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State-of-Art of Shear Connectors Configurations in Reinforced Concrete Composite Beams and Slabs

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ABSTRACT

Composite steel and concrete constructions are structures with excellent behavior and properties due to enhance the defect of brittle phenomena of concrete. This paper deals with a systematic review of different shear connecters configurations used in composite steel and concrete structures. A systematic literature review was conducted of specimen type (slab and beams), the type of concrete, and the type of shear connecters. Most articles are interested in push- off tests in addition to the beam specimens, that more than 75% of published research. The steel studs considered significant type of connecters in many composite constructions. The V or L-shaped steel connectors may enhance the results till to 50%, in other wise many more novel connectors are still in research stage and it may develop in the future to assist the structural designer in choosing the suitable kind of connectors.

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1. Introduction

Composite structures are widely used in multistory buildings and seismic areas in order to provide the foundations for economic and social prosperity. In bridge deck members, were in-suite cast concrete and steel composite or sandwich slabs, where the sections in steel are frequently employed. Shear connections are used to transfer forces from the concrete deck to the steel girders. The most popular shear connectors are end-welded shear studs.

There are many tests for composite structure such as push out test and push-off test. In 2015, Erica Frankenberg made a review for push out test (Frankenberg, Welner, Mathis, Berkshire, & Gunn, 2015). After deep research about it, there are a little review for push-off test, so this review will help researchers who interest about push-off test and shear connectors.

The methodology of this survey may be summarized in figure (1). However, this paper deals with a review about the important parameters which effect on choosing the suitable shear connecters of composite beams and slabs.

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The selected keywords of this survey were: push-off test, shear studs (connectors), composite beams, slabs, and steel connectors. The publications duration 2005-2022 (till 1/10/ 2022). When the data chosen for search engine were: google, Scopus, and Scielo. From the data collected with automatic search, the number of papers called were 112 journal articles. But when downloaded and complete reviewing all these articles, the authors selected only 45 papers, that are deals with this study and it interested with configurations of shear connectors.

