



STUDY ON DUCTILITY BEHAVIOR OF DIFFERENT TYPES OF SHEAR CONNECTORS IN COMPOSITE STRUCTURAL ELEMENTS

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ABSTRACT

Composite Structures have several advantages over traditional reinforced concrete which incorporate high strength to weight ratios, dimensional stability and structural integrity. Late years have seen a considerable increment in the utilization of composite structures and improved research went for creating new strategies for combining steel and concrete. composite structures result in efficient design and economy in construction time hence used especially in construction of building floors and bridges. Wide construction practices involve connecting Concrete slab and hot rolled steel beam sections by shear connectors. Shear Connectors are used to enhance proper connection and resist horizontal shear forces. A Composite member has to be designed in such a way that before composite structural element reaches ultimate capacity, shear connectors should not fail due to lack of ductility. In this study Finite Element Analysis has been done on four types of shear connectors for ductility criteria. Push-out test Specimen and Composite beam modeling with four different types of shear connectors is done in ANSYS and are analyzed. The Analytical results are presented and focused on the study of ductility behavior and load slip behavior of connectors of varying height in composite beams.

Key words: Shear connectors, Push-out test, Composite beam, Ductility, Load slip behavior.

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1. INTRODUCTION

Since 1920 there has been an incredible increment in the usage of composite structures in Bridge and tall building construction. Generally the construction strategy employs connecting a Concrete slab and Steel beam sections by different types of connectors to suite the purpose. Resistance offered in compression and tension by Concrete and Steel respectively is completely utilized by connecting them properly through Shear connectors. Shear connectors which are generally welded to the flange of steel section resist the horizontal Shear forces present at the interface of concrete and steel and also ensures a legitimate bond between them.

Shear connectors are of various sorts and depending upon the purpose of use, quality, strength and deformation they can be divided as Rigid and Flexible shear connectors. If the failure of the connector occurs by front side shearing and there is an accumulation of stress in the surrounding concrete then the connector can be called as rigid shear connector. This type of connector results in concrete area failure or failure by cracking of weld. If the failure of connector is by shearing of connector at the root or connection point and if it undergoes plastic deformation then the connector can be called as flexible connector. Flexible connectors are more ductile connectors. Different types of shear connectors have been developed in accordance with time and use.

1.1. Headed Studs

Headed stud is a short round piece of cold drawn steel which is welded to the beam at one edge and has a greater diameter head at the other end in to the concrete slab which helps in uplifting of concrete slab from the steel beam. It is the most commonly used connector because of its ease in placing and welding. They prove to be non ductile connectors and result in large interfacial slip. They go in coherence when used with concrete of low strength. Breakdown of shear connection can occur by stud shearing failure or crushing of concrete.

1.2. Perfobond Shear connector

In recent years (1980) a connector called perfobond shear connector was developed by Leonhardt, Andra and partners to overcome the fatigue issues caused by stud connectors when used in bridges. Generally a steel plate with a number of circular openings welded to beam flange can be called as perfobond connector. The concrete which flows through these connector holes helps in creating a dowel action amongst concrete and connector. Thus it improves the bondage property and offers good resistance in both horizontal and vertical directions. The structural behavior of these connectors is highly impacted by its dimensional properties, number of holes, diameter of holes, thickness, length and height of plate.

1.3. Channel Connectors

When one flange of rolled Channel section is welded to steel beam flange, it can be called as Channel connector. Channel connectors are rarely used where field installations are required and are generally shop welded. A very small number of channel connectors can supplant a large number of headed studs because of their expected higher load carrying capacity. Inspection procedures required for channel connectors are low because of high reliable and dependable welding system adopted.

1.4. I-shape Shear Connectors

Various reasons like monetary contemplations and strength aspects has persuaded in development of I-shape shear connector. Due to its symmetry in both the axes, it offers more resisting in bending. Similar to channel connector, connection is established by welding one flange of rolled I section to flange of steel beam.

Connectors are those with adequate deformation capacity to legitimize any inelastic redistribution of shear assumed in design can be called as ductile connector. A Shear connector can be called as ductile connector if its characteristic slip is at least 6mm [Euro code 4]. In this paper an attempt has been made to study about ductility and load slip behavior of different shear connectors analytically by nonlinear static analysis and the results are compared by software package ANSYS.

2. ANALYTICAL STUDY

Ductility, bondage and shear strength of a connector can be discovered from the push-out test. Properties of connector like height of connector, embedded depth of connector, modulus of elasticity etc., influences it's behavior under load. Behavior of Shear connectors is also influenced by grade of concrete and the reinforcement provided in the concrete slab.

2.1. Finite Element Analysis in ANSYS

Push-out test specimen is modeled in ANSYS. Concrete is modeled using SOLID 65 element and BEAM 189 element is used for modeling Steel. SOLID 65 is a eight node element with six degrees of freedom at each node. This element is used for Reinforced or plain concrete models. When considered in structural analysis point of view, this element has large deflection and stress stiffening capabilities. Geometry, node locations and coordinate system of this element are shown below.

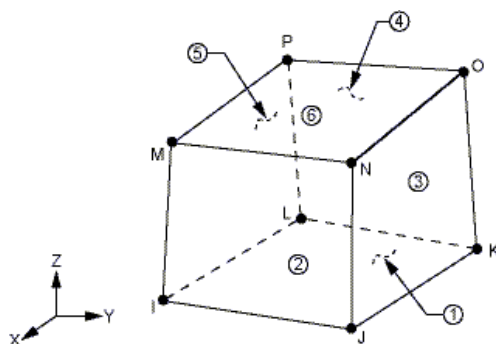


Figure 1 Solid 65 Element

BEAM189element is suitable for analyzing slender to moderately thick beam structures. This element has six degrees of freedom at each node which include translations and rotations in the x, y, and z directions. An additional option of restrained and unrestrained warping is also available with this element. When considered in structural analyses point of view, this element has large rotation, stress stiffness and large-strain nonlinear applications. Geometry, node locations and coordinate system of this element are shown below.

