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Investigation of pipe shear connectors using push out test

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Abstract. Mechanical shear connectors are commonly used to transfer longitudinal shear forces across the steel-concrete interface in composite beams. Steel pipe as a new shear connector is proposed in this research and its performance to achieve composite strength is investigated. Experimental monotonic push-out tests were carried out for this connector. Then, a nonlinear finite element model of the push-out specimens is developed and verified against test results. Further, the finite element model is used to investigate the effects of pipe thickness, length and diameter on the shear strength of the connectors. The ultimate strengths of these connectors are reported and their respective failure modes are discussed. This paper comprises of the push-out tests of ten specimens on this shear connector in both the vertical and horizontal positions in different reinforced concretes. The results of experimental tests are given as load-deformation plots. It is concluded that the use of these connectors is very effective and economical in the medium shear demand range of 150-350 KN. The dominant failure modes observed were either failure of concrete block (crushing and splitting) or shear failure of pipe connector. It is shown that the horizontal pipe is not as effective as vertical pipe shear connector and is not recommended for practical use. It is shown that pipe connectors are more effective in transferring shear forces than channel and stud connectors. Moreover, based on the parametric study, a formula is presented to predict the pipe shear connectors' capacity.

Keywords: push-out test; pipes; shear connectors; reinforced concrete; composite beams; monotonic loading

1. Introduction

Steel–concrete composite structural systems are widely used in buildings and bridges around the world. The most general form of such a system is the composite flexural members that are formed by connecting a steel beam to a concrete slab by shear connectors (Ahn *et al*. 2007, Khorramian *et al*. 2015, Rehman *et al*. 2016, Shariati *et al*. 2016, Tahmasbi *et al*. 2016). The efficiency of composite beams stems from the fact that concrete slab is strong in compression and steel beam is strong in tension. Concrete can also provide support for compression steel against lateral-torsional and local buckling of the compression flange. Composite beams offer several advantages over conventional beams such as, a reduction in size due to higher strength and a reduction in deflection and floor vibration due to higher stiffness. However, mechanical connectors for shear transfer are needed in such beams to achieve the desired composite behavior. The shear connectors are placed at the interface between the steel beam and concrete slab, and they are responsible for transferring the horizontal shear forces that are formed due to flexural action. The connectors also transfer shear forces resulting from earthquake inertia loads generated in the floor diaphragm. In addition, the connectors prevent premature separation of the steel beam from the concrete slab in the vertical direction (Safa *et al*. 2016).

A variety of shapes and devices have been used as shear connectors in steel-concrete composite structures since these structures are types of system that combines the advantages of steel and reinforced concrete structure. Economic considerations continue to motivate the development of new systems. The most commonly used type of shear connector is the headed stud, known as the Nelson stud (Fig. 1(a)). Viest (1956) was the first researcher who studied the behavior of headed studs.

Leonhardt *et al*. (1987) developed a new type of connector called the Perfobond rib (Fig. 1(b)). This connector was introduced in recognition of the unsatisfactory fatigue performance of headed studs caused by live loads on composite bridges.

In the scope of a study on Perfobond connectors, Vianna *et al*. (2009) presented another alternative connector for headed studs, called the T-Perfobond (Fig. 1(c)). This was created by adding a flange to the vertical plate to enhance performance.

Another type of shear connector is Oscillating Perfobond Strips (Fig. 1(d)) that their performance was tested by Galjaard and Walraven (2000). As compared to the headed studs and T-shape connectors, this type of

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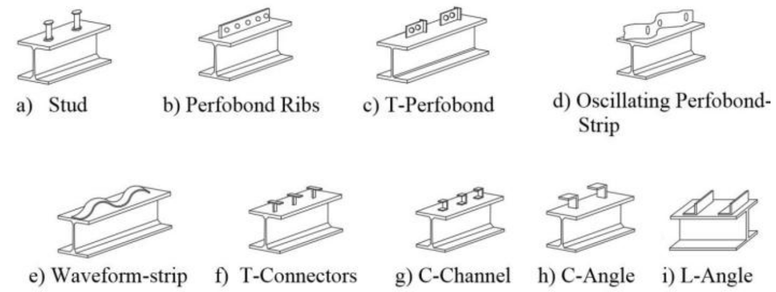


Fig. 1 Typical shear connectors

connector has larger load capacity.

