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STATIC BEHAVIOR OF DIFFERENT SHEAR CONNECTORS OF COMPOSITE SLAB USING ANSYS

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Abstract - Headed stud shear connectors are commonly used to transfer longitudinal shear forces across the steel-concrete interface. In the areas of high shear, many studs should be welded to the top flanges to provide full shear connection in terms of strength. However, this causes long welding time, raise safety concerns, and also makes it difficult to remove a deteriorated concrete slab, which may damage. In this study, the static behaviour of Channelled, Tee, and Spiral shear connectors used in composite steel concrete beams was analytically examined using ANSYS. Ten specimens were modelled and analysed to determine the maximum deformation, load slip behaviour, failure modes and stress of the proposed composite beam with these shear connectors; these results and then compared with the corresponding values of shear stud. The static behaviour of all the tested shear connectors satisfied the ductility requirements. By comparing the values of maximum deformation and corresponding ultimate load obtained for stud, channel, tee, and spiral shear connectors; tee type shear connector bears a higher load with a deformation of 23.125 mm and a minimum load slip value. Compared to stud type shear connector, rest of the connectors could carry higher loads with higher deformation and higher equivalent stress especially tee type shear connector. Hence, it is concluded that the proposed shear connectors are suitable in the construction of composite beams, as they are stronger than the standard headed studs and the other available shear connectors. They are sufficiently strong as well to perform composite actions.

Keywords – Shear connectors, headed stud shear connectors, Steel composite slabs

1.INTRODUCTION

A composite floor system conventionally consists of a reinforced concrete slab, supported on a set of steel joists. The composite integrity is provided by shear connectors. Recently, there has been a wide use of composite beams in buildings and bridge construction. Their advantages include high bending capacity and stiffness due to the benefits of composite action and high speed of fabrication and construction. Shear connectors between concrete slabs and steel beams in composite construction can play an important role in the seismic response of a structure. They provide the necessary shear connection for composite action in flexure and can be used to distribute the large horizontal inertial forces in the slab to the main lateral load resisting elements of the structure. Despite, several composite structures failed in satisfying their structural and functional demands due to stud shearing off or concrete crushing as a direct result of fatigue [5]. In order to prevent these failure modes, experimental tests focused on shear connectors' mechanical behaviour under fatigue loads. Headed stud shear connectors are the most common type of shear connectors, and studs used in composite bridges are typically 19 or 22 mm in diameter. In the areas of high shear, many studs should be welded to the top flanges to provide full shear connection in terms of strength. However, this causes long welding time and also makes it difficult to remove a deteriorated concrete slab, which may damage the studs as well as the steel girders. A dense distribution of shear connectors could also raise safety concerns for field workers because of little space on the top flange.[7] For these reasons, the use of various type of shear connectors in composite beams could give more advantages and conveniences. The main aim of the study is to analyse the effectiveness of use of different type of shear connectors such as channelled, tee, spiral in composite structures and to compare its performance with stud types of shear connectors. A detailed analysis was conducted on static behaviour of different shear connectors of steel composite slab using ANSYS. The main objectives of the study are to evaluate the total deformation and equivalent stress of stud, spiral, channeled, and T- type shear connectors. Also, to compare the load slip behavior and failure modes of different type of shear connector.

2. ANALYTICAL STUDY

Finite element analysis was conducted on static behaviour of different shear connectors of steel composite slab using ANSYS. Finite element (FE) is a numerical analysis method that divides the structural member into much smaller elements and then simulates static loading conditions to evaluate the response of the element members when subjected to loadings to provide an accurate prediction [4]. The use of FE analysis has become preferred method to study the behaviour of elements like concrete and steel as it is much faster than the experimental methods and also is cost effective. Push-out tests are commonly used to determine the capacity of the shear connection and load slip behaviour of the shear connectors. In this study, push out test were performed to analyse the behaviour of different shear connectors in a composite beam with a solid slab and steel section. The main components in the composite beam are concrete slab, steel beam and shear connectors. The interaction between components is also very important. Both geometric and material nonlinearity were included in the finite element analysis. The capacity of the shear connection, the load slip behaviour of the headed studs, channelled, tee and spiral shear connector and the failure modes were accurately predicted by the finite element model.

