



# Spatial Calculation of Metal Truss Structure in Joint Work with Reinforced Concrete Slab

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**Abstract.** Improving the new design solutions and the actual load-bearing capacity de-termination for steel and concrete composite structures is not possible without further experimental research. To confirm the theoretical results, there were fulfilled the experimental studies of three steel truss structures combined with different types of monolithic slabs, with a span of 6.0 m. The crack resistance of the monolithic slabs was also investigated. During the experimental tests, longitudinal deformations were measured on the steel truss structures and on the reinforced concrete slab and vertical displacements were also measured. Tests of cube specimens were performed to obtain the actual strength and deformability characteristics of using concrete. A comparison of the values of experimental and calculated limit stresses performed according to DBN 2.6-98: 2009, DBN 2.6-160: 2010, and DBN 2.6-163: 2010, showed good convergence of results for full-scale structures. The deviation of the experimental values from the theoretical ones was  $-12.2\% \dots -1.1\%$ .

**Keywords:** Metal truss structure · Composite steel-concrete structure · Spatial work · Steel deck · Stress-strain · Experimental research

## 1 Introduction

In today's world, lightweight structures are widely used to cover various spans and there is no need to make a significant number of standard structures.

The development of new design solutions requires improving their structure, increasing the use of efficient types of rolled metal, reducing metal consumption and complexity of manufacture and installation. Analysis of the new structural forms development [1–4], conditions of manufacture and installation of bearing structures, shows that one of the promising areas of further development is the use of composite metal systems with reinforced concrete slabs. Along with the use of reinforced concrete structures, new structural forms are created, new structures with low material consumption are introduced. These are steel-concrete structures, they combine the best properties of steel and reinforced concrete structures. This type of construction due to the savings of embedded parts have a much smaller mass and differ from steel with lower metal consumption. According to [5], composite steel-concrete structures - are structures using rolled steel that are combined with concrete, which can be reinforced with rod reinforcement [6].

Metal profiled deck, which are initially used as non-removable formwork, can be used as external stretched reinforcement. This is a wide range of building structures that differ in design features and the level of use of joint work of steel and concrete [7].

Metal structures composite with concrete slabs are successfully used in the reconstruction and reinforcement [8] of residential, public, industrial, warehouse and other types of buildings. They are used as the load-bearing elements of floors and roofs, as well as girder structures.

Studies of metal structures composite with reinforced concrete slabs [9–16] provide an opportunity to find new progressive structural forms and solutions depending on the length of the span, the load, technological features for both individual elements and for spatial systems. One of the areas of improvement of composite steel-concrete structures is the development of effective parts for the combination of concrete and steel [17, 18], which have sufficient load-bearing capacity, strength, the necessary rigidity.

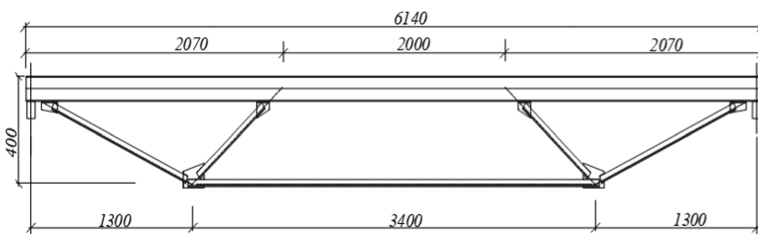
The advantages of using such structures are reduction of labor costs, increase of spans, reduction of total mass, increase of stiffness, reduction of metal consumption, increase of labor safety and fire safety at the stage of installation.

## 2 Methodology of Experiments

During the experimental research, three full-scale experimental samples were prepared. The calculation of members and cross-sections of both the metal sub diagonal structures and the reinforced concrete slab was performed according to the method [19, 20].

Each sample consisted of two identical metal truss structures, which were composite with a monolithic reinforced concrete slab on the level of the upper chord.

The length of the metal structure was 6.14 m (span 6.0 m) and height 0.475 m (in the axes 0.39 m). (Fig. 1). The upper chord of metal construction is made of rolled steel I-beam profile № 12 according to DSTU 8768:2018.



**Fig. 1.** Drawings of metal truss structures

The diagonal structure elements (compressed and tensioned members and tie) are made of paired steel angles  $45 \times 45 \times 4$  mm and  $50 \times 50 \times 5$  according to DSTU 2251-93, steel class - S245. The upper chord that serves as a stiffness beam is combined with suspension elements by means of gusset of 5 mm thick. The connection is made by electric welding using electrodes according to DSTU EN ISO 17632:2019.