Waveform Strips is another connector with curves (Fig. 1(e)). The objective of the curved form is to improve the transfer of force between the steel and the surrounding concrete as opposed to a straight connector (Galjaard *et al*. 2001). T-Connectors as another shear connector is a piece of a standard T-section welded to the flange of an H or I section with fillet welds (Fig. 1(f)). T-connectors were investigated by Oguejiofor and Hosain (1997).

Presently, the headed stud is the most widely used shear connector in composite construction. Its popularity stems from the proven performance and the ease of installation using a welding gun. Nonetheless, due to the small load carrying capacity of stud connectors, they have to be installed in large numbers. This usually produces a cluttering effect and an unsafe working place. In many areas of the world, channel shear connectors are widely used due to the availability of cheap labor for welding. The C-shaped shear connectors can be made with both angle (Fig. 1(g)) and channel (Fig. 1(h)) profiles. The angle profiles can also be used as L-shaped shear connectors (Fig. 1(i)).

Channel shear connectors were used in the scale-model of composite bridges and were initially tested at the University of Illinois by Siess *et al*. (1952).

Angle connectors, as compared to channel connectors, could be more economical due to the absence of bottom flange which ultimately saves more steel. However, the shear capacity of angle connectors is lower. Rao (1970) described the primary results of the push out tests conducted on samples with several shear connectors comprise of angle shear connectors.

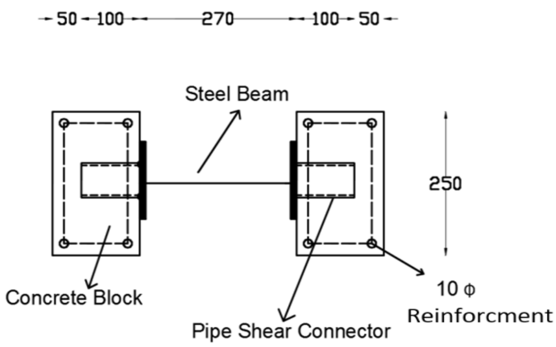
Currently, the North American steel design codes for buildings and bridges only provide design strength formulas for channel and stud connectors. The shear strength of connectors is usually determined by the push-out tests or complete full scale composite beam tests (Slutter and Driscoll 1965, Maleki 2002, Maleki and Bagheri 2008, Shariati *et al*. 2012a). The complete full scale composite beam test is more accurate, but very costly. The direct pull-out test is also another option but it needs special equipment. The push-out tests have been widely performed on stud connectors in reinforced concrete or concrete with profiled steel sheeting (Dallam 1968, Yan *et al*. 2014). Several tests have also been performed on channel shear connectors by the authors of this research (Maleki and Bagheri 2008, Shariati *et al*. 2012b) and other researchers (Dallam 1968, Pashan 2006) as well.

This paper investigates the possibility of using steel pipes as shear connectors (Figs. 2 and 3) in composite steel beams. A limited number of experimental studies are available on the shear transmission by steel pipes in composite systems. For example, Frosch (1999) conducted an experimental study to evaluate the shear transfer between precast infill wall panels and concrete elements of the building frame using steel pipe connectors. Also, shear transfer between a concrete slab and a laminated veneer lumber (LVL) beam using steel pipe was investigated experimentally by Deam *et al*. (2008). However, experimental and analytical investigations of steel pipes as composite beam shear connectors have not been documented. The pipe connector can be installed vertically as in Fig. 2 or horizontally as shown in Fig. 3. It will be shown later that the latter is more efficient and carries more load.

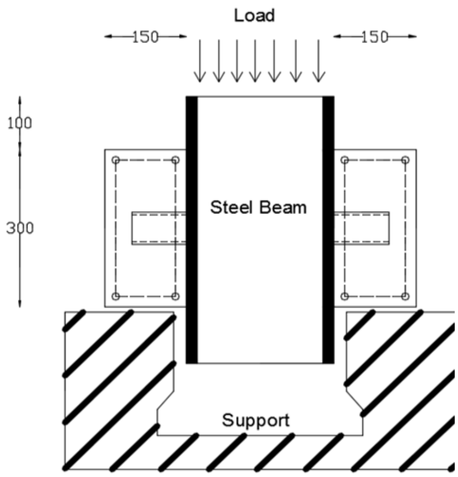
In this paper, the results of ten push out tests on different sizes of steel pipes are presented. All pipes are welded vertically to the beam flanges, except for one specimen which is horizontally welded.