2.1 PUSH-OUT TEST.

The Pushout test specimen contains four main components which are: concrete slab, steel beam, slab reinforcements, and shear connectors. All these components are shown in Fig 1.

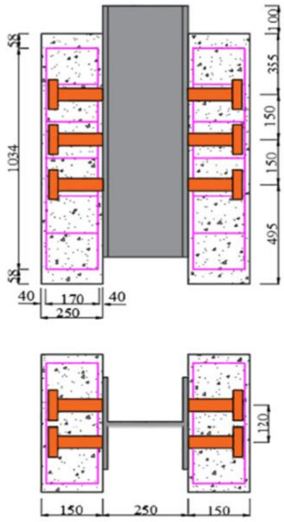

Fig. 1. Details of pushout specimen

A shear connector is a steel projection provided on the top flange of steel composite girders to provide necessary shear transfer between the steel girder and composite slab to enable composite action. The most widely used form of shear connector is the headed stud, or shear stud. Other forms of shear connector are spiral, tee, flat bar, block, hoop, and channel connectors are shown in Fig. 2 [3].

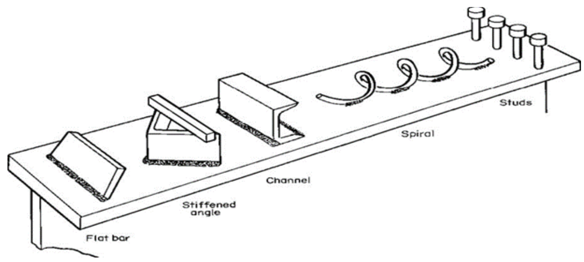

Fig. 2. Different types of shear connectors

A. Geometry of Pushout Test

In this study, specimen is in accordance with the standard push-out specimen (EUROCODE) [4]. The geometry of the specimen is shown in Fig. 1. The width and thickness of the concrete slab is 400 and 250 mm, respectively. The thickness of the steel beam is 14 mm. The rebar diameter is 16 mm. All the concrete slabs were reinforced by hot-rolled plain bars with yield strength of 400 MPa. The longitudinal reinforcement ratio was 0.785% and the bar diameter was 10 mm. The lateral reinforcement with diameter of 8 mm provided with central spacing 110 mm resulting in a reinforcement ratio of 0.67%. The steel beam manufactured using H steel with the dimension of 250 mm X 250 mm X 14 mm X 14 mm and the yield strength was 400 MPa. Details of shear connectors in the analysis are given in table 1.

Table 1. Details of shear connector

STUD	CHANNELED	TEE	SPIRAL
DIA: 21mm	100mm x 150mm x 50m	100mm x 100mm x 10mm.	Bar dia: 20 mm
Friction coefficient of 0.4.			Pitch circle dia: 125 mm

B. Validation of Simulation

For validation, a simply supported beam with stud type shear connector were analysed using ANSYS and the load-deformation values obtained analytically were compared with the experimental results obtained for Ahmed I. Hassanin et.al [3]. The deformation obtained from the analysis reveals that the load is taken as 22.66 kN with a deformation of 43.785 mm. The experimental result shows that for the load of 22.66 kN the corresponding deformation obtained is 42.961 mm. There are only 2% variations between experimental and analytical results.

C. Finite Element Model

In order to obtain accurate results from the finite element analysis, all components in the composite beam must be properly modelled. The interaction between components is also very important. Elements used in model are given table 2.

Table 2. Elements used in the model.