The structures were mounted on supports at a distance between the axes of the beams of 2.0 m.

Monolithic reinforced concrete slab was made on top of metal beams. Its dimensions are 6140 × 3000 mm. Concrete class - C20/25. Reinforcement step - 200 mm, working reinforcement  $\varnothing 8$  and 12 A500S, structural -  $\varnothing 8$  A240S according to DSTU 3760-2019. Reinforcement was performed in the lower zone - continuous and in the upper zone - above the supports (Fig. 2).

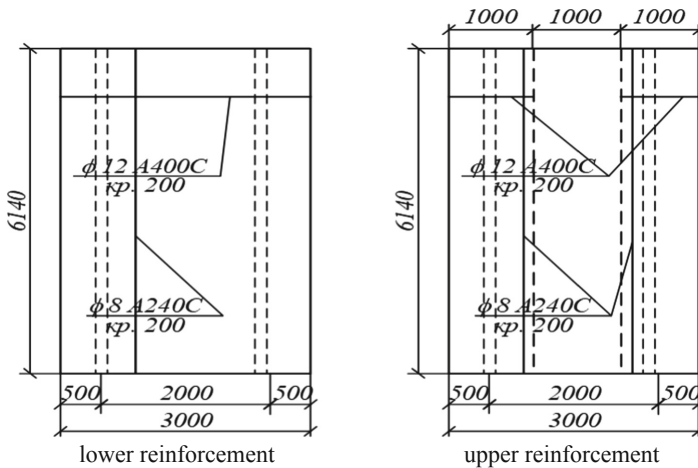


Fig. 2. Scheme of slab reinforcement

Experimental samples differed in the shape of the slab:

KSB-1: the slab was made using the usual formwork (Fig. 3, a);

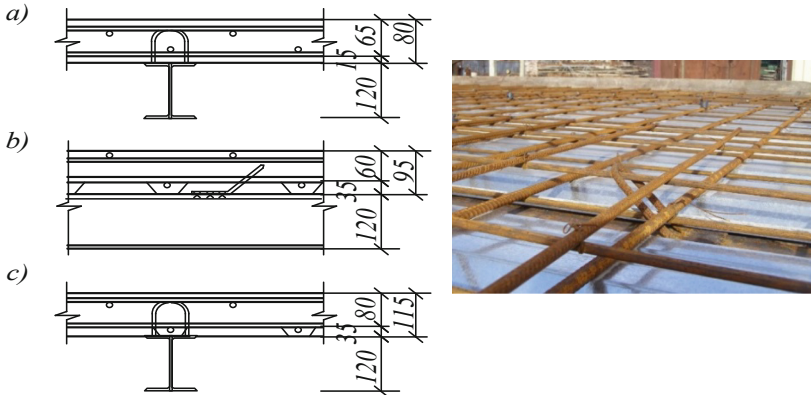
KSB-2: as a formwork was used the steel deck TP-35, 0.5 mm thick according to TU U B.2.6-28.7-30703438-001: 2010, arranged with ribs across the metal structures (Fig. 3, b);

KSB-3: as a formwork was used steel deck TP-35, 0.5 mm thick according to TU U B.2.6-28.7-30703438-001: 2010, arranged with ribs along the metal structures (Fig. 3, c).

The joint work of truss structures with the slab was ensured by means of an inclined anchor (Fig. 3), made of steel bar  $\varnothing 8$  A500S. The pitch of the anchors is 500 mm, according to the calculation of shear forces. The connection is made by electric arc welding using electrodes according to DSTU EN ISO 17632:2019.

The concrete mix was ordered from Shchyretsky Plant of Reinforced Concrete Products LLC and transported to the site by a concrete mixer truck.

The composition of concrete is taken cement:sand:crushed stone = 1:1,28:2,55, with a water-cement ratio  $W/C = 0,45$ . Concrete for monolithic slabs was made on the basis of Portland cement of the M500 brand of the Nikolaev cement plant. The sand of the Yasnys'koho quarry with a fraction of 1.32–1.36 mm and a modulus of size  $M_{cr} = 1.4$  was used as a fine aggregate.



**Fig. 3.** Three types of samples slabs: a) on the usual panel formwork; b) on the steel deck across metal structures; c) on the steel deck with ribs along the metal structures

Granite crushed stone of fraction 5–20 mm from the Klesivske II deposit was used as a large aggregate.

Ordinary, tap water is used for concreting.

The concrete mix in the structure was laid with vibration.