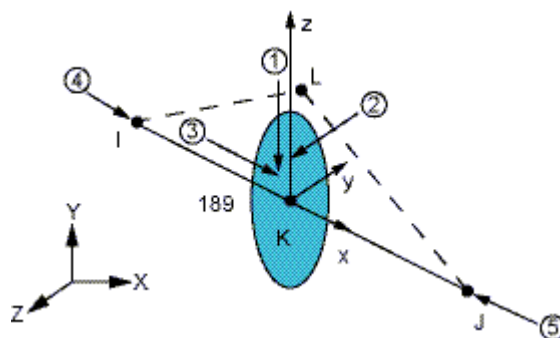


Figure 2 BEAM 189 Element

M 40 and Fe 250 are the grades of concrete and steel used for modeling respectively. The material properties adopted for the different elements in analysis are given in table below.

Table 1 Material Properties

Material	Poisson ratio	Young's modulus of Elasticity(N/mm ²)
I beam	0.3	200000
Shear connectors	0.3	200000
Concrete slab	0.17	31620

Uniformly distributed load is applied and increased at the rate of 50kN for each load step. The loading conditions are applied on the nodes of steel beam at the top until 6mm slip is observed at the base. The load and support conditions are maintained same in all models with different connectors.

2.2. Description of Push-Out Test Specimen

The Push-out specimen comprises of hot rolled steel section with concrete slab and shear connectors attached to both of its flanges. The push-out test specimens are modeled according to Eurocode 4 specifications with only the variation made in its dimensions. The dimensional properties of push-out specimen are given below.

- Hot rolled Steel beam section: ISMB 200 @ 25.4 kg/m
- Width of concrete slab on either side of flange: 100 mm
- Breadth of Concrete slab: 250 mm

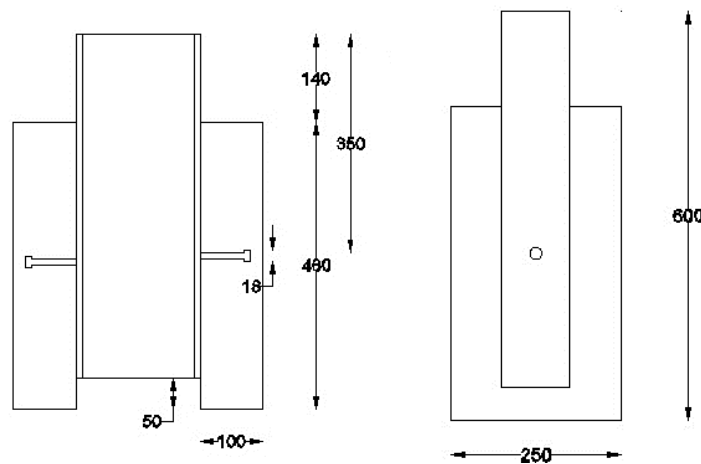


Figure 3 Details of push-out specimen used for analysis

Four of different types of Shear connectors are modeled and their load slip behavior is analyzed under load. The length and thickness of connectors is taken as 80mm and 10mm and are maintained constant for all these connectors. The Dimensional details of these connectors are given as follows.

Study on Ductility Behavior of Different Types of Shear Connectors in Composite Structural Elements

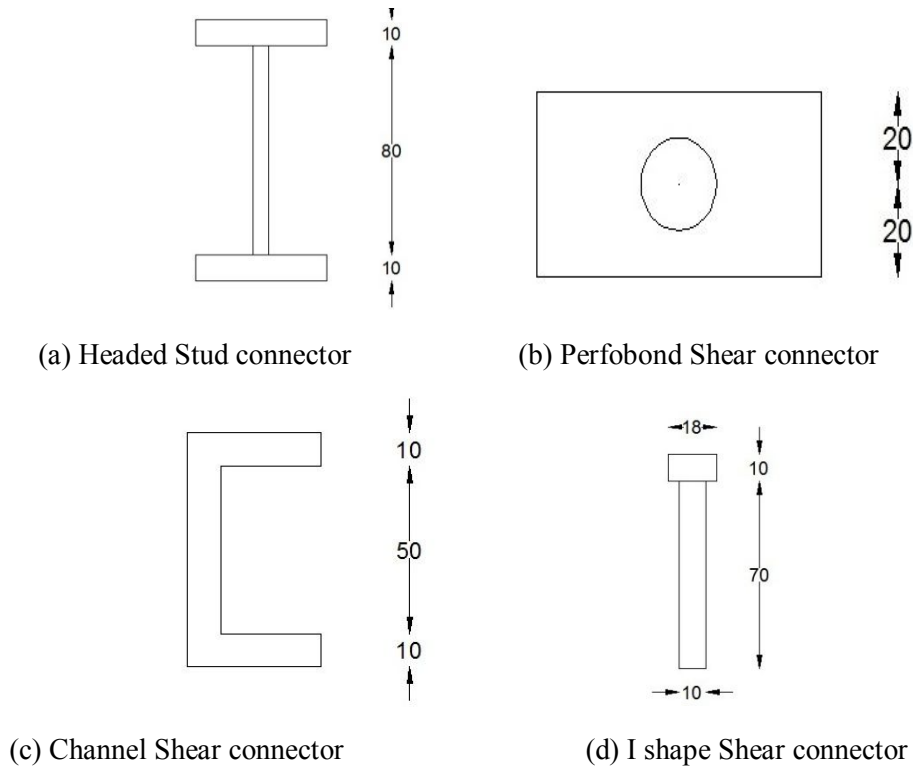
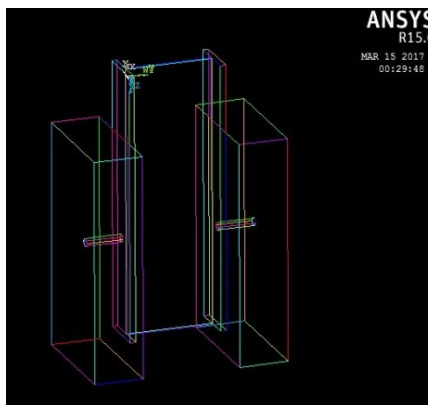


