NUMERICAL STUDIES OF BEHAVIOR OF A CURVED STEEL AND CONCRETE COMPOSITE CABLE SPACE FRAME

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ABSTRACT

The paper studies behavior of steel and concrete composite cable space frames under uniformly distributed load. The composite cable space frames are a new kind of roof system to covering different both long-span and short-span buildings. The composite structure has been developed in Poltava National Technical Yuri Kondratyuk University on department of structures from a metal, wood and plastics.

The particular feature of the steel and concrete composite cable space frames lies in the fact that bottom chord made of flexible rods and top chord is made of rectangular reinforced concrete slabs. The flexible rods are made from short-length segments of steel cables that have special details at the ends through of which the segments are joining to each other. The bottom chord is not complex and its manufacturing and assembly takes not much time. Due to use steel cables the total weight of the structure decreases, besides we can save materials, and as the result the total cost of construction decreases.

INTRODUCTION AND PROBLEM STATEMENT

The development of the construction industry is accompanied by the introduction of new effective structures. The structures have the necessary strength characteristics and its using allows to get technical-economic benefits [1].

Now, the grid systems are the best known among long span and spatial structures. These systems have a great ability and flexibility to the form finding that evidenced by lots of original shapes in the world [1].

In the modern construction field in most cases, there is a need to find more effective structure systems, including roof system. The main requirements that apply to the structure systems of buildings, in addition to reliability and load capacity, is an architectural expression, aesthetics, ergonomics and good indicators of energy efficiency. The important designing aspect and constructive concept finding of new designs consist in the using of reliable and advanced materials. Steel and concrete belong to the materials that satisfy modern requirements of construction field and are used very widely all over the world.

The effectiveness of the steel and concrete composite cable space frames depend on both how materials are used and behavior under a load, it means that materials should resist well under forces, for example, steel is used rationally as stretched or compressed elements, but concrete as compressed elements only.

ANALYSIS OF RECENT SOURCES OF RESEARCH AND PUBLICATIONS

The analysis has showed the most of large-span structures are made entirely of steel members, including space frames [1]. However, there are examples of steel combined systems [2]. In addition, steel-concrete composite structures are used widely for the construction different buildings [3, 4]. To these structures belong the steel and concrete composite cable space frames that are used in many sectors of the industrial and civil construction [5].

Today, the steel and concrete composite cable space frames are experimentally investigated very widely. [6-11].Behavior of steel and concrete composite cable space frames under load has been studied on both similar models and full-scale structures [12].

UNSOLVED ASPECTS OF THE PROBLEM STATEMENT

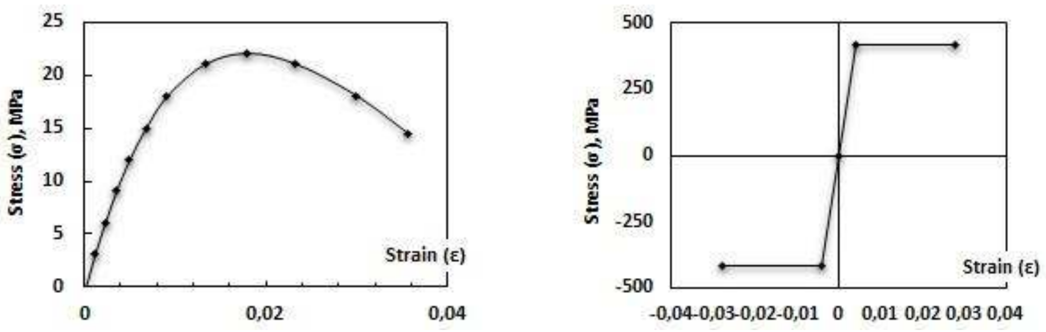
Based on the analysis of previous studies the steel and concrete composite cable space frames has not fully investigated and few studies behavior of the structures under load are being carried out. There are not studies behavior of steel and concrete composite cable space frames under uniformly distributed load.

PROBLEM FORMULATION

The aim of the study is to investigate the behavior of the steel and concrete composite cable space frames under uniformly distributed load by a numerical way.

