MODIFIED TEST ON SHEAR CONNECTORS WITH PROFILED STEEL SHEETING TRANSVERSE TO THE BEAM

AUTHORS

Denis Popovski
PhD, Assistant professor
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
Bul. Partizanski odredi No. 24, 1000 Skopje
popovski@gf.ukim.edu.mk

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

Petar Cvetanovski
PhD, Full Professor
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering – Skopje
cvetanovski@gf.ukim.edu.mk

When the design rules are not applicable, the design can be based on tests, carried out in a way that provides information on the properties of the shear connection required for design [1].

Testing the shear connectors gives necessary relevant data revealing the real behaviour of the composite structure, and the capability of achieving the full plastic capacity of the designed cross section.

The modified testing, scope of this paper, is a part of a large experimental trials conducted for retrieving of larger volume of relevant data on the different behaviour of composite structures.

The modified testing on shear connectors is conducted on such way that represents the real behaviour of the composite structure, using three identical specific samples.

Keywords: composite structures, shear connectors, headed stud.

1. STANDARD TESTING

The rules for testing arrangements, preparation of specimens, testing procedure and test evaluation are given in EN 1994-1-1, Annex B, Part B.2.

1.1 TESTING ARRANGEMENTS AND PREPARATION

When the shear connectors are part of T-beam with uniform concrete slab, or with haunches, standard testing is used for determination of the behaviour of the shear connectors. In other cases, with use of profiled sheeting decks, longitudinal or transversal to the beam, modified test can be used.

For modified tests the dimensions and the arrangement of the parts that create the cross section must be as the designed, but in accordance of the rules given in EN 1994-1-1, Annex B, such as the length of each slab should be related to the longitudinal spacing of the connectors. The width of each slab should not exceed the effective width of the slab of the beam. The thickness of each slab should not exceed the minimum thickness of the slab in the beam and the slabs should have the same haunch and reinforcements as the beam.

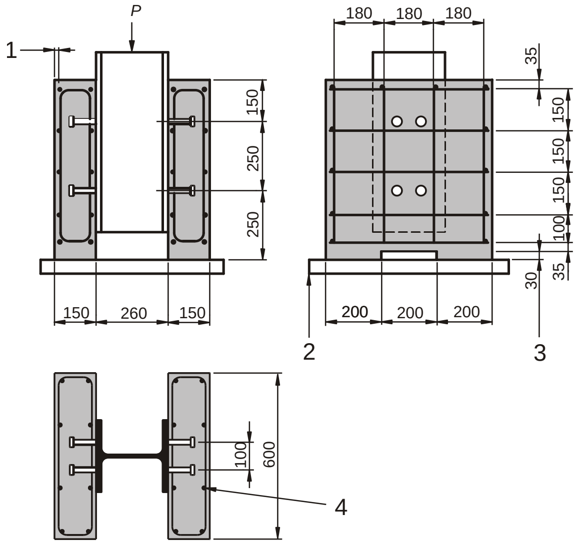

Figure 1. Test specimen for standard testing

Where 1) is cover of 15mm, 2) is bedding from mortar or gypsum, 3) is recess and it is optional and 4) is reinforcement ribbed bars and steel section.

The casting of the concrete slabs is in horizontal position, as for the real composite beam, and the specimen should be air-cured. For each mix of concrete minimum three specimens of cylinders or cubes should be prepared for determination of the concrete strength.

The yield strength and the maximum elongation of a representative sample of the shear connector material, steel beam, and steel sheeting should be determined.

1.2 TESTING PROCEDURE AND EVALUATION

The testing procedure is the same for the standard and for the modified tests. The load is applied in increments up to 40% of the expected failure load and cycled 25 times between 5% and 40%. After the cycled loading, subsequent load increment is imposed until failure occur in not less than 15 minutes. The longitudinal slip between the concrete and the steel section should be measured continuously until the load dropped to 20% below the maximum load. Also, the transverse separation between the steel section and the concrete should be measured, closely to the groups of connectors.

If the results of the three specimens does not exceed 10%, the design resistance can be determined as follows:

- The characteristic resistance P_{rk} should be taken as the minimum failure load reduced by 10%
- The design resistance P_{rd} should be calculated as given in (1)

$$P_{Rd} = \frac{f_u \cdot P_{Rk}}{f_{ut} \cdot \gamma_v} \leq \frac{P_{Rk}}{\gamma_v} \quad (1)$$

Where,

- f_u is the minimum specified ultimate strength of the connector material
- f_{ut} is the actual ultimate strength of the connector material in the specimen
- γ_v is the partial safety factor for shear connection

If the deviation from the main exceeds 10%, three more tests should be made, and the test evaluation should be carried in accordance with EN1990, Annex D.

