Numerical Investigation On The Behaviour of Steel-UHPC Composite Beams using Different Shear Connectors

Anusree K
Dept. of Civil Engineering
Govt. College of Engineering, Kannur
Kannur, India

Prof. Manu P Raj
Dept. of Civil Engineering
Govt. College of Engineering, Kannur
Kannur, India

***Abstract*—High-Strength Steel (HSS) and Ultra-High-Performance Concrete (UHPC) are widely used construction materials nowadays. In steel-concrete composite construction, shear connectors play an integral part. Shear connections are designed to transmit longitudinal shear, prevent the separation of steel and concrete slabs, and increase the overall structural effectiveness of the system. In the present study, the ultimate load carrying capacity of steel-UHPC beam with different shear connectors is to be evaluated using finite element software Ansys Workbench 2022 R2. The failure modes, strength and overall behavior of the specimens is studied in this paper. The composite beam is numerically validated and a comprehensive parametric study was conducted to determine the effect of the following parameters. Different types of shear connectors and diameter of stud are selected as parameters for the current study. Using finite element software Ansys Workbench 2022 R2, the influence of these parameters on the ultimate strength, load-deflection behaviour, and load-slip behaviour of the composite beam is examined.**

Keywords— Ultra-High-Performance Concrete; longitudinal shear; composite beam

I. Introduction

Due to its potential for broad applications in civil engineering, studies on high-strength steel (HSS) and ultra-high-performance concrete (UHPC) is expanding. An emerging approach called composite construction can be adopted in buildings with high initial stiffness, ductility and bearing capacity. Steel-UHPC composite beams consists of steel beam and UHPC slab. Ultra-high-performance concrete beams have higher ultimate strengths, large yield loads, and elastic stiffness when compared to beams manufactured of conventional strength concrete. They are used as high-performance structural members in engineering applications like temporary bridge systems, short span overpass bridges, floors of buildings. In this study, composite beam subjected to bending is examined. L Tong et al. investigated the load-bearing capacity of steel-UHPC composite beam with stud connectors under pure bending by experiments and FE analysis [1].

A. *Composite Construction*

The purpose of composite construction is to create a monolithic action between cast-in-situ concrete slabs and prefabricated steel beams. In order for the two component construction units to work as single unit and resist the load through composite action, sufficient shear connection must be established between the two components where the concrete carries the majority of compression and steel beams carry the majority of tension.

B. *Advantages of Steel-Concrete Composite Construction*

Steel-concrete bridges are widely used due to their aesthetic appearance and strong structural capacity. Steel bridges offer many advantages over conventional RC bridges. Some of them are listed below.

- High strength to self-weight ratio: Steel bridges have high strength to self-weight ratio which helps to carry dead loads, especially when ground conditions are unfavourable.
- Flexibility of construction.
- Durability.
- High resistance to seismic and cyclic loading.
- Good artistic appearance.
- The benefits of both prefabricated and cast-in-place construction will be present in composite construction.
- This technique results in the creation of innovative, cost-effective constructions that are heavily prefabricated, significantly increasing the quality of structure.
- The lifting and carrying of light steel girders require the use of light cranes rather than heavy ones.
- In order to gain advantages from both the concrete slab and the steel beam, highway bridges with RC slabs on top of the beams can be effectively used in composite structures.

II. Numerical Modelling

The numerical modelling of the composite beam was done using ANSYS Workbench 2022 R2. A four-point bending test simulation in the programme was used to determine the beam's flexural behaviour. The modelling was done by adopting the material properties of the specimen from the experimental study conducted by L Tong et al. (2022).

A. *Description of the Experiment*

In the experimental study conducted by L Tong et al. (2022) [1], composite beams with UHPC slab and steel beam were introduced. The beams used for the study was made through a sequence of steps. First, a steel beam was made using Q690 steel by welding web and flanges on top of it stud connectors were welded. Then a UHPC slab was casted. Four-point bending test was used to determine the beam's flexural behaviour. With the use of the load cell and spreading beam, the load applied to the beam was displacement-controlled.

