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Research Paper

Comparison between experimental and analytical behaviour of the steel – concrete composite pushout specimen with stud and channel shear connector

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To investigate the behaviour of composite action with various shear connectors, push-out tests were performed for eight specimens. Test parameters includes are type of shear connector (headed stud connector and channel connector), number of connectors (one and two) and specimen with or without decking sheet. Test results showed that performance of the push-out specimens depends greatly on type of connector and decking sheet. From the experimental study it was observed that the performance and shear capacity of channel connector was 60 % more than the stud connector. The shear resistance between the steel and concrete was enhanced up to 50 % for the push out specimen without decking. The specimen with two numbers of stud and channel connector increases the strength by 58% and 23% respectively as compared to specimen with single connector. The behaviour of the push out specimen was stimulated by three-dimensional finite element model using software ANSYS workbench. The analytical behaviour was well agreement with the real push out specimen studied experimentally.

1 Introduction

The load-slip between the steel and concrete and shear capacity are the essential characteristics for the design of steel-concrete composite structures. The standard push-out test was conducted to study the composite action. The composite action between the steel-concrete will be achieved by provided proper shear transfer mechanism. In the past, mostly composite action was achieved by providing headed stud connectors. Many researchers done both experimental and numerical investigation to study the composite action by conducting push-out specimen. Table 1 summarises their contribution and conclusions to achieve better bonding between steel and concrete.

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Table 1 Analysis of previous literatures concentrated on load-slip behaviour of the push-out specimens.

Type of specimen	Type of shear connectors	Inference	References
Push-out specimen studied numerically using software ATENA	Headed stud connector	Developed quarter model similar to real behaviour of push-out specimen and carried out parametric analysis for varying flange thickness and spacing of the connectors.	[1]
Push-out specimen studied experimentally	Headed stud connector	Tested 13 specimens by varying geometry of the steel beams and the type of steel anchors(Z and C section)	[2]
Modified Push-out specimen	Headed stud Connector	Strength and stiffness of high strength steel stud was studied experimentally and compared with Eurocode 4 recommendations.	[3]
Numerical study on steel-elastic concrete composite structures.	Headed stud Connector	Study the influence of rubber in concrete to know the elastic behaviour of I-beam.	[4]
Push-out specimen studied experimentally	Headed stud Connector	Load-slip behaviour and load-strain behaviour were studied.	[5]
Experimental investigation on composite action with channel connectors.	Channel Connectors	Strength and stiffness of the channel connector	[6, 7]

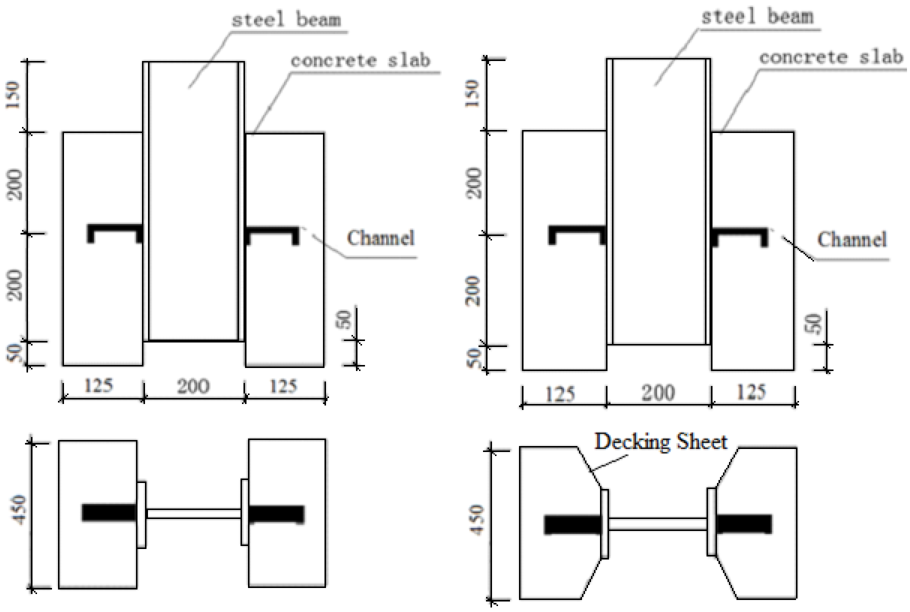


Fig. 1 – Schematic diagram of the push out specimen (CC-1 & CC-1-DS)

However more literature available to stimulate the composite action using push-out test with stud and channel connector both by experimental and analytical, but a minimal work was reported to compare the effect of two different connector (stud and channel) to achieve composite action and compare shear strength and load-slip behaviour.

In this paper, the push-out test was conducted to study the behaviour of headed stud connector and channel connector to improve the composite action between steel and concrete. Eight push-out specimens were tested to failure. The type of connector and number of connectors are the parameters varied in the specimen along with or without decking sheet. The numerical study was carried out against eight push-out specimen's result using ANSYS Workbench. The shear capacity, load-slip and load-strain behaviour were compared between experimental and analytical in this work. Finally, FE analysis was recommended [8] to find the shear capacity of the connectors and study the composite action.

2 Experimental study

The pushout specimens were fabricated using ISMB with two different shear connectors (Headed stud connectors and Channel connectors). Fig.1, shows the specification details of specimen with channel connector along with or without decking sheet. The dimension of the all the eight push-out specimens is listed in Table 2. In the Table specimen identification was used as, for example in specimens CC-1-DS and SC-2, the CC represent Channel Connector, 1 & 2 represents number of connector and DS represents Decking Sheet and SC represents Stud Connector. The shear strength of the pushout specimens was tested under the universal testing machine of capacity 600kN. The load was applied at the top of the steel section at the uniform rate. The slip between steel and concrete was observed using dial gauge with the least count of 0.01 mm [9, 10]. The pushout specimens were subjected to three strain gauges pasted (Fig.2) on the shear connector, steel beam and concrete slab respectively. Fig.2 shows the specimen under testing using UTM.