The slip capacity δ_u is the maximum slip measured at the characteristic load level. The characteristic slip capacity δ_{uk} is the minimum test value of δ_u reduced by 10% or statistical evaluation from all the results in accordance with EN 1990, Annex D.

2. MODIFIED TESTING

The modified test sample is T-beam cross section with IPE270 as main steel beam, with transverse steel sheeting Bondeck 600 with stud shear connectors through deck welded with diameter d=19mm and height h_{sc}=100mm. The concrete slab thickness is 52+58=110mm, where 52mm is the height of the steel sheeting deck, and 58mm is the continuous concrete plate, reinforced with Q273 (Ø6/100mm), as shown in Figure 2. The concrete strength class is C25/30 according to EN 1992-1-1, Table 3.1.

At the top of the steel beam, detail for receiving the force is constructed, composed from steel plate 200x300x15mm and UNP100 profiles as stiffeners. The bottom face of the concrete slab is bedded in mortar (exmal) with thickness approximately of 50mm.

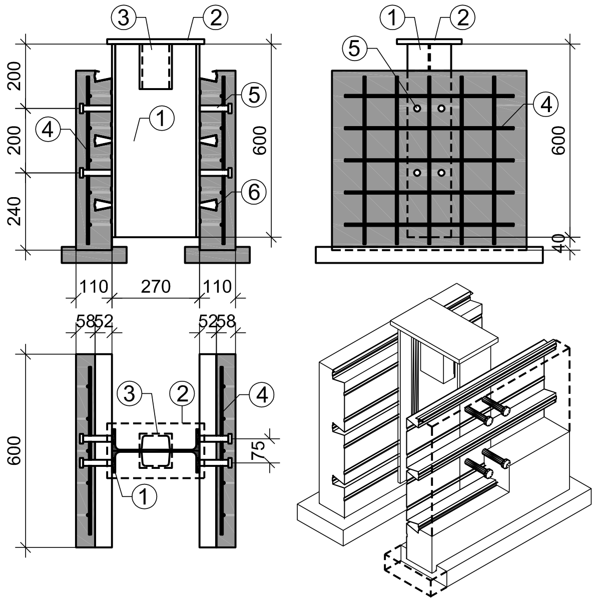

Figure 2. Test specimen for modified testing

Where, 1) is steel beam IPE200, 2) is steel plate 200x300x15, 3) is UNP100 as stiffeners, 4) is reinforcement Q283 (Ø6/100mm), 5) is headed stud type Nelson d=19mm, h_{sc}=100mm and 6) is steel sheeting Bondeck 600 t=1.0mm.

The casting of the concrete slabs was made in horizontal position, as the casting of the beam in reality. After seven days the samples were rotated for 180 degrees and the second composite slab was casted in horizontal position with same strength class concrete.

Figure 3. Casting of the concrete

2.1 TESTING THE STRENGTH OF THE CONCRETE

After every casting of the concrete a sample was taken for testing the strength of cubes with dimensions 150x150x150mm. the testing of the cubes for the strength of the concrete was carried out on the 29th day from the casting of every concrete slab. For concrete strength class C25/30, according to EN 1992, the strength of cylinder is f_{ck}=25N/mm2, and the strength of cube is $f_{ck,cube}$=30N/mm2.

Because of the time needed for application of the measuring equipment, the test models were tested on the 34th, 35th and 38th day from the casting of the concrete slab, i.e. 5th, 6th and 9th day from the testing of the concrete samples.

The results of the first casting are with standard deviation of 1.95 and resulted with strength of cube $f_{ck,cube}$=31.71MPa, +5.7% from the specified strength. The second casting is with standard deviation of 0.46 with strength of cube $f_{ck,cube}$=30.19MPa, +0.6% from the specified strength.

2.2 TESTING THE STRENGTH OF THE STEEL

The yield strength, the tensile strength and the maximum elongation of a representative sample of the shear connector material, steel beam, reinforcement and steel sheeting is determined.