In parallel with the concreting of full-scale samples control cubes were made from the same concrete mixture. In total, to determine the strength characteristics of concrete were made 2 samples -cubes with a size of  $100 \times 100 \times 100$  mm (Fig. 4).



**Fig. 4.** Experimental concrete samples-cubes

Concrete samples-cubes specimens were made in the same conditions as the experimental structures - at an ambient temperature of  $+12$  to  $+18$  °C. Pouring of concrete mix was carried out in inventory metal forms.

Testing of samples was performed to determine the actual characteristics of concrete, which were then used for calculation.

The experimental structure (Fig. 5) was installed on the ring supports located on the foundation blocks FBS-24.4.6. To ensure the spatial work and the overall stability of the structure, the lower nodes of the sub diagonal elements are fastened with metal ties of a square pipe  $40 \times 40 \times 3$  mm according to DSTU B V.2.6-8-95.

The load on the structure was carried out both symmetrically and asymmetrically, according to the research tasks. The calculation assumes a uniformly distributed load, which was applied to the top of the reinforced concrete slab. Loading of experimental structures was carried out with pre-weighed sandbags.



**Fig. 5.** General view of the experimental full-scale construction.

Experimental studies were conducted to determine:

- stresses in cross sections;
- stiffness characteristics;
- determination of crack resistance of the experimental structure.

During the experimental tests, longitudinal deformations were measured on a metal sprung structure and a reinforced concrete slab and vertical displacements.

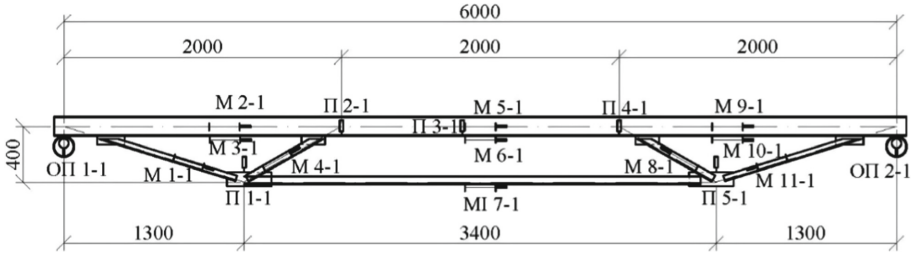
The tests were performed after gaining concrete design strength.

Longitudinal deformations of the metal sub diagonal structure were determined using clock-type microindicators with a division price of 0.001 mm. They were arranged on pre-glued metal holders with a base of 200 mm.

Longitudinal deformations of a monolithic reinforced concrete slab were measured by strain gages with a base of 20 mm, with an electrical resistance of 99.5... 100.5  $\Omega$ , which were served by an automatic strain gauge AVD-4M. Microindicators similar to those used for the metal structure were installed in several places.

Deflections of the structure were measured with PAO-6 deflection gauge with a division price of 0.01 mm, and clock-type indicators with the same division price. With the help of clamps, the deflection gauge were fixed directly to the metal sub diagonal structures. Clock-type indicators were mounted on a separate rigid frame that was not connected to the test structure.

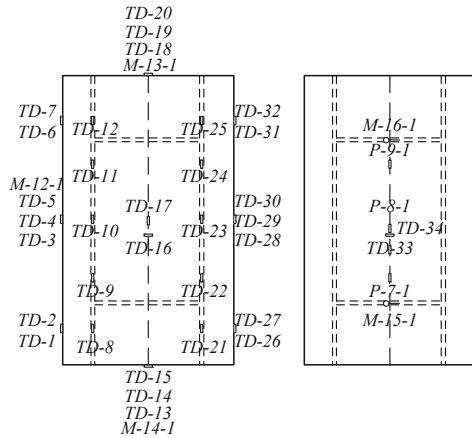
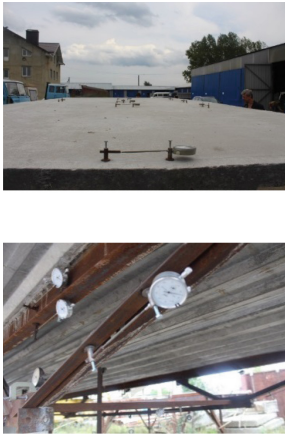
Deflections of the structure were monitored at the joins of the sub diagonal structure and in the middle of the span. Also deflections in the middle part of the slab between the metal structures were recorded (Fig. 6 and Fig. 7).



