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STUDY OF BEHAVIOR OF FLEXIBLE RODS AS A PART OF THE STEEL AND CONCRETE COMPOSITE CABLE SPACE FRAME

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Abstract. ***Purpose.*** Steel and concrete composite cable space frame is double-layer roof system, consisting of spatial modules, connected to each other via bolted joints. The shaping of the structure is made through the flexible elements of the bottom chord, which are manufactured as cables. Taking into account the fact that the steel and concrete composite cable space frame is a completely new type of structure with the original design, then the investigation of the stress-strain state of individual elements of the structure is a pressing issue. Therefore, the purpose of the work is to determine the specifics of the behavior and study the stress-strain state of flexible rod elements of the bottom chord that are a part of the new steel and concrete composite cable space frame assembled from the spatial modules via bolted joints. ***Methodology***. To design and produce an experimental full-size sample of the steel and concrete composite cable space frame. Experimentally determine the specifics of the behavior and the nature of deformation of the flexible elements of the bottom chord of the new steel and concrete composite cable space frame under a uniformly distributed load. Measurement of deformations was carried out by using strain gauges. The location of the strain gauges was carried out in the most characteristic sections of the investigated elements of the structure. According to the results of the experiment, the conclusion is drawn about the effectiveness of the constructive solution of the designed structure and the accepted method of ensuring the joint operation of the components of the structure. The obtained experimental data are compared with the results of theoretical investigations. . ***Findings.*** The efficiency of the constructive solution and the adopted method for ensuring the joint operation of the components of the structure was confirmed. The peculiarities of the operation of flexible elements of the bottom chord as part of the space structure are established. The dependence of deformation of the investigated elements on the level of loading was established. ***Originality.*** It is defined the stress-strain state of the flexible elements of the bottom chord of the new steel and concrete composite cable space frame. ***Practical value.*** Studying of the specifics of the operation and the stress-strain state of individual bearing elements of the structure enabled to confirm the effectiveness of the proposed constructive solution and the method of ensuring the joint operation of the modular elements. That, in turn gives impetus to the further solving the general issue and overcoming the obstacle to the introduction of new structure into the construction practice.

Keywords: structure; steel and concrete composite construction; roof; stress-strain state; module; flexible rod

ДОСЛІДЖЕННЯ РОБОТИ ГНУЧКИХ ЕЛЕМЕНТІВ У СКЛАДІ ПРОСТОРОВОЇ СТРУКТУРНО-ВАНТОВОЇ СТАЛЕЗАЛІЗОБЕТОННОЇ КОНСТРУКЦІЇ

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Анотація. ***Ціль.*** Просторова структурно-вантова сталезалізобетонна конструкція є двопоясною системою покриття, що складається з просторових модулів, які поєднуються між собою за допомогою розроблених болтових з’єднань. Формоутворення конструкції здійснюється за рахунок використання гнучких елементів нижнього пояса, які виготовляються як ванти. Беручи до уваги, що структурно-вантова сталезалізобетонна конструкція є абсолютно новою з оригінальним рішенням системою покриття, то дослідження напружено-деформованого стану її окремих елементів є актуальною проблемою. Отже, ціль роботи полягає у визначені особливостей роботи та дослідженні напружено-деформованого стану гнучких стрижневих елементів нижнього пояса, які є складовою частиною нової структурно-вантової сталезалізобетонної конструкції покриття, зібраної з просторових модулів за допомогою болтових з’єднань. ***Методика.*** Розробити та виготовити експериментальний повнорозмірний зразок структурно-вантової сталезалізобетонної конструкції покриття. Експериментальним шляхом визначити особливості роботи та характер деформування гнучких елементів нижнього пояса нової просторової структурно-вантової сталезалізобетонної конструкції покриття при дії рівномірно розподіленого навантаження. Вимірювання деформацій здійснювалося за допомогою тензорезисторів. Розміщення датчиків здійснювалося у найбільш характерних перерізах досліджуваних елементів конструкції. За результатами експерименту зроблено висновок про ефективність конструктивної схеми розробленої конструкції та прийнятого способу забезпечення сумісної роботи складових елементів. Виконано порівняння отриманих експериментальних даних з результатами теоретичних досліджень. ***Результати.*** Підтверджено ефективність конструктивного рішення та прийнятого способу забезпечення сумісної роботи складових елементів. Встановлено особливості роботи гнучких елементів нижнього пояса в складі просторової конструкції. Встановлено залежність деформування досліджуваних елементів від рівня завантаження. ***Наукова новизна.*** Визначено напружено-деформований стан гнучких елементів нижнього пояса нової конструкції – сталезалізобетонного структурно-вантового покриття. ***Практична значимість.*** Вивчення особливостей роботи та напружено-деформованого стану окремих несучих елементів досліджуваних конструкцій дало змогу підтвердити ефективність запропонованого конструктивного рішення та способу забезпечення сумісної роботи модульних елементів, що у свою чергу дає поштовх до подальшого вирішення загальної проблеми та подолання перешкоди на шляху впровадження нових конструкцій у практику будівництва.

