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Rational Large Span Structure of Pultrusion Composite Trussed Beam

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Abstract. **Trussed beam with the 46 m span was considered as an object of investigations. Pultrusion composite profiles and steel cables were considered as the materials of the trussed beam top chord, web and bottom chord, correspondingly.**

Trussed beam with strut frames, trussed beam with triangular web and trussed beam with vertical struts were compared from the point of view of maximum vertical displacements. The trussed beam with vertical struts is characterized by the increased deformability in case if the load is uniformly distributed by the half of the span. It was shown, that the application of additional diagonals allows to decrease the deformability of trussed beam with vertical struts.

The dependence of load-bearing capacity on construction height and material consumption was obtained for the trussed beam with vertical struts with the 46 m span. It was shown, that load-bearing capacity of trussed beam changes within the limits from 11.4 to 26.1kN/m when the height of the trussed beam changes from 3 to 7 m, correspondingly. The materials consumption changes within the limits from 1705 to 2516 kg at the same time.

Keywords: **trussed beam, pultrusion composite profiles, large span structure**

INTRODUCTION

Increasing of structural spans is one of the most significant problems at the present moment [9].

The composite pultrusion profiles are widely used for the bended elements during the last time.

Using of composite materials instead of traditional ones, such as steel, allows to decrease the structural weight. Composite materials possess increased in comparison with the traditional materials, specific strength. It is very significant for large span structures, where structural dead weight is the most significant component of the load.

Mechanical properties of composite materials can be regulated by the regulation of several ingredients amount. Resistance to chemicals, electrical and thermal insulating properties are significant advantages of composite materials in comparison with the traditional ones [4].

Composite materials have steadily gained ground in nearly all sectors. The rise in use of composites can be explained by better and more comprehensive knowledge of the fundamental properties of composites and their long service life. This has enabled more specific uses and has reduced security factors to realistic levels [4].

But the most significant problem of the pultrusion composite profiles usage is an imperfect overall stability in plane of bending moment action. The problem can be fixed by the development of rational structure of the trussed beam, where the overall stability of the top chord will be provided by the corresponding solution of the web.

Other problems of composite pultrusion profiles are that serviceability limit state is determinative for large spans, so cross-section is not used completely, and composite pultrusion profile cross-section height offered by manufactures is limited, so it is difficult to develop large span constructions. These problems also can be fixed by developing of rational structure of trussed beam.

In this connection, the aim of the work is to consider posibility to develop a large span construction with the sub-elements from the composite pultrusion profiles. The dependence of load-bearing capacity on construction height and material consumption also must be determined.

SOLUTION OF THE PROBLEM

Different types of trussed beams constructions with strait top chord where analyzed (Fig.1), such as trussed beam with strut frames; trussed beam with triangular web; trussed beam with vertical struts.

Beam top chord is strait, so construction can be used for wide range of buildings. The construction support type is similar to freely-supported beam. It allow to use such kind of construction with more wide range of columns, in comparison with fixed-end type of support, where large longitudinal forces acts.

The construction of bottom chord is cambered, because this type better fits to bending moment distribution diagram.

The largest avaliable I type composite pultrusion profile is profile with height equal to 360 mm, so it was considered as the cross-section type of top chord (Fig.2).

The most rational from the point of view of displacements type of trussed beam is beam with the vertical struts. Trussed beam with triangular web works better, when non-uniformly distributed load is applied. But the displacements are larger when uniformly distributed load is applied. Organization of pretension is another problem of the trussed beam with triangular web.