B. *Geometric Modelling*

The material properties of beam and its dimensions by experimental study conducted by L Tong et. al. (2022) [1] are used for the validation of the FE model. The beam has a span 3200 mm, width and depth of slab was 580mm and 80 mm respectively; the steel beam section with flange thickness 20 mm, web thickness 10mm, total height of 450 mm, diameter of stud 19 mm for connection are the dimensions of the beam used for the validation purpose. A schematic representation of steel-UHPC composite beam is given in Fig.1. The geometry of the basic model used for study is given in Fig.2. Dimensional details of the model are given in Table I. Various dimensions of this basic model were changed accordingly to conduct different parametric study.

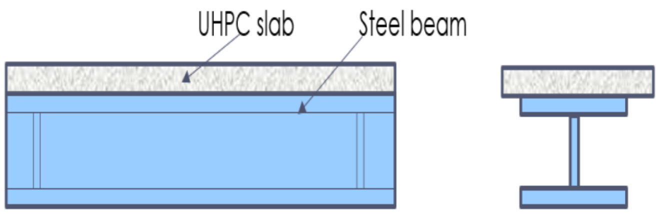

Fig. 1. Schematic representation of steel-UHPC beam

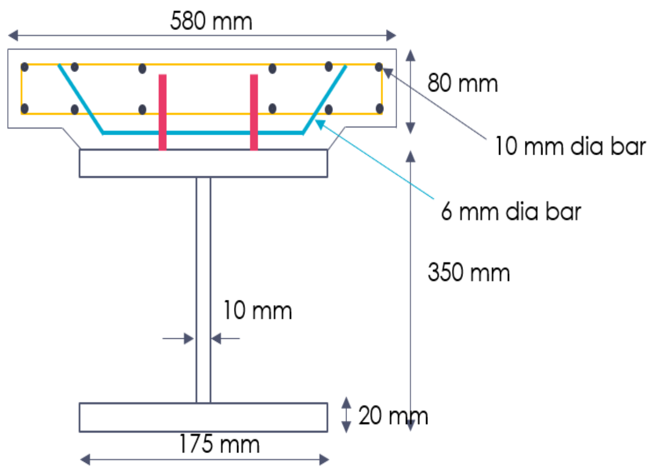

Fig. 2. Dimensions of steel-UHPC beam

The different components of the model are modelled in Ansys. As Ansys is a user-friendly software, the model was created without much difficulty.

TABLE I. DETAILS OF SPECIMEN

Geometric parameters	***Dimension (mm)***
Steel beam	350x230x10x20
Height	450
Span	3200
d_{stud}	19
l_{stud}	80
$V_{interval}$	110
$H_{interval}$	75

C. *Material Modelling*

L. Tong et al. (2022) [1] developed a constitutive replica of the steel parts based on the tensile coupon test conducted by them. The material properties of steel and concrete adopted for this study are given in Table II and III respectively. The steel reinforcements in the UHPC slabs were made of HRB400 and had a 10 mm reinforcement diameter. The constitutive relation of the Q690 steel beam and the HRB400 reinforcement is shown in Fig. 3.

TABLE II. MATERIAL PROPERTIES OF STEEL

Properties	***Value***
Young's modulus	225000 MPa
Poisson's ratio	0.3
Yield strength	690 MPa

TABLE III. MATERIAL PROPERTIES OF CONCRETE

Properties	***Value***
Young's modulus	49000 MPa
Poisson's ratio	0.2
Uniaxial compressive strength	140.1 MPa
Uniaxial tensile strength	5 MPa

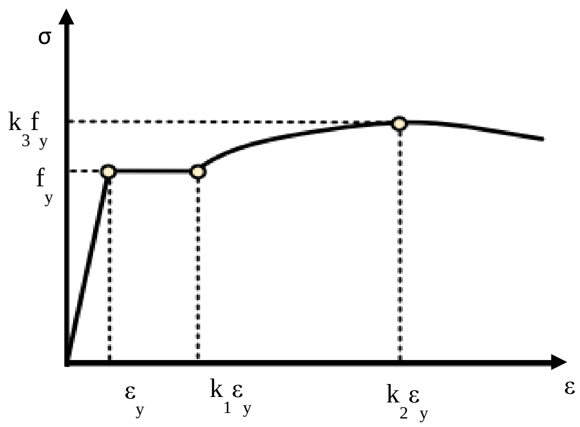

Fig. 3. Constitutive relationship of Q690 steel beam and HRB400 reinforcement

where fy is yield strength of steel, Es represent elastic modulus of the reinforcement and steel beam, εy is the yield strain and k_1–k_3 are control parameters of the beam.