Ключові слова: структура; сталезалізобетон; покриття; напружено-деформований стан; модуль; гнучкий стрижень

ИССЛЕДОВАНИЕ РАБОТЫ ГИБКИХ ЭЛЕМЕНТОВ В СОСТАВЕ ПРОСТРАНСТВЕННОЙ СТРУКТУРНО-ВАНТОВОЙ СТАЛЕЖЕЛЕЗОБЕТОННОЙ КОНСТРУКЦИИ

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Аннотация. ***Цель.*** Пространственная структурно-вантовая сталежелезобетонная конструкция является двухпоясной системой покрытия, состоящего из пространственных модулей, которые соединяются друг с другом с помощью разработанных болтовых соединений. Формообразования конструкции осуществляется за счет использования гибких элементов нижнего пояса, которые изготавливаются как ванты. Принимая во внимание то, что структурно-вантовая сталежелезобетонная конструкция это абсолютно новый тип конструкции с оригинальным решением, то исследования напряженно-деформированного состояния ее отдельных элементов является актуальной проблемой. Итак, цель работы заключается в определении особенностей работы и исследовании напряженно-деформированного состояния гибких стержневых элементов нижнего пояса, которые являются составной частью новой структурно-вантовой сталежелезобетонной конструкции покрытия, собранной из пространственных модулей с помощью болтовых соединений. ***Методика.*** Разработать и изготовить экспериментальный полноразмерный образец структурно-вантовой сталежелезобетонной конструкции покрытия. Экспериментальным путем определить особенности работы и характер деформирования гибких элементов нижнего пояса новой пространственной структурно-вантовой сталежелезобетонной конструкции покрытия при действии равномерно распределенной нагрузки. Измерение деформаций осуществлялось с помощью тензорезисторов. Размещение датчиков осуществлялось в наиболее характерных сечениях исследуемых элементов конструкции. По результатам эксперимента сделан вывод об эффективности конструктивной схемы разработанной конструкции и принятого способа обеспечения совместной работы составляющих элементов. Выполнено сравнение полученных экспериментальных данных с результатами теоретических исследований. ***Результаты.*** Подтверждена эффективность конструктивного решения и принятого способа обеспечения совместной работы составляющих элементов. Установлены особенности работы гибких элементов нижнего пояса в составе пространственной конструкции. Установлена зависимость деформирования исследуемых элементов от уровня загрузки. ***Научная новизна.*** Определено напряженно-деформированное состояние гибких элементов нижнего пояса новой конструкции – сталежелезобетонного структурно-вантового покрытия. ***Практическая значимость.*** Изучение особенностей работы и напряженно-деформированного состояния отдельных несущих элементов исследуемых конструкций позволило подтвердить эффективность предложенного конструктивного решения и способа обеспечения совместной работы модульных элементов, что в свою очередь дает толчок к дальнейшему решению общей проблемы и преодоления препятствия на пути внедрения новых конструкций в практику строительства.

Ключевые слова: структура; сталежелезобетон; покрытие; напряженно-деформированное состояние; модуль; гибкий стержень

Problem definition. The steel and concrete composite cable space frame is the new type of building structure with the original constructive solution. The steel and concrete composite cable space frame includes spatial modules and bottom chord made from flexible rods. This constructive solution helping to reduce material consumption due to the management of them.

Reducing of material consumption achieved due to usage concrete for compressed components of the structure and usage flexible steel elements for stretched components of the structure. It allows obtaining economic and technical advantages. The proposed structure can be widely used in the construction of both large-scale and small-scale buildings and constructions as roof systems. However, despite of the economic and technical advantages of the steel and concrete composite cable space frame, there is the issue that consists in not enough studying of stress-strain state of components of the structure.

