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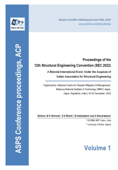

Numerical Studies on Composite Deck Slab With Floor Openings

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Abstract

Openings in slabs are provided mainly for service works. According to the purpose of the services, the size of the openings was classified as small, medium, and large. The provision of openings in a composite slab was not addressed in design codes like EC-4 & IS 11384. Normally the Longitudinal shear interaction is the influencing factor in determining the capacity and elastic rigidity of a composite slab which may be affected by the presence of openings. In the market, there are various forms of embossment/indentation available to enhance the interlocking at the interface of the Cold Form Steel decking sheet and the topping concrete thereby an increased longitudinal shear resistance can be achieved at the interface. In this numerical study, Among the various type of embossments, combined types of embossments (rectangular and chevron) are considered then the m & k values are determined with the help of the Penalty Friction interaction approach and the same was verified with the known experimental values for a solid slab. In addition, Finite Element [FE] models with various sizes of floor openings were created under the guidelines of SCI publication P300 and SDI Technical Guidance on Deck Damage and Penetrations. The effects of those openings located in the high shear region and no shear region are studied. The simulated load-deflection responses of various FE floor opening models were compared.

Keywords: Steel-Concrete Composite slab; Floor openings; Horizontal shear bond; Numerical modelling.

1. Introduction

Composite floor deck construction has become very popular because it combines structural efficiency with a speed of construction to offer an economic solution for a wide range of building types including commercial, industrial, health, and residential building sectors. The composite deck slab refers to a structural slab system created by combining concrete with a cold-formed steel decking sheet as illustrated in figure 1. Besides, the steel deck serves as permanent formwork for supporting the concrete.

The strength and performance of the composite slab are also influenced by various factors such as the profile geometry, thickness of steel sheeting, concrete density, the strength of steel and concrete, shear interactions in the form of dimples or indentation, span length, and presence of openings in the composite slab.

Openings in floor decks are a common part of any building. These openings can range from small holes for pipes and conduits to large size openings in composite floor decks, opening for mechanical ductwork, storm drain pipes or a group of small holes. Openings in composite deck floor structures, affect the mechanical behaviour of composite floors such as bearing capacity, rigidity, and stability of the deck slab.

Marimuthu et al.[1] conducted an experimental investigation to study the shear bond behaviour of the embossed composite deck slab under simulated imposed loads using conventional concrete. For this research, six sets of slabs were tested, each comprised of three slabs with an altered shear span for each set. Based on these test results it was determined that the behaviour of the composite slab depends on the shear span length. Failure of the shorter shear span slab was governed by shear bond failure, whereas, for longer shear spans the slab responded with flexural failure.

Redzuan Abdullah et al.[2] carried out a finite element model to simulate the global shear-bond behaviour of composite slabs with Abaqus. They compared the numerical results relative to previous small-scale tests. The concrete was modelled as a brittle cracking material and the steel deck was considered an elastic-plastic material. The steel-concrete interface was modelled with radial-thrust connectors with an average bond-slip relationship calculated using the ‘‘force equilibrium” method previously developed. However, it was carried out as a quasi-static analysis because the brittle cracking material was simulated with Abaqus Explicit only.

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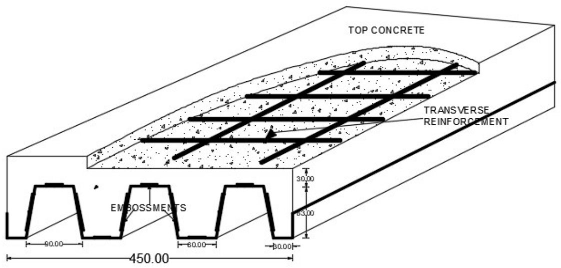

Fig. 1. Components of a composite slab

Yu-Hung Wang and Jian-Guo Nie [3] studied the effective flange width of steel-concrete composite beams with openings in the concrete slab by the finite element method. The entire loading history of composite beams with openings in the concrete slab was verified by test results, and the axial normal stress distribution was analyzed in detail based on finite element analysis results. The parametric analysis was carried out for obtaining the practical simplified design method for calculating the effective width of steel-concrete composite beams with openings in the concrete slab. Also, the predicted deflection of composite beams with openings in the concrete slab was compared with test results and finite element analysis results. The simplified method for calculating the effective flange width of steel-concrete composite beams with openings in the concrete slab had enough precision and was found suitable for practical design.