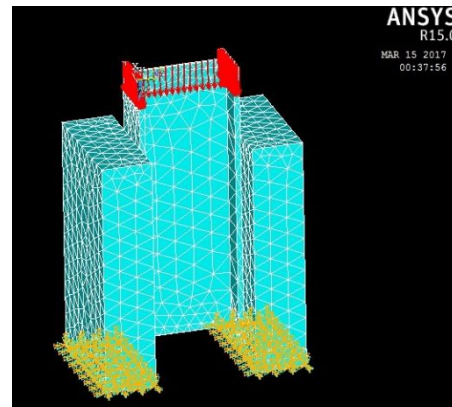
Figure 4 Details of Shear connectors used for analysis

2.2.1. Push-Out Test Analysis with Stud Connector

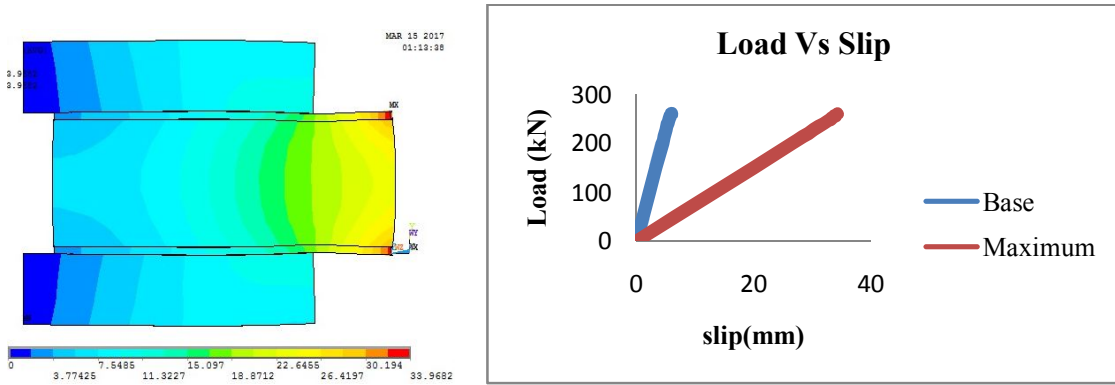
The Push-out test specimen is modeled with stud connector and meshing is done using a free mesh. The model consists of 5832 nodes and 25438 elements. Fixed end conditions are adopted to the nodes of concrete at the bottom of slab restraining all the degrees of freedom. The model, meshing, support conditions and the analytical results for stud connector specimen are as shown in figure 5.



(a) Model of Push-out test specimen



(b) Meshing of Push-out test specimen



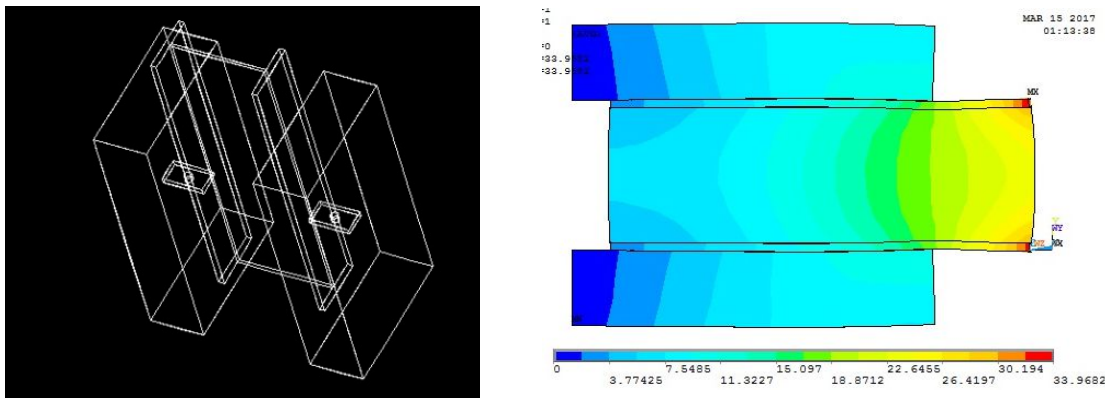
(c) Nodal displacement of push-out test specimen

(d) Load Vs Slip behavior

Figure 5 Push-out test specimen with Stud connector

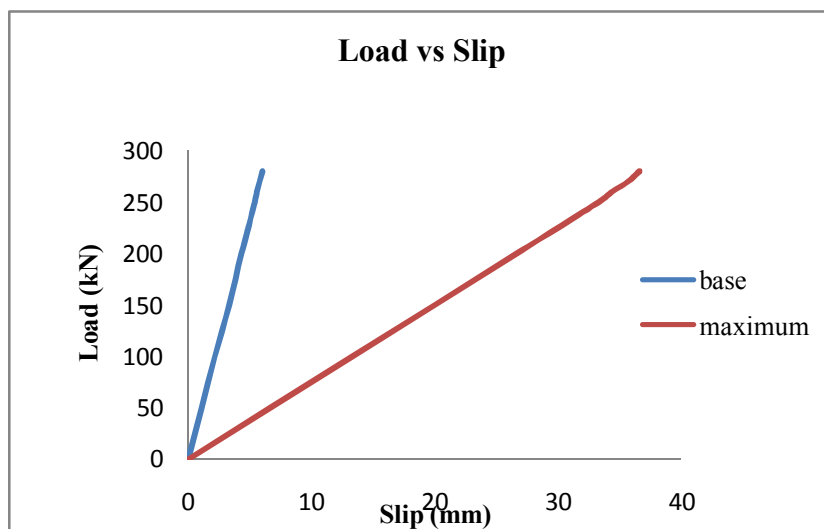
2.2.2. Push-Out Test Analysis with Perfobond Connector

The model consists of 6380 nodes and 26905 elements. The model, and the analytical results for perfobond connector specimen are as shown in figure 6



(a) Modeling of push-out test specimen

(b) Nodal displacement of push-out specimen



(c) Load Vs Slip behavior

Figure 6 Push-out test specimen with Perfobond connector

2.2.3. Push-Out Test Analysis with Channel Connector

The model consists of 9192 nodes and 38201 elements. The model and the analytical results for channel connector specimen are as shown in figure 7.