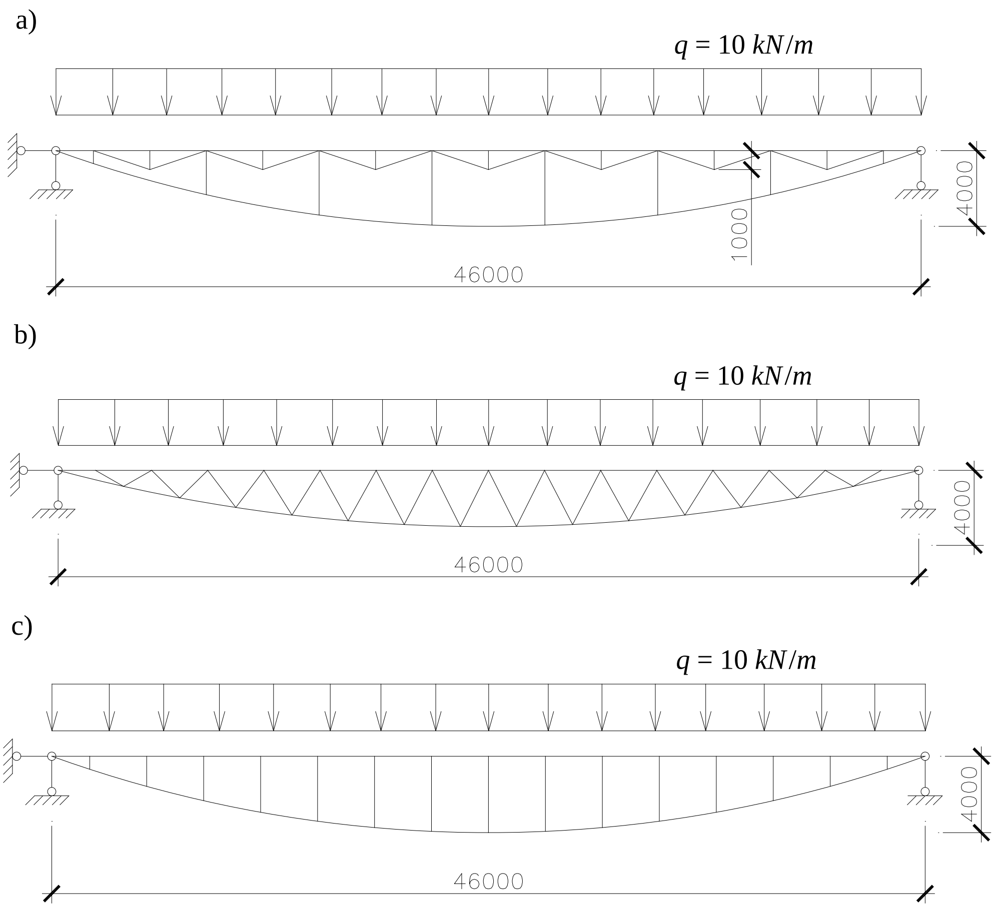

Fig.1. Types of trussed beams. a) – trussed beam with strut frames; b) – trussed beam with triangular web; c) – trussed beam with vertical struts (Spatial bracings conditionally are not shown in Fig.1)

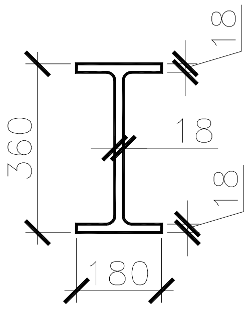

Fig.2. Selected type of bottom chord cross-section

The step of pillars was equal to 3 m. This step is most appropriate for composite beams with cross-section height equal to 360 mm, because load bearing capacity is almost identical by ultimate limit state and by serviceability limit state. The edge spans were equal to 2 m to justify the values of internal forces, because the scheme of edge element fixation and middle element fixation is different.

It was assumed that construction is fixed in the plane perpendicular to bending moment action plane with links in the joints.

Different types of joints of top chord with struts were analyzed (Fig.4).Hinge joints allow to decrease bending moment in the connection of the struts and top chord, but fixed end joints allow to decrease effective length for struts by 30 %, and allow to decrease deflections for chosen construction type by 25%. So, fixed end joints were chosen for connection of all struts and elements of top chord, excluding edge ones. The hinge end joints were used for the connection of edge elements of top chord with the struts due to the large bending moment acting in the joints.

Usage of trussed beam type with strut frames allow to decrease material consumption of pillars by 20% or by 35 kg, but it is necessary 683 kg of additional cable. Trussed beams with span 46 m and beam height 4 m were considered under the action of uniformly distributed load with intensity 10 kN/m. Bottom chord is prestressed.

Trussed beam with vertical struts was considered as an object of investigation (Fig.3). The span of the beam was equal to 46 m.

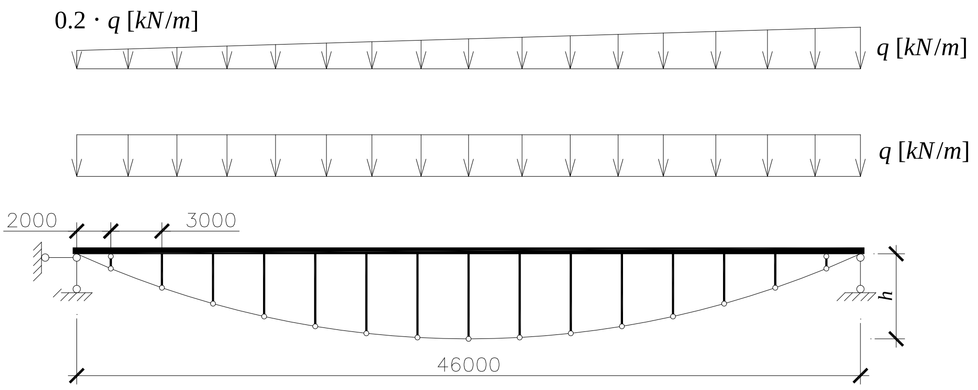

Fig.3. Design scheme of trussed beam. *q* – load bearing capacity, *h* – height of trussed beam. (Spatial bracings conditionally are not shown in Fig.3)