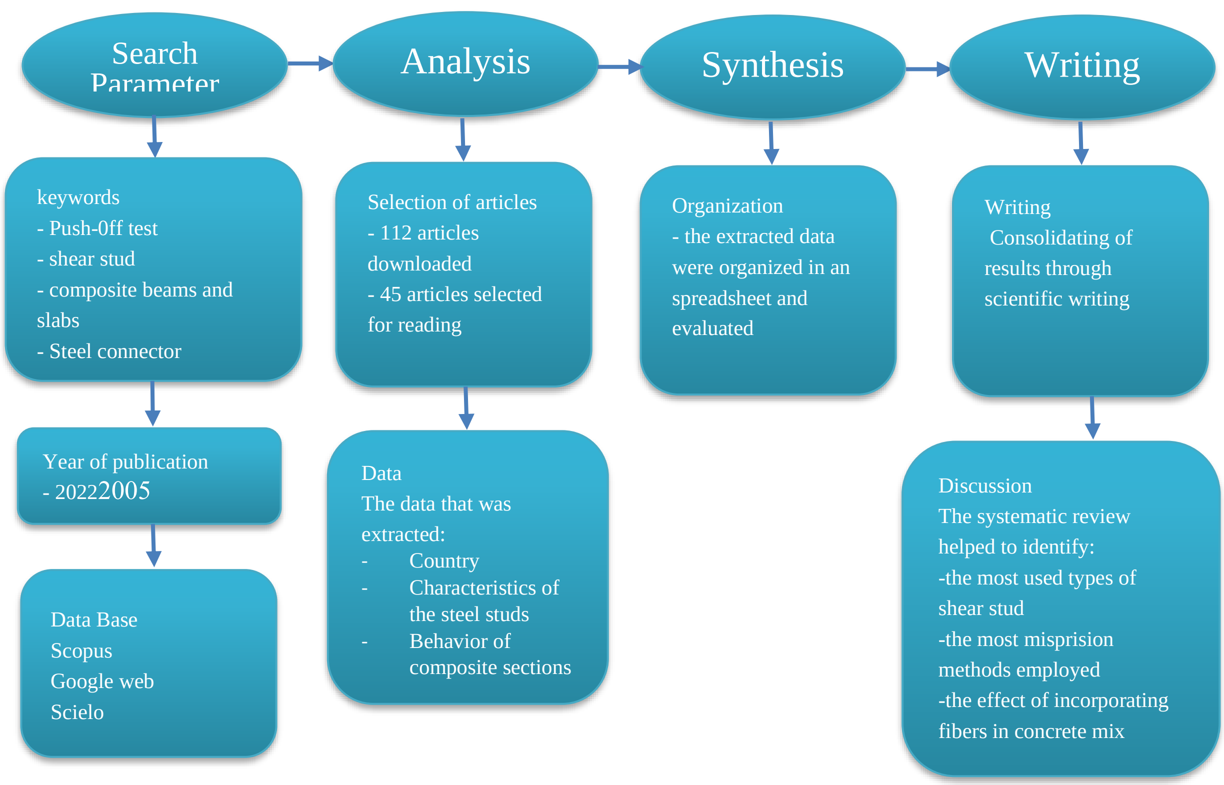

Fig. 1 State of systematic literature review

2. Literature Review

Chan et al., 1986 investigated of forty-two end stub assemblages' push-off tests. The existing Canadian Standards Association on shear connectors, which was written for conventional composite construction, provides minimal assistance for design of stub girder. For a stud connector's theoretical shear capacity to fully develop in the system of stub girder, a requirement of stud spacing four times the diameter of stud doesn't seem to be sufficient. The required minimum stud spacing for 13 mm long was appeared to be (5-6) times the stud diameter. Additionally, CSA recommended pin connector shear strength should be reduced to account for lever load effects. It is suggested to apply a modification factor of 0.9 for a stud connector with a 13 mm diameter. When tests were conducted on specimens with 19 mm studs, the shear capacity continued to decrease. However, a solid recommendation won't be made until after additional tests. Prying pressures, stud arrangement, and spacing, as well as the amount and placement of reinforcement, must all be taken into account when determining a stud connector's shear capacity. For connections using 13mm single row studs, if the stud spacing is less than six times the bolt diameter, a derating factor equal to the bolt spacing divided by six times the bolt diameter is recommended. The adjustment factor for staggered stud's connections is determined by multiplying the stud spacing by five times the stud diameter for the smaller bolt spacing (Chan, Rezansoff, & Hosain, 1986).

Lam and El-Lobody,2005 had been study theoretically the load-slip characteristics of the headed shear stud in a solid reinforced concrete slab, a finite element model has been created. The concrete and shear stud's linear and nonlinear material properties are taken into account by the model. The finite element results were in good agreement with the experimental POT results and the stipulated data taken from the codes. The FE model successfully anticipated each mode of failure. The formulas provided in EC4 had a fair correlation with the experimental findings and finite element solutions, according to the parametric research, but it appears that the BS5950 and the AISC may have overstated the headed stud shear capacity. Additionally, it appears that all codes overestimate the shear capability of the all the codes appear to overestimate the 22 mm diameter headed stud's shear strength. Additional tests should be performed to confirm the 22 mm diameter headed stud's shear capability since just a small number of POTs were performed on it. In conclusion, advancements in this type of finite element model may eliminate the necessity for pricey experimental push-off experiments to ascertain the shear connectors' shear capacity (Dennis Lam & El-Lobody, 2005).

Jayas and Hosain experimentally conducted 4 composite beams that cast as full-size test, in addition another two full-size specimens for push off tests are presented in this research. The ribbed metal deck in these specimens was positioned perpendicular to the beam span. The main failure mode was the pulling away of concrete. The authors' proposed empirical equation reasonably predicted the ultimate horizontal shear stresses that were seen in the push-off specimens. The indirect calculation of the expected results had been a good agreement with the experimental outcomes (Jayas & Hosain, n.d.).

Y. Liu & Alkhatib in 2013 adopted the behavior of shear studs' strength used in composite bridge deck applications. Also, it used to evaluate the detailed requirements indicated in the code requirements, an experimental procedure commerce with the testing of 25 push-out specimens were experimentally applicated. The test criteria were reinforcement mesh location, stud head presence, and stud height. Adjustable studs, a type of shear stud, were also studied and their performance was compared to that of regular studs. The location of the reinforcing mesh was discovered to impact the failure mechanism of the specimen and the ultimate load. When the mesh intercepted the studs, the maximum ultimate stress was reached and the failure happened via stud shear-off, as opposed to situations where the mesh was positioned flush with the stud-head or above the stud. Shear-studs with heads produced a higher ultimate load in specimens than shear-studs without heads. When conventional and adjustable shear studs were compared, it was discovered that while they both had identical failure mechanisms, adjustable studs had lower load capabilities on average. Only specimens with reinforcing mesh that met the detailed criterion were able to fulfill the code required strength for all of the specimens under consideration (Y. Liu & Alkhatib, 2013).