Table 2 - Specification of the specimen

Specimen	Type of Connector	No. of connectors	Shank diameter (mm)	Shank length (mm)	Head diameter (mm)	Head thickness (mm)	Length of the Channel (mm)	Breadth of the Channel (mm)	Thickness of Channel (mm)
SC-1	Stud	1	18	88	30	8	-	-	-
SC-1-DC		2	18	88	30	8	-	-	-
SC-2		1	18	88	30	8	-	-	-
SC-2-DC		2	18	88	30	8	-	-	-
CC-1	Channel	1	-	-	-	-	50	25	5
CC-1-DC		2	-	-	-	-	50	25	5
CC-2		1	-	-	-	-	50	25	5
CC-2-DC		2	-	-	-	-	50	25	5

SC-Stud Connector, CC-Channel Connector, DS-Decking Sheet

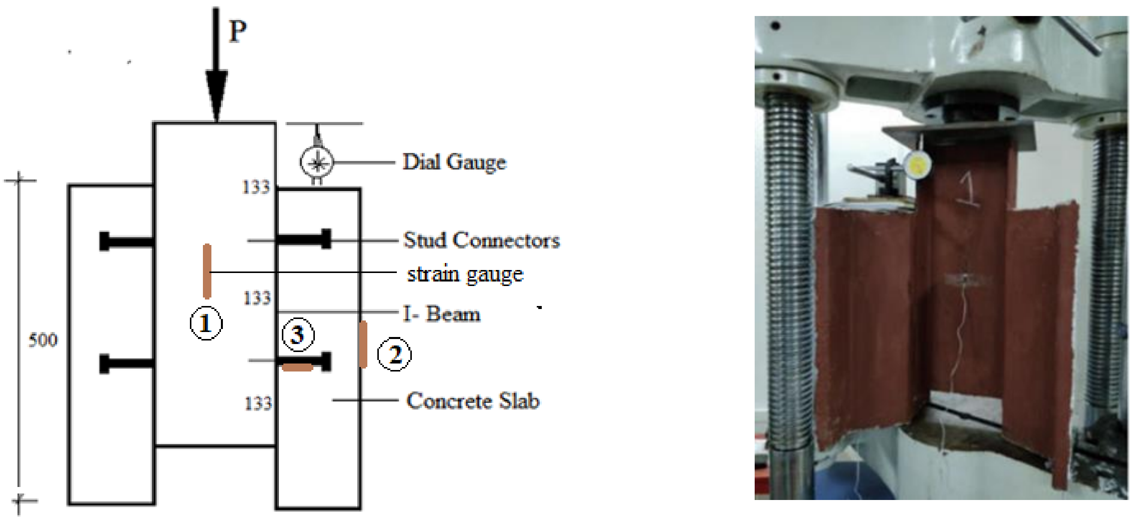


Fig. 2 – Push out specimen test set-up and location of stain gauge

3 Finite Element models

ANSYS workbench software were used to analysis the specimen. Pushout specimens were modelled and analyzed. In this study the Drucker-Prager, elastic- plastic model was developed to carry out the non-linear analysis of pushout specimen. The bottom of concrete slab was restrained from the displacement along X, Y and Z axis whereas the top of the steel beam

[11, 12] was restrained along X and Z and along Y axis all the nodes were free to translate. The load was applied in load-steps.Fig.3 shows the loading and boundary condition of FE model.

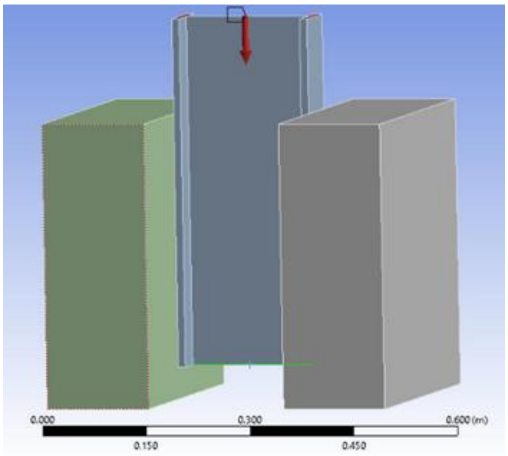


Fig. 3 – Loading and boundary condition

4 Result and discussion

4.1 Failure mode

Fig. 4 to Fig. 7 shows the FE models failed by fracture of the stud connectors at the bottom of the connectors. From Fig.4 and Fig.5, It is also observed that the intense of stud failure at the bottom of connectors with single connector (SC-1) is more than the specimen with two studs (SC-2). The specimens SC-1-DC and SC-2-DC shows the shank failure of the stud connectors [13] and then dissipated to the decking sheet, and it is shown in Fig. 6 and Fig.7. The failure of the specimen SC-2-DC get prolonged due to the presence of two studs and shear capacity improved. Similarly, failure mode was observed for the specimens with channel connectors [CC-1, CC-2, CC-1-DC & CC-2-DC] and it is shown in Fig. 8 to Fig. 11.