Fig. 2 Pipe shear connector-Vertical Pipe

Fig. 3 Pipe shear connector-Horizontal Pipe



(a) Plan view

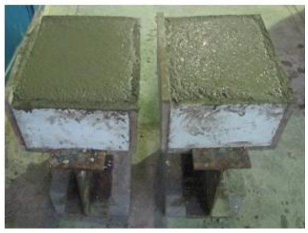


(b) Front view

Fig. 4 Schematic view of push-out test for pipe connector

(a) Beams with welded pipes

(b) Molding and rebar replacement



(c) Poured concrete

Fig. 5 Construction of push-out specimens

2. Experimental program

2.1 General

The shear capacity of any connector embedded in concrete can be evaluated by the push-out test. Fig. 4 shows a typical push-out test experimental set up.

The steel beam is connected to concrete blocks on both flanges via shear connectors and is pushed down by the testing machine monotonically till failure. The concrete blocks are supported from below and the steel beam is free to move vertically. Currently, the dimensions of the push-out test specimen is only standardized by Eurocode 4 (1997). EC4 uses 650×600×150 mm concrete blocks on the two sides of a steel beam and two rows of stud shear connectors. However, most available test data are not strictly following the suggested dimensions especially, when the connector is not a stud shear connector.

2.2 Push-out specimens

Ten push-out specimens with dimensions and properties as shown in Tables 1 and 2 were constructed.

The specimens consist of a rolled steel IPE270 profile with two pipe shear connectors attached perpendicular to each flange via fillet welds. These shear connectors were embedded in 150×250×300 mm concrete blocks with 50 MPa average compressive strength at 28 days. Their behaviors when embedded in reinforced normal concrete are used since the loading environment plays a significant role in influencing the performance of concrete structures

Table 1 Specimens properties

Specimen designation	Specimen number	Pipe diameter (mm)	Pipe thickness (mm)	Pipe length (mm	Concrete strength (MPa)
P60-3	1&2	60.3	2.9	100.0	50.0
P70-4	1&2	79.2	4.0	100.0	50.0
P90-4	1&2	88.9	4.0	100.0	50.0
P114-3	1&2	114.0	3.2	100.0	50.0
P60-4	1	60.0	4	100.0	21.50
Ph114-5 (Horizontal)	1	114.0	5.0	50.0	23.50

Table 2 Steel properties

	Steel part	Size (mm)	Yield strength (MPa)	Ultimate strength (MPa)
1	Beam	IPE270	240.0	380.0
2	Pipes	60.0, 70.0, 90.0, 114.0	320.0	385.0
3	Rebar	Φ10	300.0	500.0

Table 3 Particle size analysis for silica sand (SS) based on BS 822: Clause 11

Sieve size (μm)	Sieve No.	WSS+ WS(g)	WS(g)	WSS(g)	Ret.%	Cum.Ret.%	Pass %
4750	3/16 in	409.9	408.3	1.6	0.32	0.032	99.68
2360	NO.7	462.3	375.7	86.6	17.33	17.65	82.35
1180	NO.14	437.2	343.0	94.2	18.85	36.50	63.50
600	NO.25	450.7	316.2	134.5	26.93	63.42	36.58
300	NO.52	379.1	288.7	90.4	18.09	81.51	18.49
150	NO.100	322.1	274.8	47.3	9.47	90.99	9.02
75	NO.200	309.9	275.2	34.7	6.94	97.92	2.08
Pan	-	250.8	240.4	10.4	2.08	-	0.00
total				499.7		388.31	

* Fineness modulus = 388.31/100 = 3.88; Water absorption for silica sand is 0.93%;
W_{SS} = Silica sand weight; W_S = Sieve weight; Cum. Ret = Cumulative retained

Table 4 Composition of cementitious materials for OPC and slag used (% by mass)

P2O5	SiO2	Al2O3	MgO	Fe2O3	CaO	MnO	K2O	TiO2	SO3	CO2	LOI
0.068	18.47	4.27	2.08	2.064	64.09	0.045	0.281	0.103	4.25	4.20	1.53

Fig. 6 Push-out test setup

(Bhutta *et al*. 2013, Chen *et al*. 2015).