Mostafa El-Shami et al [4]presented the behaviour of composite space truss in the presence of openings. Both experimental and analytical with different end conditions for various location of openings are carried out. The reduction in load carrying capacity and optimum location of floor openings are investigated. The FE model developed by ABAQUS has been tested by comparing results with those obtained from the experimental tests on space truss.

Natasha Zamani, Ph.D., P.E. [9] presented the article regarding accommodating the installation of various mechanical and electrical application systems with openings in composite floor decks. Openings in the deck may be categorized by their size as small (openings up to 12”), medium (1’ to 4’), and large (over 4’) openings. The provision of openings with the help of the methods like core drilling, boxing out and the reinforcement around those openings are studied. Also, the provisions of Fire stopping system is studied since the primary focus of today’s building code is to safeguard the people. A through-penetration firestop system is an assembly of materials designed to prevent the spread of fire and its byproducts for a prescribed period under defined test conditions (usually 1, 2, or 3 hours) through openings which are made in floors or walls. Hassan et al. [5] studied the influence of opening in the concrete flange of a composite beam by conducting experiments on eleven beams. It was observed that the ultimate capacity decreases with increasing opening ratio because of decreasing the effective width.

2. Numerical Study

The Numerical investigation process consists of the following steps:

- Identification of parameters for analysis.
- Finite element modelling of Profiled deck composite slab by using the commercial finite element software package ABAQUS 2019.
- Suitable Meshing identification.
- Non-Linear static analysis with short shear span of solid composite slab.
- Validate the results of solid slab with the known experimental work for combined rectangular and chevron type of embossments.
- Introduction of small (60mm X60mm), medium (90mm X90mm, & 120mm X120mm), Large (160mm X 160mm, & 200mmX200mm) openings in high shear and no shear region of the slab model to find the behaviour of the slab numerically.

The deck profile and height of the concrete portion of the slab is shown by cross section figure 2. The combined type (rectangular and chevron type) of embossments of depth 2.5mm is used in this study. The thickness of the deck profile will be 1mm.

3. Finite Element Modeling

FE (Finite Element) models of composite steel deck slab were developed in ABAQUS. These composite slabs with square holes were tested in four-point bending in accordance with EC-4. The steel deck profile sheet components, concrete slab was modelled as an isotropic and elastic-plastic material. The cross-sectional view of the sheet and concrete slab portion were sketched by plotting their coordinates and the sketched cross section could be extruded to the required length.

The transverse reinforcement modelled by using wire and it was embedded into concrete. Dimensions of steel rod, deck sheet, concrete are followed according to experimental model.

