ДГКС ASES

Друштво грађевинских конструктера Србије

Association of Structural Engineers of Serbia

SIMPOZIJUM 2016. ZLATIBOR 15-17. SEPTEMBAR

ZBORNIK RADOVA 2016

U SARADNJI SA

POKROVITELJ

Република Србија
Министарство грађевинарства, саобраћаја и инфраструктуре
Министарство просвете, науке и технолошког развоја

SPONZORI

CIP - Каталогизација у публикацији
Библиотека Матице српске, Нови Сад

624(082)
69(082)

ДРУШТВО грађевинских конструктера Србије. Симпозијум (2016 ; Златибор)
Zbornik radova [Elektronski izvori] / Društvo građevinskih konstruktera Srbije, Simpozijum, 15-17. septembar, Zlatibor ; [urednici Đorđe Lađinović, Zlatko Marković, Boško Stevanović]. - Beograd : Društvo građevinskih konstruktera Srbije, 2016. - 1 elektronski optički disk (CD-ROM) ; 12 cm

Radovi na srp. i engl. jeziku. - Bibliografija uz svaki rad. - Rezime na engl. jeziku uz pojedine radove.

ISBN 978-86-7892-839-0

a) Грађевинарство - Зборници
COBISS.SR-ID 308004359

Izdavač: **Društvo građevinskih konstruktera Srbije**
Beograd, Bulevar kralja Aleksandra 73/I

Urednici: prof. dr **Đorđe Lađinović**
prof. dr **Zlatko Marković**
prof. dr **Boško Stevanović**

Tehnički urednik: doc. dr **Jelena Dobrić**

Tehnička priprema: asist. **Nina Gluhović**
asist. **Marija Todorović**

Gafički dizajn: asist. **Tijana Stevanović**

Dizajn korica: asist. **Jelena Dragaš**

Štampa: **Grafički centar – GRID**
Fakultet tehničkih nauka Univerziteta u Novom Sadu

Tiraž: **250 primeraka**

Beograd, septembar 2016.

ДГКС
Друштво грађевинских конструктера Србије
ASES
Association of Structural Engineers of Serbia
SIMPOZIJUM 2016
ZLATIBOR
15-17. 09. 2016.

Nina Gluhović[1]*, Zlatko Marković*[2]*, Milan Spremić*[3]*, Marko Pavlović*[4]

S-31

EKSPERIMENTALNO ISPITIVANJE X-HVB MOŽDANIKA U PREFABRIKOVANIM SPREGNUTIM PLOČAMA

Rezime:

Savremeni trendovi u građevinarstvu koji se ogledaju u povećanim zahtevima u pogledu ubrzane gradnje i što manjem obimu radova na gradilištu, uslovili su razvoj različitih vrsta prefabrikovanih ploča i grupnu raspodelu moždanika. Kratak prikaz osnovnih karakteristika X-HVB moždanika i eksera za vezivanje moždanika sa čeličnim profilom dat je u ovom radu. Ekspreimentalno ispitivanje X-HVB moždanika kroz standardni test smicanja, prema EC4:2004, prikazano je u ovom radu. Ispitivane su dve različite orijentacije moždanika u odnosu na pravac sile smicanja.

Ključne reči: X-HVB moždanik, prefabrikovane spregnute ploče, test smicanja

EXPERIMENTAL INVESTIGATION OF X-HVB SHEAR CONNECTORS IN PREFABRICATED COMPOSITE DECKS

Summary:

Increasing demands towards fast construction and smallest possible quantity of work resulted in development of different types of prefabricated composite decks and group arrangement of shear connectors. Short presentation of basic characteristics of X-HVB shear connectors and powder-actuated fasteners is given in this paper. Experimental investigation of X-HVB shear connectors through standard push-out tests, according to EC4:2004, is presented in this paper. Two different orientations of shear connectors, forward and backwards to the shear force are experimentally investigated.