In order to see the effect of concrete strength on shear capacity, P60-4 specimen with 21.5 MPa concrete strength was also tested. Specimen Ph114-5 is the only specimen with the pipe in horizontal position. The construction process is shown in Fig. 5 and the concrete was poured from the top of the pipes, as is the case in practice.2

The ten specimens (2 of each from the first four rows of Table 1) have different pipe diameters and thicknesses but have a constant length of 10 cm to fit in the concrete block thickness of 15 cm. The specimens are designated by their nominal diameter and wall thickness (see Table 1).

2.3 Materials and mix proportions

Natural gravel with maximum nominal size of 12.5 mm was used as coarse aggregate in the concrete mix. The particle size analysis of the fine aggregates is given in Table 3 (Razak and Sajedi 2011).The cement used in all mixes was normal Portland cement, which corresponds to ASTM C150 (Sajedi and Razak 2010) type II with chemical properties shown in Table 4 (Sajedi 2011). The water cement ratio was kept at 0.45 for all mixes.

Following ASTM C39 for compressive strength test, six standard 150×300 mm cylinders were cast from the mix design. The specimens were cured in water at a temperature of 23±1. After curing, the cylinders were tested in compression with a loading rate of 5 kN/s. The average compressive strengths of the specimens are shown in Table 1. The properties of steel which was used in test specimens are shown in Table 2. To attach the pipe shear connectors to the beam flanges, 4 mm fillet weld made with E6018 electrode was used.

2.4 Push-out test setup

Push-out test specimens were tested by the Universal (MTS) Machine. Displacement control method of loading was used with a rate of 0.1 mm/s. The uniform load was applied to the top of IPE270 profile and the two bottom ends of concrete blocks were supported on the bench.

The load-slip curve was automatically plotted by the MTS software. The tests continued until failure occurred in the specimens. The push-out test setup is shown in Fig. 6.

3. Push-out test results

The results of the monotonic push-out tests of the ten specimens are presented in Fig. 7 and Table 5.

All results for shear capacity are reported for one shear connector. After the test, for investigating the behavior of pipe shear connectors, concrete blocks of specimens were demolished. The dominant failure modes observed were either failure of concrete block (crushing and splitting) or shear failure of pipe connector. The former occurs due to