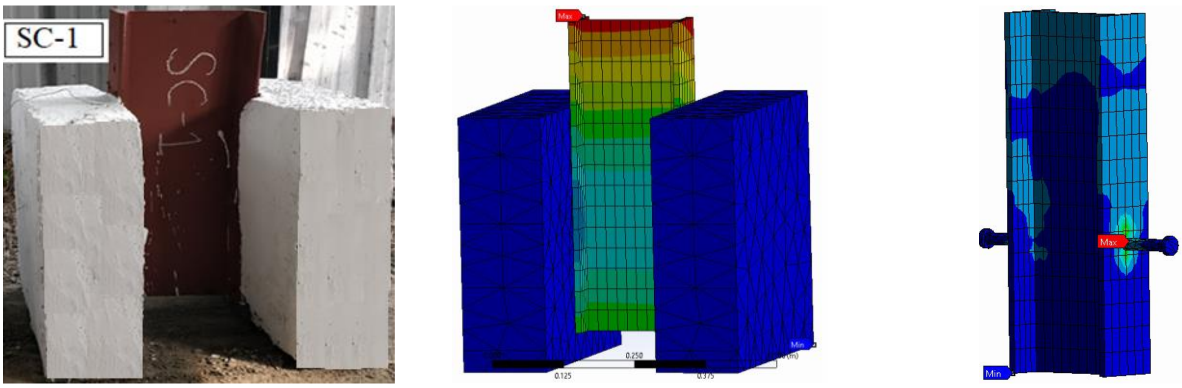


Fig. 4 – Specimen SC-1 and its analytical plot

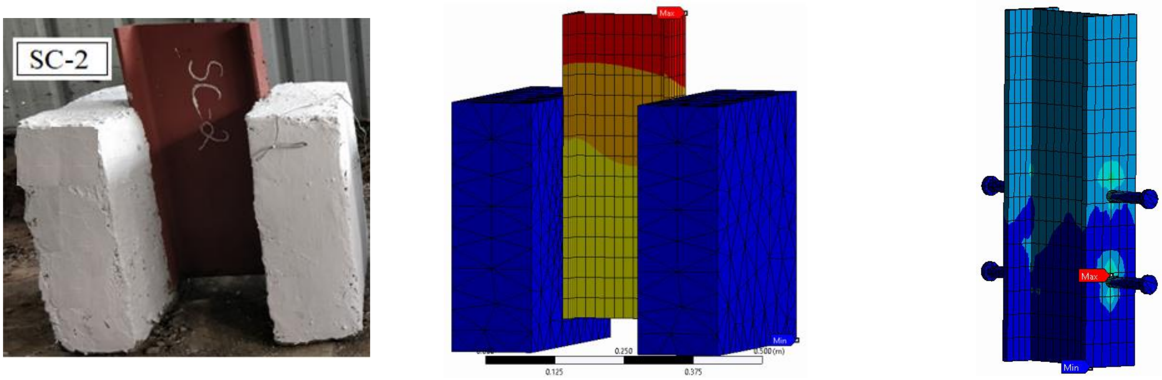


Fig. 5 – Specimen SC-2 and its analytical plot

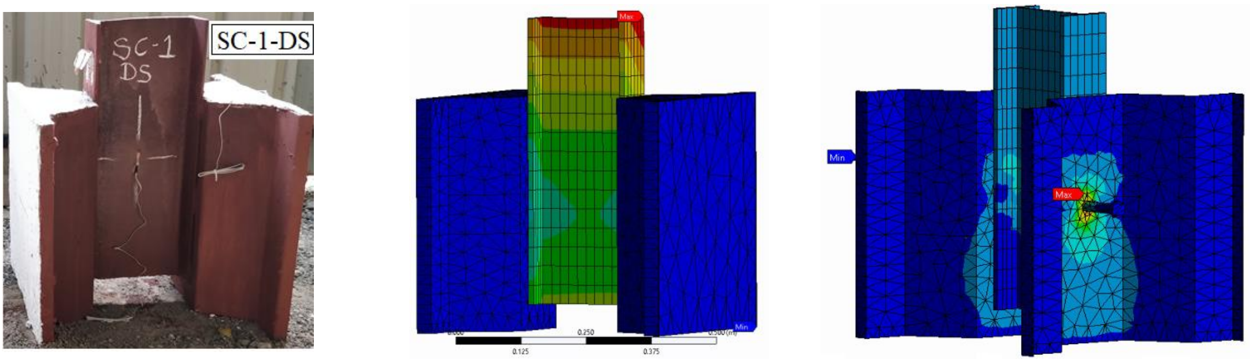


Fig. 6 – Specimen SC-1-DS and its analytical plot