BEAM ELEMENT	USED ELEMENT
Concrete slab	Solid65
Steel section	Shell181
Shear connectors	Solid45
Slab reinforcement	Link180

Three-dimensional brick element with 8 nodes (SOLID 65) was the selected element to simulate concrete slab. Shell element was used to model the steel beam, which has four-node element having six degrees of freedom for each node. Shear connectors were modelled as a three-dimensional body with multiple elements consisting of stud body and stud root which connect with bonded connection with welding collar modeled with a brittle material property. The ANSYS needs the uniaxial stress-strain relationship for concrete in compression. The Solid65 element needs linear isotropic and multilinear isotropic material properties to properly model the concrete. The multilinear isotropic material uses the Von-Mises failure criterion to define the failure of the concrete. Fig. 3 and Fig. 4 shows the stress-relation of concrete and steel. The nonlinear behaviour of the concrete material is presented by an equivalent uniaxial stress strain curve of concrete. Both compressive and tensile stress is shown in this figure. For concrete in compression, three parts of the curve have been identified. The first part is initially assumed to be in the elastic range to the proportional limit stress. . Poisson's ratio of concrete is taken as 0.2. Properties of each material in the analysis are given in table 3.

Table 3. Material properties

	I-BEAM	R.C SLAB	SHEAR CONNECTORS
Yield stress (MPa)	400	–	406.5
Ultimate stress (MPa)	458.03	(f_{cu}) =38.85	509
Es (GPa)	200	27.42	205

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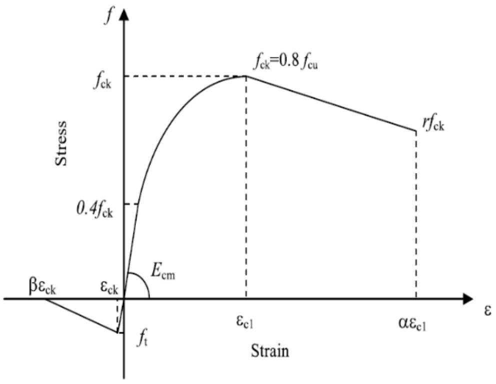


Fig. 3. Stress-strain relationship for concrete

The stress strain relationship of structural steel and reinforcement steel was modelled by the bi-linear curve. The curve presents a simple elastic plastic model. The mechanical behaviour for both tension and compression is assumed to be similar. The shear connector material is of great importance in the push-out test simulation. The material was modelled by a tri-linear stress-strain curve as shown in Fig. 5 [6]. The material behaviour is initially elastic followed by strain softening and then yielding

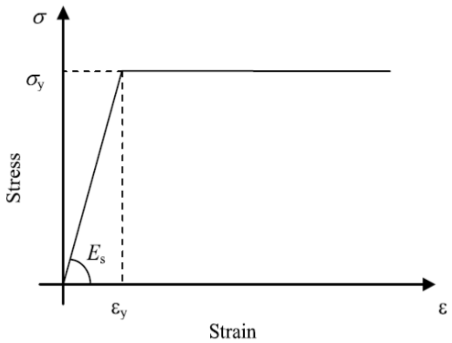


Fig. 4. Stress-strain relationship for structural and reinforcement steel.

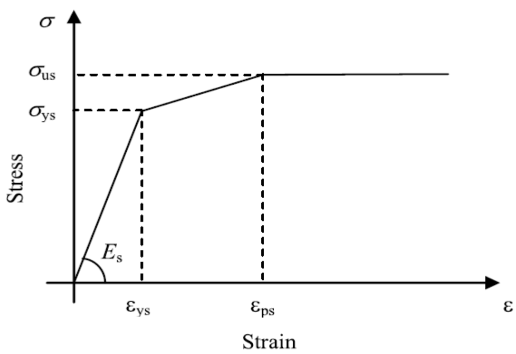
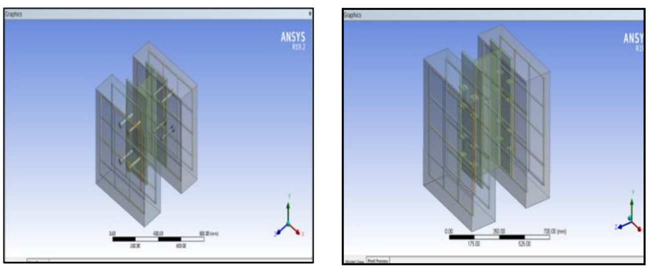
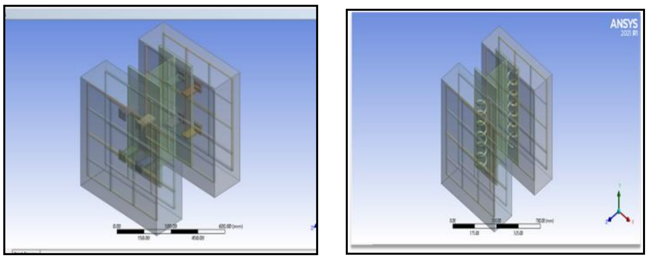