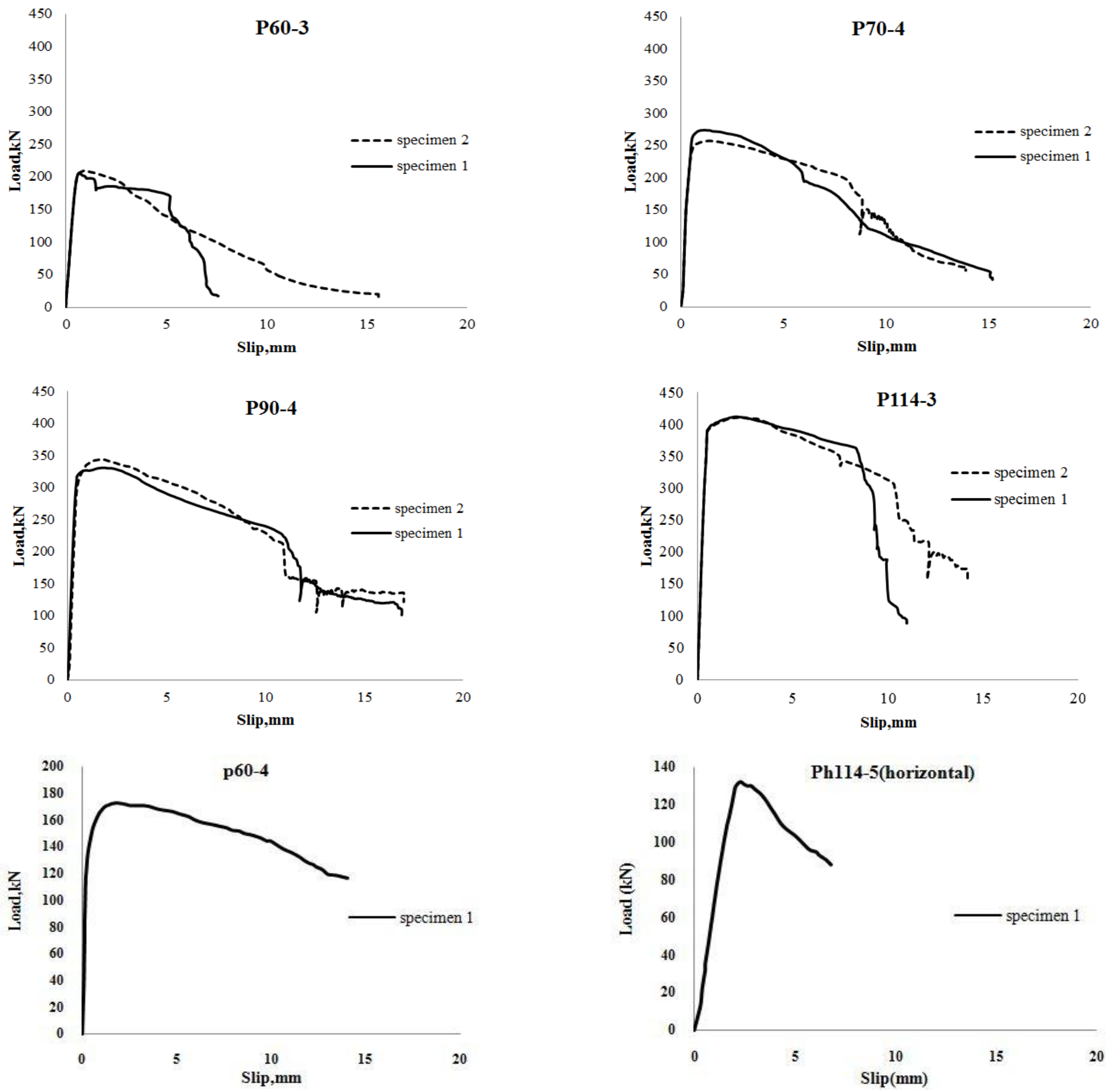


Fig. 7 Experimental load-slip curve

high compressive stress at the bottom surface of concrete block and tensile cracking above the connector because of connector's slip. The shear connector failure initiates with yielding and cracking at the base of the pipes just above the weld.

Specimen-1 of P60-3 showed wide cracks above the shear connector and eventually failed by yielding of the left side pipe connector. At this instant the load-slip diagram drops down sharply. Specimen 2 had the same behavior at a slower rate. Apparently, the connector lasted longer. However, the concrete splitting was excessive.

In specimens P70-4, load reduction occurred at a slow rate after reaching the ultimate strength. Because of increasing slip, large cracks in concrete were observed, which led to failure. The pipe connector also showed small cracks. The behavior of specimen P90-4 is very similar to P114-3. Because of larger pipe diameters the confined concrete inside the pipes play a bigger role in controlling the shear and the peak load increases. In these specimens the pipes did not fail and the mode of failure was always concrete crushing/splitting. Specimen P60-4 carried an ultimate load of 173 kN, slightly lower than 200 kN that P60-3 carried, and that is despite 1 mm extra thickness. This is mainly due to compressive strength of concrete, which was less than half of the P60-3 specimen. It will be shown later that the shear strength is related to square root of fc.

Specimen Ph114-5 is the only horizontal pipe specimen and is presented for comparison purposes. As seen from Fig. 6 the ultimate load carried was 133 kN with a very ductile behavior. As seen from Fig. 7, specimen P114-3 which has the same diameter pipe carried 400 kN of shear load with 50 MPa concrete strength. This clearly shows that the horizontal pipe is not as effective as vertical pipe shear connector and is not recommended for practical use. From Fig. 7, one can also conclude that larger diameter pipes increase strength and ductility of the composite system. No significant separation between the concrete block and the beam in the perpendicular direction was observed in the

Table 5 Failure modes of pipe shear connectors

No.	Specimen's name	Failure mode	Specimen 1	Specimen 2
1	P60-3	Pipe shear failure in 1 Concrete crushing/splitting in 2		
2	P70-4	Concrete crushing/splitting		
3	P90-4	Concrete crushing/splitting		
4	P114-3	Concrete crushing/splitting		

tests. This usually shows up as sliding of concrete blocks on the bench in the outward direction. Note that friction between the concrete block and the seat bench is the only restraining force in the horizontal direction with this test setup arrangement.

