Original Scientific Paper

doi:10.5937/jaes14-10471 Paper number: 14(2016)1, 359, 109 - 114

SHEAR RESISTANCE OF LONGITUDINAL SHEAR CONNECTION WITH GROUPS OF HEADED STUDS

Milan Spremić
University of Belgrade, Faculty of Civil Engineering, Belgrade, Serbia
Zlatko Marković
University of Belgrade, Faculty of Civil Engineering, Belgrade, Serbia
Jelena Dobrić
University of Belgrade, Faculty of Civil Engineering, Belgrade, Serbia
Dragan Buđevac
University of Belgrade, Faculty of Civil Engineering, Belgrade, Serbia

The frequently applied solution for shear connection in steel and concrete precast composite structures is the discontinuous shear connection with a headed stud in group arrangement. Application of shear connection with headed studs in group arrangement and calculation of shear resistance for studs group in typical precast composite floor beam is presented. The possibility and feasibility of shear connection construction with headed studs in group arrangement was considered. It is shown that the shear connection in precast composite floor beams can be constructed with a group of four headed studs.

Key words: Prefabricated composite beams, Shear connection, Group of headed studs

INTRODUCTION

In designing and constructing prefabricated composite structures, the most common realization of longitudinal shear connection between steel and concrete is implementation of headed studs in a group arrangement. Groups of headed studs can be used for subsequently executed shear connection. Headed studs in group arrangement can be successfully applied for the reinforcement and renovation of the existing longitudinal shear connection between structural steel and concrete slab. Figure 1 presents the solution for subsequently executed shear connection with group of headed studs placed in hole in concrete made by drilling.

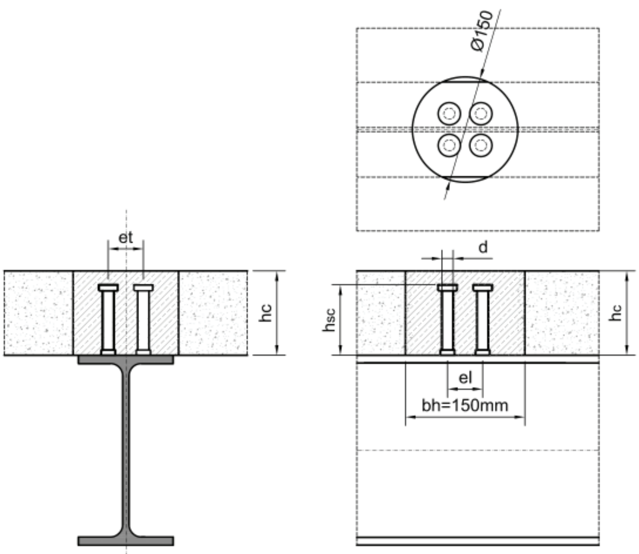

Figure 1: Subsequently executed shear connection, geometry of studs group

* University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, Belgrade, Serbia
spremic@grf.rs

In an opening with 120-150 mm in diameter four headed studs in a group can be made, with reduced values of longitudinal direction according to the minimum prescribed in actual codes. The reduction of the spacing between the adjacent headed studs is aimed to form a group of smaller dimensions, which eventually results in small dimensions of a hole in the RC slab, and a smaller discontinuity of an RC slab. The paper has shown that with a group of four headed studs having diameter of 16 or 19 mm a full longitudinal shear connection can be realized for a standard composite beam of a span up to 12,0 m.

When the longitudinal shear connection is constructed with the headed studs in a group, the shear connection can be characterized as discontinuous. The groups of headed studs are constructed in discreet locations on the beam at the openings in prefabricated RC slab. It is two possibilities for the arrangement of the headed studs in the group:

- With minimum prescribed distances between the headed studs or
- With the smaller distances between the headed studs than the prescribed minimum.

This paper presents the calculation of longitudinal shear connection, with studs in group arrangement. The studs group with smaller distances between the studs in shear force direction, than the prescribed minimal distances in Eurocode 4, was considered in typical composite floor beam.