D. Finite Element Modelling

The finite element (FE) model was created in ANSYS Workbench 2022 R2. Fig.4 shows the FE model of the beam obtained from software. The boundary conditions of the FE model are given as simply supported. The loading is given as displacement-controlled till failure occurs.

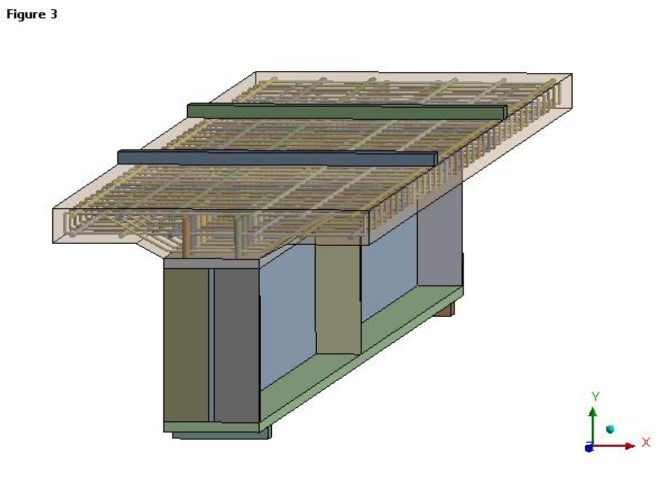

Fig. 4. Composite beam modelled in Ansys Workbench 2022 R2

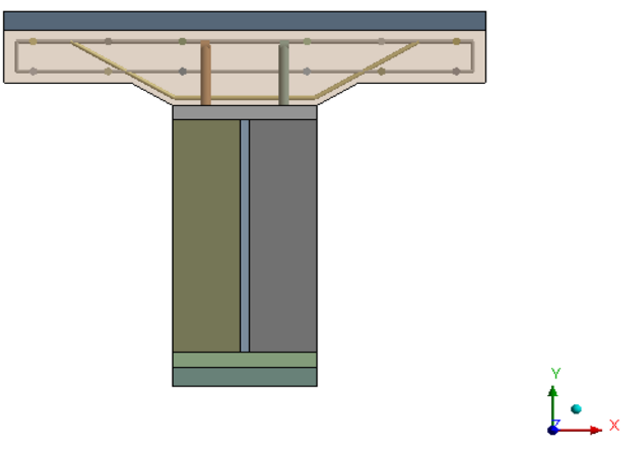

Fig. 5. Isometric view of the beam in Ansys Workbench 2022 R2

E. Meshing

To select a suitable mesh, FE model with 5 different mesh sizes were analysed. Beam was meshed with size of 40mm, 50mm, 60mm, 65mm and 70mm. To choose the most precise mesh size for the investigation, the outcomes of the FE analysis were contrasted with those of the tests. A total of 2358 elements were presented in the model. In order to reduce the running time, the model was made half symmetrical. Based on the mesh convergence study mesh size of 50 x 50 mm was considered for the geometric model developed for the validation. The Hexahedron element SOLID186 was used for the analyse of the beam. SOLID186 has 20 nodes with 3 DOF per node, which helps to catch the flexural behaviour accurately. Beam 188 is a two-node, three-dimensional, linear, quadratic, or cubic beam element that can be used to analyse thin to moderately thick beam structures. It has six or seven degrees of freedom at each node.

III. VALIDATION OF THE MODEL

The numerical model developed was validated using results obtained by L Tong et al. The deviation observed was 2.91%. Fig.6 represent the load-deformation curve of the specimen.