Key words: X-HVB shear connectors, prefabricated composite decks, push-out test

[1] Teaching assistant, PhD student, Faculty of Civil Engineering, University of Belgrade
[2] Full professor, PhD, Faculty of Civil Engineering, University of Belgrade
[3] Assistant proffesor, PhD, Faculty of Civil Engineering, University of Belgrade
[4] Assistant proffesor, PhD, Faculty of Civil Engineering and Geosciences, Delft University of Technology

1 INTRODUCTION

Construction industry is constantly facing new demands towards fast construction and smallest possibly quantity of work at the construction site. Steel-concrete composite beams have been used in the construction of buildings and bridges for decades. In the field of steel-concrete composite structures, in-situ casted concrete decks often require great quantity of work at the construction site and additional time needed for concrete to achieve the necessary strength. In the recent decades, development of different types of prefabricated composite decks has taken an important place in the field of composite constructions.

Composite action between steel profile and prefabricated composite deck is achieved with group arrangement of shear connectors in envisaged openings of prefabricated decks. Less quantity of work at the construction site is related with smaller quantity of concrete needed to infill openings. The most important characteristics of X-HVB shear connectors and powder-actuated fasteners are shown in this paper. Also, results of experimental investigation of X-HVB shear connectors positioned in envisaged openings of prefabricated composite decks through standard push-out tests are presented in this paper. Different characteristic shear resistance and ductility is obtained for two examined orientations of shear connectors.

2 SHEAR CONNECTORS

Different types of shear connectors used for composite action between steel profile and concrete deck were developed during decades and are shown in Figure 9.

a) headed studs [1]   b) bolted connectors [2]   c) X-HVB connectors

d) perfobond rib [3]   e) T-perfobond [3]   f) U channels [2]

Figure 9 - Different types of shear connectors

The use of various types of shear connectors for composite constructions (see Figure 9) consider important differences regarding different quantity of work during installation, different preparation process of base material and appropriate atmospheric conditions during installation. Also, three main properties of shear connectors: shear resistance, stiffness and ductility are specific for each type of shear connector and need to be considered for their application in composite constructions.

Welded headed studs (Figure 1a) are the most often used shear connectors for steel-concrete composite decks of buildings and bridges. Design rules for those shear connectors can be found in current design codes, such as EC4:2004 [4] and ANSI/AISC-360-05 [5]. This type of connector is used worldwide, mainly due to a high degree of automation on work site. Also, it has some restrictions considering structures submitted to fatigue and requirements for specific welding equipment. Recent experimental and numerical investigations are related to the behavior of different group arrangement of headed studs positioned into envisaged openings of prefabricated composite decks through standard push-out tests [1]. The findings of the study [1] are that the reduction of the distance between the adjusted headed studs in force direction can be allowed. Experimental results confirmed that it is no need for reduction of studs' group shear resistance even in cases when the distance between the headed studs is smaller than the value prescribed by EC4:2004 [4]. Also full-scale beam experiments have been conducted in recent period in order to investigate strengthening of existing composite steel-concrete beams utilizing bolted shear connectors and welded studs [6].

Bolted shear connectors have been rarely used in construction, actually just for rehabilitation works, because there is a lack of detail research and design recommendations for this type of shear connector. Different types of bolted shear connectors can be used for composite action, such as: friction grip bolts, bolts without embedded nuts, bolts with single embedded nut (see Figure 1b) and bolts with double embedded nuts. Different stiffness, ductility and resistance is obtained for different types of bolted shear connectors and the most similarities considering welded headed studs are obtained with bolts with single embedded nut. Experimental and numerical investigation of bolted shear connectors in prefabricated composite decks, conducted in recent years, proposed connections with two nuts, one of which is embedded in the concrete as the best solution [2].

X-HVB shear connectors are used with powder-actuated fasteners for achievement of composite action between steel profile and composite decks. Basic characteristics of this type of shear connector and powder-actuated fasteners will be explained in this paper.