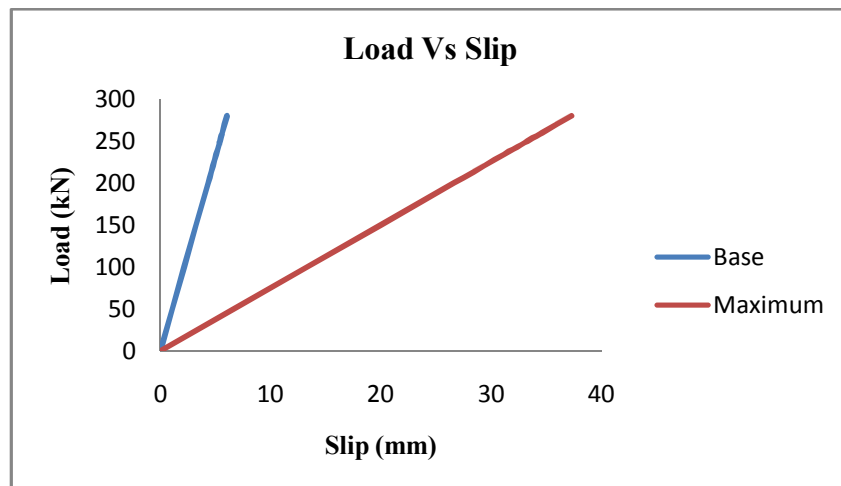
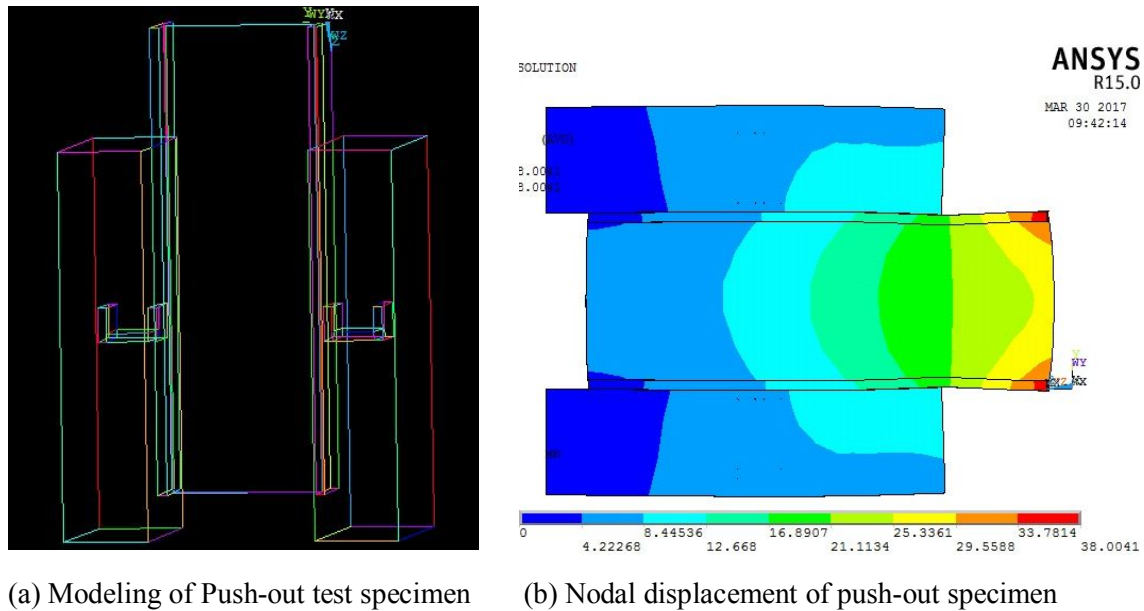
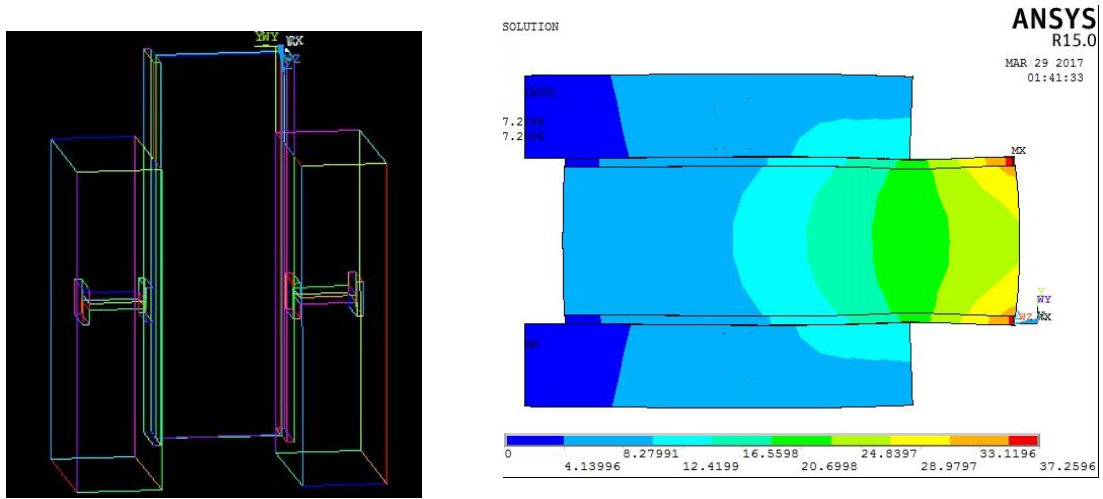