Currie & Currie, 2015, studied the behavior of five beam specimens with different cross-sectional geometries and tested reinforcement details in a custom-made single-sided bead breaker to pass along the specimen and rivet lines. The experimental technique, which included monotonic and pseudo-cyclic shear loading, was adapted from Eurocode 4 (1994) instructions. The latter investigated how such minimal force affected specimen performance and failure. Portal gauges were used to measure the horizontal and vertical fracture initiation and propagation components in great detail. All samples failed due to longitudinal splitting along the stud line, which is contrary to Clause 13.4.10.4 of NZS 3404: Part 1:1997. The transverse deformation zone and compressive and tensile stress levels were found to be significantly concentrated and non-uniform around the studs. It was assumed that low level pseudo-cyclic loading would cause concrete to microcrack. Although it had little to no impact on specimen act and was definitely unlikely to encourage premature failure, it was observed to engender curvilinear modifications to monotonic failure behavior. But more research is required, including full-scale testing, higher level pseudo-cyclic and completely reversed cyclic loading, inclusion of profiled steel cold-formed sheet steel decking establishing industry standard "hollow" slabs having steel and concrete composite beams (Currie & Currie, 2015).

Rehman et al. in 2016, reported an experimental examination on the ductility, stiffness, and shear strength of demountable shear connections in composite deck slabs utilizing push-off tests. Full-scale specimens (Twelve symbols) for push-off lab experiments were carried out with varying concrete strengths, connection counts, and connector sizes. According to the testing results, metal decking composite slabs with demountable shear connections have the same shear capacity behavior for creating shear studs and meet the Eurocode 4 minimum ductility criteria of 6 mm. The bolted connection was compared to the shear capacity prediction techniques in Eurocode 3, Eurocode 4, AISC 360-10, and ACI 318-08, as well as welded shear connection prediction methods. It was discovered that for specimens having per trough one shear connection, the AISC 360-10 technique overvalued shear capacity whereas the ACI 318-08 method underestimated it. The Eurocodes technique provided an accurate prediction for specimens with a single or a pair of demountable connections per trough. Furthermore, the prediction techniques offered in both AISC 360-10 and ACI 318-08 for welded shear studs underestimated the samples shear capacity with 22 mm diameter demountable studs that failed in concrete crushing (Rehman, Lam, Dai, & Ashour, 2016).

Lowe et al., 2020 studied the results of fifteen push-off experimental tests, the longitudinal splitting strength qualities of a concrete slab in a novel steel-concrete composite beam with headed shear stud connections. A customized test rig was used in place of the normal push-off test rigs. The trials allowed researchers to look at a variety of previously unknown effects of various loads on steel-concrete composite components, such as the effects of transverse loading and low-level cyclic loading on shear stud capacity. The findings allowed us to define the splitting failure mode in previously unheard-of detail. When many cycles of cyclic loading were utilized, it was revealed that the composite beam did not fail early but instead improved the beam's resistance to longitudinal splitting. This is important for composite parts that are subject to fluctuating loads, like floor-supporting by beams in parking garages. Additionally, it was demonstrated that the transverse compression stresses across the stud bases would strengthen the beam's resistance to longitudinal splitting. The variations and restrictions between New Zealand (NZS) and Euro Code 4 standards, as well as their effects on composite beam failure characteristics, were also examined. It was demonstrated that the loss of load-bearing capacity would occur gradually when anti-splitting reinforcement was present as opposed to abruptly absent. According to the NZS standard, longitudinal splitting in composite materials occurs even with enough side protection, as per the NZS standard, from the stud to the edge of the concrete longitudinal splitting in composite beams is still seen (Lowe, Roy, Das, Clifton, & Lim, 2020a).

