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ДРУШТВО НА ГРАДЕЖНИ КОНСТРУКТОРИ НА МАКЕДОНИЈА

MASE

MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS

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INTERNATIONAL SYMPOSIUM

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Друштво на градежните конструктори на Македонија

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OF THE 19th INTERNATIONAL SYMPOSIUM OF MASE

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University "Ss. Cyril and Methodius", Skopje, North Macedonia*

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Партизански одреди 24,
П.Фах 560, 1001 Скопје
Северна Македонија

MASE
MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS

Partizanski odredi 24,
P. Box 560, 1001 Skopje
North Macedonia

SS - 8

mase@gf.ukim.edu.mk
http://mase.gf.ukim.edu.mk

TESTING THE BEHAVIOUR OF SHEAR CONNECTORS WITH DIFFERENT TRANSVERSE STEEL DECKS

Nikola NISEV [1], Denis POPOVSKI [2] , Mile PARTIKOV [3]

ABSTRACT

The topic of this paper is the analysis of the behavior of shear connectors with transversal sheeting. To determine the behavior of the shear studs, i.e. to determine the maximum carrying capacity of the connector and its ductility, test specimens were made with a variation of the sheeting as well as the number of connectors in the cross-section. The research methodology and the test procedure is conducted according to the rules and guidelines in Eurocode 4. Before testing the specimens, quality control of the composite materials is conducted and the results are used to determine the design shear resistance for headed studs automatically welded. The testing procedure is carried out according to rules and recommendations in Eurocode 4, EN 1994-1-1, Annex B. All of the samples are tested with the same equipment and the same testing conditions. First, the load is applied until it reaches 5% of the expected failure load without a partial safety coefficient. Then the load is cycled 25 times between 5% and 40% of the expected failure load. After the 25th cycle, from 5%, the load is increased until failure is achieved in one or more of the elements of the test sample. The results from the testing are processed and presented as a P-δ diagram.

Keywords: shear connectors, composite structures, headed stud.

[1] PhD Student, MSc, Faculty Civil Engineering, University “Ss. Cyril and Methodius”, Skopje, Republic of North Macedonia, nikolanisev@yahoo.com
[2] Associate. Prof., Faculty of Civil Engineering, University “Ss. Cyril and Methodius”, Skopje, Republic of North Macedonia, popovski@gf.ukim.edu.mk
[3] Assistant Prof, Faculty Civil Engineering, University “Ss. Cyril and Methodius”, Skopje, Republic of North Macedonia, partikov@gf.ukim.edu.mk

1. INTRODUCTION

The general idea for the use of composite structures arises from the need for maximum utilization of the mechanical characteristics of the concrete slab and the steel profile. This approach for designing the composite structures is based on using the compressive strength of the concrete slab, also its horizontal rigidity within the composite structure, combined with the bending resistance of the steel profile to achieve maximum load capacity.

The cross-section of this structure is a composition of steel profile that carries a concrete slab laid on a metal sheet. The connection of the steel and the concrete slab can be achieved with :

- design of a mechanical connection between the metal sheet and the concrete slab with ribbing or protruding the sheets.
- using a mechanical shear connector that can be welded directly on the steel profile or with the method of trough deck welding.

The use of composite structures shortens the construction time of the building because it eliminates the need for scaffolding and cladding, which drastically reduces the time required for construction and the cost of labor. These structures compared to the reinforced concrete structures, have between 20 and 40 % less self-weight which is positive for constructions that are in seismically active areas.

If we take into consideration the entire process of construction of the composite structures, it can be concluded with certainty that its economically far more cost-effective than the classic reinforced concrete structure.

Fig. 1. Constructed composite structure

Fig. 2. Shear studs welding process

Fig. 3. Through-deck welded stud

2. HEADED SHEAR STUD CONNECTORS IN SOLID SLAB

2.1 Design resistance

The headed shear stud connector resistance in accordance with EN 14555 for automatically welded studs in composite cross-section is determined with :

$$P_{Rd} = \frac{0.8 \cdot f_u \cdot \pi \cdot d^2 / 4}{\gamma_V} \tag{1.1.}$$

или

$$P_{Rd} = \frac{0.29 \cdot \alpha \cdot d^2 \cdot \sqrt{f_{ck} \cdot E_{cm}}}{\gamma_V} \tag{1.2.}$$

Whichever is smaller, with:

$$\alpha = 0.2 \cdot \left(\frac{h_{sc}}{d} + 1 \right) \quad \text{for} \quad 3 \leq \frac{h_{sc}}{d} \leq 4 \tag{1.3.}$$

$$\alpha = 1 \quad \text{for} \quad \frac{h_{sc}}{d} > 4 \tag{1.4.}$$

γ_V is the partial safety factor witch value is recommended to 1.25.

d is the diameter of the shank of the stud, a variable value between 16 and 25mm

f_u is the specified ultimate tensile strength of the material of the stud but not greater than 500 N/mm^2.

f_{ck} is the characteristic cylinder compressive strength of the concrete at the age considered, of density not less than 1750 kg/m^3.

h_{sc} is the overall nominal height of the stud.