Figure 7 Push-out test specimen with channel connector

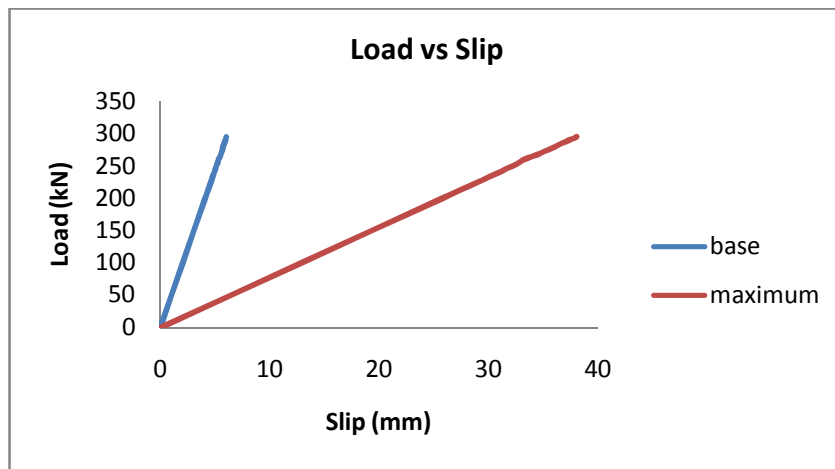
2.2.4. Push-Out Test Analysis with I-Shape Shear Connector

The model consists of 9192 nodes and 38201 elements. The model and the analytical results for I-shape shear connector specimen are as shown in figure 8



(a) Modeling of Push-out test specimen

(b) Nodal displacement of push-out specimen



(c) Load Vs Slip behavior

Figure 8 Push-out test specimen with I shape shear connector

The displacement of the nodes at the base of I beam is calculated. The Nodal displacement at the base and the maximum displacement are as follows in Table 2.

Table 2 Slip values of different shear connectors

LOAD (kN)	SLIP (mm)							
	STUD		PERFOBOND		CHANNEL		I-SHAPE	
	Base	Max	Base	Max	Base	Max	Base	Max
50	1.12	6.66	1.08	6.66	1.07	6.65	0	6.44
100	2.24	13.32	2.16	13.32	2.15	13.3	2.05	12.88
150	3.36	19.98	3.32	19.99	3.23	19.96	3.08	19.32
200	4.48	26.64	4.32	26.65	4.32	26.61	4.11	25.76
250	5.6	33.3	5.4	33.31	5.4	33.27	5.14	32.2
260	6.02	34.36	5.57	34.38	5.61	34.6	5.35	33.24
270			5.79	35.71	5.81	35.93	5.59	34.78
280			6.02	36.63	6.04	37.26	5.76	36.07
290							5.97	37.36
295							6.04	38.04

2.3. Description of Composite Beam Specimen

A Composite Beam consists of hot rolled steel beam section connected to concrete slab by shear connectors. Composite beams specimens are analysed with different shear connectors and load slip behavior is studied. Uniformly Distributed load is applied at the rate of 50 kN for each load step up to 450kN. The dimensional details of beam are maintained constant when analysed with different types of shear connectors. Dimensional properties of Composite beam are as follows

Length of beam: 1500mm

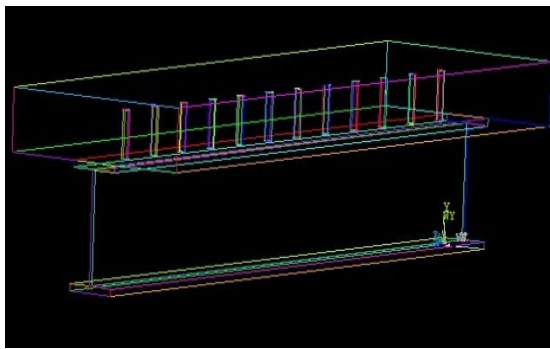
Depth of concrete slab: 150mm

Width of concrete slab: 400mm

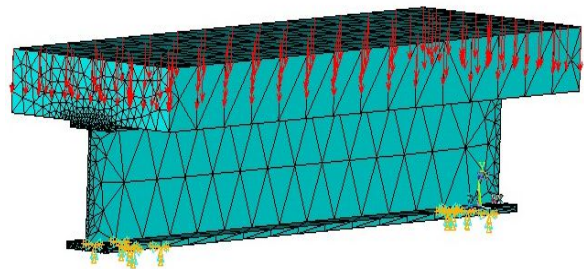
Distance between supports: 1300mm

2.3.1. Composite Beam with Stud Connectors

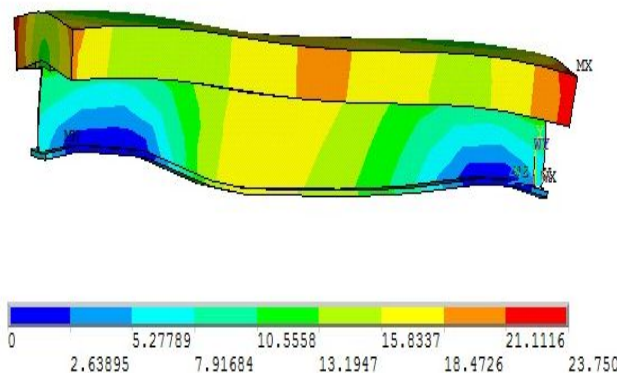
Stud connectors of 75mm length and a diameter of 16mm are modeled in the beam and load-slip behavior is analysed. The element and material properties are adopted as stated above. Modeling, meshing, support conditions and the analytical results for stud connector beam specimen are as shown below.



(a). Modeling of composite beam



(b) Meshing of composite beam



(c). Nodal Displacement

Figure 9 Composite beam with Stud connector

The composite beam is analysed with stud connectors of different heights namely 65mm,75mm and 100mm and load slip behavior is observed. Dimensions of beam, Material and element properties are maintained as above.