Perfobond rib (see Figure 1d) was developed in the late 1980s in attempt to overcome fatigue problems caused by live loads in composite bridges, and included rectangular steel plate with number of holes, welded to the beam flange. The resistance in both horizontal and vertical direction is enabled with concrete which flows through holes in steel plate. A numerous push-out and composite beam tests, as well as numerical simulations have been used in studies on the shear capacity and behavior of the perfobond rib connectors which resulted in different design recommendations of this type of connector. The structural response of perfobond rib connectors is influenced by several geometrical properties such as the number of holes, the plate height, length and thickness, the concrete compressive strength, and the percentage of transverse reinforcement provided in the concrete slab [3], [7]. T-perfobond connectors (see Figure 1e) were developed by adding a flange to the perfobond rib plate, which acts as a block combining the large strength of a block type connector with some ductility and uplift resistance arising from the holes at the perfobond rib connector. For similar longitudinal plate geometries, the resistance and stiffness of T-perfobond connectors are higher than that of perfobond rib connectors.

Chanel shear connectors (see Figure 1f) offer higher amount of shear resistance due to its large contact area with surrounding concrete. This type of connector does not require special equipment and standard welding procedures are adequate for installation process. The results of the push-out test showed that the resistance of the composite construction can be affected by other factors apart from the concrete strength, which include flange thickness, web thickness and channel length. Design recommendations for this type of shear connector are given in current design codes, such as ANSI/AISC-360-05 [5] and CAN/CSA-S16-01 [8]. Experimental investigation of channel type shear connectors, which represent different European channel profiles named UPN profiles, with various heights and lengths and considering different concrete material properties has been performed in recent period [9], [10].

2.1 CHARACTERISTICS OF X-HVB SHEAR CONNECTORS AND POWDER-ACTUATED FASTENERS

X-HVB shear connectors (see Figure 1c) are connected to the steel profile with two powder-actuated fasteners and represent alternative for the headed studs and bolted shear connectors for construction of steel-concrete composite structures. Compared to the former mentioned types of shear connectors, X-HVB shear connectors have some advantages, such as:

- Minimal installation equipment and short installation time which are very important considering new demands towards fast construction. X-HVB shear connectors are directly fastened to steel profile with two X-ENP-21 HVB nails and require no welding. A portable, hand-held, powder-actuated fastening tool is used to drive a high-strength steel fastener directly into the base material.

- Installation quality is not affected by atmospheric conditions (such as moisture), by base material coatings (zinc coatings) or paints, resulting in less work interruptions due to atmospheric conditions or additional preparation of base material at the position of connectors. This ensures relatively simple and fast installation of X-HVB shear connectors for construction of new buildings and also for renovation of existing buildings.

- Simple check of installation quality, performed through visual checking of the stand-off over the surface of the fastened material, or for fasteners that don’t allow an accurate visual check, the use of stand-off template is recommended. Installation quality recommendations for X-ENP-21 HVB nails used for X-HVB shear connectors are shown in Figure 10.

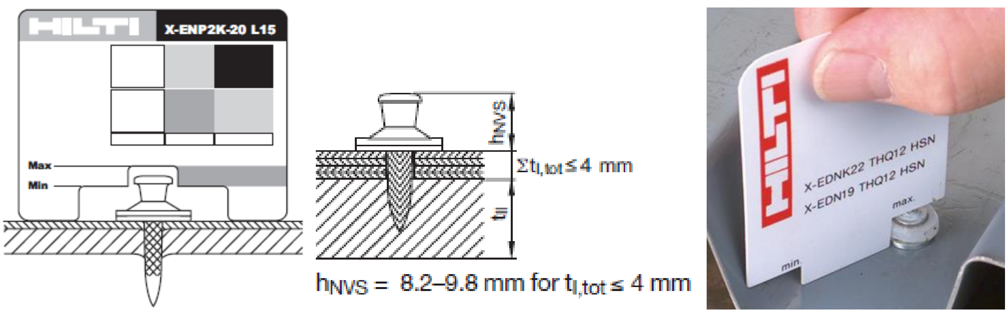


Figure 10 - Installation quality recommendations for X-ENP nails [11]

Powder-actuated fasteners are nails or threaded studs made from high-strength steel, used to fasten components to steel, concrete and masonry [12]. During installation process, depth of fastener penetration is the distance between upper surface of the base material and the point of the fastener. Fastener stand-off h_{NVS} is the distance from the head of the fastener to the surface of the fastened component materials with thickness $t_{I,tot}$. Fastener stand-off h_{NVS} is the reference dimension used to check the depth of penetration and thus the quality of the fastening installation (see Figure 10).