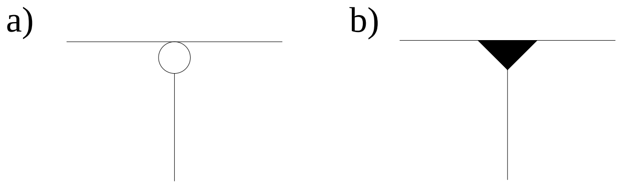

Fig.4. Types of joints. a) – hinge joint, b) – fixed end joint

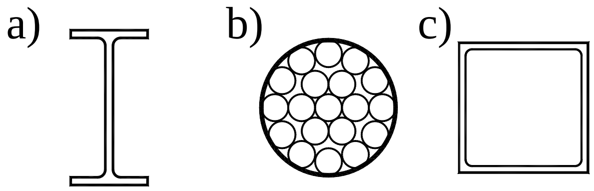

Fig.5. Cross-section types. a) – cross-section type of top chord, b) – cross-section type of bottom chord, c) – cross-section type of struts

Beam height was chosen as variable factor.

The pultrusion composite was chosen as a material of top chord and struts. The steel was chosen as a material of bottom chord. The mechanical properties of chosen materials are listed in the Table 1.

Cross-section type of top chord is I – type profilie with height 360 mm, corss-section type of struts is square tube, and cross-section type of bottom chord is cable (Fig 5).

TABLE 1

Mechanical Properties of Materials

Element	Top chord	Bottom chord	Pillars
Material	Composite pultrusion	Steel	Composite pultrusion
Elasticity modulus	E_{0°=28000 MPa	E_{0°=23000 MPa	E_{0°=167000 MPa
Flexural strength	$f_{b,0^\circ}$=240 MPa		$f_{b,0^\circ}$=240 MPa
Tensile strength	$f_{t,0^\circ}$=240 MPa		$f_{t,0^\circ}$=240 MPa
Compressive strength	$f_{c,0^\circ}$=240 MPa		$f_{c,0^\circ}$=240 MPa
Rope grade		R_r=1960 MPa	

The following calculations were made: ultimate limite state and serviceability limite state were checked. Maximum allowed deflection is aqual to 1/300 from beam span. The aim of calculations was to determine maximum load bearing capacity and to ensure that cross-sections was fully used by ultimate limit state and serviceability limit state. Material consumption also must be obtained.

Internal forces, which acts in the beam elements, when load is applied, where determined using finite element method. Dimensions of cross-sections of struts and bottom chord where determined then on the base of obtained internal forces.

Top chord of the trussed beam and middle struts are subjected to compressed force and flexural moment. The normal compressive force and the flexural moment are interdependent, as the transverse deflection in connection with the normal force causes a moment in the profile (allowance for deflection). Allow for this by multiplying the moment (which is determined without taking deflections into account) by a moment intensification factor.

The maximum compressive stress in the profile is:

$$\sigma_{\max} \le \frac{f_{c,0^\circ}}{\gamma_{m,f}}, \tag{1}$$

$$\sigma_{\max} = \frac{N_d}{A} + \frac{1}{1 - \frac{N_d}{N_{cr}}} \cdot \frac{M_d}{W}, \tag{2}$$

where

N_d – design value of normal compressive force;

M_d – flexural moment (determined without taking profile deformations into account);

A – cross-section area of profile;

W – section modulus of profile;

$f_{c,0^\circ} / \gamma_{m,f}$ – design value for compressive strength of profile;

$f_{c,0^\circ}$ – compressive strength;

$\gamma_{m,f}$ – partial coefficient for f in unlimate limit state, in our case equal to 1.3;

N_{cr} – critical compressive force for profile.

Critical compressive force:

$$N_{cr} = \frac{F_d}{1 + \frac{F_d}{N_{el}}}, \tag{3}$$

$$F_d = \frac{A \cdot f_{c,0^\circ}}{\gamma_{m,f}}, \tag{4}$$

$$N_{el} = \frac{\pi^2 \cdot E_{0^\circ} \cdot I}{\gamma_{m,E} \cdot L_{ef}^2}, \tag{5}$$

where

I – moment of inertia;

E_{0° – modulus of elasticy;

$\gamma_{m,E}$ – partial coefficient for E in ultimate limit state, in our case equal to 1.3;

L_{ef} – effective length;

N_{el} – load according to elastic theory (Euler load);

F_d – compressive load.