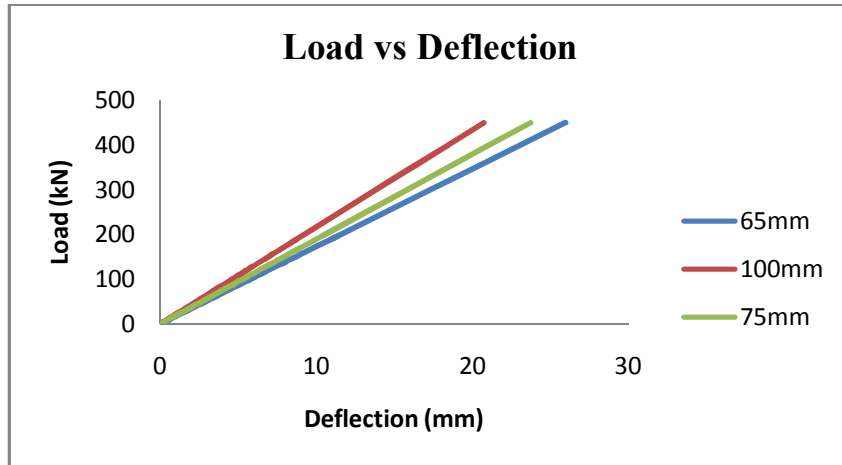
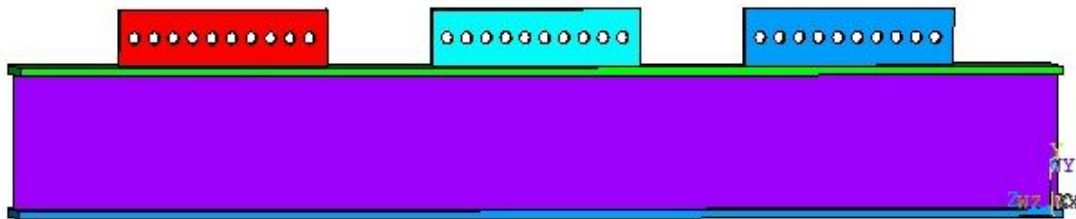


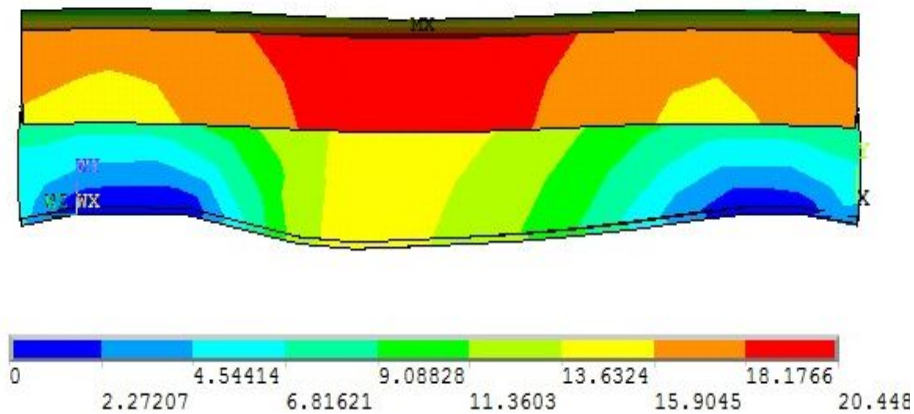
Figure 10 Load Vs Deflection behavior for varying height of stud connectors

2.3.2. Composite Beam with Perfobond Connectors

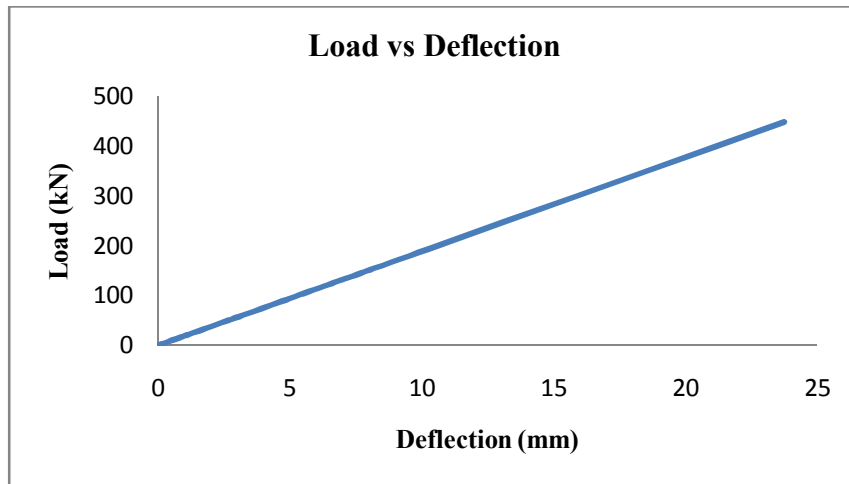
Perfobond connectors of 75mm height and 300mm length are modeled in the beam and load-slip behavior is analysed. The element and material properties are adopted as above. The model and the analytical results for perfobond connector beam specimen are as shown .in figure 11.



(a) Modeling composite beam



(b) Nodal displacement



(c) Load Vs Deflection behavior

Figure 11 Composite beam with Perfobond connector

The composite beam is analysed with Perfobond connectors of different heights namely 75mm,85mm and 100mm and load slip behavior is observed.

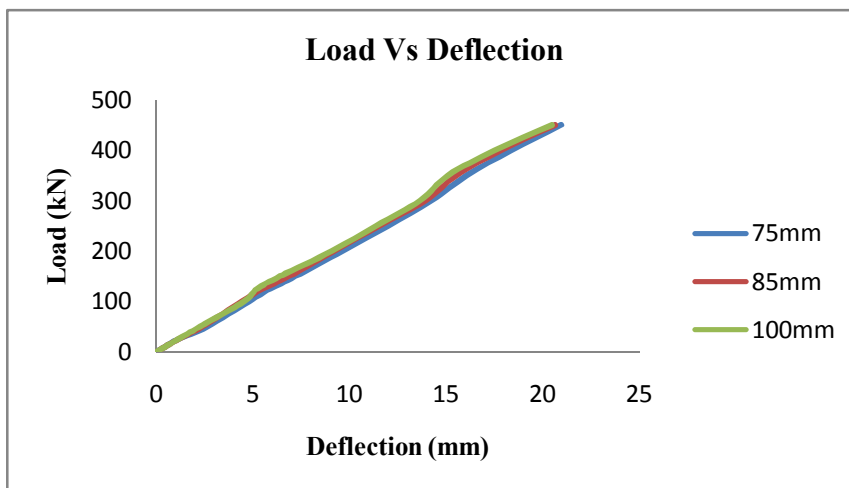
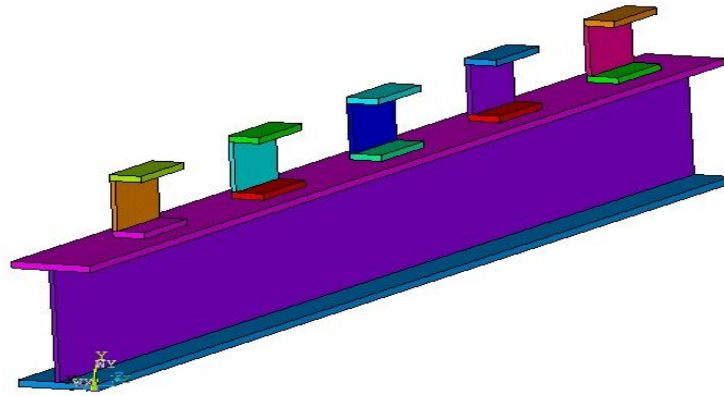