Analysis of recent research and publications has shown that among of existing building structures there is not similar to the ones developed. The most closely on the steel and concrete composite cable space frame are combined structures consisting of reinforced concrete slab and steel grid [3, 4, 6, 9] or steel profiles [5, 7, 10]. Such structures have rigid chord and different connections of components [8]. In addition, there are some both experimental and theoretical studies of steel and concrete composite cable space frame among of recent investigations. Most of them have been allocated to investigating deformation of scale models of steel and concrete composite cable space frame or studying the stress-strain state of components of the steel and concrete composite cable space frame.

All these studies show that steel and concrete composite cable space frame can be used effectively for the construction of buildings for different purposes as a roof system. Currently, there is the justification of the efficiency of steel and concrete composite cable space frame. Also, it was improved of constructive solution, it was developed both a method of ensuring the joint operation of components and the nodal connections.

Highlighting outstanding issues. Based on the results of previous studies and given that the steel and concrete composite cable space frame is the new type of a building structure, some part of the general issue has never been investigated. However, the behavior of the flexible components jointly with other ones in the structure subjected to loading has never been investigated

Problem statement. The behavior of the flexible components jointly with other ones in the structure need to be established.

The main material. The steel and concrete composite cable space frame is the new type of space building structure consisting of spatial modules and flexible bottom chord, which can be made of cable or rods. The design of the steel and concrete composite cable space frame is described in [2] and the technical and economic benefits are described in [1].

The flexible bottom chord from is a part of the structure. The bottom flexible chord consists of a flexible bar and two steel plates that have holes. Through the holes, the bottom flexible chord is connected to the other elements with bolts. Before studying experimentally of the behavior of the flexible bottom chord under load, a computer designing of some parts of the bottom flexible chord was conducted. Then design and produce the experimental full-size sample of steel and concrete composite cable space frame was made (Fig. 1).

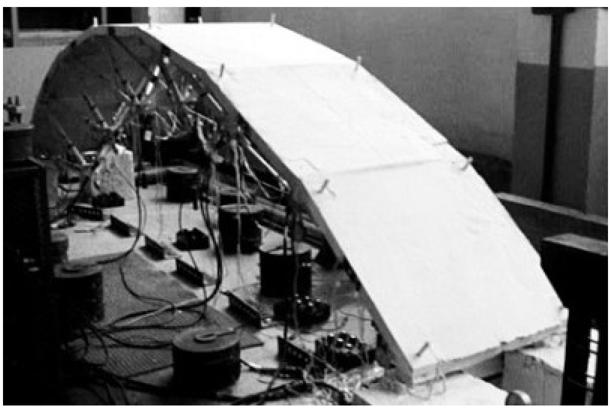

Fig. 1 – The experimental full-size sample of the steel and concrete composite cable space frame (l=5.6 m)

To studying experimentally of the behavior of the flexible bottom chord under load, the strain was measured in the specifics cross-sections (Fig. 2).

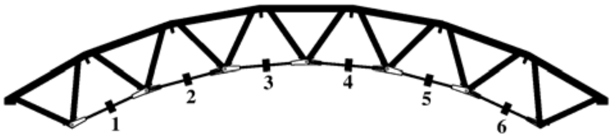

Fig. 2 – The placement of cross sections where deformations were measured

In each cross-section two strain gauges were glued with glue BF2 (Fig. 3).

Fig. 3 – The placement of strain gauges on surface of flexible bottom chord of the steel and concrete composite cable space frame

The experimental sample of the steel and concrete composite cable space frame subjected to operational loading was tested (Fig. 4).

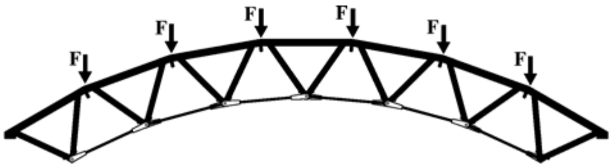

Fig. 4 – Model of the experimental full-size sample of the steel and concrete composite cable space frame subjected to the loading

As a result of the performed experiment data were obtained, the analysis of which allowed to investigate the behavior of the sample of the steel and concrete composite cable space frame under the load. Simultaneously with testing, a visual inspection of the experimental sample of the steel and concrete composite cable space frame was carried out on the detection of cracks, deformations, destruction of the nodal joints or structural elements.