2.2 Metal sheeting with ribs transverse to the supporting beams

When the sheeting in the composite cross-section is transversely placed relative to the steel profile the shear resistance of the headed studs is reduced by correction factor k_t. Design shear resistance of the solid slab should be taken into consideration and it should not be greater than 450 N/mm^2. Reduction factor k_t :

$$k_t = \frac{0.7}{\sqrt{n_r}} \cdot \frac{b_0}{h_p} \cdot \left(\frac{h_{sc}}{h_p} - 1 \right) \tag{1.5.}$$

h_p the total height of the metal sheeting ribs

h_{sc} the height of shear stud, maximum h_p+75mm

n_r, the number of shear studs in cross-section is not greater than 2.

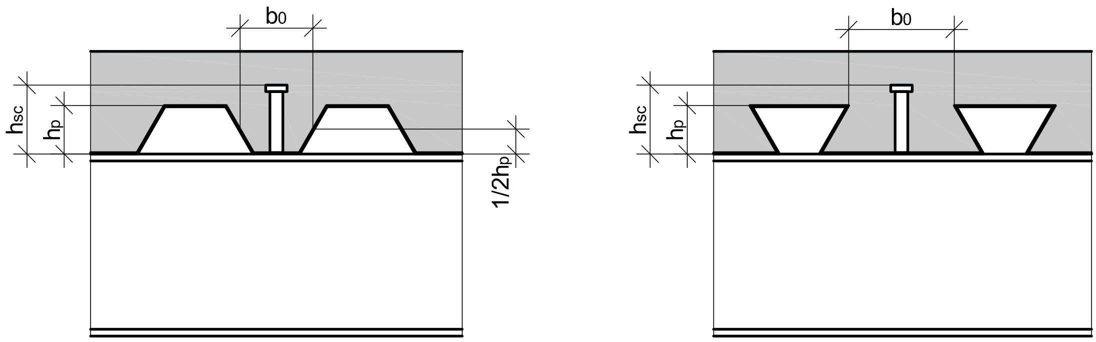


Fig. 4. Composite cross-section with transversally set sheeting

The factor k_t should not be greater than $k_{t,max}$ given in Table 1.

Table 1. Upper limits $k_{t,\,max}$ for the reduction factor k_t

Number of stud connectors per rib	Thickness of sheet (mm)	Studs not exceeding 20 mm in diameter and welded through profiled steel sheeting	Profiled sheeting with holes and studs from 19 to 20mm
n_r=1	≤ 1	0.85	0.75
	>1	1.00	0.75
n_r=1	≤ 1	0.70	0.60
	>1	0.80	0.60

The values for k_t are applicable in case when the following conditions are satisfied:

- The steel sheeting profile should not exceed a height greater than 85mm and the distance between ribs of the sheeting should not be smaller than the height.
- Shear studs that are used in the composite cross-section should be with a diameter smaller than 20mm if they are welded with the method of through-deck-welding.
- Shear studs welded directly to the steel profile should not exceed a diameter greater than 22mm.

3. TESTING THE SHEAR CONNECTORS

3.1 Modified test on shear connectors

To prove the load capacity of the shear studs in the composite cross-section with the quality of the material in Macedonia, modification of the standard test method should be performed. The modification is by the regulation and rules from Eurocode 4. The modified test was performed on test specimens whose cross-section is composed of metal sheets that are placed transversely relative to the steel profile from both sides of steel profile flanges, shear studs welded in two ways either directly to the steel profile or with a procedure called through deck welding, at the end the cross-section package is formed by casting a concrete slab over the metal sheets.