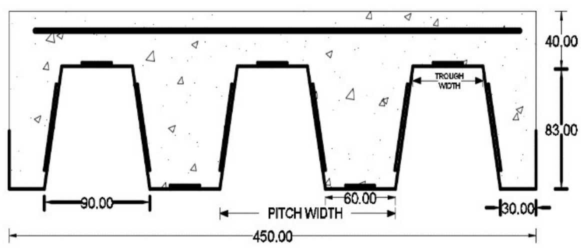

Fig. 2. Cross section of the composite slab

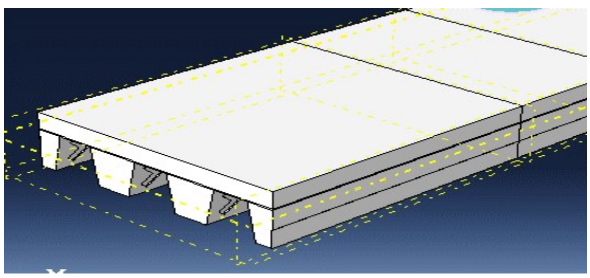

Fig. 3. Part - Concrete

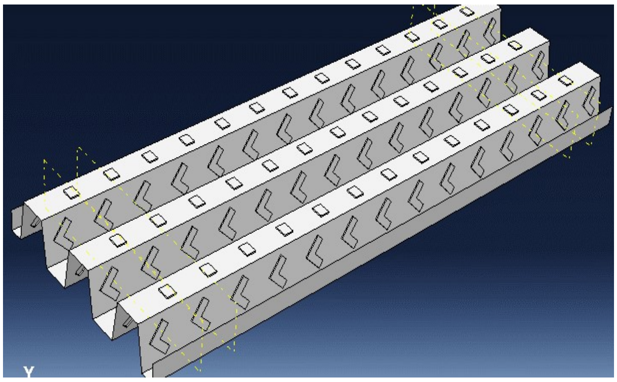

Fig. 4. Part -Deck sheet

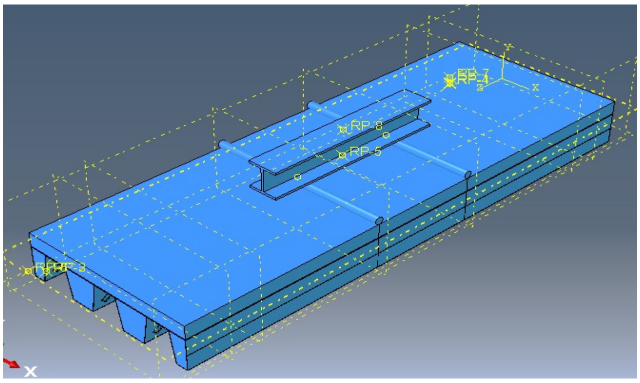

Fig. 5. Assembled structure

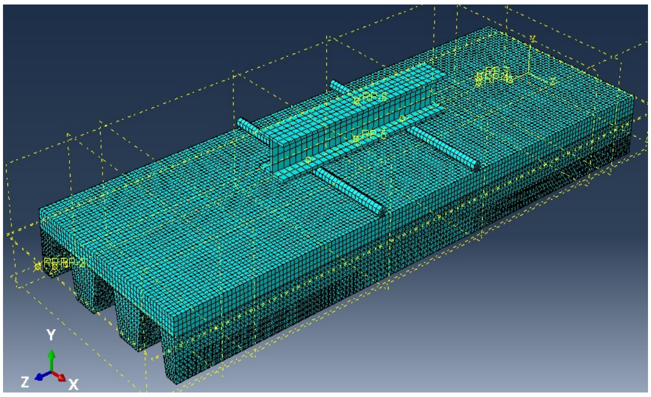

Fig. 6. Meshed structure

ABAQUS software provides the capability of simulating the damage using any of the three crack models for reinforced concrete elements:

(1) Smeared crack concrete model,
(2) Brittle crack concrete model, and
(3) Concrete damaged plasticity model.

Out of the three concrete crack models, the concrete damaged plasticity model was selected in the present study as this technique has the potential to represent complete inelastic behaviour of concrete. Since other methods mainly reports the brittle behaviour of concrete and assumes compression behaviour of concrete is always linear elastic which doesn't realistic.

The concrete damage plasticity [CDP] model uses concepts of isotropic damage elasticity in conjunction with isotropic tensile and compressive plasticity to represent the inelastic behaviour of concrete. It allows strain hardening in compression, which resembles the behaviour of concrete more realistically.