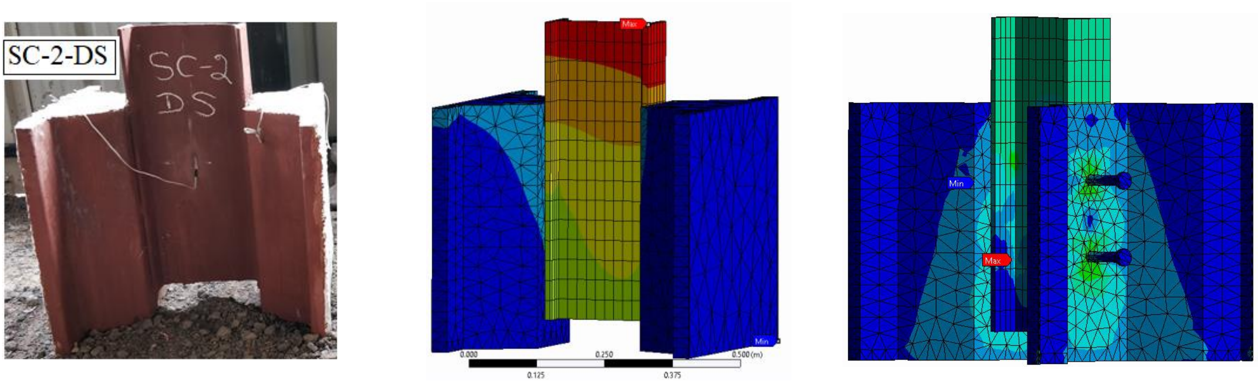


Fig. 7 – Specimen SC-2-DS and its analytical plot

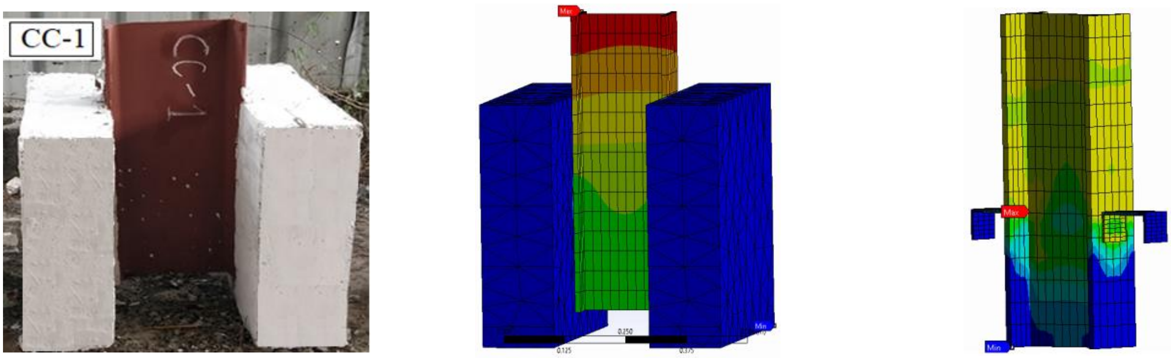


Fig. 8 – Specimen CC-1 and its analytical plot

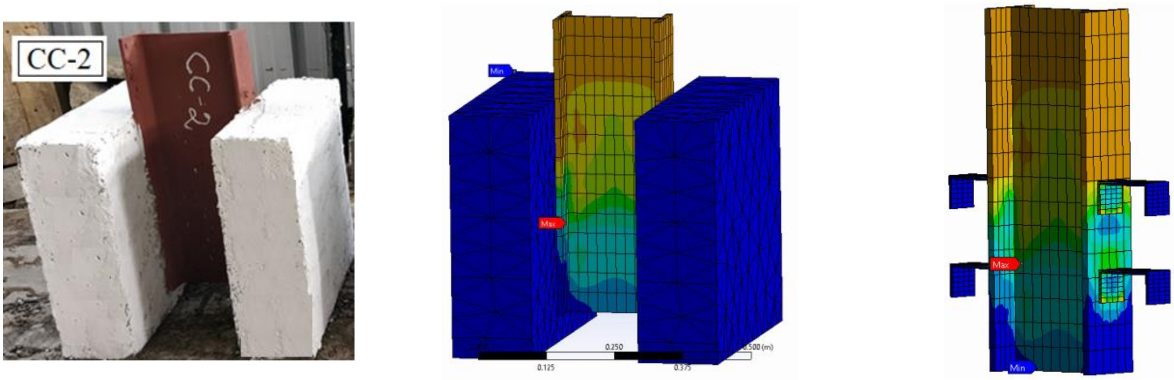


Fig. 9 – Specimen CC-2 and its analytical plot