The materials used for this modified test are by the regulations and rules of Eurocode 4. For the steel profile in the composite cross-section, IPE270 with a length of 600mm was used because it is the smallest profile with enough width of the flange so two shear studs can be welded. On the top of the steel profile, a metal plate with a thickness of 15mm is welded with an additional UPN profile just below the plate to provide better force transmission and to improve the rigidness of the joint. Metal sheets used in the test specimens were with a thickness of the sheet of 1.0mm and indented or open profile, or more specifically BONDECK 600 with a distance between ribs of 200mm and HIDECK 75 with a distance between ribs of 180mm.

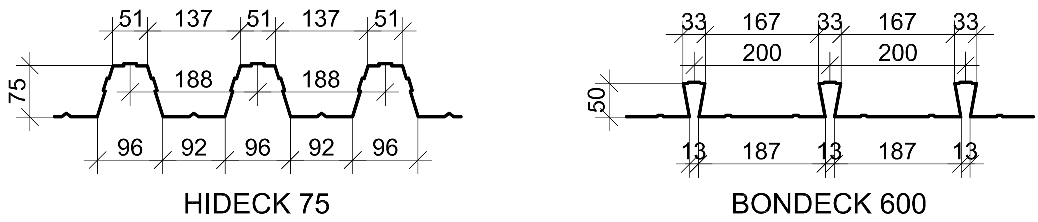
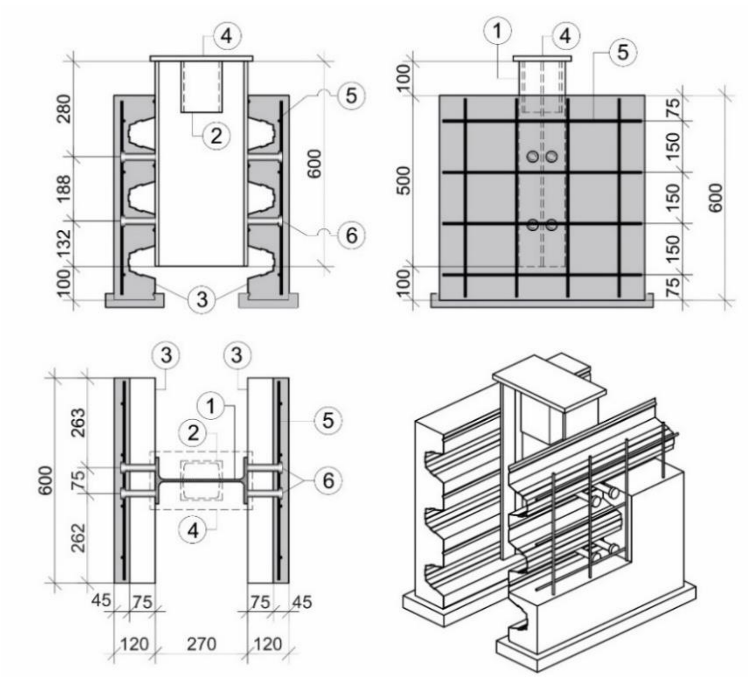


Fig. 5. Steel sheeting for composite structures

The shear studs used in this test were from the manufacturer NELSON with a height of the stud, h = 100mm, and the diameter of the body of the shear stud, d=19mm. Shear studs were arranged in different variations in the composite cross-section either in a single-row or double-row depending on the metal sheet and test model combinations. The reinforced concrete slab was with a total height of 120mm with concrete class C25/30 and reinforcement steel Q166, Ø6/15cm. This experiment covers the testing and analysis of four different test models with different shear stud distribution along the cross-section and the method of studs welding.

Table 2. Test specimens combinations

Model	Metal sheet		Shear studs		Through-deck welding
	Bondeck 600	Hideck 75	One-row	Two-row	
1		√		√	√
2		√	√		√
3	√		√		√
4	Solid slab			√	



1/ IPE 270 … 600mm
2/ UPN 120 … 150mm
3/ Hideck 75, t=1.0mm
4/ ≠170.15…300mm
5/ Q188 (Ø6/15cm)
6/ Nelson h_{sc}=100mm, d=19mm

Fig. 6. Test specimen for a modified experiment on shear connectors

3.2 Testing process

The full test procedure of the modified test on shear connection was made in correspondence with the recommendations of Eurocode 4 and related to the rules of the standard test. Before the start of the testing, all the test specimens need to be in a nearly ideal vertical position so that we can have a true distribution of the applied force. For the application of the vertical compression force, 100T press was used connected with an electronic dynamometer that will show the applied force values in real-time.

Controlling of the horizontal detachment of the concrete slab in relation to the steel profile was made with four inductive displacements measurement sensors with a measuring range of 10_{mm}. On the bottom of the steel profile on both sides, vertical displacements were measured with three sensors with a measurement range from 200_{mm}. The loading scheme is given below in figure 4.18.