Steel – concrete interface contact was defined by a friction model that enables force resisting the relative tangential motion of the surfaces in the mechanical contact analysis, the 'tangential behaviour' was specified. Friction formulation field between the contact surfaces was selected as 'penalty' to allow some relative motion of the surface

The normal contact behaviour for the interface was also defined as "Hard" contact for pressure-over-closure. Rigid body constraints for roller, and I-section with reference point. Embedded constraint for reinforcement rod to the concrete model.

The loading was defined by specifying a Reference Point (RP) and assigning a prescribed displacement to the RP. The RP position was aligned by the centre of the rigid body I-section, located above the rollers at the top of the specimen from the mid-span

The Steel section is modelled using shell element. S3R element type was chosen. S3R is a 3-noded doubly curved thin shell element, reduced integration, enhanced hourglass control. Concrete is modelled using solid elements. C3D8R element type was chosen for the top rectangle portion of concrete. C3D8R is an 8-noded linear brick 3D solid element, reduced integration, enhanced hourglass control. C3D4 element type was chosen for the corrugated portion of concrete. C3D4 is a 4-noded linear brick 3D solid element, reduced integration, enhanced hourglass control. The reinforcement bar is modelled using T3D2 element type, a two-node linear 3D. R3D4 element type was chosen for Rigid body elements (I-section, Roller).

3.1 FE models with openings

The slab models with various size of openings were created as shown in Figures 7. i.e., (a) Holes created in no shear region. (b) Holes created in the high shear region. In all patterns, the loading was applied as displacement and the behaviour of the slab was observed. Also, reinforcement around the opening was provided in medium and large size openings. The provided reinforcement was not used to improve the slab strength. It was used to get required behaviour (avoiding local buckling of sheet) of the slab model and also avoid convergence problems of elements in the analysis.

4. Parametric studies & Results

The analysis was conducted in step-1 (Dynamic, Explicit), which is a step after the initial step. Abaqus/Explicit solves certain types of static problems more readily than Abaqus/Standard does. One advantage of the explicit procedure over the implicit procedure is the greater ease with which it resolves complicated contact problems. Applying the explicit dynamic procedure to quasi-static problems requires some special considerations. Since a static solution is, by definition, a long-time solution, it is often computationally impractical to stimulate an event in its natural time scale. To obtain an economical time increment, the event must be accelerated in some way. For this study, to determine the deflection response of composite slab under monotonic loading conditions, using displacement control is the most feasible analysis method.

The slab visualizations with various sizes of openings after successful FE analysis are shown in Fig.8. In all patterns, the bending behaviour of the slab while loading was observed.