The reinforcement steel is class B, in accordance with EN 1992-1-1, Annex C, table C.1 and C.3N, with yield strength of f_{yk}=597MPa, tensile strength f_{uk}=662MPa, with $k=f_{uk}/f_{yk}$=1.11 and ε_{uk}=9.9%.

The steel for the headed studs is class S235J2+C450, in accordance with EN 13918, with yield strength f_y=502MPa, tensile strength f_u=552MPa, with $k=f_u/f_y$=1.10 and δ=18.5%.

The steel for the steel sheeting deck is class S550GD Z275, in accordance with EN 10147, with yield strength f_y=675MPa, tensile strength f_u=770MPa, with $k=f_u/f_y$=1.14 and δ=24.6%.

The steel for the beam is class S275JR, in accordance with EN 1993, with yield strength f_y=275MPa, tensile strength f_u=424MPa, with $k=f_u/f_y$=1.54 and ε_u=18.9%.

The results from the testing of the steel meet the requirements from EN1992 and EN 1993.

2.3 TESTING PROCESS

The tree samples for the modified testing of the behaviour of the shear connectors are tested in the same environment, with same testing equipment and testing conditions.

The testing is carried out in accordance with EN 1994, Annex B, with cycled loading steps to 40% and then 25 cycles from 5% to 40%. After the cycled loads, the samples were loaded until failure in time not less than 15 minutes.

For the purpose of the testing, measuring and loading equipment is used. The load us applied through 100 ton press, where the force is regulated with electronic dynamometer. The longitudinal slip between the concrete slab and the steel section is measured with 4 electronic and 4 dial comparators. The accuracy of the testing equipment is in the range of ±1.5%.

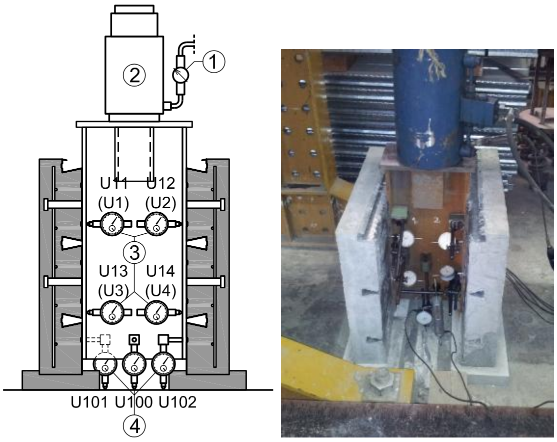

Figure 4. Disposition of the loading and measuring equipment

Where 1) is dynamometer for load measuring, 2) is 100 ton press for load application, 3) dial (U11-U14) and electronic (U1-U4) comparators for transverse separation, 4) electronic comparators (U100-U102) for longitudinal slip.

The electronic equipment is connected to HBM Quantum data acquisition system amplifier with direct connection to computer. The measuring of the electronic equipment is carried out through the whole testing in real time.

2.4 ANALYSIS OF THE DESIGN RESTITANCE AND EXPECTED RESULTS

The analysis of the design resistance of the shear connectors is made in accordance with EN 1994-1-1 (6.6.3.1), for headed stud type Nelson with d=19mm and h_{sc}=100mm. The headed studs are through deck welded to the beam. The steel sheeting is type Bondeck 600 with thickness of t=1.0mm.

The designed resistance of the headed stud, automatically welded through deck in accordance with EN 14555, is determined according to EN 1994-1-1, (6.18), (6.19) and (6.21).

$$P_{Rd}^{(1)} = \frac{0.8 \cdot f_u \cdot \pi \cdot d^2 / 4}{\gamma_V} = 90.68 kN \quad (2)$$

$$P_{Rd}^{(2)} = \frac{0.29 \cdot \alpha \cdot d^2 \cdot \sqrt{f_{ck} \cdot E_{cm}}}{\gamma_V} = 73.73 kN \quad (3)$$

Where $\alpha = 1$ for $h_{sc} / d = 5.26 > 4$ (4)

$$\min\left(P_{Rd}^{(1)}, P_{Rd}^{(2)}\right) = P_{Rd}^{(2)} = 73.73 kN \quad (5)$$

Where,

- f_u is specified ultimate strength of the stud connector,
- f_{ck} is characteristic cylinder compressive strength,
- γ_V is the partial safety factor, recommended value 1.25,
- h_{sc} is the overall height of the stud
- d is the diameter of the stud.