Wang et al., 2021 examined the positive moment section's region of composite beams in compressive conditions, which is the core focus on this research on the behavior of High-strength bolted shear connectors (HSBSCs). A three-dimensional (FEM) model was utilized in this study to assess how well HSBSCs performed under inverse push-off stresses. The FEM considered material nonlinearities as well as interactions between components. The supplied push-off test results were originally utilized to check the validity and reliability of the proposed FEM. The validated FEM was utilized to perform more studies on the load-carrying capacity and load slip response of the HSBSCs under inverse push-off loading. A parametric analysis was used to determine the influence of concrete strength, bolt diameter and tensile strength, and clearance between the concrete was conducted. The impact of the bolt's diameter, tensile strength, clearance from the concrete slab, bolt pretension, and shear performance of HSBSCs. Design suggestions for predicting the shear load at the initial slide and load-bearing resistance of HSBSCs were proposed and proven based on the extensive parametric analyses (Wang, Zhang, Ding, & Zhou, 2021).

Sun et al., 2022 examined the slip development of the continuous composite box girder's web and diaphragm by combining the stud's nonlinear shear deformation parameter analysis with the diaphragm's stress analysis, and the following findings were reached: (i) Web flange studs are principally responsible for the O- shear resistance plane of box girder having composite section concrete and steel. In contrast the flanged studs lead to avoid the slippage between two surfaces (steel and concrete). The studs should be placed favorably on the flange (i.e. the level fiber had maximum shearing stress) to enhance their use rate. (ii) The diaphragm might not be organized with the shear studs after the rigidity of the diaphragm has been strengthened because this will not increase the composite beam shear connection degree. The load on the diaphragm can be reduced by removing the arrangement of diaphragm studs, and this can theoretically allow for less diaphragm stiffeners.(Sun, Yue, He, & Ibrahim Shah, 2022)

3. Results and Discussions:

This study adopted the survey from forty-five published papers [(Sriboonma, 2021)(Marlow et al., 2018)(Russell, Clifton, & Lim, 2021) (Hameed Saleh Hassan AL-Falahy & Ismail Al-Hadithi Yousif Khalaf Yousif Al-Obaidi Shawwal, 2022) (Feyissa & Kenea, 2022)(Ding, Yin, Wang, Wang, & Guo, 2017)(Smith & Couchman, 2010)(Jebara, Ožbolt, & Hofmann, 2016)(Tahir, Shek, & Tan, 2009)(Ranzi et al., 2009) (Hicks & Smith, 2014)(Chou & Chen, 2013)(Sun et al., 2022)(Moon Ii, Ii, & Gillespie, n.d.)(Badie, Morgan Girgis, Tadros, & Nguyen, 2010) (Dennis Lam, Dai, Ashour, & Rehman, 2017)(S. Liu, Matsuda, Liu, Morita, & Yamamoto, n.d.)(Currie & Currie, 2015)(D Lam, Elliott, & Nethercot, 2000) (Lowe, Roy, Das, Clifton, & Lim, 2020b)(Nguyen & Kim, 2009) (Davaadorj, Calvi, & Stanton, n.d.) (D Lam & Ei-Lobody, 2001) (Hassan, Khalid Al-Hadithy Asst, & Abdul Jabbar Hassan, 2015) (Mirza & Uy, n.d.) (Mirza & Uy, 2009)(Jongvivatsakul, Attachaiyawuth, & Pansuk, 2016) (Karkare, 2011) (Dennis Lam, 2007) (Albarram, Qureshi, Abbas, & Abbas, 2017) (Albarram, Qureshi, & Abbas, n.d.) (Lowe, Das, & Clifton, 2014) (Badie et al., n.d.) (D Lam, Elliott, &

Nethercot, n.d.) (Badie, Morgan Girgis, Tadros, & Sriboonma, 2011) (Johnson & Yuan, n.d.)]. These collected papers are arranged according to the structure member types, concrete type, and stud's configrations. The first thing that is offered is a summary of the key traits of the articles that were found in the literature review. This study assisted in identifying the key contributors to the field and provided a foundation for the formulation of various experimental program variables.

3.1. Slabs and beams:

As shown in table (1) the main characteristics of push-off test used in this article for beams and slabs. Regarding the total number, 71% was for beams compared for slabs, 15.5% was full-scale push-off test for beams and slabs. 28.8% from articles were used finite element method to simulated the samples. 33.3% works on standard push-off test with various materials or studs.