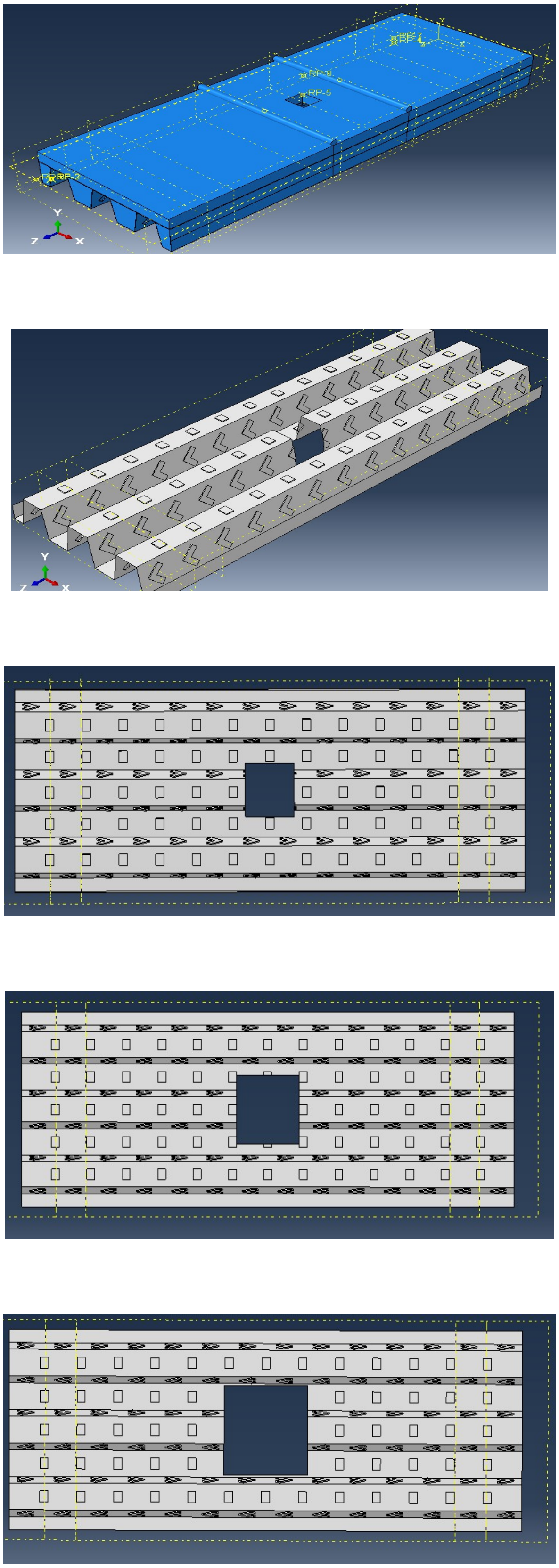

Fig. 7(a). Composite slab models with openings @ middle

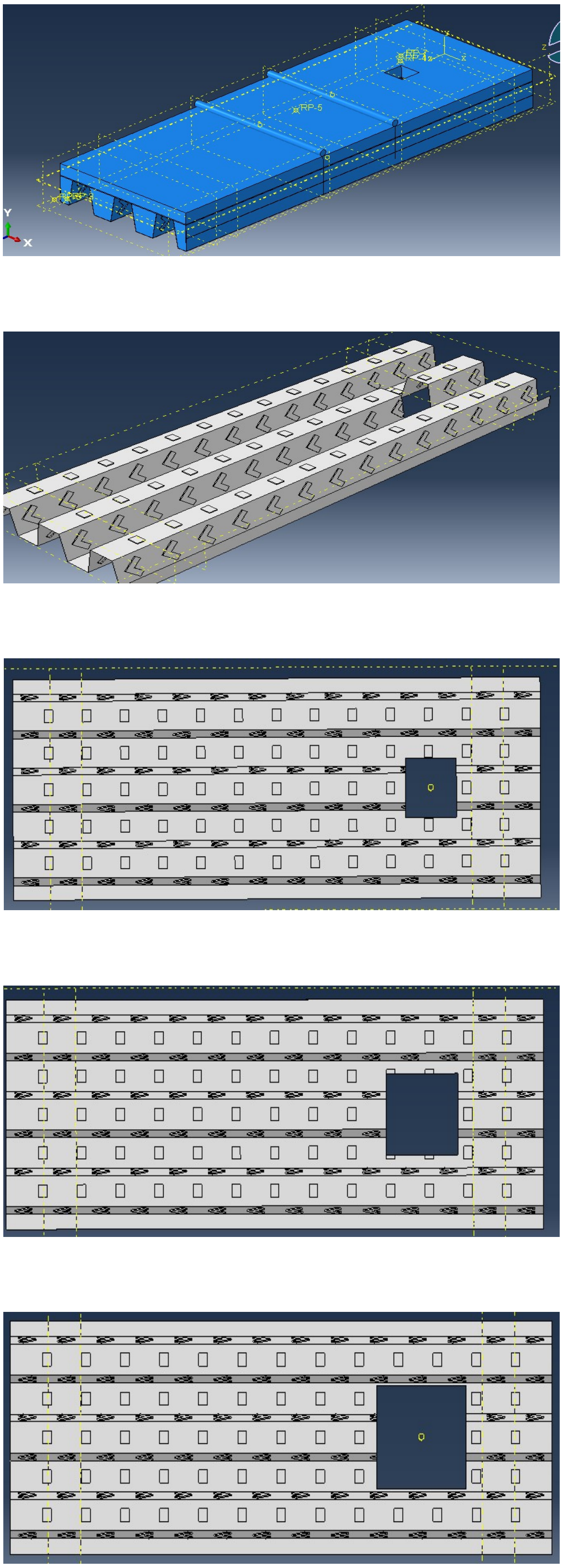

Fig. 7(b). Composite slab models with openings @ support

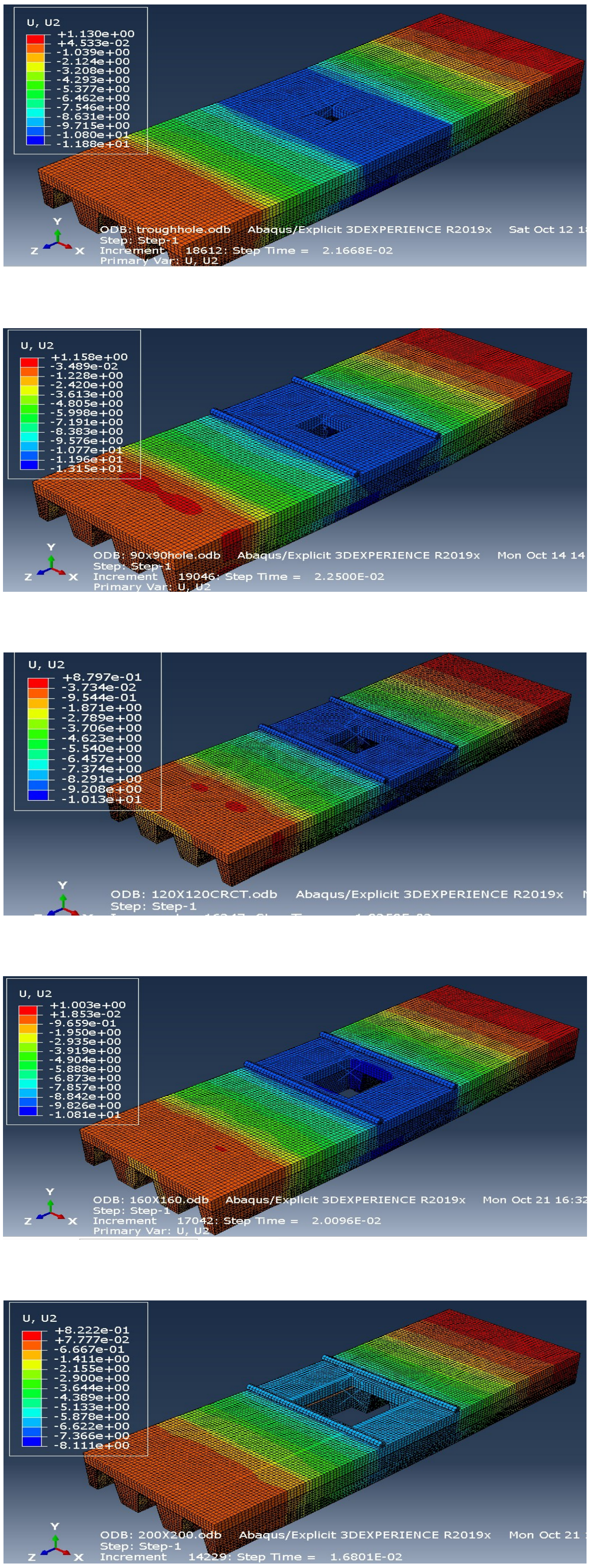

Fig. 8(a). Visualisation of slab models with openings @ middle