To cancel out the parasitic influences in the cross-section and to ensure that the results obtained for the slip are correct, the test body is loaded with a force of 40% of the failure load. The next stage in the loading of the test specimen is cycled 25 times with a force between 5% to 40% of the predicted failure load. The expected failure load must not be reached in time less than 15 min. After achieving the failure load, the examination of the test specimen is completed and the results are saved, which will be displayed later in the form of force/displacement or (P / δ) diagrams.

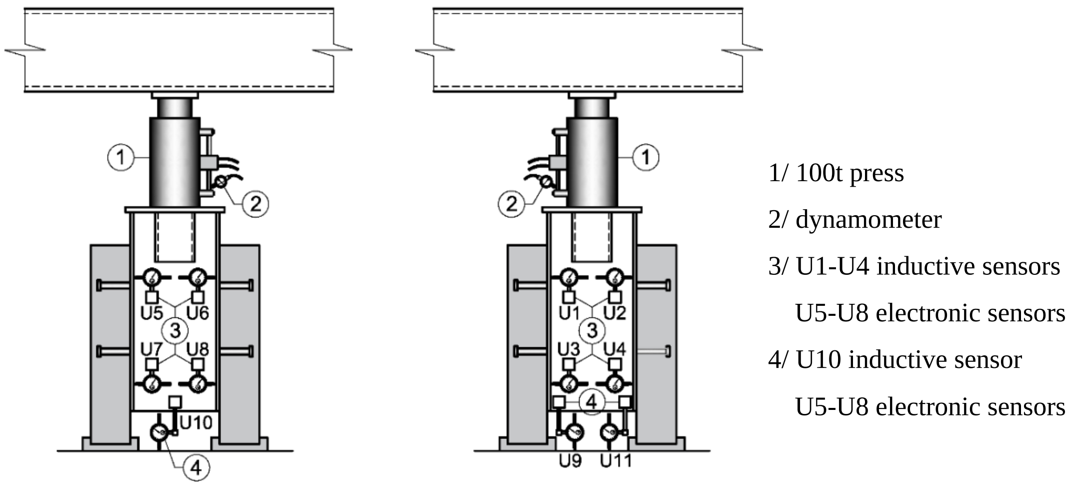


Fig. 7. Loading scheme of the test specimen (both sides)

3.3 Testing results

After the completion of the test and after the processing of the readings obtained from the instruments was performed, the following results were obtained for the values that show a realistic picture of the load capacity and ductility of the shear stud connectors:

- The characteristic resistance P_{rk} for a single shear connector

2) Slip capacity of the specimen δu, measured as a maximum slip for characteristic load level,

3) The characteristic slip capacity δ_{uk}, which should be taken as the minimum test value of δ_u reduced by 10%.

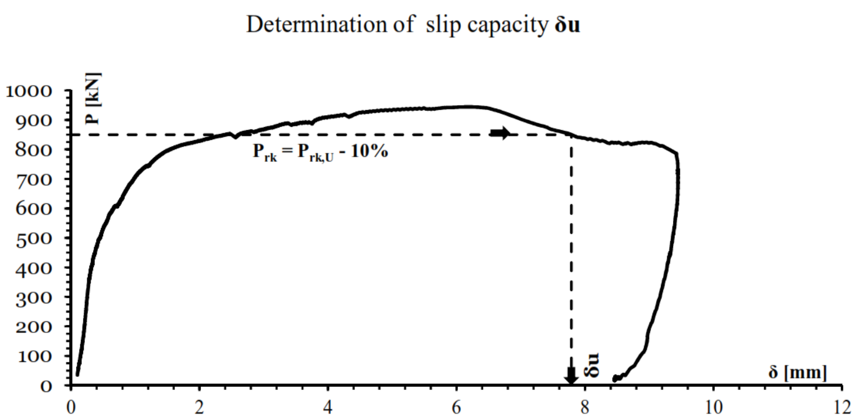


Fig. 8. The procedure of calculating the slip capacity of a single shear connector

