COMPARISON OF CONTINUOUS COMPOSITE BEAMS BEHAVIOUR

AUTHORS

Denis Popovski
Assistant Prof.
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
popovski@gf.ukim.edu.mk

Petar Cvetanovski
Prof.
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
cvetanovski@gf.ukim.edu.mk

Mile Partikov
Assistant
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
partikov@gf.ukim.edu.mk

Composite steel and concrete structures are best solution for decks on steel structures. The composite steel and concrete continuous beams have nonlinear behaviour even on the lower values of the ultimate plastic moment resistance. For the needs of larger volume of relevant data, experimental trials are conducted for testing the different behaviour of the composite continuous beams. Therefore, the experimental testing was conducted on two identical composite continuous beams, with various principles of improvements of the bearing capacity, especially at the middle support. For obtaining greater value of the bearing capacity of the beams, the first model is reinforced with two layers of mesh reinforcement at the middle support, where the second model, with the same reinforcement, is additionally pre-stressed by controlled imposed deformations. In this paper the results of the behaviour of the mentioned beams are presented, compared with each other.

Keywords: composite structures, composite slabs, steel structures

1. CHARACTERISTICS OF THE MATERIALS

Materials used for composing the continuous composite beams are in accordance with the Euronorms. The characteristics of all materials were previously tested, where the yield strength, the tensile strength and the maximum elongation of a representative sample of the steel elements are determined. For the main beam is used S275JR, with tested yield strength f_y=275N/mm^2, and tested tensile strength f_u=424N/mm^2, with $k=f_u/f_y$=1.54 and ε_u=18.9%, according to EN1993. The material used for the shear connectors is S235J2+C450, with f_y=502N/mm^2, and f_u=552N/mm^2, where $k=f_u/f_y$=1.10 and δ_5=18.5%, according to EN13918. The material used for the steel sheeting deck is S550GD Z275, with f_y=675N/mm^2, and f_u=770N/mm^2, where $k=f_u/f_y$=1.14 and δ=24.6%, according to EN10147. The material for the reinforcement is class B, according to

EN1992, with f_{yk}=597N/mm^2, and f_{uk}=662N/mm^2, where $k=f_{uk}/f_{yk}$=1.11 and ε_{uk}=9.9%.

The material for the concrete is predicted for the strength class of C25/30 according to EN1993. Testing the characteristics of the casting for the first model “ГН1”, the compression strength of cube is $f_{ck,cube}$=36.64MPa, the compression strength of cylinder is f_{ck}=29.51MPa, the tensile strength is f_{cm}=2.95MPa, and the modulus of elasticity is E_{cm}=31.97GPa. The shrinkage at the time of the loading of the first model, at the 29th day of casting, is measured 0.255%, where the calculated value of the shrinkage in accordance with EN1992 is 0.230%. Testing the characteristics of the casting for the second model “ГН2”, the values are $f_{ck,cube}$=32.03MPa,f_{ck}=31.65MPa, f_{cm}=2.97MPa, and E_{cm}=31.65GPa. The shrinkage at the time of the loading the second model, at the 32nd day of casting, is measured 0.241%, where the calculated value of the shrinkage in accordance with EN1992 is 0.273%.

The results from the testing the characteristics of the materials meet the requirements given in EN1992 for the concrete, and EN1993 for the steel.

2. TESTING THE CAPACITY OF THE SHEAR CONNECTORS

The behaviour of the shear connectors was also tested, and is part of this complex experimental and theoretical research of the continuous composite (steel and concrete) beams. The testing is conducted in accordance with EN1994, on three separate modified models.

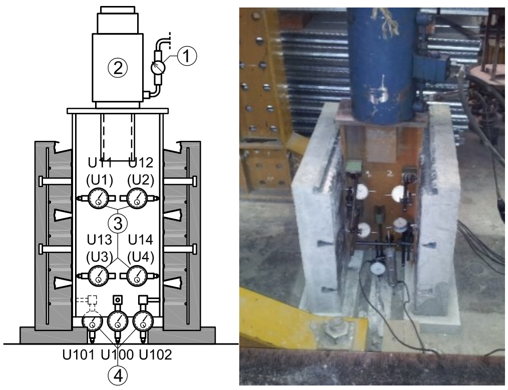

Figure 1. Testing model with applied measuring instruments

Where: 1) dynamometer for load measuring; 2) 100 ton press for load application; 3) dial (U11 to U14) and electronic (U1 to U4) comparators for transverse separation between the steel beam and the concrete slab; 4) electronic comparators (U100 to U102) for longitudinal slip.