It should be noted that, in accordance with the task, the sample of the steel and concrete composite cable space frame was investigated under the operational load, which was 70% of the destructive, that is, the sample was not destroyed.

After testing of the experimental sample of the steel and concrete composite cable space frame, the strains were obtained and plotted curve load-strain for each cross-section (Fig. 5 – Fig. 10). All curves are linear because the elements were in an elastic stage. Curve load-strain in the longitudinal direction was plotted too (Fig. 11).

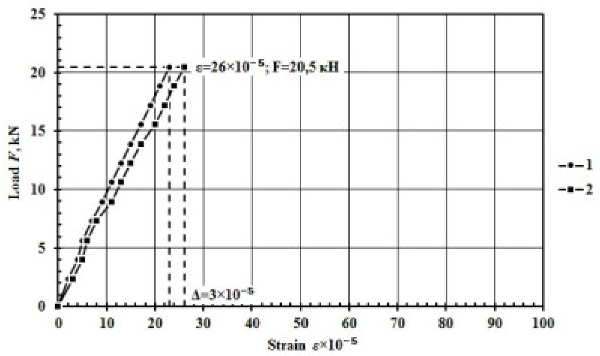

Fig. 5 –The load-strain curve for cross-section 1

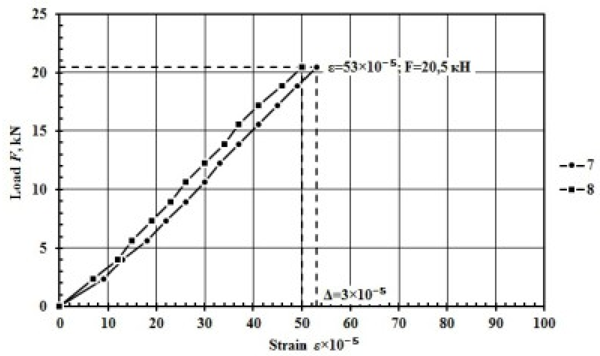

Fig. 8 –The load-strain curve for cross-section 4

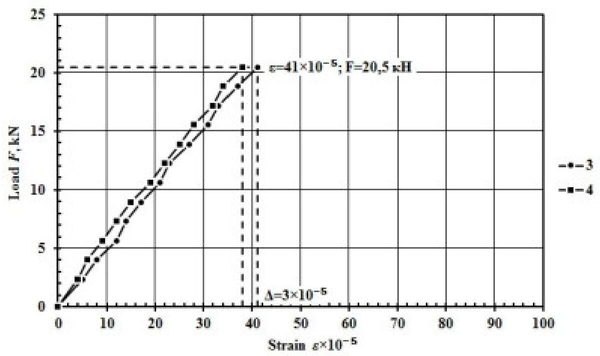

Fig. 6 –The load-strain curve for cross-section 2

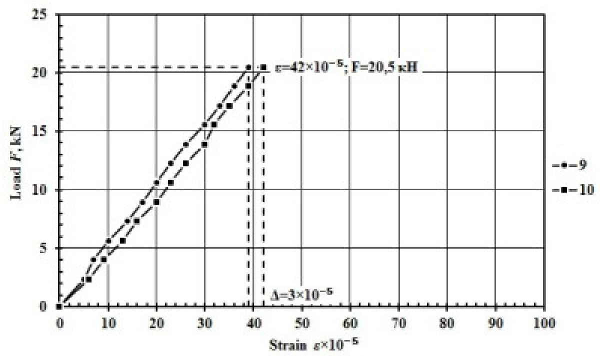

Fig. 9 –The load-strain curve for cross-section 5

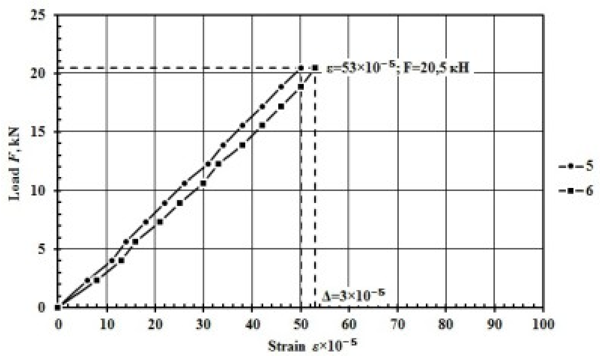

Fig. 7 –The load-strain curve for cross-section 3

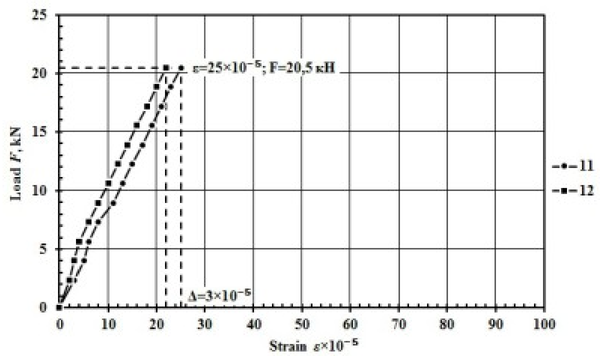

Fig. 10 –The load-strain curve for cross-section 6

Having analyzed the curves it is evident that the newly designed connections of the flexible elements of the bottom chord provide their joint operation. Deformations along the lower belt grew smoothly from ends to the middle. As expected, the maximum deformations arose in the middle of the structure in the cross-sections 3 and 4, which on average 54% exceeded the deformations in the