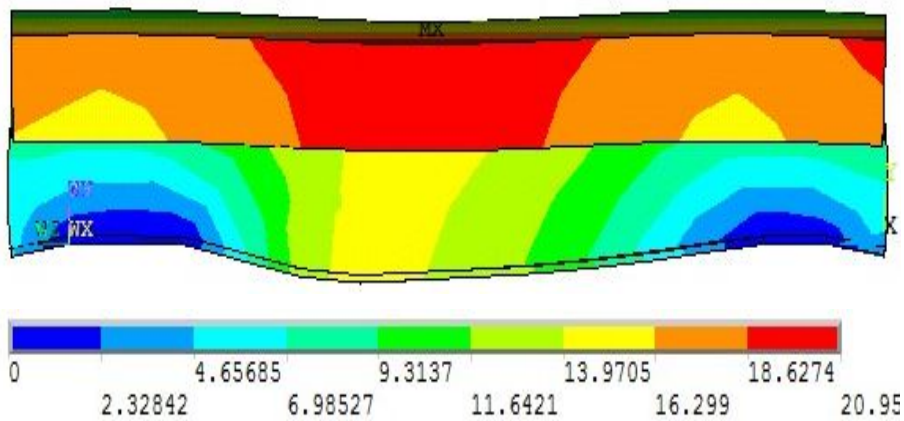
Figure 12 Load Vs Deflection behavior for varying height of Perfobond connectors

2.3.3. Composite Beam with Channel Connector

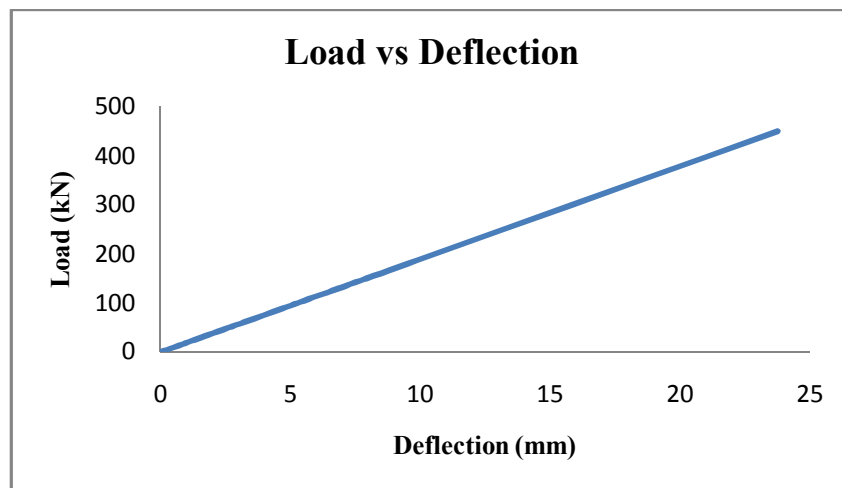
Channel connectors of 75mm height and 100mm length are modeled in the beam and load-slip behavior is analysed. The model and the analytical results for Channel connector beam specimen are as shown in figure 13.



(a) Modeling of composite beam



(b) Analytical result of composite beam



(c) Load Vs Deflection behavior

Figure 13 Composite beam with Channel connector

The composite beam is analysed with Channel connectors of different length namely 75mm,100mm and 125mm and load-slip behavior is observed.

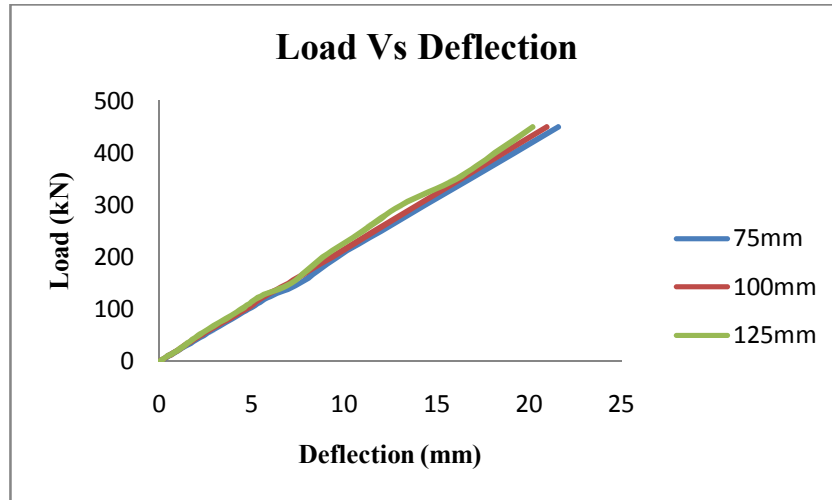
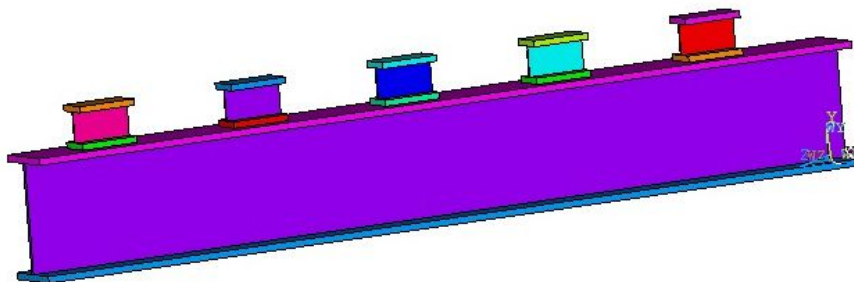