4. Conclusions

This paper reported the results of a series of monotonic push-out tests performed on pipe shear connectors in the vertical and horizontal positions. A nonlinear finite element model of the push-out test was created for parametric studies and was verified against the test results. Based on the extensive numerical studies and the limited experimental results, the following conclusions can be drawn: The dominant failure modes observed were either failure of concrete block (crushing and splitting) or shear failure of pipe connector. The former occurs due to high compressive stress at the bottom surface of concrete block and tensile cracking above the connector because of connector's slip. The shear connector failure initiates with yielding and cracking at the base of the pipes just above the weld. It is concluded that the use of these connectors is very effective and economical in the medium shear demand range of 150-350 kN. One can also conclude that larger diameter pipes increase strength and ductility of the composite system. The results show clearly that the horizontal pipe is not as effective as the vertical pipe shear connector and therefore is not recommended for practical use. No significant separation between the concrete block and the beam in the perpendicular direction was observed in the tests. Vertical pipes are more effective in shear than horizontal pipe connectors. Shear capacity of vertical pipe connectors increases with concrete strength and is proportional to the square root of fc. Shear capacity of vertical pipe connectors increases with increased pipe diameter and thickness. The diameter has much more profound effect. Shear capacity of vertical pipe connectors is not sensitive to pipe length in the usual range of practical use. The pipe connector has shown a ductile behavior for the diameters considered in this paper. No significant separation between the concrete block and the beam in the perpendicular direction was observed in the tests and the FE models. The pipe outperforms studs in the low range and channels in the upper range in this demand interval. A formula is presented (Eq. (7)) for predicting pipe shear capacity based on the limited tests and extensive parametric FE study.

References

Ahn, J., Kim, S. and Jeong, Y. (2007), "Fatigue experiment of stud welded on steel plate for a new bridge deck system", *Steel Compos. Struct., Int. J.*, **7**(5), 391-404.

Bhutta, M.A.R., Maruya, T. and Tsuruta, K. (2013), "Use of polymer-impregnated concrete permanent form in marine environment: 10-year outdoor exposure in Saudi Arabia", *Constr. Build. Mater.*, **43**, 50-57.

Chen, L.Z., Ranzi, G., Jiang, S.C., Tahmasebinia, F. and Li, G.Q. (2015), "Behaviour and design of shear connectors in composite slabs at elevated temperatures", *J. Constr. Steel Res.*, **115**, 387-397.

Cornelissen, H.A.W., Hordijk, D.A. and Reinhardt, H.W. (1986), "Experimental determination of crack softening characteristics of normalweight and lightweight concrete", *Heron*, **31**(2), 45-56.

Dallam, L.M. (1968), "Push-out tests of stud and channel shear connectors in normal-weight and lightweight concrete slabs", Bulletin Series, University of Missouri-Columbia, Columbia, MI, USA.

Deam, B.L., Fragiacomo, M. and Buchanan, A.H. (2008), "Connections for composite concrete slab and LVL flooring systems", *Mater. Struct.*, **41**(3), 495-507.

Frosch, R.J. (1999), "Shear transfer between concrete elements using steel pipe connection", *ACI Structural Journal*, **96**(6), 1003-1008.

Galjaard, H. and Walraven, J. (2000), "Behaviour of shear connector devices for lightweight steel-concrete composite structures: results, observations and comparisons of static tests", *Second International Symposium on Structural Lightweight Aggregate Concrete*, Kristiansand, Norway, June.

Galjaard, H., Walraven, J.C. and Eligehausen, R. (2001), "Static tests on various types of shear connectors for composite structures", 1313-1322.

Hillerborg, A., Modéer, M. and Petersson, P.E. (1976), "Analysis of crack formation and crack growth in concrete by means of fracture mechanics and finite elements", *Cement Concrete Res.*, **6**(6), 773-781.

Khorramian, K., Maleki, S., Shariati, M. and Sulong, N.R. (2015), "Behavior of Tilted Angle Shear Connectors", *PLoS ONE*, **10**(12), e0144288.

Leonhardt, E.F., Andra, W., Andra, H.P. and Harre, W. (1987), "New improved shear connector with high fatigue strength for composite structures", *Neues vorteilhaftes Verbundmittel fur stahlverbund-Tragwerke mit hoher Danerfestigkeit*), *Beton-Und Stahlbetoubau*, **12**, 325-331.