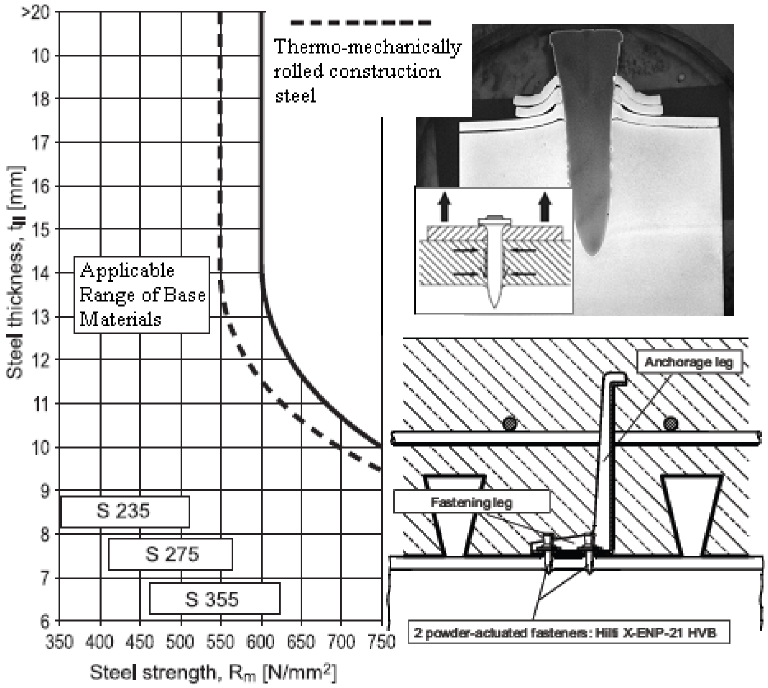
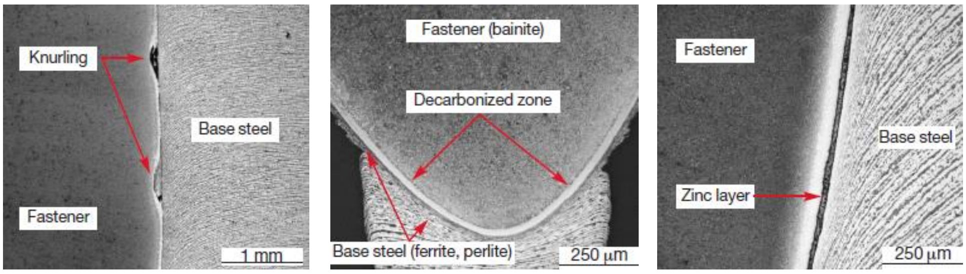


Figure 11 – Application limit diagram and clamping of the powder-actuated fastener [11]

Application range of the X-ENP-21 HVB nails used for installation of X-HVB connectors (see Figure 11) are determined by the thickness and strength of fastened component material (t_{II}) and base material.



a) keying *b) welding* *c) soldering*

Figure 12 – Anchorage mechanisms of powder-actuated fastener [11]