SHEAR RESISTANCE OF HEADED STUDS GROUP

Among all the standing regulations, groups of headed studs are mentioned as a structural solution of the shear connection in EN 1994-2 [07] and Standard Specifications for Steel and Composite Structures published by JSCI [04]. According to EN 1994-2 headed studs may be placed in groups. In this case consideration of: non-uniform flow of longitudinal shear, the greater possibility of slip and the local resistance of the concrete slab, must be provided. For design and calculation of longitudinal shear connection with headed studs in group arrangement JSCI [04] refer to research realized and published by Okada et al. [01]. Design shear resistance for a group of headed studs could be determined as sum of single headed studs shear resistances:

$$\mathrm{P_{Rd,G}} = \sum P_{Rd} \quad (1)$$

The previous expression can be used when headed studs are constructed at the distances prescribed by the technical regulation. If the minimum prescribed distances between the headed studs according to EN1994-1-1 [03] or ASCE, 5d and 6d respectively are used, the dimensions of the group are up to two times bigger than the dimensions of the group constructed with the reduced distances between the headed studs. In order to reduce the dimensions of the group, it is necessary to reduce the distance between the headed studs el in the direction of the shear force. The prescribed minimum distances perpendicular to the direction of the shear force et are negligibly bigger than the technologically minimal required distance which is around 2d. When the groups of headed studs are constructed with the distances between the headed studs being el<5d it is necessary to reduce the shear resistance in some cases. The shear resistance of a group with the reduced distance between the studs is equal:

$$\mathrm{P_{Rd,G}} = \alpha_G \cdot \sum P_{Rd} \quad (2)$$

The value α_G in the previous equation presents the reduction factor for shear resistance ($\alpha_G \le 1$). All existing recommendations for calculation of shear resistance, for headed studs in group arrangement, are based on the reduction factor. Many authors have researched in the recent years the shear resistance and behavior of a group of headed studs in longitudinal shear connections. Experimental research of group shear resistance with reduced distance between the studs in the shear force direction were realized only by Spremic [06] and Shim C.S. [05]. In three studies, the authors proposed and provided recommendations for the calculation of shear resistance of a headed studs in group arrangement:

- Okada et al. [01] analyzed the shear resistance of a group of nine studs in the 3x3 arrangement. In the framework of the experimental tests, they did not test the shear resistance of the group with reduced values of distances between the headed studs. As the result of the research, they proposed the calculation procedure of the reduction coefficient which is the function of the distance between the headed studs and compressive strength of concrete:

$$\mathrm{P_{Rd,G}} = f(e_l, f_{ck}) \cdot \sum P_{Rd} \quad (3)$$

- Shim C.S. et al. [05] in their research has experimentally tested groups of nine headed studs in 3x3 arrangement. The research included also the headed studs group with reduced distances between the studs, 3d and 4d, in the shear force direction. The value of the proposed reduction coefficient in research [6] is a linear function of distance between adjacent headed studs:

$$P_{Rd,G} = f(e_l) \cdot \sum P_{Rd} \quad (4)$$

- Spremic [06] within his research, experimentally analyzed shear resistance and behavior of 4 headed studs in 2x2 arrangement. The dimensions of the group are adapted to the typical composite floor beams in buildings. The result of the research is a proposed procedure, for calculation of shear resistance of a group of headed studs which is the function of the group geometry and not only of the distance between the headed studs. The value of the reduction factor is in relation with: diameter of single studs in a group – d, headed stud height hsc, number of studs in a group in direction of shear force - nr, number of studs in a group perpendicular to the direction of shear force -nc and the distance between the studs in direction of shear force el (3d<e_l<5d).

$$P_{Rd,G} = f(d, h_{sc}, n_c, n_r, e_l) \cdot \sum P_{Rd} \quad (5)$$

The value of the reduction factor according to the solution proposed by Okada et al. [01] is less than 1, even in the cases when the distances between the headed studs are higher than 5d. This is not in agreement with the presented results of experimental researches. The value of reduction factor according to Shim C.S. [05] provides good results only in case of the group of headed studs which is, in terms of the group dimensions and dimension of individual stud, similar to experimentally tested specimens in [05]. In other cases, the proposed solutions from [06] is prominently conservative. The table 1 shows the reduction factor values for the group of four headed studs having diameters 12, 16 and 19 mm in 2x2 arrangement. The reduction factor according to the proposal from [03] and [06] have the same values for all three analyzed groups which is in opposite to the available experimental results. The detailed comparative analysis of the reduction factor values which were proposed in the mentioned researches are presented in [06].