Edge struts of the trussed beam are subjected to compression. The design value of the normal force *Nd* must be lower than the critical column load *Ncr*:

$$N_d \le N_{cr} . \tag{6}$$

The bottom chord is tensioned and its cross-sectional area was determined by the equation (7) (Ермолов 1991):

$$A \ge \frac{\gamma_m \cdot N}{k_p \cdot R_r} \tag{7}$$

where

A – cross-sectional area of the bottom chord;

N – force acting in the bottom chord;

R_r – rope grade;

k_p – coefficient, taking into account the drop in the breaking force of the cable, caused by the inhomogeneity of stress distribution, in our case equal to 0.75;

γ_m – reliability index of the material, in our case equal to 1.6.

NUMERICAL RESULTS

Beams with differents heights were analyzed. Load bearing capacity is larger for beams with larger height. But further beam height increase is limited by cross-sections of the struts (Table 2).

TABLE 2

Numerical results

Height, h, m	3	5	7
Load-bearing capacity, q, kN/m	11,4	18,8	26,1
Pretensioning force, kN	20,0	4,2	2,2
Top chord dead weight, kg	1042,5	1042,5	1042,5
Pillars dead weight, kg	152,5	334,2	646,4
Bottom chord dead weight, kg	390,7	424,0	458,8
Material consumption, P, kg	1585,6	1800,7	2147,7

On the picture (Fig.6) you can see the dependence of load-bearing capacity on construction height and material consumption.

The dependence indicates that load-bearing capacity of trussed beam changes within the limits from 11.4 to 26.1 kg when the height of the trussed beam changes from 3 to 7 m, correspondingly. The materials consumption changes within the limits from 1585 to 2147 kg at the same time.

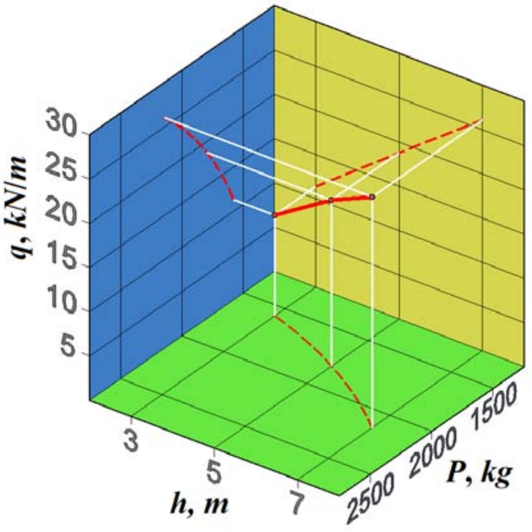

Fig.6. The dependence of load-bearing capacity on construction height and material consumption. *q* – load bearing capacity, *h* – construction height, *P* – material consumption

The constructions were checked also under the action of non uniformly distributed load. The dimensions of cross-sections and pretension force was the same as for uniformly distributed load.

The ultimate limit state is ensured for all considered structures with chosen cross-section types. In the picture (Fig.7) you can see the shape of deflections.

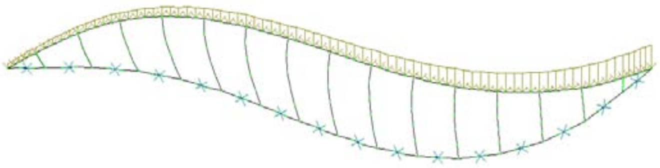

Fig.7. Deformed shape of trussed beam under the action of non-uniformaly distributed load

Deflections of trussed beam under the action of non-uniformaly distributed load are listed in the Table 3.

TABLE 3

Maximum vertical displacements

Beam height, h, m	Maximum deflection (upwards), w^+, mm	Minimum deflection (downwards) w^-, mm
3	358	63
5	396	183
7	551	252

The deflections are not in the available limit 150 mm for considered span, so serviceability limit state is not ensured.

To prevent this, diagonals can be used (Fig. 8). It is not necessary to place diagonals in all blocks. Material and cross-section type for diagonals was chosen as for struts. But it is neccesary from 120 to 370 kg of additional material for diagonals depending on construction height.