The term “anchorage” refers to the hold obtained by the fastener in the base material [12]. Pull-out of the fastener from the base material is the result of the failure of the anchorage (see Figure 11). Metals with pronounced plastic behavior used for base material generally provide suitable anchorage for the powder-actuated fasteners. Different anchorage mechanisms and principles are pronounced considering powder-actuated fasteners such as clamping, keying, welding and soldering (see Figure 11 and Figure 12). Clamping is the primary anchoring mechanism. This anchoring mechanism is a result of the steel base material displacement radially and towards base material surface and fastener point during installation providing pressure on the nail surface and friction. Keying and welding are very important anchoring mechanisms for fasteners that do not penetrate through base material. Keying mechanism is characteristic for knurled fasteners, such as X-ENP-21 HVB nails. Knurled surface of the fastener enables accumulation of zinc and base material during installation process (see Figure 12a). Welding mechanism is observed mostly at the point of a fastener where the temperature during installation can be expected to be the highest and is influenced by the base material surface which is in the contact with fastener point and decarbonized zone (see Figure 12b). Soldered zinc layer between fastener and base material further form the fastener point (see Figure 12c) also contributes to the pull-out resistance and represent another anchoring mechanism.

X-HVB shear connectors are L shaped connectors which consists form fastening leg connected to the base material with the two powder-actuated fasteners (X-ENP-21 HVB nails) and anchorage leg which is cast into the concrete (see Figure 11). Shear resistance of different types of X-HVB connectors are determined through push-out tests and beam tests using solid concrete decks and composite decks and design recommendations are given in HILTI Direct Fastening Technology Manual [11]. X-HVB connectors show ductile behavior, considering recommendations given in EC4:2004 [4]. Shear resistance of this type of shear connectors is a combination of different parameters, such as hole elongation in the fastening leg, anchorage mechanisms, bending of the fasteners, deformation of the concrete in the connectors surrounding zone.

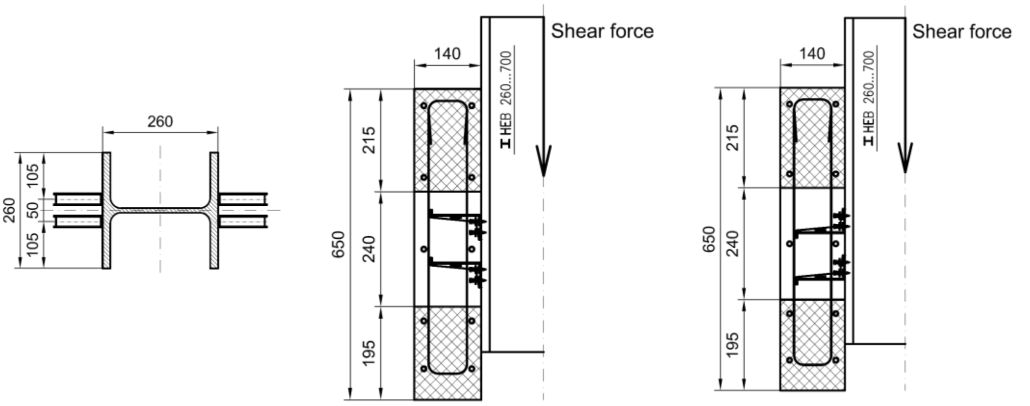
3 STANDARD PUSH-OUT TESTS

Standard push-out tests were prepared and examined in the Laboratory of Materials and Structures at the Faculty of Civil Engineering in Belgrade, according to EC4:2004 [4]. Experimental investigation of X-HVB shear connectors was performed in order to investigate the behavior of X-HVB shear connectors positioned into envisaged openings of full depth prefabricated composite decks, including influence of different orientations of connectors.

3.1 TEST SET-UP

Concrete slabs (600x650x140 mm) with standard reinforcement layout (ribbed bars ø10 mm, grade R500) are prefabricated by casting them in horizontal position. Openings with dimensions 240x240 mm in the middle of the slabs are envisaged for later assembly of shear connectors. X-HVB 110 shear connectors were installed to HEB 260 steel profile flange at the transversal distances of 50 mm and longitudinal distances of 100 mm, which are minimal distances recommended by HILTI [11]. Shear connectors are positioned in two directions, forward (HSF specimen) and backwards (HSB specimen) to the shear force. Layout and dimensions of the specimens are shown in Figure 5.