Fig. 5. Stress-strain relationship for shear connectors.



a. Stud b. Channelled



c. Tee d. Spiral

Fig. 6. Model of Composite beam with different shear connectors

D. Meshing

The concrete slab and the steel beam are meshed differently. To get a good result from the Solid65 element, the use of a tetrahedral mesh was suggested [5]. To reduce the analysis time, the coarse mesh was applied as an overall size. The fine mesh was applied at the region around the interface between concrete and studs to achieve the accurate results. In the headed stud, the mesh size was also reduced at the joint between the stud and steel beam where the stud would fail under shear force. Shape and size of mesh for each component are given in table 4. The overall mesh size was 25 mm, and the smallest size was about 5 mm. The finite element mesh of the specimen is presented in Fig. 7.

Table 4. Shape and size of mesh

COMPONENTS	SHAPE	SIZE (mm)
Concrete slab	Tetrahedral	1. 25
I – section	Quadrilateral	25
Shear Connectors	Tetrahedral	5

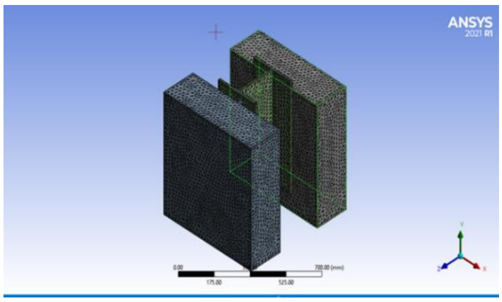


Fig. 7. Meshing of model

E. Loading and Boundary Conditions

The specimen is fixed at the bottom edge of concrete slabs. In this analysis displacement control was applied. Loading was given as downward enforced displacement which is applied to the top surface of the steel beam as shown in Fig. 8. Displacements are given as loads. Displacement Convergence is given in 30 load steps with an increment of 2 by setting auto time setting with 15 sub steps. The slip was measured as the relative displacement between the nodes on the steel flange and on the concrete slab near by the stud. The load was measured as the total reaction acting on the loading surface.

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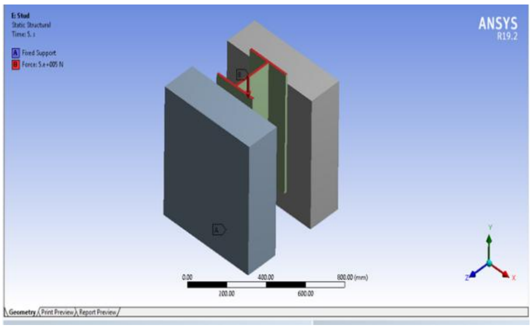


Fig. 8. Loading and Support Condition

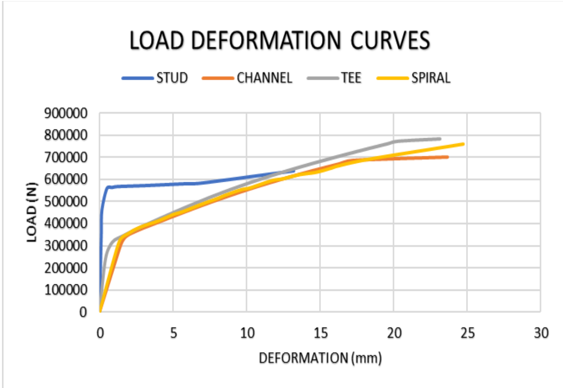


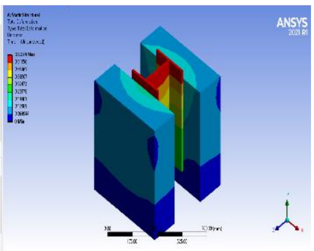
Fig. 10. Combined load deformation curve