THE MAIN MATERIAL AND RESULTS

Numerical study included modeling of the steel and concrete composite cable space frames that have similar physical and mechanical properties of materials of structures that were tested earlier by the experimental way (Fig. 1) [12].



(a) (b)

Figure 1. The stress-strain curve:
a) concrete; b) steel

Geometric scheme of the steel and concrete composite cable space frame was created as a spatial system of plates and rods (Fig. 2).

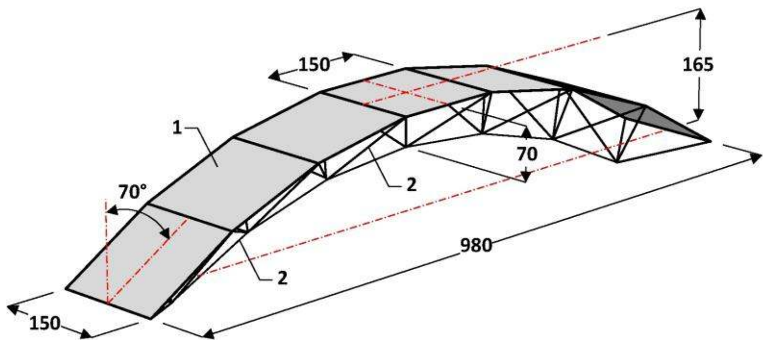


Figure 2. The geometric scheme of the curved steel and concrete composite cable space frame:
1 – plate; 2 – rod

The load was applied to the top chord by intensity q. Also on the scheme were superimposed border conditions in the extreme nodes, which had degrees of freedom equivalenced to the pinned and roller supports (Fig. 3).

Meshing models of curved steel and concrete composite cable space frame was made in compliance with recommendations that apply to finite elements, namely: the ratio of the maximum to the minimum length of the element $\frac{L_{max}}{L_{min}} = 1$; the ratio of the maximum to the minimum angle between the sides of the element $\frac{\alpha_{max}}{\alpha_{min}} = 1$; finite element form factor $\frac{L_i^2}{S} = \frac{150^2}{150^2} = 1$.

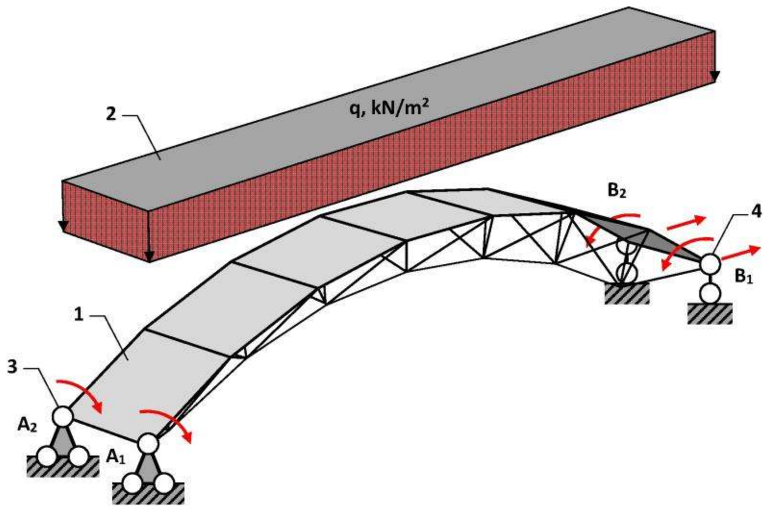


Figure 3. Loading diagram:
1 – model of the curved steel and concrete composite cable space frame;
2 – uniformly distributed load; 3 – pinned support; 4 – roller support

To the most accurate results and identify the fact of convergence of the results, model of the curved steel and concrete composite cable space frame was calculated a number of times with different meshing degrees. It four models was solved (Fig. 4).