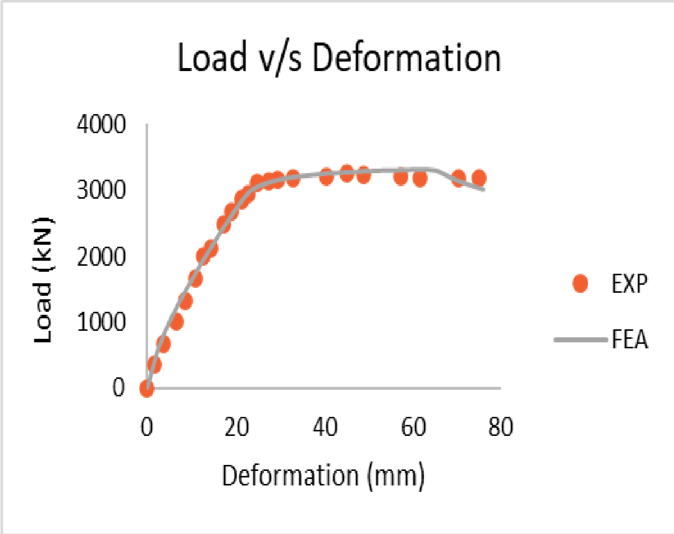

Fig. 6. Load-deformation curve

IV. PARAMETRIC STUDY

The parametric study was conducted by using different shear connectors by replacing stud connectors. The parametric study included the effect of stud diameter, height of stud and failure mode of different connectors. For studying the effect of these parameters, shape of the specimen and direction of loading in corresponding study were kept constant.

A. Effect of stud diameter on load bearing capacity

Keeping all other properties of the specimen constant, the diameter of stud was changed. 10mm, 13mm, 16mm, 19mm 22mm and 25mm were the diameters chosen. The capacity of the specimens was found to be unaffected by the stud diameter ratio. Fig.7 shows the load-deformation curve for studs with different diameters. The peak load obtained in each case is tabulated in Table IV.

TABLE IV. MAXIMUM LOAD AND DEFORMATION

Stud diameter (mm)	*Max load (kN)*	*Max deformation (mm)*
10	61.885	3317.6
13	60.945	3314.4
16	61.96	3316
19	49.367	3296.2
22	61.299	3321.4
25	61.983	3327.2

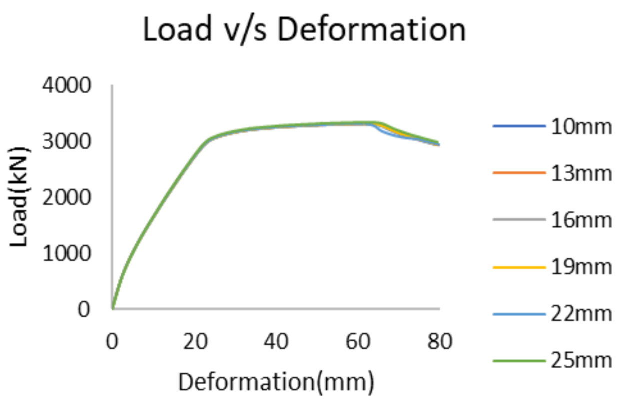

Fig. 7. Load-deformation curve for different stud diameters

B. *Effect of slip on different shear connectors*

Slip between steel and concrete is measured. Different shear connectors adopted in this study are stud, double T head, Triple T head, Plate T1, Plate T2, half ring circular, half ring plate connector. Fig.8 shows the load-slip curve for different connectors.