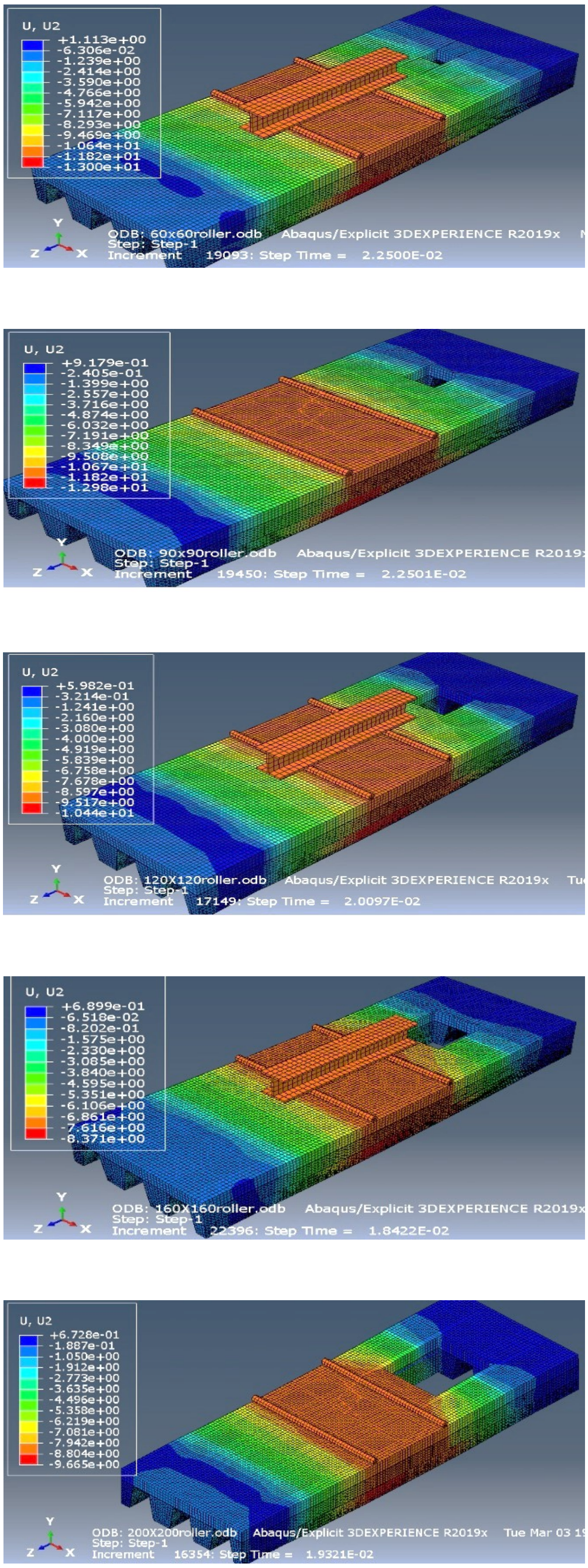

Fig. 8(b). Visualisation of slab models with openings @ support

4.1 Comparison of FE models with openings

A comparison between the Load- Deflection behaviour of the FE models with opening placed at high shear region and no shear region are compared corresponding to size of the openings with the solid slab is presented.

It is observed that the load carrying capacity of the slab was affected little higher for high shear region hole slabs compared to no shear region hole slabs in all the opening sizes namely small, medium and large with respect to the solid slab.