The electronic equipment is connected to HBM Quantum data acquisition system amplifier, directly connected to personal computer. The measuring is carried out through the testing in real time.

For this testing it’s used the same cross section of the steel beam, the same materials, the same strength class of concrete and reinforcement as the main testing models. The materials meet the requirements according to EN1994.

The objective of this testing is obtaining information for the achievement of full plastic capacity of the designed cross section, and obtaining the “P-δ” diagrams for the theoretical research, which is scope for another paper.

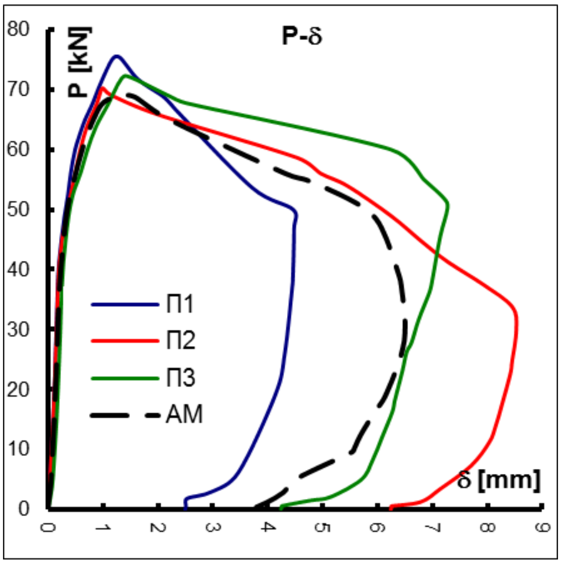

Figure 2. “P-δ” diagrams of the tested models

From the testing, among other things, it is concluded that the shear connectors have the required capacity for development of full plastic moment resistance of the designed cross section.

3. TESTING MODELS, MEASURING AND LOAD APPLICATION EQUIPMENT

For the purpose of the testing, two identical models were created, first model “ГН1” as composite (steel and concrete) continuous