Table 1 – Characteristics of push-off test used for Beams-slabs

	Type of specimens	No. of articles
Beam Group	Standard POTs	11
	Full- scale	4
	finite element method FEM	11
	Self-compacting concrete	1
	Recycled aggregate	1
	Bi-direction	1
	High strength concrete with FEM	1
	Cyclic load	1
	Elevated temperature	1
Slab Group	Sum	32
	POT for slabs	4
	Floor	1
	Full-scale slab	3
	Hollow core floor slab	2
	Deck slab	2
	Lightweight Ribbed slab FEM	1
	Sum	13

3.2. Type of concrete

Table (2) showed that 82.22% from articles used normal concrete for slabs and beams because of it widely used in structures. 6.6% used Lightweight concrete for beams and slabs.

Table 2 – Type of concrete

	Type of concrete	No. of articles
1	Push-off test (POT) for beams	32
	Normal concrete	26
	Self-compacting concrete	1
	Recycled aggregate	1
	High strength concrete with FEM	1
	Light weight concrete + plastic fiber	1
	Ultra-high strength concrete + reactive powder concrete	1

	Precast concrete	1
	POT for slabs or floor slab	13
2	Normal concrete	11
	Lightweight Ribbed slab	1
	Lightweight Girder	1

Below are some of the most prominent researches in this field. Saleh and Majeed, in 2022 studied the shear strength of concrete and the behavior of headed stud connections placed in self-compacting concrete created using recycled coarse aggregates (RCA), which represents a trend in manufacturing environmentally friendly concrete. The influence of the replacement ratio of RCA, the compressive strength of concrete, and the diameter of the headed stud were all included in the study. It was founded on the development and testing of 36 push-out test specimens. The ultimate shear strength, ultimate slip, and load-slip behavior of the stud are evaluated and compared to that anticipated by the Eurocode 4 and AASHTO LRFD equations as shown in figure (2). The use of SCC with RCAs reduces the shear strength of headed stud connections. By increasing the compressive strength of the concrete (and/or) the diameter of the studs, this harmful effect may be lessened. The reduction in concrete bearing resistance in the area supporting the headed studs, which occurred as a result of the higher aggregate crashing value of RCAs in comparison to NCAs, caused the shear stiffness and ultimate slip of the tested push-out specimens to be inversely proportional to the RCA ratio. By raising the compressive strength of the concrete, it may be possible to reduce the rise in ultimate slip caused by the RCA ratio (Saleh & Majeed, 2022a).

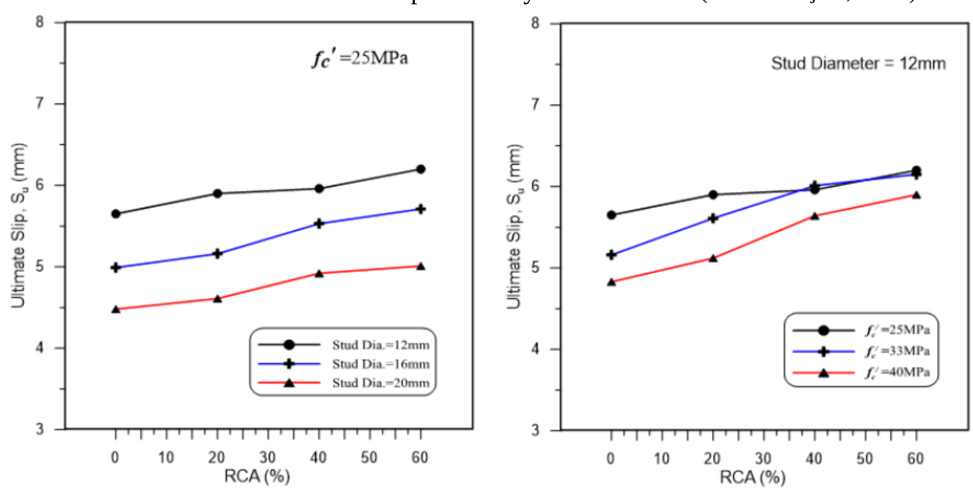

Fig. 2 Variations in the ultimate slip with RCA ratio. Variations in the ultimate slip with RCA ratio (Saleh & Majeed, 2022b)