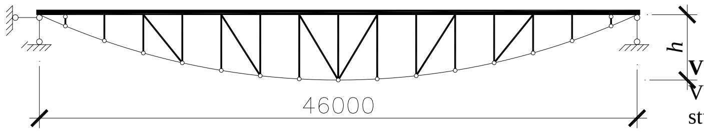

Fig.8. Rational structure of trussed beam. (Spatial bracings conditionally are not shown in Fig.8)

CONCLUSIONS

Possibility to develop large-span structure from the pultrusion composite material was stated. It was shown, that application of diagonal elements in some blocks of lattice allows to provide satisfaction of the serviceability limit state.

The dependence of load-bearing capacity on construction height and material consumption was obtained. It was shown, that load-bearing capacity of trussed beam changes within the limits from 11.4 to 26.1 kN/m when the height of the trussed beam changes from 3 to 7 m, correspondingly. The materials consumption changes within the limits from 1705 to 2516 kg at the same time.

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Vadims Goremikins, Kārlis Rocēns, Dmitrijs Serdjuks. Šprenģeļsijas no pultrūzijas kompozītiem racionāla liellaiduma konstrukcija
Konstruktīva laiduma palielināšana ir viena no problēmām, ko risina mūsdienā. Pēdējā laikā arvien plašāk pielieto pultrūzijas kompozītmateriālu profilus.
Kompozītmateriālu profiliem ir vairākas priekšrocības salīdzinājuma ar tradicionāliem materiāliem. Bet vislielākā pultrūzijas kompozītmateriālu problēma ir kopējas noturības zudums lieces momenta darbības plaknē liellaiduma konstrukcijām. Problēma var būt atrisināta ar špreneļsijas racionālas konstrukcijas izstadāšanu, kur kopēja augšējas joslas noturība būs nodrošināta ar atbilstošu režģojuma risinājumu.
Apskatīta šprenģeļsija ar laidumu 46 m. Augšējā josla un režģojuma elementi izgatavoti no pultrūzijas kompozītu profiliem, bet apakšējās joslas vants no tērauda.
Analītiski salīdzinot atšķirīgus šprenģeļsiju veidus parādīts, ka gadījumā, ja konstrukcija slogota ar vienmērīgi izkliedētu slodzi labākais variants ir šprenģeļsija ar vertikāliem spraišļiem (statņiem). Savukārt šim variantam palielināta deformējamība gadījumā, ja vienmērīgi izkliedēta slodze ir pielikta tikai pusei no laiduma. Parādīts, ka šo palielināto deformējamību var novērst ievietojot papildus slīpus spraišļus, bet tas palielina materiāla patēriņu.
Darba gaitā iegūtā sakarība starp šprengeļsijas materiālu patēriņu, tās nestspēju un augstumu konstrukcijai ar laidumu 46 m. Parādīts, ka šprengeļsijas nestspēja mainās robežas no 11.4 līdz 26.1 kN/m ja šprengeļsijas augstums mainās robežas no 3 līdz 7m, bet materiāla patēriņš mainās robežos no 1705 līdz 2516 kg ar papildus ievietotiem slīpiem spraišļiem.

Вадим Горемыкин, Карлис Роценс, Дмитрий Сердюк. Рациональная конструкция большепролетной шпренгельной балки из пультрузионных композитных материалов
Увеличение конструктивного пролёта – одна из проблем, которые решают в современное время. В последнее время всё чаще стали использовать пультрузионные композитные профиля. Пультрузионные композитные профиля обладают множеством приимуществ по сравнению с традиционными материалами. Самый существенный недостаток пультрузионных композитных профилей – потеря общей устоичивости в плоскости действия момента для большепролётных конструкций. Проблему можно решить, разработав рациональную конструкцию шпренгельной балки, где устойчивость верхнего пояса буден обеспечена соответствующим решением решетки.
Шпренгельная балка пролетом 46 м рассмотрена в качестве объекта исследования. Верхний пояс и элементы решетки шпренгельной балки выполнены из пультрузионных композитных профилей. Стальной трос рассмотрен в качестве материала нижнего пояса.
Путем сопоставления результатов расчета различных вариантов шпренгельных балок установлено, что наиболее жестким в случае приложения равномерно распределенной по пролету, нагрузки, является вариан с вертикальными стойками. Однако, данный вариант отличается повышенной деформативностью в случае приложения равномерно распределенной нагрузки к половине пролета. Путем решения проблемы является установка дополнительных диагональных элементов.
Для шпренгельной балки с вертикальными стойками и пролетом 46 м получена зависимость расхода конструктивного материала от несущей способности и высоты шпренгельной балки. Показано, что несущая способность шпренгельной балки меняется в пределах от 11.4 до 26.1 кН/м при изменении высоты от 3 до 7 м. соответственно. Расход материала, в то же время, менялся в пределах от 1705 до 2516кг.