Envisaged openings are filled in horizontal position with three-fraction concrete. In order to minimize initial cracks due to shrinkage, specimens are kept in wet condition during first three days. After three days, half assembled specimens are turned and second assembling phase is performed in the same way as the first one.



a) steel profile *b) forward orientation-HSF-1* *c) backward orientation-HSB-1*

Figure 13 – Specimens layout

Test set-up for both specimens is shown in Figure 6. Longitudinal slip between the steel profile and both concrete slabs is measured with 4 sensors, two on each side. Separation between steel profile and concrete slabs is measured on the front side, as close as possible to connectors. Separation between prefabricated slabs is measured on the front side, 15 cm above the slab support.

a) testing frame

Figure 14 – Test set-up

The loading regime is adopted as specified in EC4:2004, Annex B [4]. Force controlled cycling load is applied in 26 cycles ranging from F_{min}=15 kN to F_{max}=110 kN, corresponding to approximately 5% and 40% of expected shear resistance. Shear resistance of eight connectors in one specimen is 280 kN, based on characteristic shear resistance of one X-HVB 110 connector F_{Rk}=35 kN, according to HILTI Direct Fastening Technology Manual 2014 [11].

3.2 EXPERIMENTAL RESULTS

Experimental investigation included different orientation of shear connector's (HSF-1 and HSB-1 specimens). Results of push-out tests for both specimens are shown in Figure 15 and Table 1.

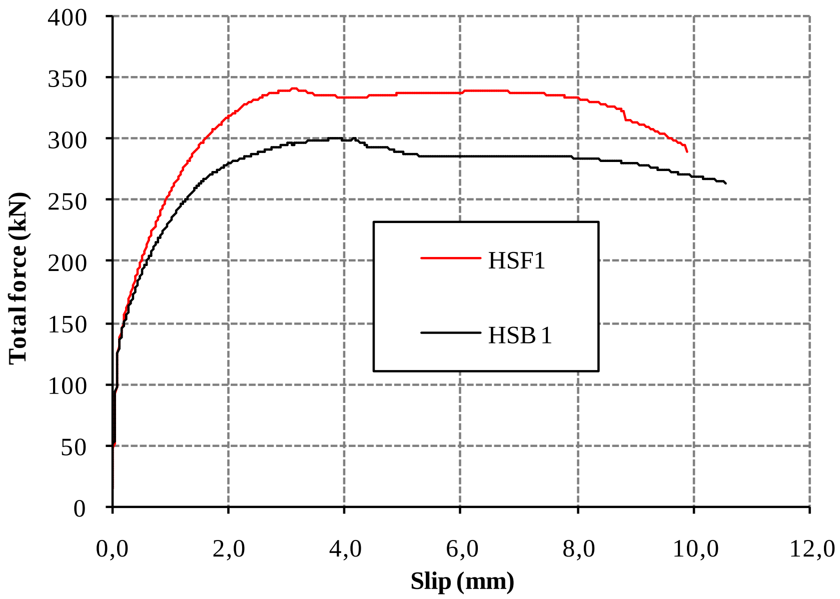


Figure 15 – Force-slip curves for HSF-1 and HSB-1 specimens

a) HSF specimen *b) HSB specimen*

Figure 16 – Infill concrete after push-out tests

Shear force P_{ult} is defined as total ultimate force for all shear connectors of one specimen. Longitudinal slip between steel section and concrete slabs is measured with four sensors and divided in initial slip during cyclic loading δ_{init} and slip to failure δ_u, as total slip $\delta_{u,tot}=\delta_{init}+\delta_u$.

Table 2 – Results of standard push-out tests

Series	Ultimate force (kN)	Slip (mm)			Separation (mm)	
		initial	to failure	total	between slabs	steel to concrete
	P_{ult}	δ_{init}	δ_u	$\delta_{u,tot}$		
HSF-1	341.7	0.12	9.69	9.81	2.32	1.69
HSB-1	301.3	0.15	10.19	10.34	2.82	2.40

Higher ultimate shear resistance P_{ult} is obtained for HSF specimen in comparison to the HSB specimen. Infill concrete zones of both specimens are shown in Figure 16. Higher damage of concrete and connector deformation is obtained for HSB-1 specimen than for HSF-1 specimen. The initial stiffness is the same for both specimens, HSF-1 and HSB-1.