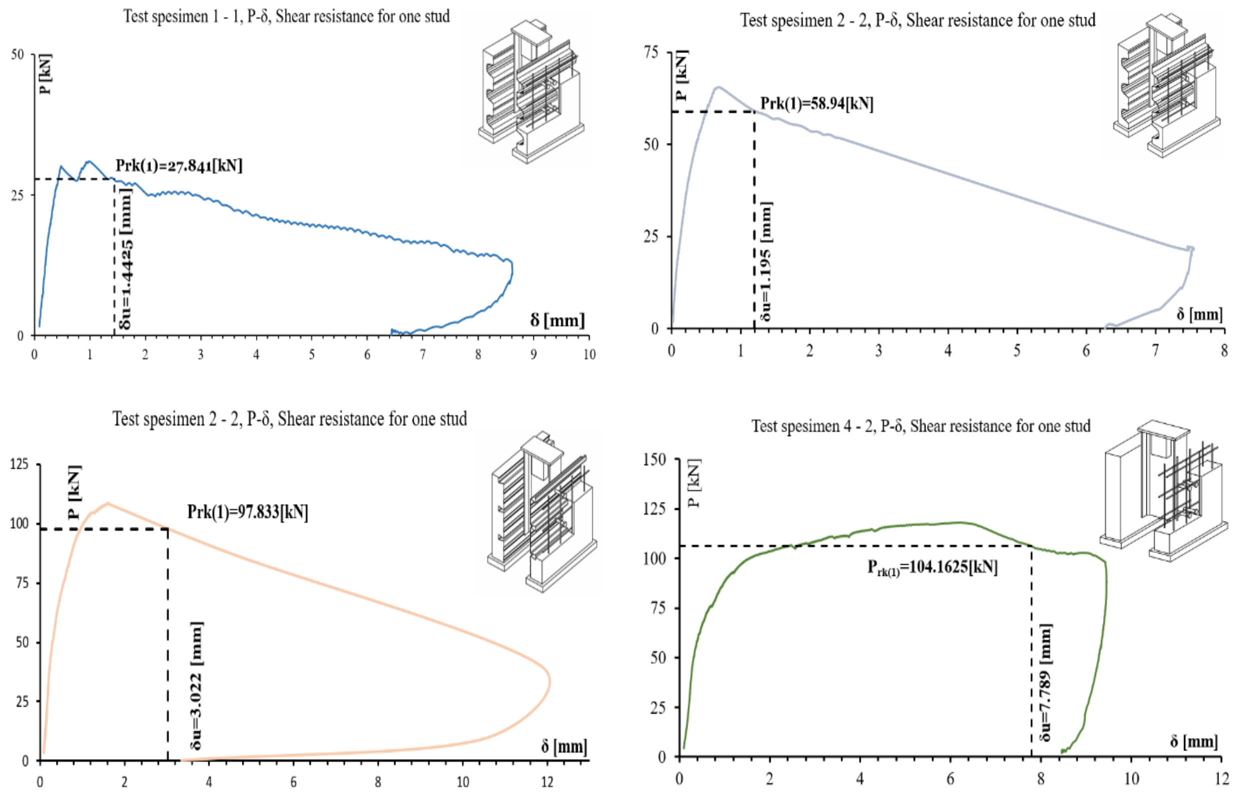


Fig. 9. Single P-δ diagrams for characteristic resistance P_{Rk} of single shear connector

For every test specimen the maximum characteristic resistance of single shear connector $P_{Rk,U}$ is shown in the individual and summary diagrams, also the maximum slip capacity is presented of the connectors corresponding to force reduced by 10% from the maximum failure load.