cross-sections 1 and 6 and 25% exceeded the deformations in the cross-sections 2 and 5. Averaged deformations of the outer fibers in mirrored cross-sections had approximately the same values. The maximum difference between the averaged values of deformations in such sections was 4%, and the average difference was 2%. A small difference between strains in the studied cross-sections suggest that the development of strain was uniform across construction. Based on the deformations obtained, stresses were calculated in the cross sections of the lower belt (Fig. 11).

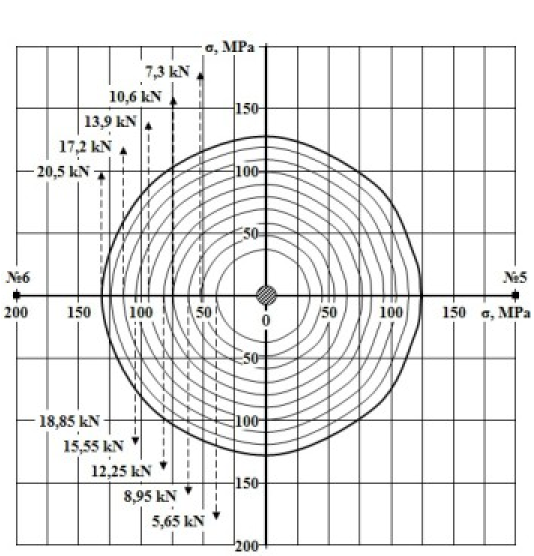

Fig. 11 – Stresses in the cross-sections 3

Figures demonstrate the strains on each side are increasing in different ways. It was due to not axial force that was applied in end of flexible elements of bottom chord (Fig. 12). This was confirmed by a numerical solution.

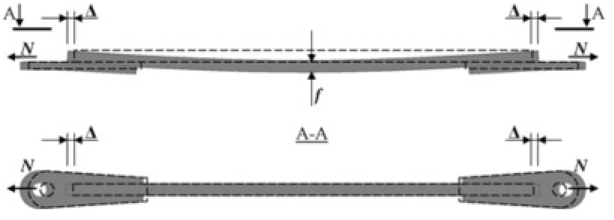

Fig. 12 – Deformation of the lower belt

For numerical solution was applied two cross-sections (Fig. 13).

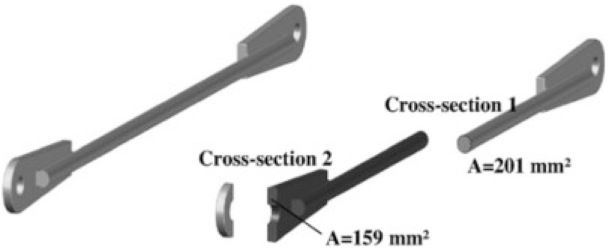

Fig. 13 – Cross-section for numerical solution

The solution result shows the failure of the flexible elements of bottom chord was occurred at cross-section 2 due to an appearance of the plastic strain (Fig. 14).

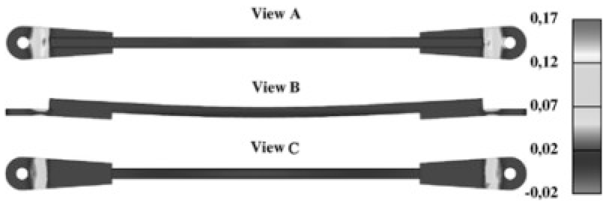

Fig. 14 – The plastic strain

Theoretically, the steel and concrete composite cable space frame was calculated by reducing the three-dimensional model (Fig. 15) in a two-dimensional (Fig. 16).