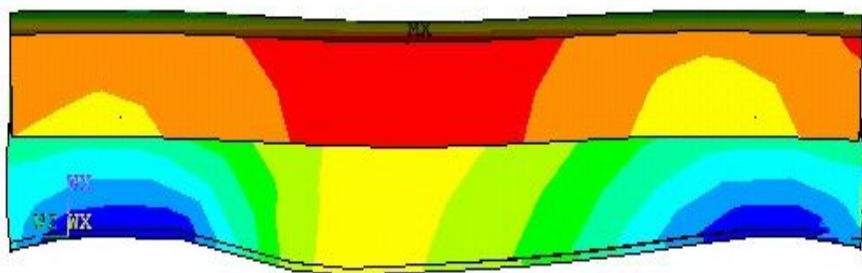
Figure 14 Load Vs Deflection behavior for varying height of Channel connectors

2.3.4. Composite Beam with I Shape Shear Connector

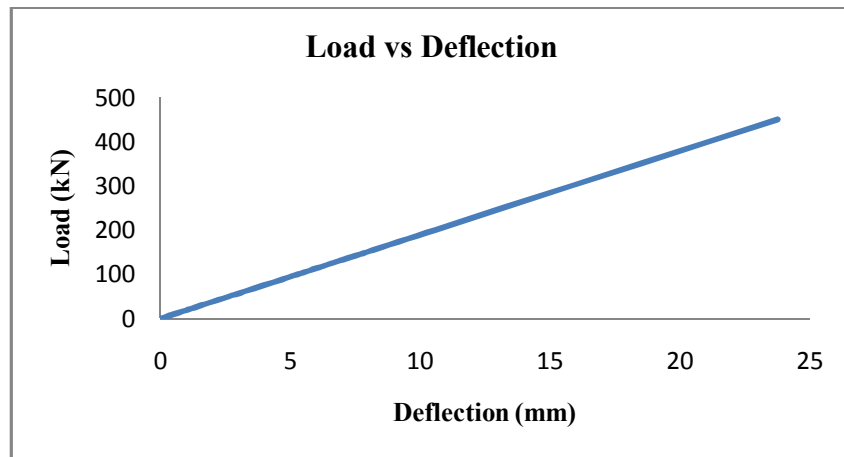
I shape shear connector of 75mm height and 100mm length are modeled in the beam and load-slip behavior is analysed. The model and the analytical results for I Shape shear connector beam specimen are as shown in figure 15.



(a) Modeling of composite beam



(b). Analytical result of composite beam



(c) Load Vs Deflection behavior

Figure 15 Composite beam with I shape shear connector

The composite beam is analysed with Channel connectors of different heights namely 75mm,100mm and 125mm and load-slip behavior is observed.

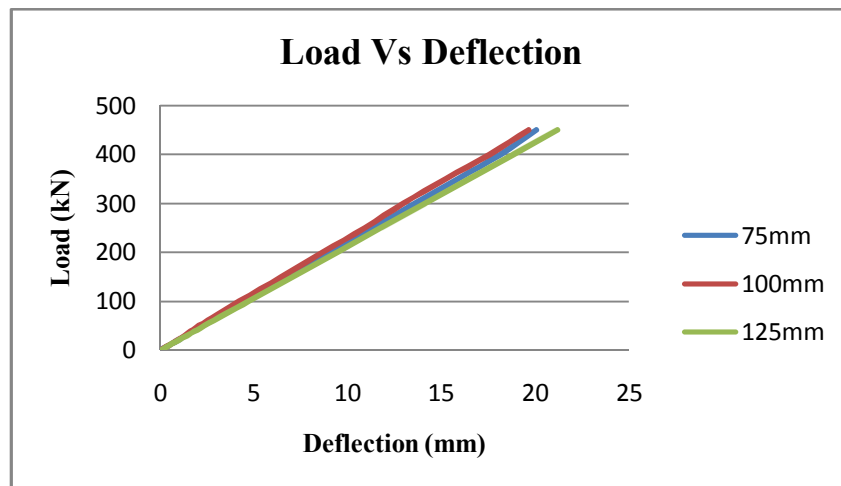


Figure 16 Load Vs Deflection behavior for varying height of I Shape connectors

3. CONCLUSION

According to Eurocode 4 if a shear connector allows at least a displacement of 6mm before failure it can be called as ductile shear connector. Finite element analysis of push-out test specimen is done and load-slip behavior is plotted for four different types of shear connectors. It is observed that the load at which Stud and Perfobond connectors reach a slip of 6mm is higher than the load carrying capacity of these connectors. This indicates that Stud and Perfobond connectors fail before reaching a slip of value 6mm. Channel and I shape connectors reach the slip value of 6mm within their load carrying capacity. According to the results obtained it can be observed that the channel and I shape connectors are ductile whereas Stud and Perfobond connectors are non ductile connectors.

When the same connectors are used in beams channel and I shape connectors show higher load carrying capacities with lesser deformations. With the increase in height of Stud connectors within range of 65mm to 100mm and Perfobond connectors in range of 75mm to 100mm the load carrying capacity of beam is increased with reduction in deformation.

Increase in height beyond 100mm both Stud and Perfobond connectors show an increase in deflection values.

With the increase in height of Channel connectors within range of 75mm to 125mm the load carrying capacity of beam is increased with reduction in deformation. Increase in height beyond 125mm channel connector show an increase in deflection values. With the increase in height of I shape connector within range of 70mm to 125mm the load carrying capacity of beam is increased with reduction in deformation. Increase in height beyond 125mm I shape connector show an increase in deflection values.

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