Lin et al. 2002 evaluated the performance of shear studs put in composite ribbed-slabs constructed by pouring lightweight-polystyrene concrete over steel-decking. A new push-off test rig was utilized to run a total of 18 tests with either lightweight polystyrene concrete or conventional weight concrete test units. This essay reports and discusses the key findings of the 18 tests. According to the findings, lightweight polystyrene concrete structures frequently exhibit high ductility and shear capability. Some design requirements are proposed based on the experiment's findings (Lin, Ingham, & Butterworth, 2002). Haber et al., 2020 investigated the ultimate performance of two newly created, simpler deck-to-girder composite connections that employ cutting-edge detailing and UHPC. The suggested methods were designed to simplify onsite building and speed manufacturing operations. Short shear-connectors on the girders, as well as shear pockets that run through the deck or rebar dowels that protrude from the underside-deck panels, are used in the two connections studied in this study. These principles were evaluated using a small direct shear testing scale and big double-shear push-off experiments. Among the experimental parameters were pocket geometry, design shear stud, rebar dowel arrangement, and dowel length. The result indicated that these unique connection details might possibly fulfill the present requirements of strength limit state in the AASHTO Bridge Design Specification for horizontal shear because they are ductile (Haber, Graybeal, & Nakashoji, 2020).

3.3. Type of studs:

Some of researchers used several types and shapes of studs. Table (3) shows that 81.8% from articles were for standard studs with various size or various long of studs. On the other hand, Al-Kroom et al., 2021used V-shape shear-connector. This study investigates the behavior of a unique form of V-shaped shear-connector. An experimental investigation employs 14 push-out tests to assess the performance of the proposed connection. The results show that the newly developed V-shaped shear-connector can transfer more shear stress than typical shear connections as shown in figure (3). Furthermore, its behavior is considered to be ductile. The geometrical characteristics of the connection are explored to see how they impact its behavior. The experiment findings show that, while the connector's ductile behavior is preserved, changing the connector's length, breadth, and thickness has a significant influence on its ultimate strength. Furthermore, the investigation shows that the connector's uplift-displacement is improved but neither adding holes nor transverse reinforcement has a substantial effect on shear resistance. The suggested shear-connector is thoroughly compared to other shear- connectors that are often utilized. An empirical equation is proposed to forecast the connector's load capacity based on the testing data (Al-Kroom, Thneibat, Alghrir, & Schmid, 2021).

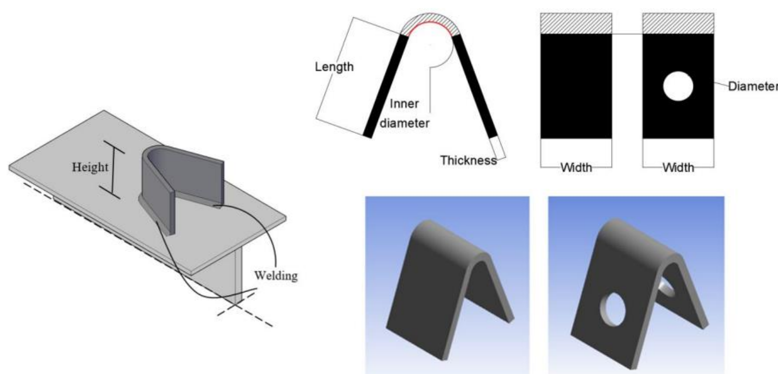

Fig 3. The shape of shear studs

Table 1 – Type of studs

	Type of studs	No. of articles
1	Headed stud	39
2	V shape shear connector	1
3	O-ring confinement	1
4	L-angle confinement	1
5	Wire-mesh confinement	1
6	Sandwich panel within shear connectors of steel truss	1
7	T- shape	1
	Sum.	45

Sriboonma & Pornpeerakeat, 2020 studied the investigation of various steel- confinements around a clustered large-size stud shear-connector utilizing a full-depth precast concrete bridge deck panel is the main goal of the study. The tests that based on Push-off tests of two major groups of samples: (i) the 4-stud shear- connectors, where three different types of confinement were adopted, including O-ring confinement, Wire-mesh confinement, and L-angle confinement; and (ii) the 8-stud shear-connectors, where two different types of confinement, including Plate-ring confinement and L-angle confinement, were investigated as shown in figure (4). The results of the test demonstrated that when contrasting the various types of confinement within the same group, the L-angle confinement type of the specimen group with 4-Stud is sufficient. The displacement was discovered to be the most extensible and progressively decreased until the failure point, due to which the failure can be detected before the structure collapses, and the maximum resistance was found to be 41 tons. According to each kind of confinement, the resistance of the group of specimens with 8-Stud was 50–100% higher than that of the group with 4-Stud. The maximum resistance for the Plate-ring confinement type was discovered at 70 tons, which was consistent with the displacement increase roughly 20 - 50%. The Plate-ring confinement demonstrated stronger resistance and a 15% greater relative displacement than the L-angle confinement when comparing specimens with 8-Stud (Sriboonma & Pornpeerakeat, 2020).