2.2. RESULTS AND DISCUSSIONS

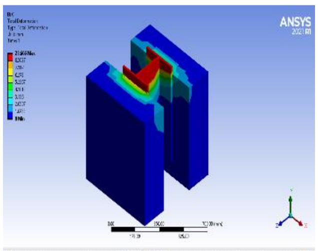
A detailed study was performed to investigate the effects of the changes in shear connectors on the strength and behaviour of shear connection in composite beams with solid slab. The load-deformation characteristics, the load slip behaviour and the failure modes of different shear connectors such as headed stud, channelled, tee and spiral were accurately predicted by the analytical investigation using ANSYS.

A. Total Deformation

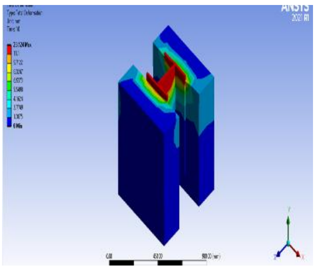
For analysis, there are two methods, force convergence method and displacement convergence method. Here, displacement convergence method is used. In this method, the input is given as displacement as load steps and the corresponding load and deformation will be produced as the result and the displacement result obtained are shown in Fig. 9. The maximum load per deformation of 4 push-out specimens obtained from the FE analyses are summarized in Table V.



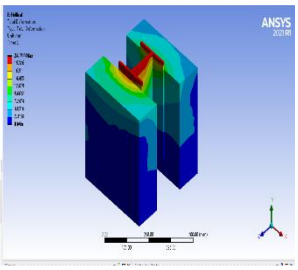
a. Stud



b. Channelled



c. Tee



d. Spiral

Fig. 9. Total deformation of 4 shear connectors

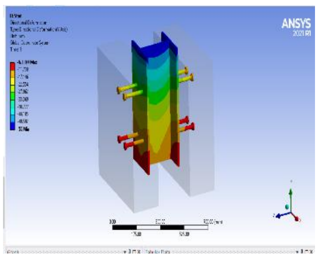
By comparing the values of maximum deformation and corresponding load; tee type shear connector bears a higher load of 606.5 kN with a deformation of 11.25mm which is 32%, 19%, and 7% higher than stud, channel, and spiral type shear connectors. A shear connector's strength capacity considerably depends on its deformation and on the ductility. Ductility describes the extent to which a structure can undergo large deformations without failing. Here from the results, it is observed that four shear connectors bear higher load with higher deformation.

Table 5. Maximum load and deformation

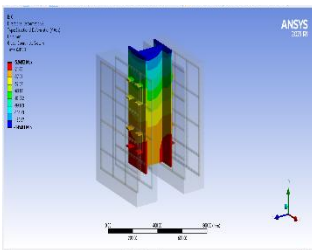
SHEAR CONNECTORS	TOTAL DEFORMATION (mm)	LOAD ON WHOLE BODY (kN)
STUD	13.174	640
CHANNEL	23.66	702
TEE	23.125	780
SPIRAL	24.705	760

B. Load Slip Behaviour

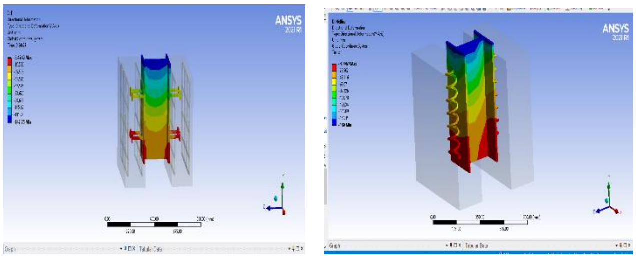
The shear load-slip curves characterized the static shear behaviour including the shear stiffness, maximum strength, structural ductility. Fig. 11 shows the directional deformation of composite beam with four different shear connectors. Directional deformation is obtained by taking deformation opposite to the direction of force acting. It will help to analyse the slip of the shear connector that may affect the composite integrity [2]. First, the effects of the total deformation of entire structure are analyzed. Then a detailed study on load slip behavior is conducted to examine how much load can bear by shear connector without slip. The failure modes and the displacement of these four connectors were analyzed to identify the best connection.