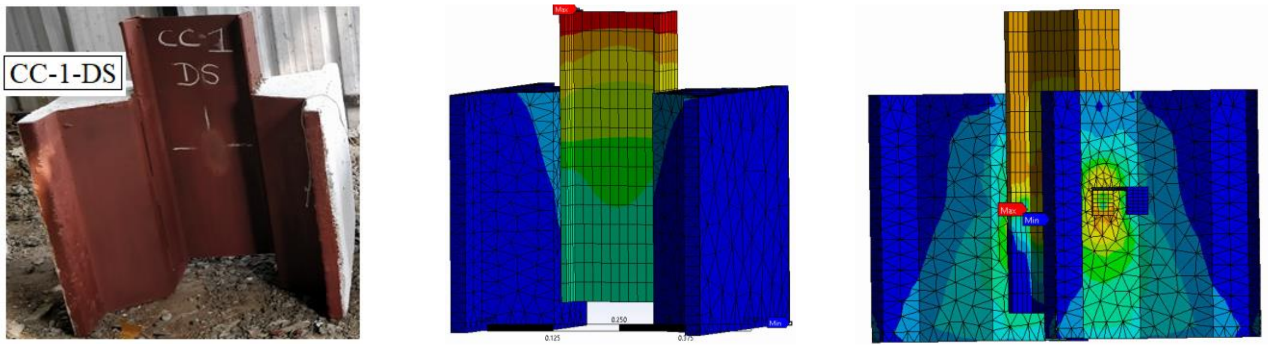


Fig. 10 – Specimen CC-1-DS and its analytical plot

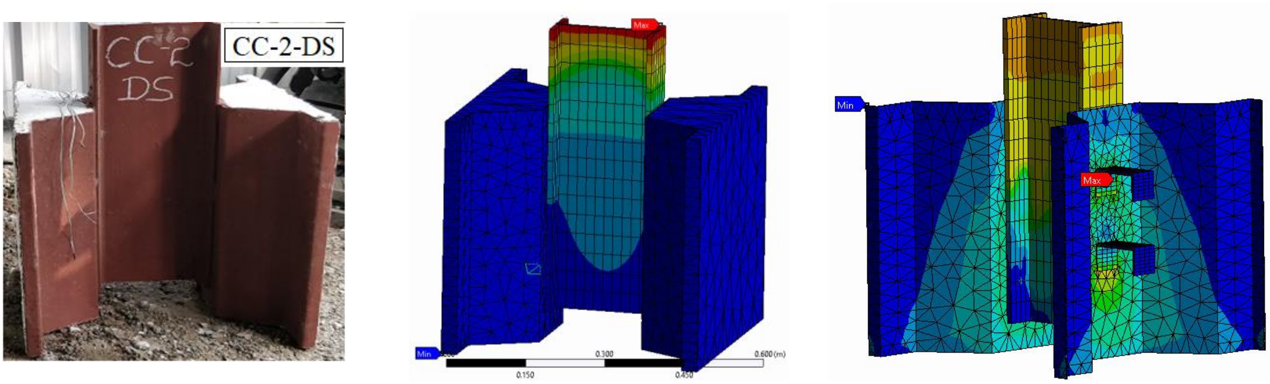
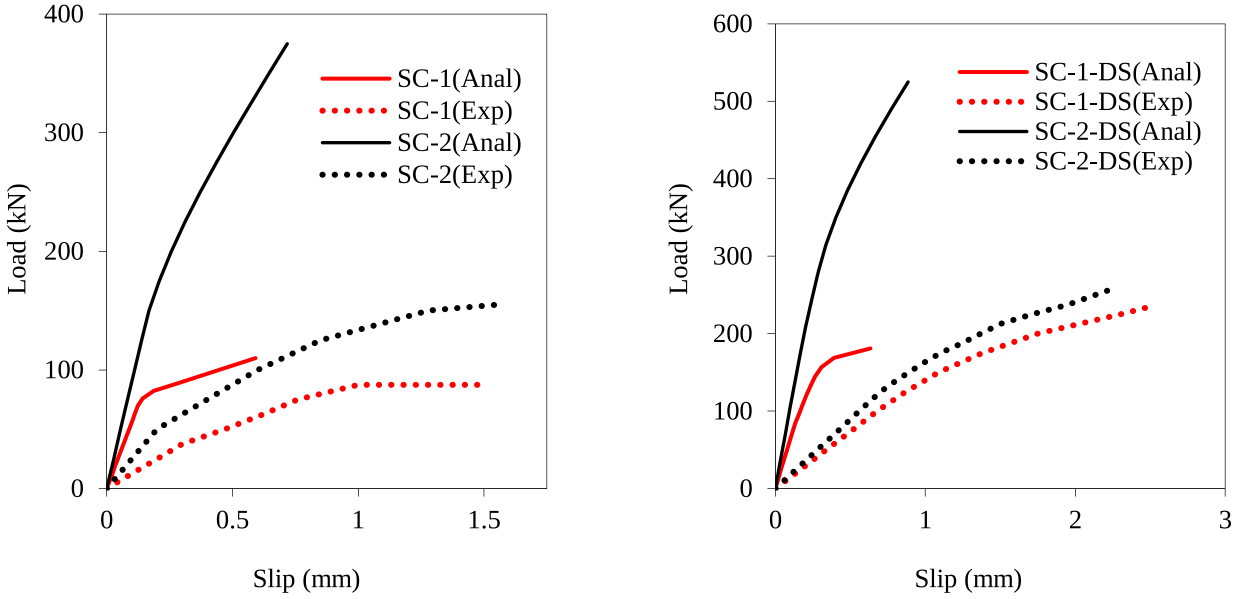


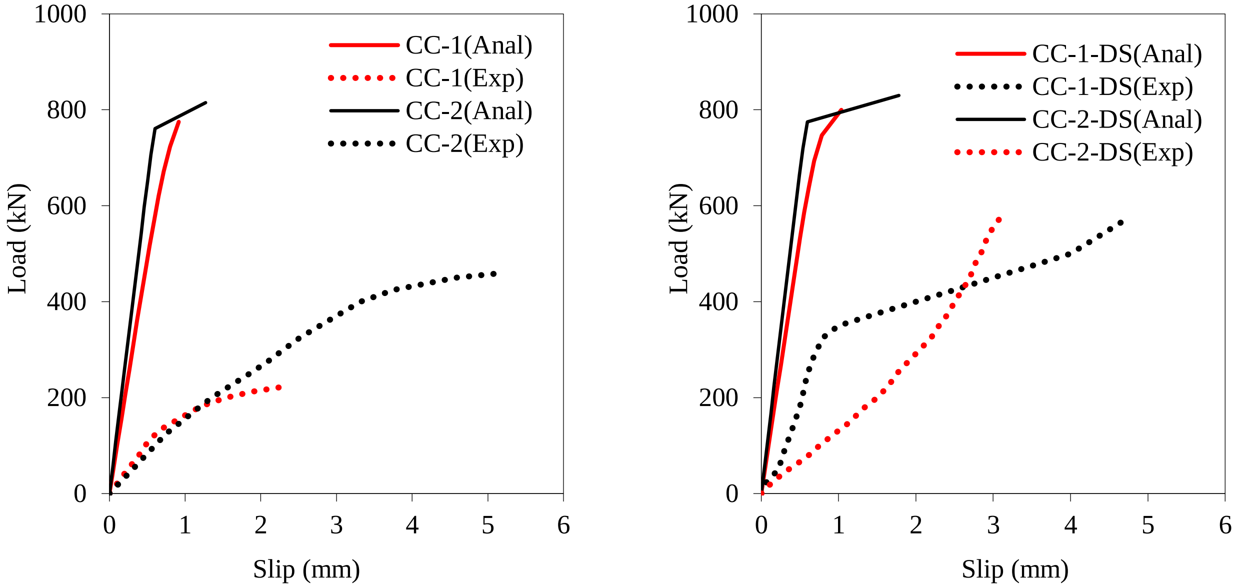
Fig. 11 – Specimen CC-2-DS and its analytical plot