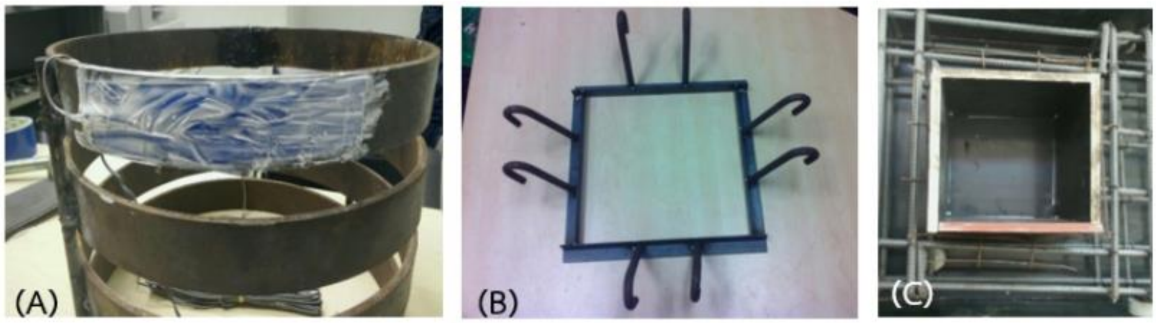

Fig. 4. Type of shear studs

Thanoon et al., 2010 studied a brand-new method for transferring horizontal shear between the pre-cast and in-situ cast concrete slab layers is proposed as shown in figure (5). The suggested approach employs the idea of interlocking and does not call for shear reinforcement. A pre-cast inverted ferrocement layer and a cast in situ brick-and-mortar layer are joined by a composite floor-slab that is used to demonstrate the interlocking concept. Investigated how well the interlocking system transfers the stresses created by the imposed load. The number of tested composite slab specimens were eleven specimens. There are cast and investigated using different steel shear-connectors adopted for bonding the steel and concrete of push-off test. The slab layers were connected to one another in the examined specimens using various interlocking techniques, continuous truss shear- connectors, and no connectivity between the two layers. The results show that the suggested interlocking system can replace the steel trusses and is just as good at resisting shear loads. This will lower the cost of the composite slab by eliminating the need for the steel trusses (Thanoon, Yardim, Jaafar, & Noorzaei, 2010).