SHEAR CONNECTION WITH STUDS GROUP

On the examples illustrating typical composite beams in the building structures, the potential for implementation was analyzed and justification for application of the group of headed studs for construction of a longitudinal shear connection. The prefabricated floor structure, with the composite beams having spans 8, 10 and 12 m, was analyzed, see table 2. The adopted spacing of floor beams was 4.0 m. Dimensions of the prefabricated RC beams were adopted in accordance with the span of the floor structure. The RC slab width 1000-1400 mm is assumed. The width of the slabs must be adapted to distance between the groups, with the one group placed in the hole at the middle of precast concrete slab and the next group is placed between the concrete slabs, see Figure 2.

Table 1: Reduction factor value

Group Layout	d [mm]	h_{sc} [mm]	e_l	αG		
				Spremic [6]	Okada [5]	Shim C.S. [4]
2 x 2	12	100	3d	1.00	0.82	0.67
2 x 2	16	100	3d	0.95	0.82	0.67
2 x 2	19	100	3d	0.86	0.82	0.67

Table 2: Analyzed typical composite floor beams

	PN1	PN2	PN3
Beam span L_1[m]	8	10	12
Beam distance λ [m]	4	4	4
Depth of concrete slab h_c [m]	16	16	16

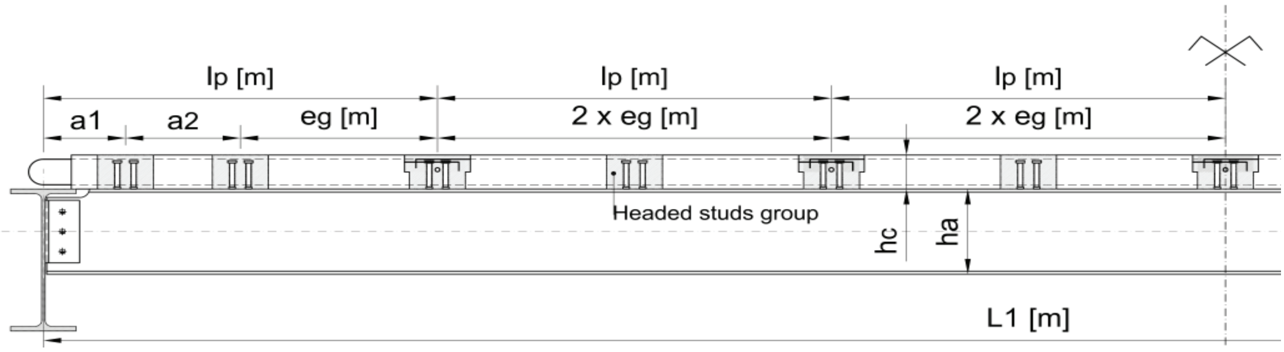

Figure 2: Composite beam with precast RC slab

Table 3: Steel cross section, capacity check in construction stage

Beam	Structural steel cross section	$M_{a,Ed}$ [kNm]	$M_{pl,a,Rd}$ [kNm]	$M_{a,Ed}/M_{pl,a,Rd}$	$V_{a,Ed}/V_{a,Rd}$
PN1	IPE 330	172.8	221.2	0.781	0.180
PN2	IPE 400	236.3	359.4	0.657	0.140
PN3	IPE 500	388.0	603.4	0.644	0.140

Table 4: Capacity check for composite cross section

Beam	M_{Ed} [kNm]	M_{Rd} [kNm]	M_{Ed}/M_{Rd}	V_{Ed} [kN]	V_{Rd} [kN]	$V_{a,Ed}/V_{a,Rd}$
PN1	424.8	522.1	0.814	212.4	489.2	0.434
PN2	630.0	735.6	0.856	252.0	677.0	0.372
PN3	955.8	1223	0.782	318.6	950.6	0.335

The characteristic value of load is in all according to EN1991-1-1. Additional dead loads from cladding, walls and installation were adopted as value of 2.5 kN/m2 in total. The live load has the intensity of 3.0 kN/m2, which corresponds to the categories of loaded surfaces A to C2 according to EN1991-1-1. Steel grade for structural steel is S275. The characteristic value of the compressive strength fck according to EN 1992 for concrete C35/45 was adopted. All the adopted cross sections are class 1. The adopted dimensions of structural steel cross section and bearing capacity check in the construction stage are presented in Table 3.