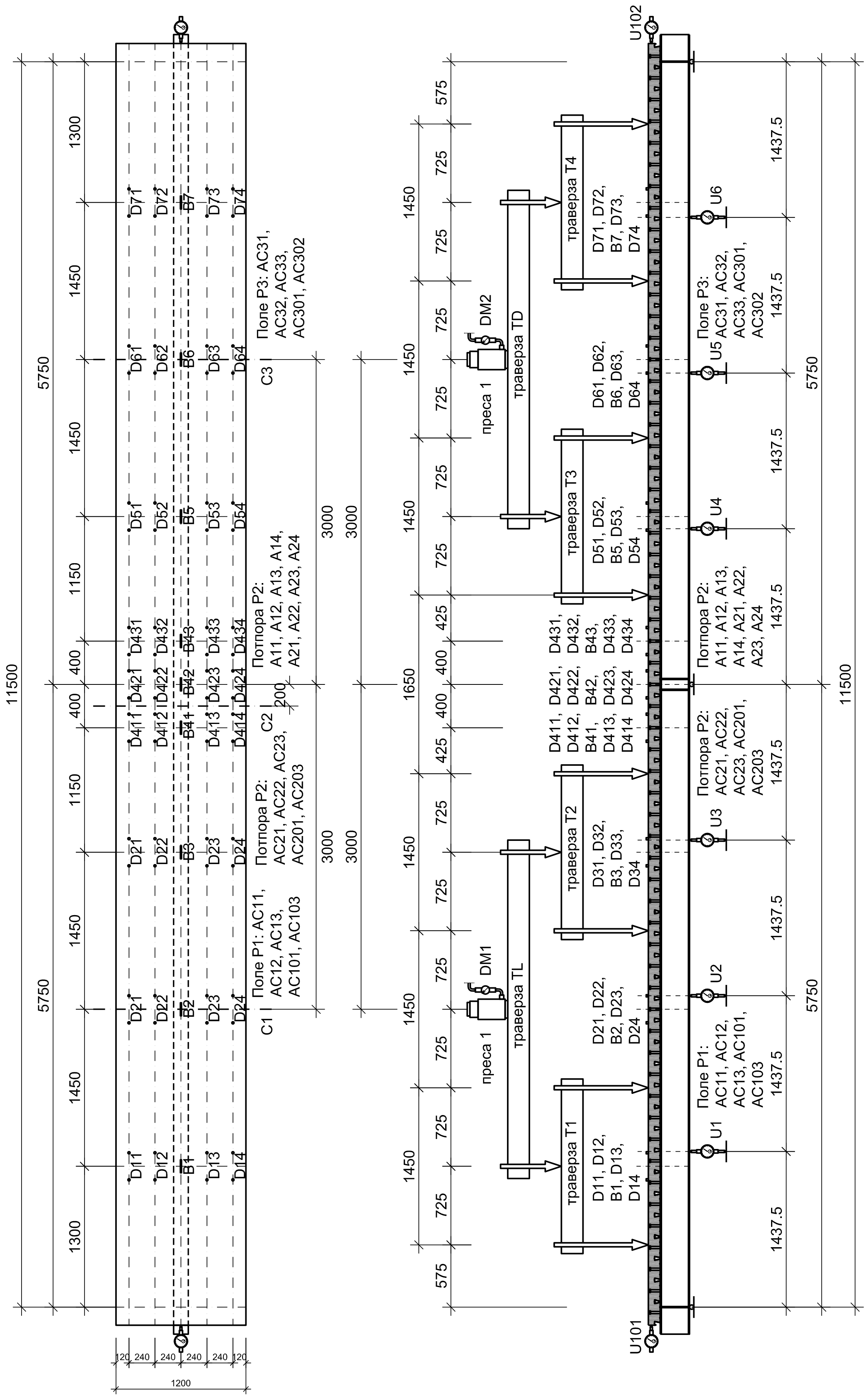

Figure 3.Testing model with measuring and load application equipment

beam, and second model “ГН2” as composite continuous beam pre-stressed by controlled imposed deformations. The beams are with “T” beam cross section made from IPE200 steel beam (1) and composite deck with steel sheeting Bondeck 600, with thickness of 1.0mm, and depth of 52mm (2). The full depth of the composite deck is 52+58=110mm, reinforced with Q273 (Ø6/100mm) (4). At the support there are two layers of the same reinforcement, for improving the bearing capacity of the concrete. For shear connectors Nelson headed studs (3) are used, with diameter of 19mm and height of 100mm, as shown in figure 4. The static system is continuous beam, with two spans of 5750mm.

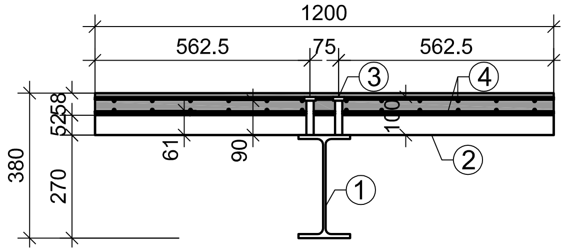

Figure 4. Cross section of the testing models

In figure 3 the loading and measuring equipment are shown. The force is introduced to the beam through two layers of transmission beams, where from two loading points, the load is distributed on eight points longitudinal to the beam, with that simulating uniform load. The load is applied through two 100 tons presses, for each lading case the force is measured with the usage of the dynamometers.

The displacements are measured with electronic comparators U1 to U6, and with dial comparators U101 and U102 the slip between the steel beam and concrete slab is measured. The strains on the top face of the concrete slab are measured with dial deformeter with main base of 250mm. The measuring points for the deformeter are D11 to D74. In the middle of the width of the concrete slab, strain gauges with main base of 120mm are used, B1 to B7. Strain gauges, with main base of 5mm, are used for measuring the strains in the steel section, AC11 to AC303, and also for measuring the strains in the reinforcement, A11 to A24.

At the end of each step, the data from the strain gauges was obtained through HBM Universal amplifier, and the data from the dynamometers and the electronic comparators was obtained from HBM Quantum data acquisition system, in real time.

The difference between the models is that the second model is pre-stressed with controlled imposed deformations. According to the analytical research, 18mm of imposed deformations is enough for the most optimal and effective improvement of the bearing capacity of the cross section at the middle support. The steel beam is constructed with elevation at the middle support of 18mm, then the steel sheeting, the welding of the shear connectors and casting of the concrete were made. After the curing of the concrete, the lowering of the middle support was conducted, osculating the behaviour and measuring the displacements and strains. With pre-stressing by the imposed deformation a compression force on the concrete slab is induced at the middle support.

The first model “ГН1” is loaded with cycled load up to 40kN in dynamometer (10kN at the loading point in contact to the testing model), then the load is applied in subsequent increments until failure occurs (up to 450kN). After every step of loading, values from the measuring equipment (deformeter and dial comparators) are obtained. From the electronic dynamometers, comparators and strain gauges, the measurements are obtained in real time throughout the testing. The second model “ГН2” is loaded similar as the first model, but the load when the failure occurs is 600kN.