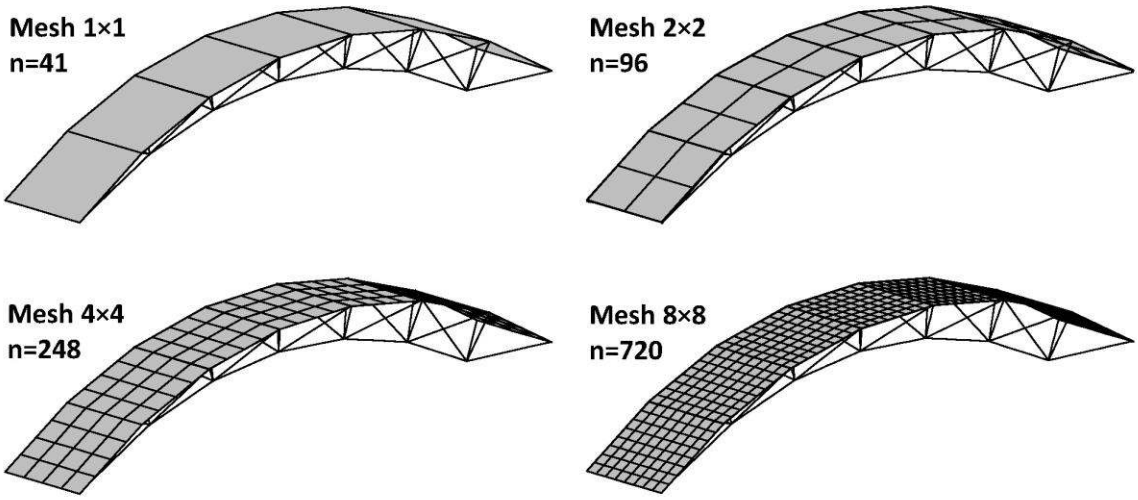


Figure 4. Meshing degrees of model of the curved steel and concrete composite cable space frame

Each model was solved by numerical method. There are results of solution in table 1 and 2.

Fig. 5 shows a deformation of model of the curved steel and concrete composite cable space frame under uniformly distributed load.

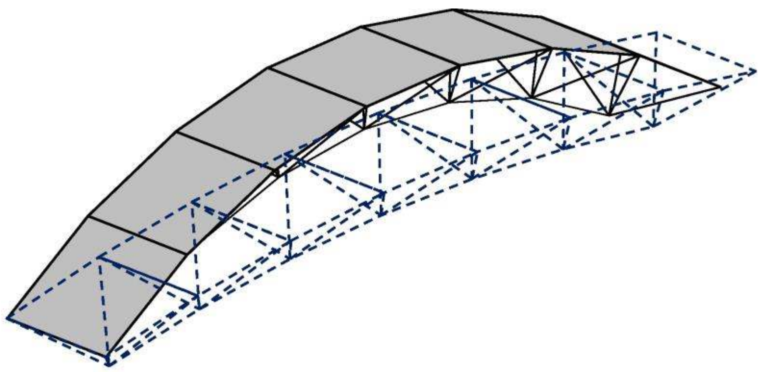
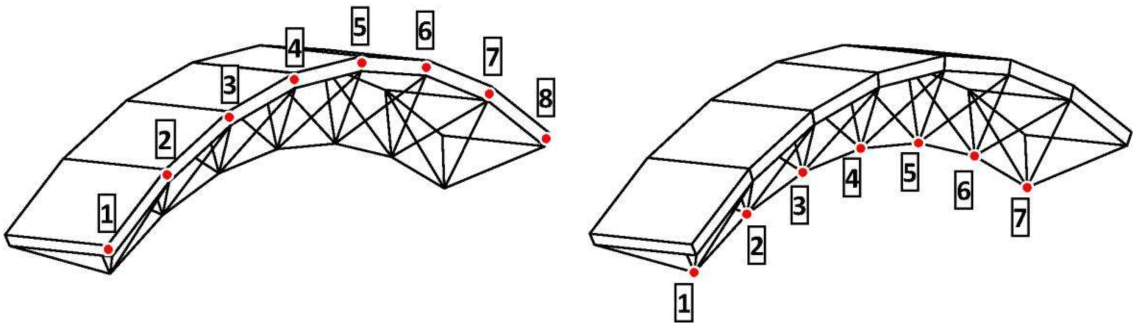


Figure 5. Deformation of model of the curved steel and concrete composite cable space frame under uniformly distributed load

As a result of the solution, deflections both the top and the bottom chord of the model of the curved steel and concrete composite cable space frame were obtained (Fig. 6).