In construction stage the lateral-torsional buckling for structural steel part of cross section was not analyzed. It is possible to laterally stabilize the beam using the structural measures. According to Hicks and Lawson recommendations [08], direction for assembly of the precast RC slab from the supports towards the middle of the span, lateral torsional buckling can be prevented.

The value of the plastic resistance moment of composite cross sections of the as well as the proof of bearing capacity were presented in the table 4. For the adopted spacing of floor beams of 4.0 m the slab thickness of 16.0 cm was adopted.

Starting from the shear resistance of the single headed stud PRd, the required number of headed studs for the full shear connection between the structural steel and concrete slab was calculated. Arrangement and distance at which the headed studs can be located in the longitudinal shear connection depends on the deformation characteristics of the connector.

Regarding the behavior, it is habitual in literature to divide the connectors into rigid and elastic – ductile connectors. The elastic-ductile connector, like headed studs, are characterized primarily by high deformability and ability to achieve prominent plastic deformations before the shear failure. The rigid – block connectors receive the shear forces exclusively by shearing, and at ultimate strength they exhibit negligible plastic deformations. Deformability of the connectors, provides redistribution of the total shear force onto a large number of connector which must transfer the force between the steel section and the concrete slab. Headed studs having sufficient deformation capacity to allow ideal plastic behavior of the longitudinal shear connection can be considered elastic or ductile. Eurocode 4 provides a condition for the experimental proof of headed studs ductility. According to Eurocode 4 the headed stud is elastic- ductile, if the characteristic slip at the ultimate shear load of headed studs is δ_{uk}>6 mm. According to experimental results presented by Spremic et al. [09], a group of four headed studs 16 mm in diameter, 2x2 arrangement can be considered as ductile, see Figure 3.

Ductility of the longitudinal shear connection realized using groups of headed studs allows implementation of partial shear connection for design and calculation of shear connection between the structural steel and concrete slab. This fact allows adopting even higher values of distance between the groups, if required by the structural design. According to results from [9], for small reductions of the number of connectors, there is no significant reduction of cross section bearing capacity .

By construction of shear connection with ductile headed studs, the required number of headed studs for the transfer of longitudinal shear force can be distributed in the part of the beam between the support point and the cross section withstanding the maximum value of bending moment. The Table 5 presents the results of the longitudinal shear connection calculation of the analyzed composite floor beams.

The structural design of the longitudinal shear connector with groups of headed studs means grouping of the individual headed studs. The adopted group for design of the shear connection is the group of four headed studs in 2x2 arrangement. The larger groups of headed studs are not suitable for floor beams in buildings because of the limited width of the upper flange of the beam which is used for placing of the headed studs. The results of the calculation according to Spremic [05] with required number of studs groups and adopting distance between the groups which are required for the full shear connections in case of the analyzed floor beams are presented in table 6.

In the case of plastic redistribution of longitudinal shear force along the steel beam, which is applicable in case of ductile connectors, an equal value of distance between the groups of headed studs along the beam can be adopted. This assumption is in agreement with the results of experimental results presented in the Figure 3. As presented in the previous table, the values of distances of the groups of headed studs in the direction of shear force ranges between 480 mm and 540 mm. These distances are in agreement with the structural design of reinforced concrete slab, which is produced in the widths of 1000 mm or 1200 mm by most of the manufacturers of prefabricated concrete elements.

When the beam span is larger than 12.0 m, the serviceability limit state, deflections and vibration become the criteria which are relevant for design of floor beams.