For steel sheeting with ribs transverse to the length of the beam, reduction factor is calculated according to EN 1994-1-1, (6.23)

$$k_t = \frac{0.7}{\sqrt{n_r}} \cdot \frac{b_o}{h_p} \cdot \left(\frac{h_{sc}}{h_p} - 1\right) = 1.47 > 1 \quad (6)$$

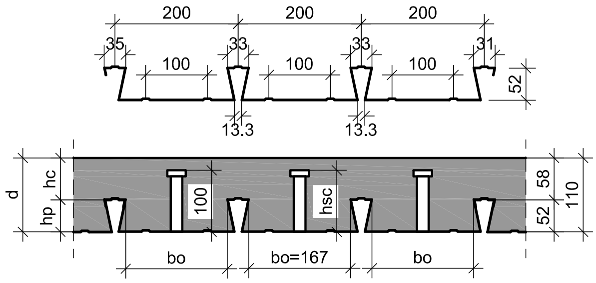

Figure 5. Steel sheeting, headed studs and concrete slab

For value of the reduction factor k_t>1, table 6.2 from EN 1994-1-1 is used, where the upper limit for the reduction factor is $k_{t,max}$=0.70.

$$P_{Rd} = k_t \cdot P_{Rd}^{(2)} = 51.61 kN \quad (7)$$

The expected results, without the safety factor γ_V=1.25, for 4 studs per side is:

$$P_{Rd,U} = 2 \cdot 4 \cdot 1.25 \cdot 51.61 = 516.10 kN \quad (8)$$

 D. Popovski, M. Partikov, P. Cvetanovski

2.3 RESULTS FROM THE TESTING

In Table 1 the results from the testing of the three specimens are given with the measured strength of the force of failure ($P_{Rk,U}$) for eight studs, and the analyzed values of the strength of one headed stud.

Table 1. Results from the testing

$P_{rd,(1)}=f_u/f_{ut} \cdot P_{Rk,(1)}/\gamma_v \leq P_{Rk,(1)}/\gamma_v$			
Specimen	П 1	П 2	П 3
P_{Rd} [kN]	51.61		
$P_{Rd,U}$ [kN]	516.10		
$P_{Rk,U}$ [kN]	602.86	561.82	578.02
P_{Rk} [kN]	542.57	505.64	520.22
$P_{Rk,(1)}$ [kN]	67.82	63.21	65.03
f_u/f_{ut}	0.996		
γ_v	1.25		
$P_{Rd,(1)}$ [kN]	54.04	50.36	51.81
Diff. [%]	+4.71	-2.42	0.39
$P_{Rd,D}$ [kN]	51.84		

Where P_{Rd} is design resistance of one stud including the partial safety factor, $P_{Rd,U}$ is ultimate design resistance of eight studs, without the partial safety factor, $P_{Rk,U}$ is ultimate design resistance of eight studs from the testing, P_{Rk} is reduced ultimate design resistance of eight studs from the testing, according to EN 1994-1-1, B2.5, $P_{Rk}=0.9 \cdot P_{Rk,U}$. $P_{Rk,(1)}$ is reduced ultimate design resistance for one stud, $P_{Rd,(1)}$ is design resistance of one stud including the partial safety factor from the testing, $P_{Rd,D}$ is design resistance for the stud from the three specimens, statistical evaluated from all the results in accordance with EN 1990, Annex D.

The difference in negative resistance of -2.42% is great part in the range of the accuracy testing equipment of ±1.5%. The deviation results from the tree specimens is not bigger than 10%, and with the design value of $P_{Rd,D}$=51.84kN>P_{Rd}=51.61kN, can be concluded that the headed studs meet the requirements given in EN 1994.

In Figure 6 (up left and right, down left) P-δ diagrams from the cyclic loading of every specimen is given separately. Additionally, (down right) the determination of the slip capacity δ_u is given, in accordance with EN 1994.