4.2 Load-slip behaviour

Fig. 12 shows the load - slip behaviour of the eight-pushout specimen which were generated by experimental results and finite element simulation. From the load-slip curve it was found that, analytical behaviour was stiffer than the experimental for the shear connectors with or without decking sheet. The characteristic slip value [14] was estimated corresponding to 0.9 Pu as per EC4 specification for the studs and channel connectors are 2.5 mm and 4.75 mm respectively.



(a)Stud Connector



(b)Channel Connector

Fig. 12 – Comparison between experimental and analytical load-slip behaviour

The stress plot (Fig.13 & Fig.14) of the push out specimen with stud and channel connectors shows that shear transfer from steel beam to the concrete slab was mainly by stud and channel connectors. All the specimens fail mainly by the failure of the shear connectors and then concrete cracking and spalling. The shear bearing capacity [15] of the channel connectors is doubled when compared to stud connectors, may be due to contact area of channel connectors with concrete was more. The specimen with decking sheet resists more shear load and fail by bending of the connectors and decking sheet. The concrete gets detached from the sheet and fails along the weaker direction.

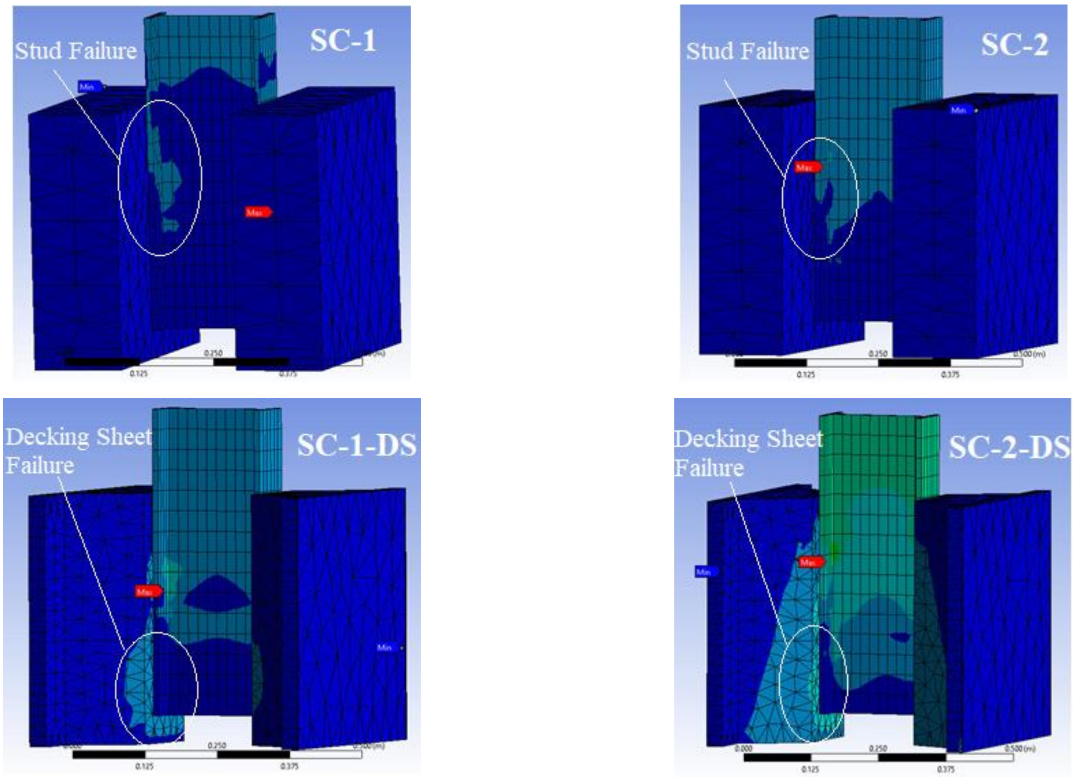


Fig. 13 – Distribution of stress in the specimen for the headed stud connectors with or without decking sheet