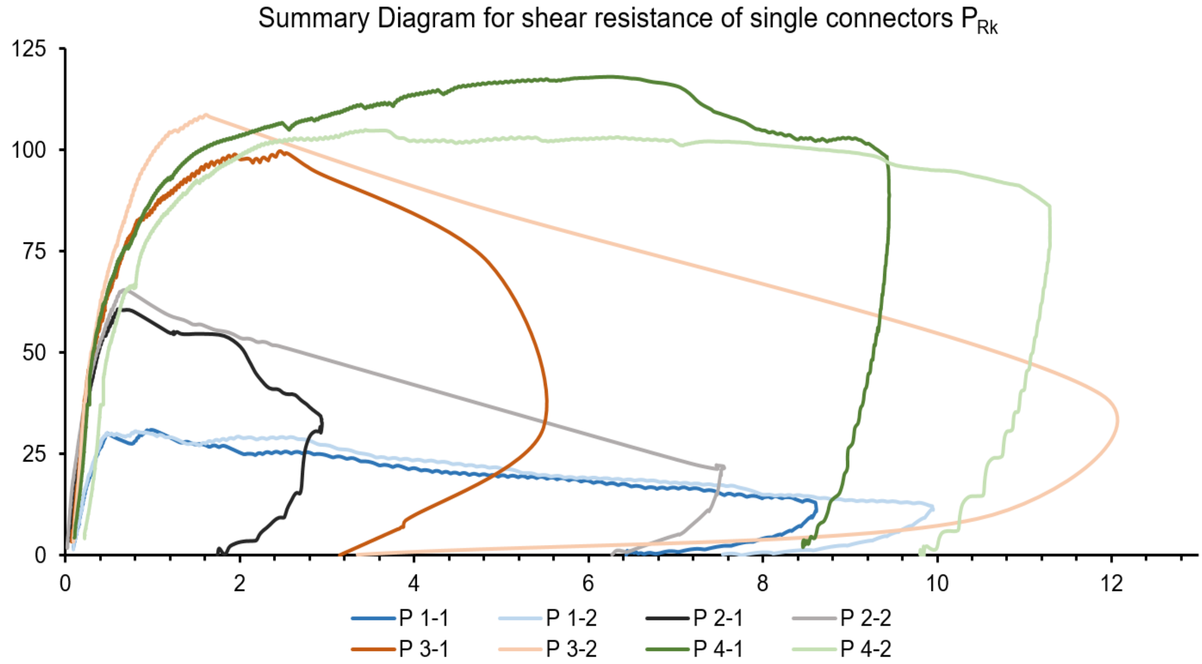


Fig. 10. Summary P-δ diagrams for characteristic resistance P_{Rk} of single shear connector

Table 3. shows all the results of the test specimens for the full shear resistance of the model considering all the shear connectors in the cross-section, also the results obtained from the testing and designed values of characteristic shear resistance of a single connector. Additionally in the following table, the results are compared with a coefficient that shows the difference between the tested value of the shear resistance and the designed value calculated by the rules of Eurocode 4.

Table 3. Results from modified testing on shear connectors

Test spec.	$P_{Rk,U}$ **[kN]**		P_{Rk} **[kN]**		$P_{Rk,U(1)}$ **[kN]**		$P_{Rk(1)}$ **[kN]**		P_{max} **(EC4) [kN]**	$P_{max,(1)}$ **(EC4) [kN]**	**Results difference coef.**
1.1	247.5	**246.2**	222.75	**221.6**	30.94	**30.78**	27.85	**27.7**	210.74	26.3425	**1.14**
1.2	244.9		220.41		30.61		27.55		210.74	26.3425	
2.1	242.9	**252.5**	218.61	**227.2**	60.73	**63.12**	54.66	**56.81**	149	37.25	**1.41**
2.2	262		235.8		65.5		58.95		149	37.25	
3.1	399	**416.9**	359.1	**375.2**	99.75	**104.2**	89.78	**93.81**	354.15	88.5375	**1.15**
3.2	434.8		391.32		108.7		97.83		354.15	88.5375	
4.1	944.5	**892.1**	850.05	**802.9**	118.06	**111.5**	106.25	**100.4**	833.3	104.163	**1.07**
4.2	839.7		755.73		104.96		94.46		833.3	104.163	

Table 4. shows the maximum slip capacity of the shears studs that are calculated for force reduced by 10% from the maximum failure load. Also, the characteristic slip capacity values are presented that are used to determine the ductility of the shear studs.

Table 4. Slip capacity of single shear connector

Test spec.	δ_u [mm]		δ_{uk} [mm]	
1.1	1.443	**2.158**	1.2983	**1.942**
1.2	2.874		2.586	
2.1	1.296	**1.245**	1.166	**1.121**
2.2	1.195		1.076	
3.1	3.398	**3.21**	3.058	**2.889**
3.2	3.022		2.719	
4.1	7.789	**8.994**	6.808	**8.095**
4.2	10.199		7.004	

4. CONCLUSION

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

The analysis recommendations from Eurocode 4, for the bearing capacity of the shear stud with transverse steel sheeting, is underestimating the real capacity of the shear connectors. According to the testing the real bearing capacity is greater from 14 to 41 % from the analysis recommended in Eurocode 4. The results for solid concrete slab are in accordance to the recommendations given in Eurocode 4.

The value of the slip capacity is $\delta_{uk}<6mm$ which means that the shear connectors for this testing case are not ductile, and that they can be applied for achievement of full plastic capacity of the designed cross section. More ductile behaviour is obtained with the solid slab model. If a more ductile behavior for the structure is needed, for the models with transverse steel deck, a smaller diameter or lesser strength quality for the headed stud shear connector is recommended.

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