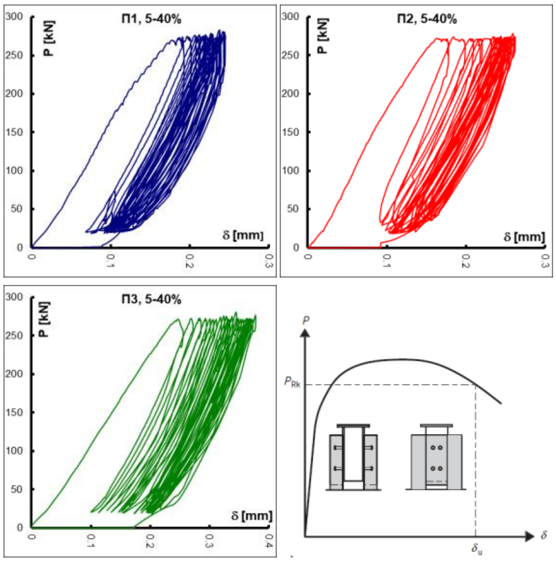

Figure 6. P-δ diagrams and slip capacity

In Figure 7 the determination of the slip capacity from the P-d diagram is given, where $P_{Rk,(1)}=0.9 \cdot P_{Rk,U}$ is reduced ultimate design resistance from the testing for one headed stud. From the value of $P_{Rk,(1)}$ and the P-δ diagram from the testing, the value of the slip capacity δ_u can be determined. The diagrams of all specimens are given (down left), including the diagram, with the average diagram (AM) if needed for further analytical research of the behaviour of the shear connectors.

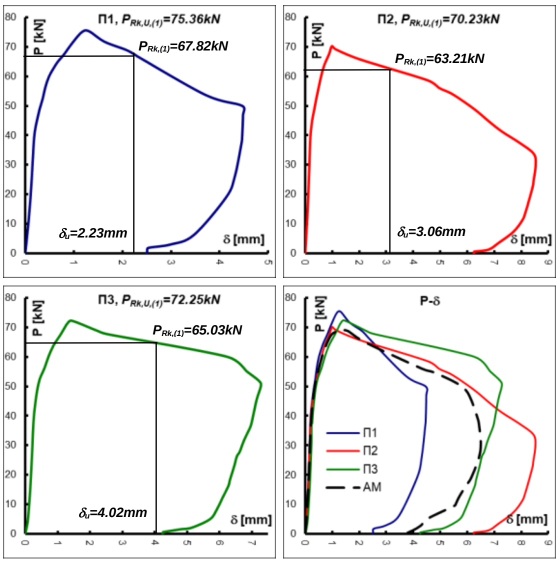

Figure 7. P-δ diagrams, slip capacity determination

The values of the determined slip capacity for each specimen are 2.23mm for П1, 3.06mm for П2 and 4.02mm for П3, where according to EN 1994-1-1, Annex B, the value from all three specimens is:

$$\delta_{uk} = 0.9 \cdot \delta_{u,min} = 2.01mm \qquad (8)$$

The value of the slip capacity from all specimens can be also determined with statistical evaluation from the results in accordance with EN 1990, Annex D, in which case the value is δ_{uk}=3.17mm.

There are no significant measured values of transverse separation between the steel beam and the concrete slab.

2. CONCLUSION

The design resistance in dependence of the concrete slab, with all dimensions and concrete strength class, determinates the main resistance of the headed stud shear connectors. If design resistance is needed to be determined not from the concrete slab, but from the headed stud, then lower quality steel for the stud or greater concrete strength class is required.

The value of the slip capacity is δ_{uk}<6mm, which means that the shear connectors from this testing case can be applied for achievement of full plastic capacity of the designed cross section.

For more ductile behaviour of the structure, a smaller diameter or lesser strength quality for the headed stud shear connector is required.

REFERENCES

[1] EN 1994-1-1: Eurocode 4: Design of composite steel and concrete structures – Part 1-1: General rules and rules for buildings, CEN, 12.2004, +AC 04.2009, pp. 55 – 60, 110 – 113.

[2] Popovski D., "Experimental and theoretical research of the effects of composite steel and concrete structures for continuous beams", doctoral dissertation, 2015, Faculty of civil engineering in Skopje, UKIM, pp. 43 – 58.

[3] Popovski D., Cvetanovski P, Partikov M., "Testing the behaviour of shear connectors", MASE 16 international symposium, October 2015, pp. 539 – 548.

[4] Popovski D., Cvetanovski P., Partikov M., "Comparison of continupous composite beams behaviour", Scientific Journal of Civil Engineering, Volume 5, Issue 1, July 2016, pp. 33 – 38.

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

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

[7] Konrad M., Kuhlmann U., "Headed Studs Used in Trapezoidal Steel Sheeting According to Eurocode 4", SEI, Volume 19, No. 4, 2009.

[8] Galjaard H. C., Walraven J. C., "Static Tests on Various Types of Shear Connectors for Composite Structures", RILEM Publications, SARL, 2001.