1.668 до 4.404 кг/м^2 и от 3.334 до 8.820 кг/м^2 для элементов с размерами в плане 1.25, 2.50 и 5.00 м, соответственно.
Показано, что использование пневматического ограждающего элемента вместо жесткого, позволяет более чем в четыре раза снизить расход энергии на транспортировку и монтаж.