For both experimentally investigated orientation of shear connectors slip to failure δ_u is higher than δ_{uk} = 6 mm which is the minimum required in EC4:2004 [4] to consider this type of shear connection as ductile.

4 CONCLUSIONS

HILTI X-HVB 110 connectors with X-ENP-21 HVB nails in full depth prefabricated concrete slabs are investigated for the purpose of possible application in prefabricated steel-concrete composite construction. Approximately 13 % higher ultimate shear resistance is obtained for HSF-1 specimen (forward orientation of shear connectors) in comparison to the HSB-1 specimen (backwards orientation of shear connectors). Different failure modes are obtained for different orientations of shear connectors, considering much higher deformation of shear connectors and concrete damage for HSB specimen. For both experimentally investigated specimens minimal required slip to consider the shear connection as ductile is achieved.

ACKNOWLEDGEMENTS

This research project is entirely funded by the HILTI Aktiengesellschaft, Schaan, Liechtenstein. This investigation is the part of TR-36048 project supported by the Serbian Ministry of Education, Science and Technological Development. Experimental investigation is conducted in the Laboratory of Materials and Structures at the Faculty of Civil Engineering in Belgrade.

REFERENCES

[1] Spremić M., Marković Z., Veljković M., Buđevac D.: *Push-out experiments of headed shear studs in group arrangements*, Advanced Steel Construction, 2013, 9(2):170-91.

[2] Pavlović M., Marković Z., Veljković M., Buđevac D.: *Bolted shear connectors vs. headed studs behaviour in push-out tests*, Journal of Constructional Steel Research, 2013; 88:134-149.

[3] J.da.C Vianna, L.F. Costa-Neves, P.C.G. da S. Vellasco, S.A.L. de Andrade: *Experimental assessment of Perfobond and T-Perfobond shear connectors' structural response*, Journal of Constructional Steel Research, 2009; 65:408-421.

[4] EN1994-1-1: Eurocode 4： *Design of composite steel and concrete structures. Part 1-1: General rules and rules for buildings*, Brussels, Belgium: European Committee for Standardization (CEN), 2004.

[5] ANSI/AISC-360-05 An American National Standard: *Specification for structural steel buildings*, American Institute of Steel Construction, Chicago, Illinois, 2005.

[6] S.W. Pathirana, B. Uy, O. Mirza, X. Zhu: *Strengthening of existing composite steel-concrete beams utilizing bolted shear connectors and welded studs*, Journal of Constructional Steel Research, 2015; 114:417-430.

[7] J.da.C Vianna, S.A.L. de Andrade, P.C.G. da S. Vellasco, L.F. Costa-Neves: *Experimental study of Perfobond shear connectors in composite construction*, Journal of Constructional Steel Research, 2013; 81: 62-75.

[8] CSA Standard CAN/CSA S16-01: *Limit states design of steel structures*, Toronto, Ontario, Canadian Standards Association (CSA), 2001.

[9] E. Baran, C. Topkaya: *An experimental study on channel type shear connectors*, Journal of Constructional Steel Research, 2012; 74: 108-117.

[10] S. Maleki, S. Bagheri: *Behavior of channel shear connectors, Part I: Experimental study*, Journal of Constructional Steel Research, 2008; 64: 1333-1340.

[11] HILTI *Direct Fastening Technology Manual* 2014, S.E. & O, Germany, April 2014.

[12] H. Beck, M. Siemers, M. Reuter: *Powder-actuated fasteners and fastening screws in steel construction*, Steel Construction Calendar, 2011, Ernest & Sohn-DSTV.

[13] EN1990:2002 Eurocode – Basis of structural design. Brussels, Belgium: European Committee for Standardization (CEN), 2002.