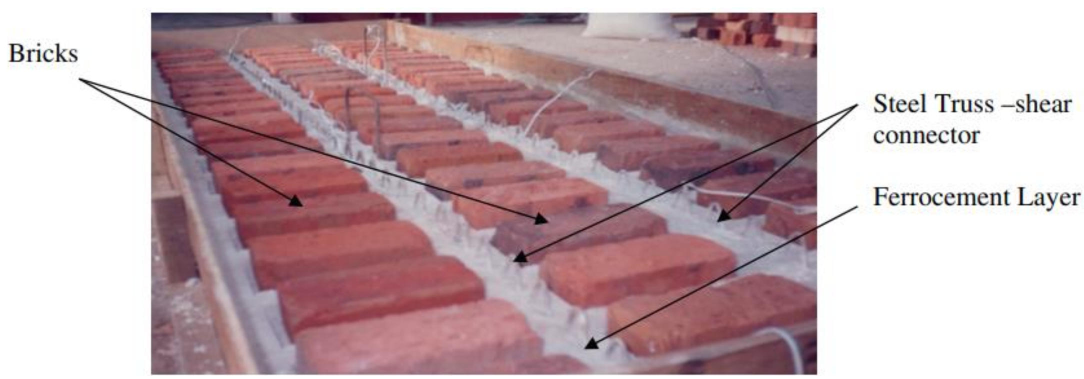

Fig 5. pre-cast inverted ferrocement layers

Rasheed, 2020 investigated the effect of RPC by integrating recycled bricks from construction sites as coarse aggregate and cementation material in place of some of the fine aggregate. The current work can be separated into two sections based on its two primary goals. In the first section, crushed brick aggregate is used as cementation material in RPC and Modified Reactive Powder Concrete (MRPC) in place of 40% fine sand, and 25% cement. A number of significant mechanical and novel properties of RPC and MRPC, such as splitting tensile strength, compressive strength, modulus of elasticity, modulus of rupture and flowability, will be examined as part of the experimental program. These properties will be affected by the type of steel fiber used in the material as well as the absence of crushed brick aggregates. Based on the results of the experiment, it can be said that in order to achieve acceptable mechanical and fresh property performance for RPC, recycled waste and demolished bricks with a maximum size of 10 mm are better suited to be partially replaced by a ratio of 40% silica sand than replacement of cement. Crushed bricks aggregate was used in RPC to obtain a high compressive strength of 138 MPa; this finding deviates from the model that suggested RPC's high compressive strength level was caused by the absence of course-aggregate. Four different shear connector types—headed stud (with varying steel fiber kinds), L-shape angle, T-shape, and Perfobond with—have their structural behavior experimentally studied as shown in figure (6). Based on the results of the experiment, it can be said that in order to achieve acceptable mechanical and fresh property performance for RPC, recycled waste and demolished bricks with a maximum size of 10 mm are better suited to be partially replaced by a ratio of 40% silica sand than replacement of cement. This finding differs from the model that claimed that RPC's high compressive strength level was caused by the absence of coarse aggregate, while crushed bricks aggregate was employed to generate a high compressive strength of 138 MPa. Experimental research on the structural behavior of four different shear-connector types, L-shape angle, T-shape, and Perfobond has been done using hooked steel fiber and L-shaped angle connectors. Also, it was observed that (f 'c) of the RPC and MRPC resulted in a reduction in the ductility of the headed-stud and T-shaped connector. Additionally, it was discovered that switching from straight to hook steel fibers significantly affects the characteristics of the load slip curves and the load-bearing capacity for specimens with stud connectors by a ratio of 13%, 2%, and 15% for RPC, MRPC1, and MRPC2, respectively (Rasheed, 2020).

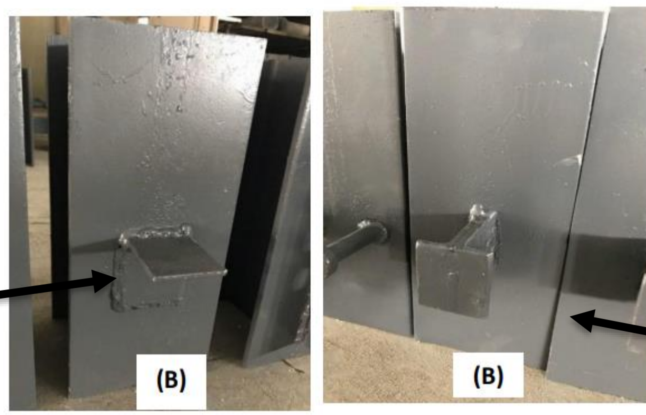

Fig 5. Different types of shear connectors

4. Conclusions:

From the review of selected papers chosen for studying the behavior of composite slabs and beams having various types of shear connector, the following conclusions may be presented:

1- The furthermost kind of shear connectors that implemented in the significant scientific articles were standard headed stud. Due to found the standard push-off test and it may use for composite if the researcher needs to present other type of shear connector.
2- The researches have deals with the behavior of shear connectors are deal with beam's specimens.
3- Very little investigations deal with full scale measurement.
4- Very few studies are depended on the strain compatibility analysis of composite structures with studs, or shear connectors.
5- No study focuses on the use of the highlighted of FRP reinforced with steel structure or the composite slabs.
6- The time-dependent analysis is not a significant study of this brand.

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Notations:

1	Push-off Test	POT
2	Canadian Standards Association	CSA
3	Finite Element Model	FEM
4	New Zealand Standard	NZS
5	High-strength bolted shear connectors	HSBSCs
6	Recycled Coarse Aggregates	RCA
7	Modified Reactive Powder Concrete	MRPC
8	Reactive Powder Concrete	RPC