a. Stud



b. Channelled.



b. Tee d. Spiral

Fig. 11. Directional deformation

The slip value of tee type shear connector is less compared to other three types of shear connectors. The ultimate slip of Tee is 3.45 mm which is 45%, 40%, 15% smaller than that of stud, channel and spiral connectors for a higher load of 440 kN.

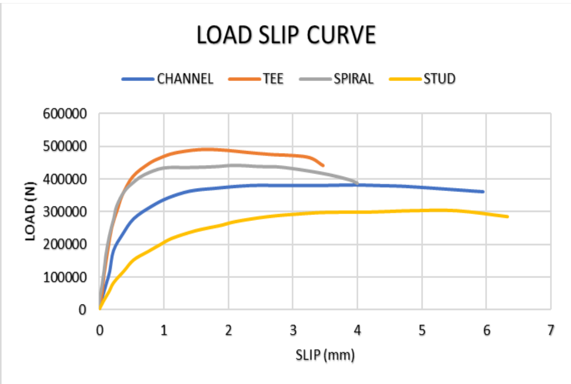


Fig. 12. Combined load slip curve

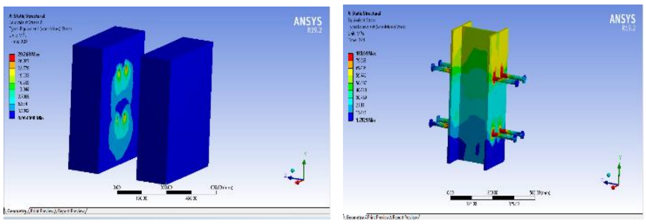
The load slip curves showed ductile plastic plateaus before fracture of specimens due to the connector fracture. Directional deformation is very high for stud when compared to others. Moreover, observing from the secant slope of load-slip curve in elastic stage, it was found that the shear stiffness of channeled, tee and spiral connectors increased around 22%, 47%, 30% than stud, when the other 3 connectors are embedded in composite structure.

Table 6. Maximum load and slip values.

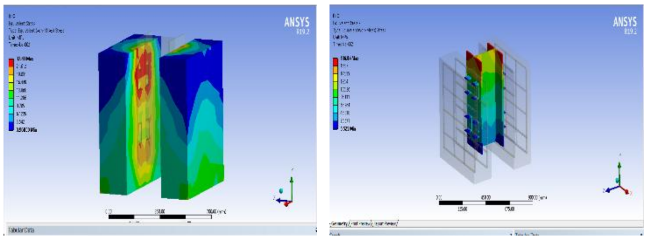
SHEAR CONNECTORS	SLIP (Y AXIS) (mm)	LOAD (kN)
STUD	-6.330	285
CHANNEL	-5.949	362
TEE	-3.474	440
SPIRAL	-4.006	387

C. Equivalent Stress and Strain

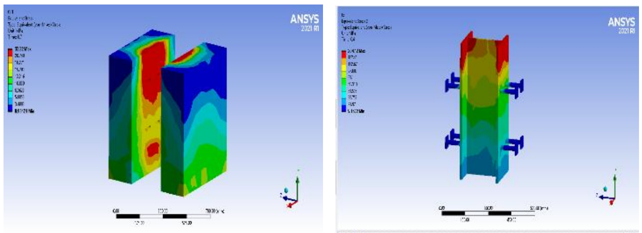
Stress concentration of composite beam with different shear connectors are shown in Fig. 13. Comparing the whole result, tee type shear connector bears higher equivalent stress with higher load. The static behaviour of all the tested shear connectors satisfied the ductility requirements. Strain in concrete of these 4 models are within the limit (< 0.0035). Stud, tee, and spiral connectors have higher strain values.