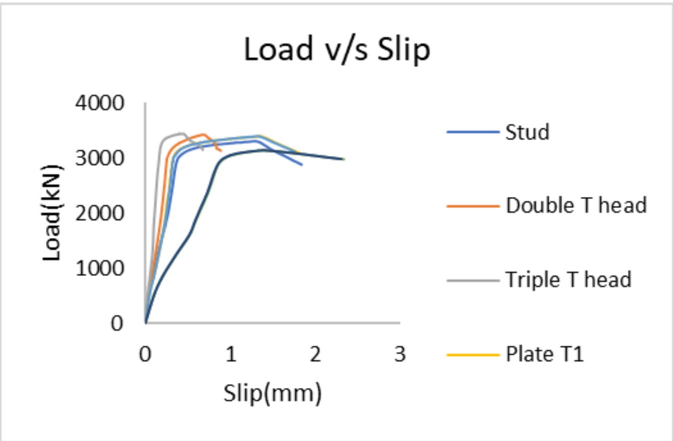

Fig. 8. Load-slip curve for different stud diameters

From the graph it is observed that the load capacity is low for half ring plate but its ductile behaviour is somewhat linear. But when it comes to triple T connector, even though the load capacity is high, its failure is sudden.

C. *Effect of load bearing capacity on different shear connectors*

Fig.9 shows the load-slip curve for different connectors.

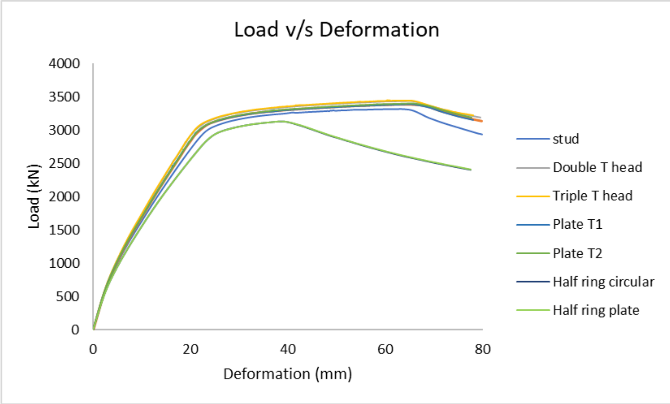

Fig. 9. Load-deformation curve for different stud diameters

From the graph, maximum deformation is for plate T2 and minimum for half ring circular. There is 25.15% increase in deformation for plate T2 while compared to that of stud connector.

V. CONCLUSIONS

The numerical model of the steel-UHPC beam was modelled in the FE software ANSYS Workbench 2022R2. The model was validated against the experimental results of L Tong et al. (2022). The parametric study was conducted to investigate the effect of stud diameter, stud height and different shear connectors on load carrying capacity. The conclusions obtained from the results are

- Type of shear connector is one of the major factors which influence the performance of steel-UHPC beam.
- Load carrying capacity increased by 5.03% for half ring circular connector.

REFERENCES

[1] Lewei Tong, Luhua Chen, Xiaoqing Wang, Jia Zhu, Xiaodong Shao, Zheng Zhao, "Experiment and finite element analysis of bending behavior of high strength steel-UHPC composite beams", Engineering Structures, vol. 266, 2022
[2] Yu-Hang Wang, Jie Yu, Jiepeng Liu and Y. Frank Chen, "Experimental and Numerical Analysis of Steel-Block Shear Connectors in Assembled Monolithic Steel–Concrete Composite Beams", Journal of Bridge Engineering, vol. 24, 2019
[3] Ali A. Semendary, Heather L. Stefaniuk, Diba Yamout, Dagmar Svecova, "Static performance of stud shear connectors and UHPC in deck-to-girder composite connection", Engineering Structures, vol. 255, 2022
[4] Ying Xing, Qinghua Han, Jie Xu, Qi Guo, Yihong Wang, "Experimental and numerical study on static behavior of elastic concrete-steel composite beams", Journal of Constructional Steel Research, vol. 123 , 2016
[5] Shreeja Kacker and Dr. Arun Kumar, "Comparative Study of the Shear Resistance of Different Types of Shear Connectors in Steel Beam-Concrete Slab Composite Construction", International Journal of Engineering Research & Technology (IJERT), Vol. 3 , 2014
[6] Brianna Ovuoba and Gary S. Prinz, "Headed Shear Stud Fatigue Demands in Composite Bridge Girders Having Varied Stud Pitch, Girder Depth, and Span Length", Journal of Bridge Engineering, Vol. 23 2018