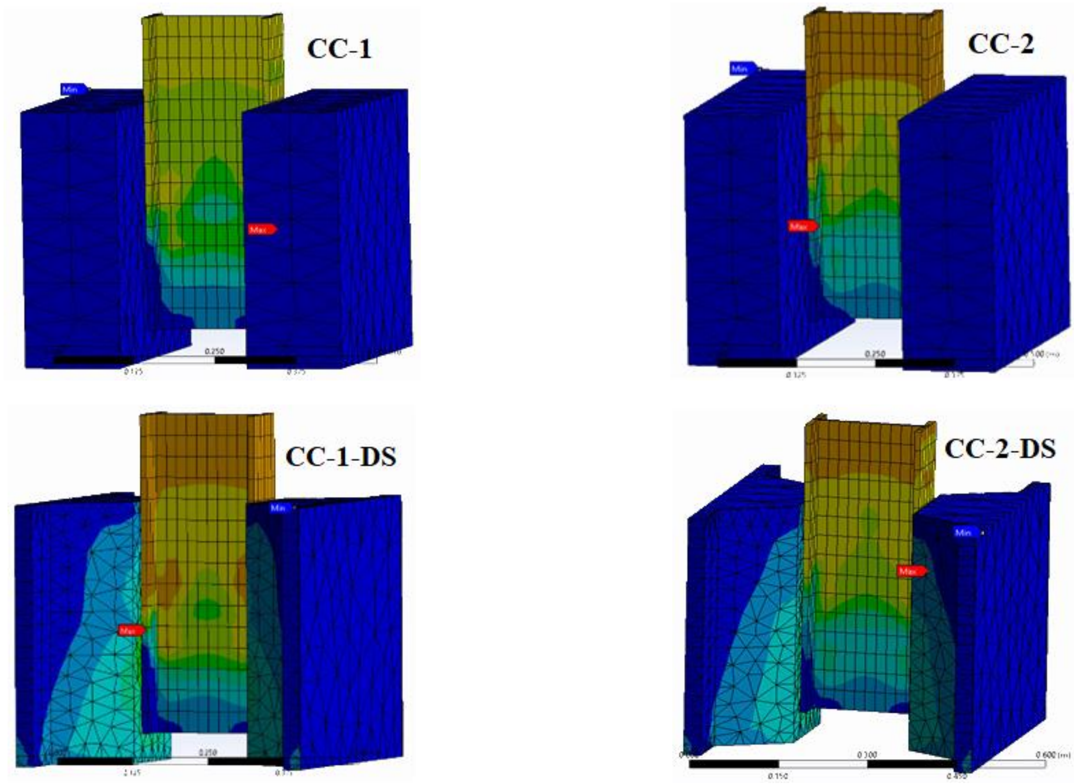
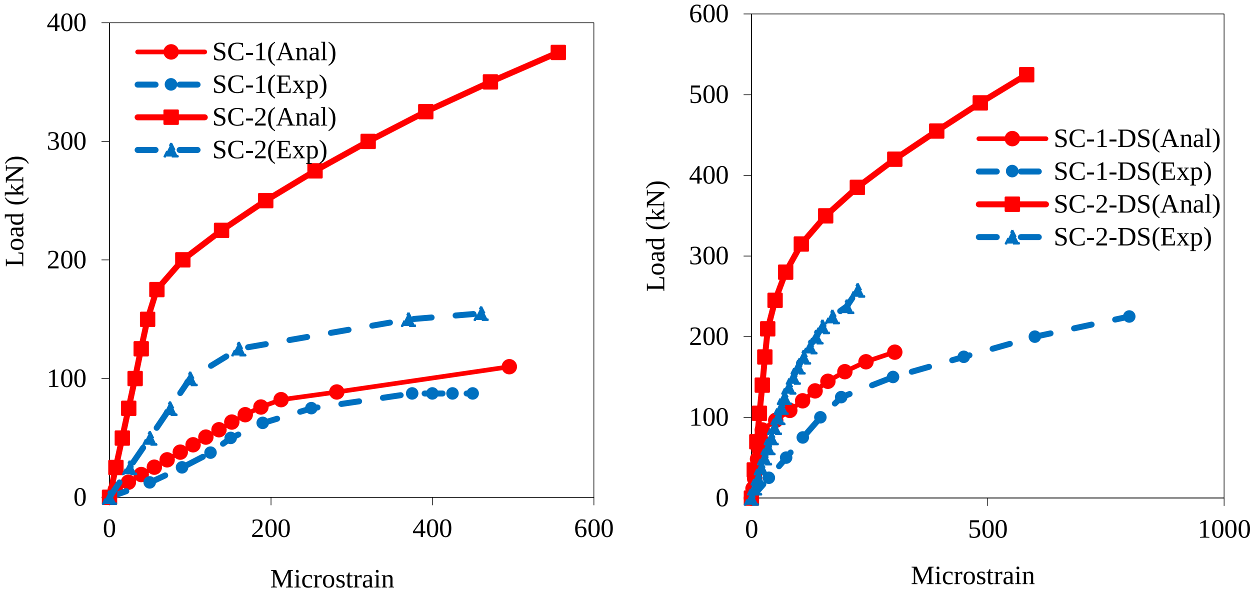


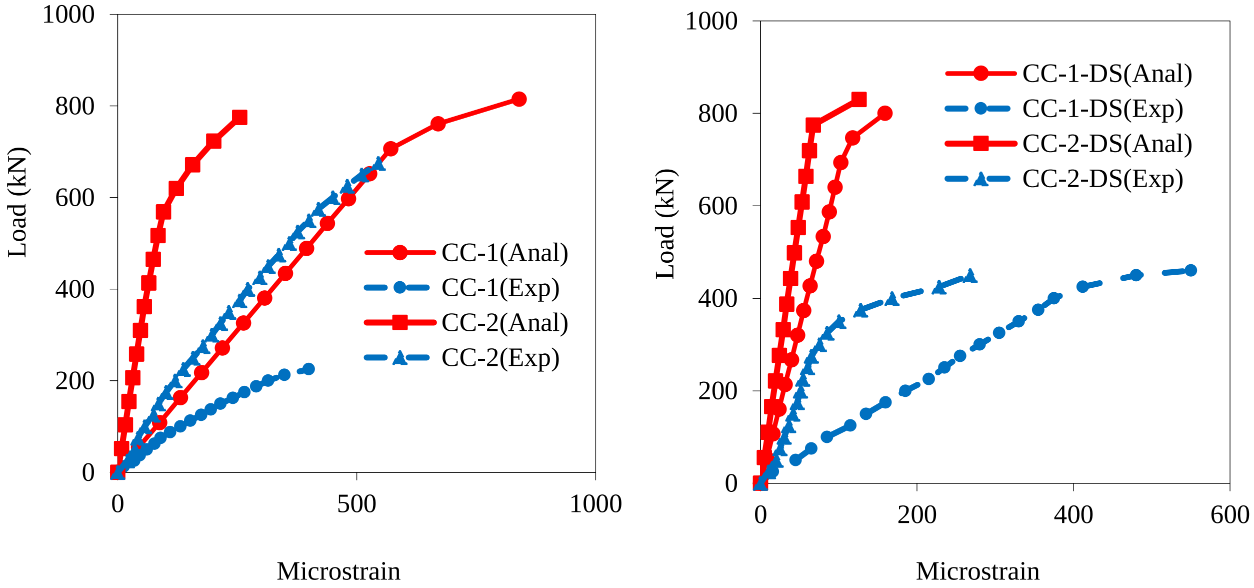
Fig. 14 – Distribution of stress in the specimen for the channel connectors with or without decking sheet