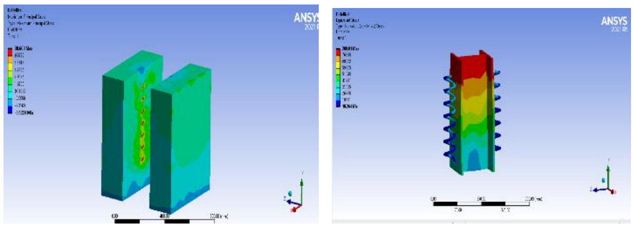
a. Shear stud



b. Channelled shear connector



c. Tee type shear connector



d. Spiral shear connectors

Fig. 13. Equivalent stress on different shear connectors

D. Modes of Failure

The ultimate capacity of the shear connector is determined when the maximum load from the push-out test is observed. Although the push-out measured displacement with increasing load provides valuable insight into the problem, it is very difficult to determine the exact failure mode of the specimen. Generally, three modes of failure were observed from the push-out test. The first mode of failure is the concrete cone failure where no shear connector failure is observed. For this mode of failure, the concrete around the shear connector started to fail in compression before stress in shear connector reached yield point, the compression failure progresses through the thickness of the concrete forming a conical shape around the connectors [3]. The second mode of failure is that stress in shear connector reaches yield point and no concrete failure is observed. This mode of failure is identified as the steel failure mode where the yield stress is reached by the connector element while maximum concrete stress of the concrete element is not reached. Finally, the third mode of failure is the combined failure of the connectors and concrete slab when maximum stresses are reached in the shear connector and concrete elements. From Fig. 13, it was observed that, in specimen with stud shear connector, the maximum stress concentration occurs both in shear connector and in concrete around the shear connector. Whereas in specimens with tee and channel shear connectors, the maximum stress concentration is observed only in concrete around the shear connectors. So, the failure of tee and channel shear connectors may happen due to the failure of concrete around the shear connectors with excessive cracking or crushing of concrete. Spiral connector shows only less stress concentration in both concrete and steel.

Table 7. Stress strain result of composite structure with different shear connectors

SHEAR CONNECTOR	MAX EQUIVALENT STRESS (MPa)		MAX STRAIN	
	CONCRETE	STEEL	CONCRETE	STEEL
STUD	29.268	183.61	0.00332	0.00120
CHANNEL	32.43	186.84	0.00296	0.00213
TEE	32.22	204.12	0.00330	0.00129
SPIRAL	30.603	208.01	0.00335	0.00104

Compared to stud type shear connector, rest of the connectors could carry higher loads with higher deformation, equivalent stress, and smaller slip value. They are sufficiently strong as well to perform composite actions. Teew type shear connector gives better result as compared to others. By comparing maximum stress concentration of steel in these 4 shear connectors, stud had a wedge-shaped failure zone near steel beam, but other three type shear connectors bear higher loads. But in tee type shear connector, stress concentration of concrete is very high, which means it can bear higher load with small cross-sectional area.

3. CONCLUSION

Shear connectors between concrete slabs and steel beams gives the composite integrity. Headed stud shear connectors are the most common type of shear connectors. In order to eliminate some of the problems and difficulties associated with standard shear studs, three other type connectors such as channeled, tee, spiral are used and analyzed on their static behavior. Based on the analytical investigation following conclusions were made:

- By comparing the values of maximum deformation and corresponding load; tee type shear connector bears a higher load with small deformation.
- The ultimate slip of Tee is 45%, 40%, 15% smaller than that of stud, channel, and spiral connectors.
- The load slip curves showed ductile plastic plateaus before fracture of specimens due to the connector fracture.
- Directional deformation is very high for stud when compared to others.
- Compared to stud type shear connector, rest of the connectors could carry higher loads with higher deformation, equivalent stress, and smaller slip value. They are sufficiently strong as well to perform composite actions.
- TEE type shear connector gives better result as compared to others.

4. ACKNOWLEDGMENT

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