(a) **(b)**

Figure 6. Numbering nodes of chords of the curved steel and concrete composite cable space frame:
a) top chord; b) bottom chord

Table 1. Deflections of the top chord of the curved steel and concrete composite cable space frame

Model	Nodes deflections, mm					
	2	3	4	5	6	7
Model 1 (1×1)	1,96	3,65	4,62	4,62	3,65	1,96
Model 2 (2×2)	1,97	3,66	4,63	4,63	3,66	1,97
Model 3 (4×4)	1,98	3,67	4,64	4,64	3,67	1,98
Model 4 (8×8)	1,98	3,67	4,65	4,65	3,67	1,98

Note. Deflections in nodes 1 and 8 equal 0.

Table 2. Deflections of the bottom chord of the curved steel and concrete composite cable space frame

Model	Nodes deflections, mm						
	1	2	3	4	5	6	7
Model 1 (1×1)	1,51	3,09	4,21	4,62	4,21	3,09	1,51
Model 2 (2×2)	1,52	3,10	4,23	4,63	4,23	3,10	1,52
Model 3 (4×4)	1,52	3,11	4,24	4,64	4,24	3,11	1,52
Model 4 (8×8)	1,52	3,11	4,24	4,65	4,24	3,11	1,52

Tables 1 and 2 show that increasing mesh density of the model causes that deflections of the models increasing too. The maximum difference in this case is about 1%. However, we can follow the trend to stabilization of the results.

Established fact of the convergence of the results indicates the reliability of the data, it is possible to argue about the correctness of the approach chosen solutions, the results of which are presented in the figures 7 and 8. The results of numerical studies were compared with experimental.

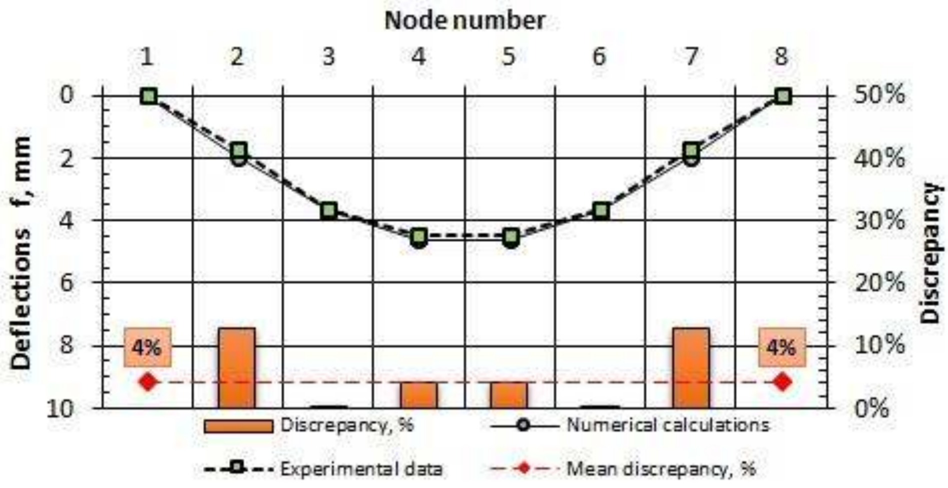


Fig. 7. Comparison nodes deflections of the top chord of the structures obtained by numerical and experimental studies