4.3 Load-strain behaviour

The load- strain behaviour of all the specimens obtained from the experimental results and analytical study was illustrated in Fig. 15(a) and Fig.15(b) for stud and channel connector respectively. The load- strain behaviour was linear upto 70% of the ultimate load. It is also observed that the behaviour was stiffer for the analytical model. The degree of stiffness [16] was relatively high for the channel connectors, whereas the stud connectors was able to transfer shear load and found to be ductile.



(a)Stud Connector



(b)Channel Connector

Fig. 15 – Comparison between experimental and analytical load-strain curve

Fig. 16 shows the comparison between the shear capacity of the push-out specimen with stud and channel connectors. From the bar chart, it was concluded that the improvement in shear capacity was observed for specimen with channel connector is 60 % as compared to stud connectors. The presence of decking sheet in the push out specimen increases the shear resistance by 48.8 % for one and two numbers of stud and channel connectors. The increase in the number of stud connector from one to two improves the strength by 58.8% and similarly for varying number of channel connector of one and two enhanced the shear strength by 23%, this implies that single channel connector is sufficient to achieve the required shear capacity and composite action.

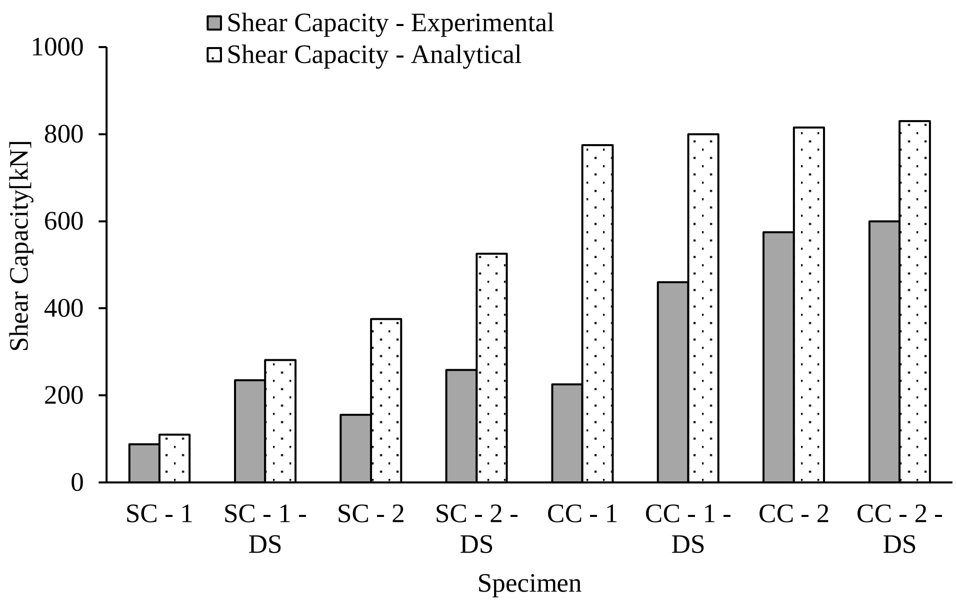


Fig. 16 – Comparison between the shear capacity of pushout specimens

5 Conclusions

This paper summarised the experimental study on the steel-concrete composite behaviour of push-out specimens. The finite element model for the specimens has been developed using stud and channel connectors along with or without decking sheet by considering the material nonlinearity. The accuracy of FE model was validated by eight push-out specimens tested experimentally. The results arrived from the experimental and analytical study are

- The push-out test on one stud connector (SC-1), two stud connectors (SC-2), One channel connector (CC-1) and two channel connectors (CC-2), the CC-2 reveals good resistance between the steel and concrete. In addition, the two stud shear connectors specimen with decking sheet (SC-2-DS) shows the excellent plastic deformation properties.
- The finite element software ANSYS Workbench was used to simulate the push-out test with eight specimens. There was good agreement between experimental and analytical behaviour. The stress and strain plot reveals the shear damage mechanism and failure of the connectors in the composite structures.
- The intense of stud failure at the bottom of the connectors with single connector (SC-1) is more than the specimen with two studs (SC-2). The specimens SC-1-DC and SC-2-DC shows the shank failure of the stud connectors.
- The characteristic slip value was estimated corresponding to 0.9 Pu as per EC4 specification for the studs and channel connectors are 2.5 mm and 4.75 mm respectively.
- The presence of decking sheet in the push out specimen increases the shear resistance by 48.8 % for one and two numbers of stud and channel connectors.

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