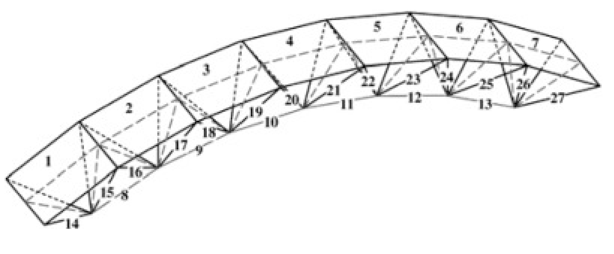

Fig. 15 – The three-dimensional model

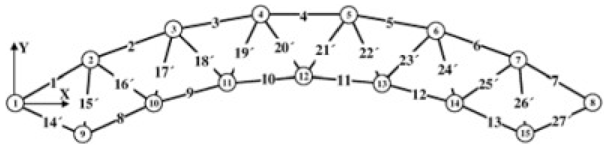

Fig. 16 – The two-dimensional model

Result calculated two-dimensional model was transitioned to the three-dimensional (Fig. 17).

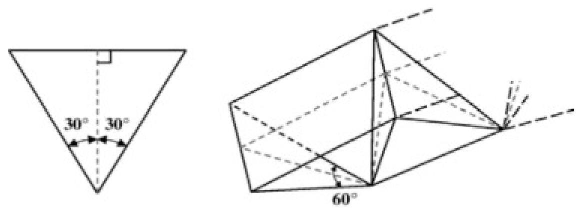

Fig. 17 – Way of the results transition

Fig. 18 shows a comparison of the axial forces in the elements of the bottom chord that were determined experimentally and theoretically.

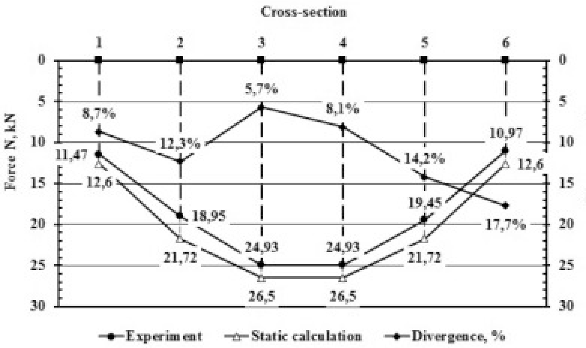

Fig. 18 – Comparison of results of the experimental and theoretical data

Comparison of results shows good convergence. The average divergence between experimental and theoretical data is 11%.

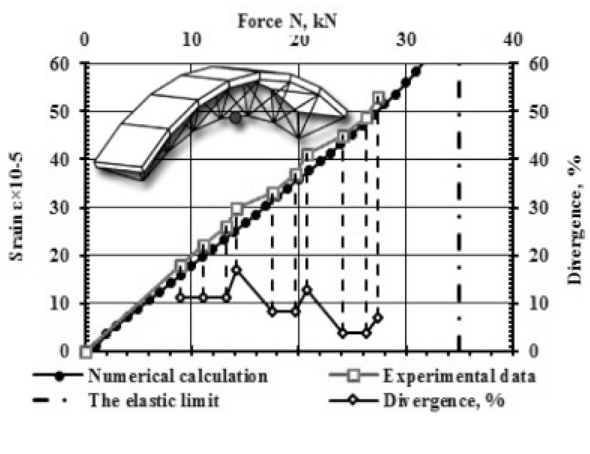

Fig. 19 – Comparison of results of the experimental and numerical data for cross-section 3

Experimental data were comparable to numerical calculations (Fig. 19). Comparison of results shows good convergence too.

Conclusions. The results of the study the behavior of the flexible components jointly with other ones in the structure was established. In general, the bottom chord of the experimental sample of the steel and concrete composite cable space frame was in an elastic stage, as evidenced by the nature and intensity of the deformation development, depending on the increase in loading. The deformations of the flexible elements of the bottom chord of the experimental sample of the steel and concrete composite cable space frame during its testing were linear and roughly the same deformation steps in all sections.

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