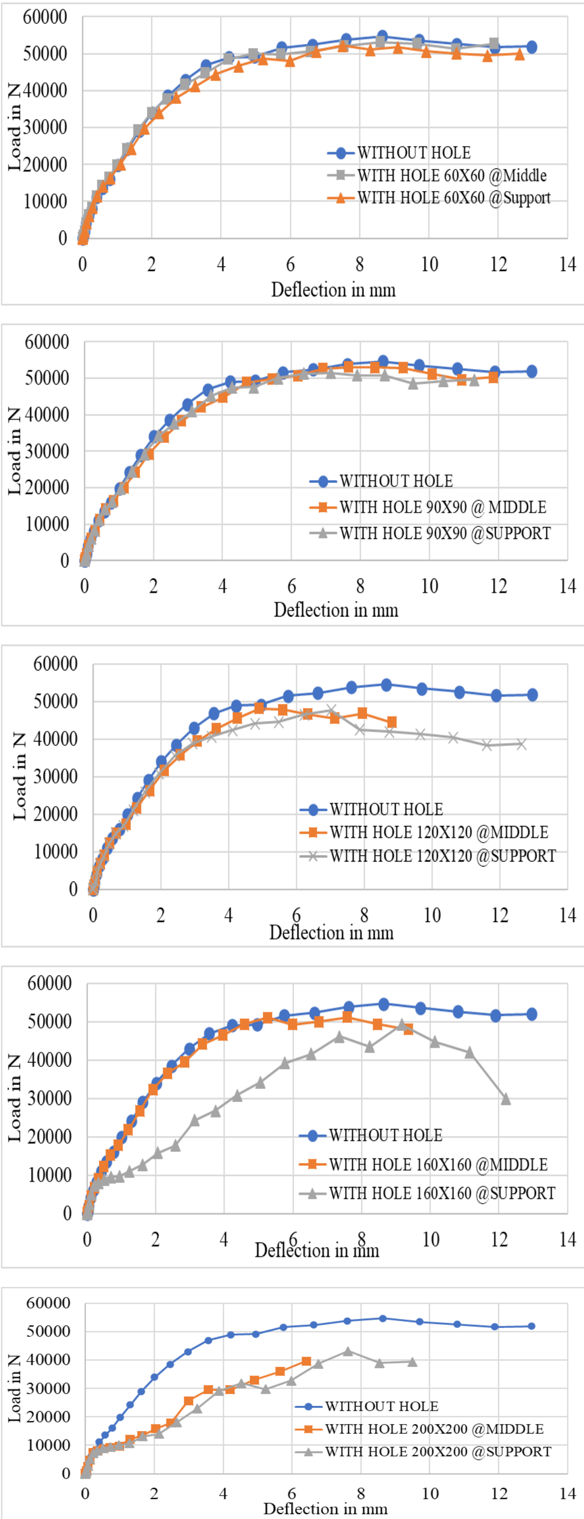

Fig. 9. Load-Deflection curve for different FE models.

4.2 Comparative study behavior of load carrying capacity

The load carrying capacity was reduced due to the presence of openings compared to a non-opening slab. The percentage of reduction was tabulated in Table-1. In High shear region openings, The capacity decreases with the increases in the size of the openings. Also, load carrying capacity reduces in High shear region holes more compared to No shear region holes.

Table - 1 Comparison of Load Bearing Capacity with Openings.

Sl. no	Opening size	FEA Load 370mm shear span	FEA Load with presence of openings at Middle	FEA Load with presence of openings at Nearby support	Load ratio		% of reduction	
	mm	solid slab, Psolid (KN)	No shear region , Pns (KN)	High shear region , Phs (KN)	Pns / Psolid	Phs / Psolid	Pns slabs	Phs slabs
1	60X60	54.68	53.867	52.190	0.9851	0.9545	1.49	4.55
2	90X90	54.68	53.01	51.508	0.9695	0.9420	3.05	5.80
3	120X120	54.68	48.21	47.773	0.8816	0.8737	11.84	12.63
4	160X160	54.68	51.17	46.172	0.9358	0.8444	6.42	15.56
5	200X200	54.68	39.66	43.245	0.7253	0.7909	27.47	20.91

5. Conclusions

The ductile behaviour of the composite slab is reduced while increasing the size of the floor openings. Load carrying capacity reduces in the presence of openings at High shear region was more compared to openings present in No shear region.

The Numerical study for 160mmX160mm hole in no shear region slab model needs to be examined further. Since it gives higher load values than the 120mmX120mm hole in no shear region slab model.

Stiffening techniques around the opening like using reinforcement, thick plate around openings is satisfied up to medium size openings. For Large size openings, special considerations or secondary beams are needed.

Disclosures

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