4. RESULTS FROM THE TESTING

The obtained data from the testing of the composite beams are adequately processed in tables, drawings and diagrams with measured strains, deflections and stresses. The appearance and the width of the cracking of the concrete at each loading step were also obtained.

The results from the testing are analyzed and compared with the procedures given in EN 1994 and with realistic complex 3D model created in the structural software for analysis and design SAP2000. In this paper, only the results from the testing are provided and compared.

4.1 FIRST MODEL “ГН1”

The first crack in the concrete is at the support with load step of 60kN in dynamometer (15kN at the loading point in contact to the testing model), producing moment around 36.37kNm. The most exposed fiber of the steel cross section at the support reached the yield strength in loading steps between 225kN and 250kN in dynamometer. The first full yielding of the steel cross section, where the ultimate limit state is reached, is at the support at loading step of 450kN, producing moment of 234.12kNm. The ultimate limit state of the composite beam at the span is reached at the loading step of 512kN in dynamometer (128kN at the loading point in contact to the testing model).

The elastic deflection of the first tested model is 12.14mm, where the deflection with plastic behaviour of the beam is 24.41mm at the loading step of 450kN in dynamometer.

4.1 SECOND MODEL "ГН2"

The first crack in the concrete of the pre-stressed continuous composite beam is at the loading step of 140kN in dynamometer. The yield of the most exposed fiber of the steel cross section is at the loading step of 375kN at the spans of the beam. The full yielding of the steel cross section at the support occurs at the loading step of 550kN, producing moment of 244.13kN, where the ultimate limit state of the cross section at the spans is at the loading step of 618kN (154.5kN at the loading point in contact to the testing model), producing moment of 297.30kNm.

The elastic deflection of the tested model is 13.04mm, where at the step of loading of 450kN in dynamometer is 20.12mm, and 51.32mm for the ultimate limit state of the beam.

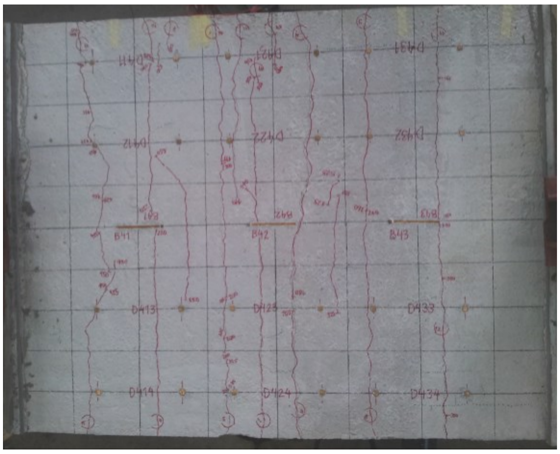

Figure 5. Cracks in the concrete slab at the support, final loading step of "ГН2"

5. COMPARISON OF THE RESULTS

From the obtained data from the testing of the two models, difference in the behaviour of the models is observed.