Maleki, S. (2002), "Effect of deck and support stiffness on seismic response of slab-girder bridges", *Eng. Struct.*, **24**(2), 219-226.

Maleki, S. and Bagheri, S. (2008), "Behavior of channel shear connectors, Part I: Experimental study", *J. Constr. Steel Res.*, **64**(12), 1333-1340.

Oguejiofor, E.C. and Hosain, M.U. (1997), "Numerical analysis of push-out specimens with perfobond rib connectors", *Comput. Struct.*, **62**(4), 617-624.

Pashan, A. (2006), "Behaviour of channel shear connectors: push-out tests", M.S. Thesis; Department of Civil Engineering, University of Saskatchewan, Canada.

Rao, S.N. (1970), "Composite construction-tests on small-scale shear connectors", *Inst. Engrs. Civil Eng.*, Australia 4.

Razak, H.A. and Sajedi, F. (2011), "The effect of heat treatment on the compressive strength of cement-slag mortars", *Mater. Des.*, **32**(8-9), 4618-4628.

Rehman, N., Lam, D., Dai, X. and Ashour, A.F. (2016), "Experimental study on demountable shear connectors in composite slabs with profiled decking", *J. Constr. Steel Res.*, **122**, 178-189.

Safa, M., Shariati, M., Ibrahim, Z., Toghroli, A., Baharom, S.B., Nor, N.M. and Petkovic, D. (2016), "Potential of adaptive neuro fuzzy inference system for evaluating the factors affecting steel-concrete composite beam's shear strength", *Steel Compos. Struct., Int. J.*, **21**(3), 679-688.

Sajedi, F. (2011), "Mechanical activation of cement-slag mortars", *Constr. Build. Mater.*, **26**(1), 41-48.
DOI: 10.1016/j.conbuildmat.2011.05.001

Sajedi, F. and Razak, H.A. (2010), "Thermal activation of ordinary Portland cement-slag mortars", *Mater. Des.*, **31**(9), 4522-4527.

Shariati, M., Ramli Sulong, N., Suhatril, M., Shariati, A., Arabnejad Khanouki, M. and Sinaei, H. (2012a), "Fatigue energy dissipation and failure analysis of channel shear connector embedded in the lightweight aggregate concrete in composite bridge girders", *Proceedings of the Fifth International Conference on Engineering Failure Analysis*, The Hague, The Netherlands, July.

Shariati, M., Sulong, N.R., Suhatril, M., Shariati, A., Khanouki, M.A. and Sinaei, H. (2012b), "Behaviour of C-shaped angle shear connectors under monotonic and fully reversed cyclic loading: An experimental study", *Mater. Des.*, **41**, 67-73.

Shariati, M., Sulong, N.R., Shariati, A. and Kueh, A.B.H. (2016), "Comparative performance of channel and angle shear connectors in high strength concrete composites: An experimental study", *Constr. Build. Mater.*, **120**, 382-392.

Siess, C.P., Viest, I.M. and Newmark, N.M. (1952), "Studies of slab and beam highway bridges: part III: small-scale tests of shear connectors and composite t-beams", Bulletin 396.

Slutter, R.G. and Driscoll Jr, G.C. (1965), "Flexural strength of steel-concrete composite beams", *J. Struct. Eng.*, 71-99.

Tahmasbi, F., Maleki, S., Shariati, M., Sulong, N.R. and Tahir, M.M. (2016), "Shear capacity of C-shaped and L-shaped angle shear connectors", *PloS one*, **11**(8), e0156989.

Vianna, J.D.C., Costa-Neves, L.F., Vellasco, P.D.S. and De Andrade, S.A.L. (2009), "Experimental assessment of Perfobond and T-Perfobond shear connectors' structural response", *J. Constr. Steel Res.*, **65**(2), 408-421.

Viest, I.M. (1956), "Investigation of stud shear connectors for composite concrete and steel T-beams", *ACI Journal Proceedings*, **53**(8), 875-891.

Yan, J.B., Liew, J.R., Sohel, K.M.A. and Zhang, M.H. (2014), "Push-out tests on J-hook connectors in steel–concrete–steel sandwich structure", *Mater. Struct.*, **47**(10), 1693-1714.

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