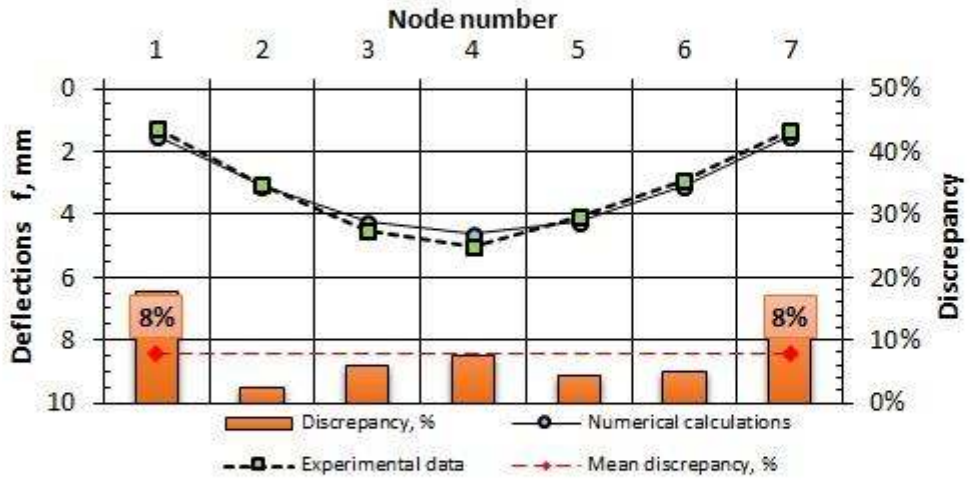


Fig. 8. Comparison nodes deflections of the bottom chord of the structures obtained by numerical and experimental studies

The analysis of the results revealed that under a uniformly distributed load of maximum horizontal displacement equal to 5.34 mm and the maximum vertical displacement units arched design equals 4.63 mm.

DISCUSSION AND CONCLUSIONS

As a result of the numerical study, deflections were made in the nodes of the curved steel and concrete composite cable space frame under uniformly distributed load, which did not exceed the ratio 1/190. Comparison of numerical data with experimental data showed an average discrepancy of 4% and 8% for the top and bottom belts, respectively.

REFERENCES

[1] Chilton J. Space grid structures. Boston: Architectural Press, 2007,180 p.

[2] Ivanyk I., Vybranets Y. and Ivanyk Y. Research of composite combined prestressed construction. Acta Scientiarum Polonorum, 2014. no. 13(2), pp. 81–88.

[3] Gasii G.M. Technological and design features of flat-rod elements with usage of composite reinforced concrete. Metallurgical and Mining Industry, 2014, no. 4, pp. 23–25.

[4] Стороженко Л.І. and Гасій Г.М. Нові композитні матеріали кріплення гірничої виробки. Науковий вісник Національного гірничого університету, 2015, no. 4, pp. 28–34.

[5] Storozhenko L.I., Gasii G.M. and Gapchenko S.A. The new composite and space grid cable-stayed construction. Academic journal. Industrial Machine Building, Civil Engineering. PoltNTU. Poltava, 2014, no. 1, pp. 91–96.

[6] Gasii G.M. Comparative characteristics of the spatial grid-cable steel-concrete composite slab. Вісник Національного університету "Львівська політехніка". Теорія і практика будівництва, 2016. no. 844, pp. 260–265.

[7] Storozhenko L.I. and Gasii G.M. Experimental research of strain-stress state of ferrocement slabs of composite reinforced concrete structure elements. Metallurgical and Mining Industry, 2014, no. 6, pp. 40–42.

[8] Gasii G.M. The flat double-layer grid-cable steel-concrete composite structure. METNET Annual Seminar in Castellon, Spain, on 11–12 October 2016, pp. 56–62.

[9] Gasii G.M. Types of Steel and Concrete Composite Cable Space Frames. Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту імені академіка В. Лазаряна, 2016, no. 6, pp. 158–165.

[10] Storozhenko L.I. and Gasii G.M. Analysis of stress-strain state of the steel-concrete composite ribbed slab as a part of the spatial grid-cable suspended structure. Academic journal. Industrial Machine Building, Civil Engineering, 2016, no. 2, pp. 81–86.

[11] Гасій Г.М. Зведення структурних сталезалізобетонних покриттів: зб. тез доповідей міжнар. наук.-техн. rонф / Г.М. Гасій // Актуальні задачі сучасних технологій. Тернопіль: ТНТУ, 2013, pp. 73–74.

[12] Стороженко Л.І., Гасій Г.М. and Гапченко С.А. Просторові сталезалізобетонні структурно-вантові покриття: Монографія, Полтава: ТОВ «АСМІ», 2015, 218 с.