**Fig. 6.** Scheme of indicators position on a metal truss structures: M - strain indicators, P - deflection

Crack formation and crack development were observed during the tests. Using the MPV-3 microscope, the formation of cracks was visually determined and the width of the opening was measured. After each stage of loading, measurements were performed on the devices and the development of cracks was recorded and recorded in the test log.

Scheme of the location of the gauges are shown in Fig. 7, the stages of loading the experimental structure - Fig. 8.



**Fig. 7.** Installation of deflection and strain gauges in the lower and upper zones of the slab layout of measuring instruments: M - microindicators, P - deflection, TD - strain gauges

1	2	3	4
3 kN/m <sup>2</sup>	3 kN/m <sup>2</sup> 6 kN/m <sup>2</sup>	6 kN/m <sup>2</sup>	9 kN/m <sup>2</sup>
5	6	7	8
12 kN/m <sup>2</sup>	15 kN/m <sup>2</sup>	18 kN/m <sup>2</sup>	21 kN/m <sup>2</sup>



**Fig. 8.** Stages of loading of research structure

The uniformity of load distribution on the structure was monitored using four annular dynamometers located on the supports of the structure.

### 3 Results and Discussion

The experimental structures were designed in such a way that they were destroyed in normal sections by the combined action of bending moment and longitudinal force. Their loading was carried out until the width of the crack opening was more than the allowable ( $a_{cr} > 0.4$  mm).

The destruction of structures and the cracks development is shown in Fig. 9.

KSB-1. At a load of 12 kN/m<sup>2</sup>, the first normal cracks appeared on the side face of the slab between the beams. As the load increased, their number and width of disclosure increased. At stage №8 (load 21 kN/m<sup>2</sup>) the crack opening width was 0.41 mm, which exceeds the allowable ones.



**Fig. 9.** Cracks in a slab (KSB-3)

At full experimental load of the structure, its total deflection was 16.9 mm, deflection at the lower nodes - 9.7 mm.

KSB-2. The first normal cracks on the side face of the slab between the beams appeared at the loading stage №5 (load 12 kN/m<sup>2</sup>). At the last stage (load 21 kN/m<sup>2</sup>) the width of crack opening was 0.25 mm.

At full experimental load of the full-scale structure, its total deflection was 15.8 mm, deflection at the lower nodes - 9.0 mm.

KSB-3. The first normal cracks on the side face of the slab between the beams appeared at the loading stage №4 (load 9 kN/m<sup>2</sup>). They reached the critical opening width (acrc. = 0.51 mm at stage №8 (load 21 kN/m<sup>2</sup>).

At full experimental load of the full-scale structure, its total deflection was 15.6 mm, deflection at the lower nodes - 8.3 mm.

The dependence of stresses on the loading stages for the three types of prototypes is shown in the graphs Fig. 10.

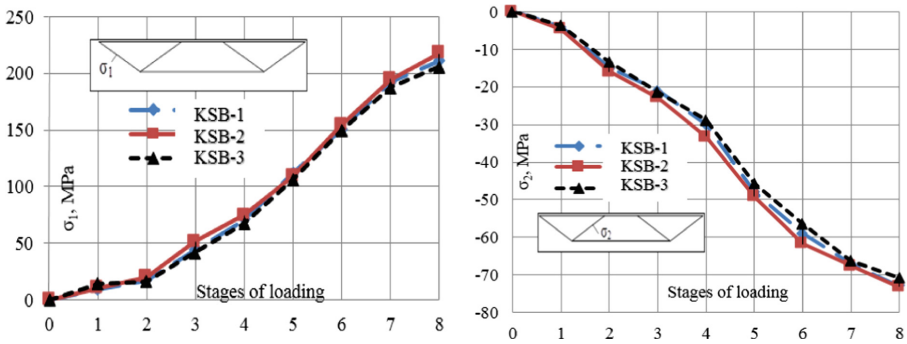


Fig. 10. Graphs of stress dependence on loading stages in the lattice of metal truss structures

## 4 Conclusions

In experimental samples, after reaching of yield strength of reinforcement, the further loading of structures was accompanied by a significant increase in deformations of reinforcement and concrete, increment of deflections and cracks opening in the middle part of the slab (between metal structures). In one case there was a loss of stability of the wall of the upper chord of the metal stiffness beam (KSB-1).

Comparison of the values of experimental and calculated limit stresses performed according to DBN 2.6-98: 2009, DBN 2.6-160: 2010 and DBN 2.6-163: 2010, showed good convergence of results for full-scale structures. The deviation of the experimental values from the theoretical ones was -12.2... -1.1%.

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