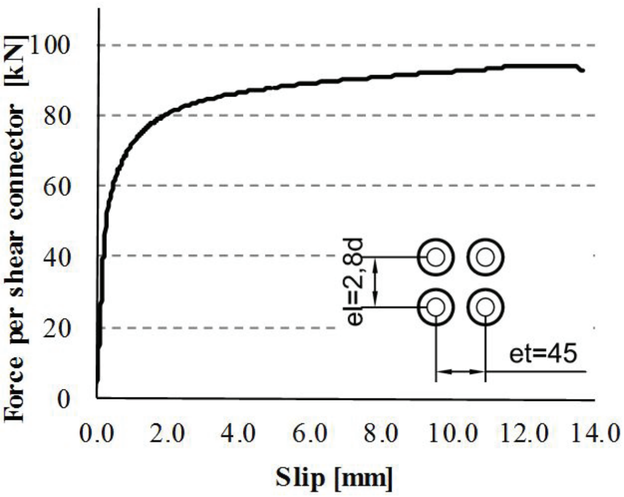

Figure 3: Load – Slip diagram for group of four headed studs d=16mm h=100 mm

Table 5: Longitudinal shear connection – Results

Beam	d [mm]	h_{sc} [mm]	P_{Rd} [kN]	$V_{l,Ed}$ [kN]	n [kom]
PN1	16	100	63.1	1721.5	27.3
PN2	16	100	63.1	2323.8	36.8
PN3	19	100	88.9	3190.0	35.9

P_{Rd} design shear resistance of single headed studs
$V_{l,Ed}$ design value of shear force
n number of headed studs for full shear connection

Table 6: Longitudinal shear connection with groups of headed studs

Beam	d x h_{sc} [mm]	Group layout [n_l × n_t]	α_G	$P_{Rd,G}$ [kN]	n_g [kom]	e_g [cm]
PN1	16x100	2 x 2	0.95	224.6	7.66	52.2
PN2	16x100	2 x 2	0.95	224.6	10.3	48.5
PN3	19x100	2 x 2	0.86	283.6	11.3	53.6

α_G reduction factor for shear resistance
$P_{Rd,G}$ design shear resistance of headed studs group
n_g number of studs group,
e_g distance between studs group

CONCLUSION

Based on these presented results it is concluded that the headed studs in grouped arrangement can be successfully used as the design and construction solution of the longitudinal shear connection for the prefabricated composite beams in typical floor structures. The following can also be concluded:

- In design of the shear connection with groups of headed studs, ductility of a group of headed studs must be proven in order to adopt equal distances between the groups of headed studs on a structural steel.
- A group of four headed studs having diameter 16 mm and 100 mm of height behaves ductile even in case when the distance between the headed studs is smaller than the prescribed 5d. A partial shear connection can be constructed in the cases when the distance between the groups is larger than the distances provided by the calculation.
- A group of four headed studs having diameter 16 mm or 19 mm can be used for construction of a full shear connection for the standardized floor beams having span of up to 12.0 m. The required distance between the groups is within 450-600 mm limits.
- For a group of four headed studs with d=16 mm and hsc≥100 mm shear resistance reduction is not required, as well as in the cases when the distance between the headed studs is less than 5d but more than 3d.

REFERENCES

1) Hicks S.J., Lawson R.M., Design of Composite Beams Using Precast Concrete Slabs, SCI PUBLICATION P287, The Steel Construction Institute, 2003
2) EN1994-1-1, Eurocode 4, "Design of Composite Steel and Concrete Structures. General Rules and Rules for Buildings", CEN (European Committee for Standardization), December 2004.
3) EN1994-2, Eurocode 4, "Design of Composite Steel and Concrete Structures. General Rules and Rules for Bridges", CEN (European Committee for Standardization), 2005.
4) Okada J, Yoda T, and Lebet J.P, "The Study of the Grouped Arrangements of Stud Connectors on Shear Strength Behavior", Structural Eng./Earthquake Eng. JSCE, Vol. 23, No. 1, pp. 75-89.
5) Shim C.S, Lee P.G, Kim D.W. and Chung C.H, „Effects of Group Arrangement on the Ultimate Strength of Stud Shear Connection", Proceedings of the 2008 Composite Construction in Steel and Concrete Conference VI, ASCE Conf. Proc. doi:10.1061/41142(396)8.
6) Spremic M, "The analysis of headed studs group behavior in composite steel-concrete beam", PhD thesis, University of Belgrade, Faculty of Civil Engineering, October 2013
7) Spremic M, Markovic Z, Veljkovic M, Budjevac D, Push–out experiments of headed shear studs in group arrangements, Advanced Steel Construction; Vol. 9, No. 2, pp. 170–191, 2013.
8) Spremić M., Budjevac D., Marković Z., Dobrić J., „The comparative analysis of the full and partial shear connection of composite beams", International conference GNP 2008, Žabljak, Podgorica 2008.
9) Standard Specifications for Steel and Composite Structures, Japan Society of Civil Engineers, December, 2009.

Paper sent to revision: 03.02.2016.
Paper ready for publication: 15.03.2016.