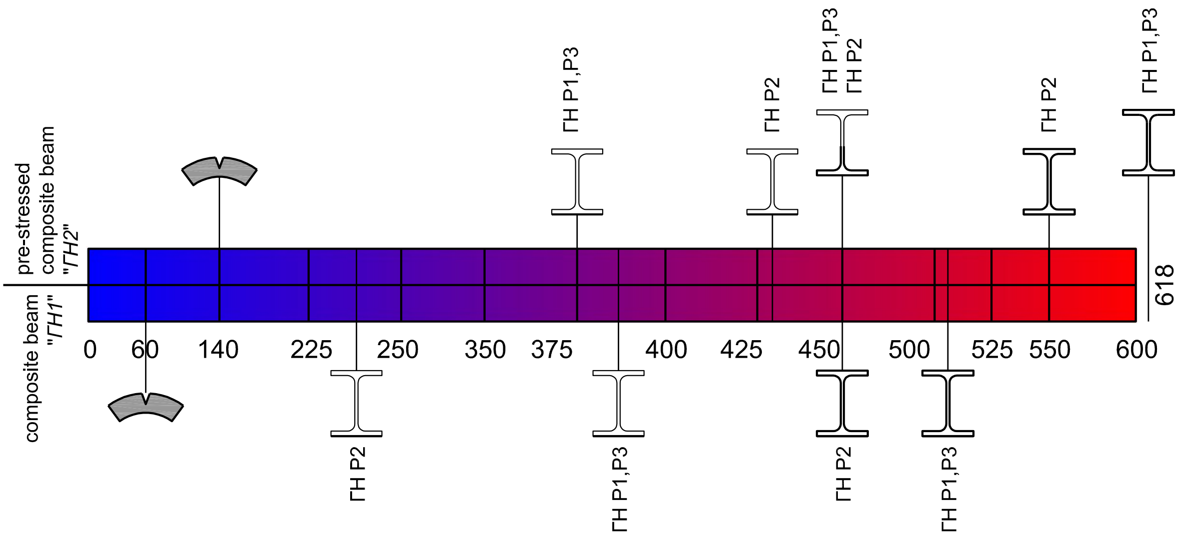

Figure 5. Display of the compared results of the tested models

It is obvious that the pre-stressed composite continuous beam "ГН2" has more advantages from "ГН1", in the field of the serviceability and ultimate limit state.

The cracking of the concrete is delayed for 80kN in dynamometer, which is a great advantage for the serviceability limit state of the structure and a great advantage for the elastic behaviour of the composite beam, which results with loading difference of 15.4kN/m'.

The full yielding at the support of "ГН1" is at the loading step of 450kN in dynamometer, where for "ГН2" is at 550kN, with difference of +22.2% or with loading difference of 19.3kN/m'. The ultimate limit state of "ГН1" is at the loading step of 512kN in dynamometer, where the same for "ГН2" is at loading step of

618kN, with difference in +20.7% or with loading difference of 20.5kN/m'.

There are advantages of "ГН2" in the deflections compared to "ГН1". At the step of loading of 450kN, the deflection of "ГН1" is 24.41mm, where for "ГН1" at the same step of loading is 20.12mm, with difference of -17.6%.

6. CONCLUSIONS

Having the results from the testing of the two composite continuous beams, and with the analysis of the results, some conclusions can be drawn.

It is obvious that the behaviour of the tested beams are completely nonlinear, especially after the occurring of the first cracks in the concrete slab at the support.

One of the advantage is greater serviceability limit state of "ГН2" compared to "ГН1", where the pre-stressed composite beam can be load with additional 15.4kN/m' until the first crack in the concrete at the middle support occurs.

In the elastic behaviour, the advantages are 2.33 times higher bearing capacity of "ГН2" compared to "ГН1". There is 1.88 times higher bearing capacity after the occurring of the cracks until the yield strength of the most exposed fiber is reached.

The pre-stressed composite beam "ГН2" has 20.7% higher ultimate limit state than "ГН1", which means that it can be loaded with additional 20.5kN/m' until the bearing capacity is reached. The ultimate load, when the ultimate limit state of the beam is reached, for "ГН1" is 98.94kN/m', where the ultimate load for "ГН2" is 119.24kN (+20.7%).

It can be concluded that with pre-stressing the composite beam by controlled imposed deformations by 18mm, there are many advantages in the behaviour of the beam compared to ordinary composite beam, and that the advantages are in the better serviceability and ultimate limit state of the beams.

REFERENCES

[1] Cvetanovski P., "Composite structures, printed lectures", 2011, Skopje, R. Macedonia.

[2] Dumovic D., Androic B., Lukasevic I., "Composite structures according to Eurocode 4, Worked Examples", 2014, Ernst & Sohn.

[3] Popovski D., "Experimental and theoretical research of the effects of composite steel and concrete structures for continuous beams", doctoral dissertation, 06.2015, Faculty of civil engineering in Skopje, UKIM, Skopje, R. Macedonia.

[4] Popovski D., Cvetanovski P., Partikov M., "Testing the behavior of continuous composite beam pre-stressed by controlled imposed deformations", SJCE, Volume 4, Issue 2, 12.2015, pp. 1-7.

[5] Spacone E., "Nonlinear Analysis of Steel-Concrete Composite Structures: State of the Art", A.M.ASCE, Journal of Structural Engineering, Vol. 130, No. 2, 02.2004.

[6] European Standard EN 1992, Eurocode 2: Design of concrete structures, Part 1-1: General rules and rules for buildings, 12.2004, European Committee fot Standardisation

[7] European Standard EN 1993, Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings, 03.2005, +AC 06.2009, European Committee fot Standardisation

[8] European Standard EN 1994, Eurocode 4: Design of composite structures, Part 1-1: General rules and rules for buildings, 12.2004, +AC 04.2009, European Committee fot Standardisation.

