Finite Element Modeling of Push-Out Test for Embossed Steel Plate Connector

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Abstract— Steel-concrete composite frames are form by casting flange of steel beam in concrete slabs or by connecting steel beam and concrete slab with the help of shear connectors. Steel-concrete composite beams, particularly, are structures consisting of two materials, a steel section located mainly in the tension region and a concrete section, located in the compression cross sectional area, both connected by metal devices known as shear connectors. This mechanical connector allows the joint behavior of the beam-slab which also restricts the vertical deflection and longitudinal deformation. Shear connector in the type of checkered plates were used in this paper to obtain the results. In the present study an accurate nonlinear finite element model of the push-out specimen has been developed to study the structural behavior, with emphasis on the beam-slab interface, the capacity of embossed steel plate connectors embedded in a solid slab in addition to vertical deflection and longitudinal deformation. Simulation is carried out using ANSYS.15 based on the Finite Element Approach. The material nonlinearities of concrete, embossed steel plate, steel beam were included in the finite element model. Contact between the elements is simulated using surface-to-surface and embedment techniques. The results obtained were compared with those provided either by Standards, experimental work or found in the literature, with variation about 15 to 20 %. It shows the good agreement of results and demonstrated ANSYS.15 is a valid tool in analyzing steel concrete composite beams performance for various parameters.

Key words: Steel–Concrete Composites, Shear Strength, Push-Out, Embossed Steel Plates, Load-Slip, Finite Element Model, ANSYS

I. INTRODUCTION

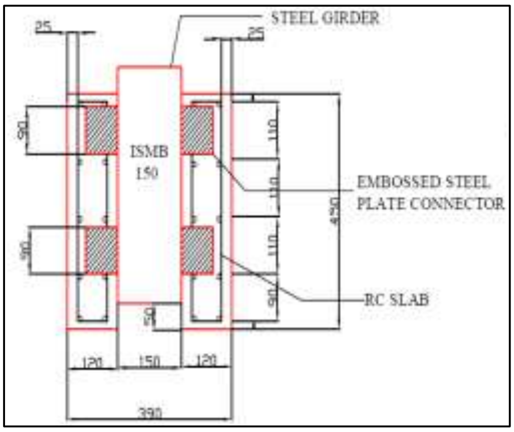
Composite steel–concrete construction, particularly for multi-storey steel frames, has achieved high market values in several countries. This is mainly due to a reduction in construction depth, to savings in steel weight and to rapid construction programmers. Composite action enhances structural efficiency by combining the structural elements to create a single composite section. Composite beam designs provide a significant economy through reduced material, slender floor depths and faster construction process. Moreover, this system is well recognized in terms of the stiffness and strength improvements that can be achieved when compared with non-composite solutions. A fundamental point for the structural behavior and design of composite beams is the level of connection and interaction between the steel section and the concrete slab. Composite construction refers to any members composed of more than one material. The parts of such composite members are rigidly connected to each other such that no relative movement can occur.

Development of composite beams includes developing materials, method of design and method of construction. The design of steel-concrete composite beams includes the design of steel beam, concrete slab and connectors. Nowadays, several types of connectors are available such as stud, channel, spiral, tendon and perfobond connectors. Enhancing steel-concrete composite bridge can be conducted through improving connection between concrete slab and steel beam, which allows the composite action to be more effective. The embossed steel plate connector is one of the newly development connectors which give a good connection behavior comparative with the stud connector.

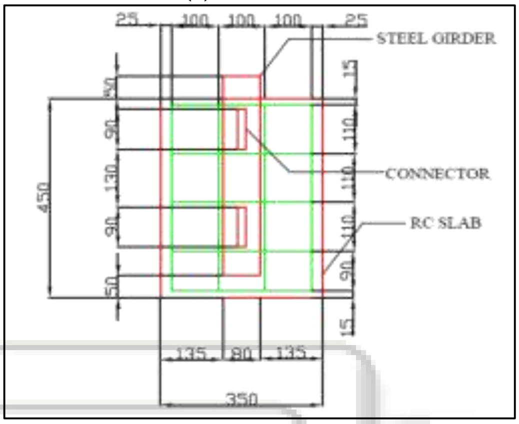
In this context, this paper proposes a new numerical model entirely based on three-dimensional solid elements and developed using the commercial software ANSYS. Its particularity relies on its ability to capture the composite response of simply-supported and continuous beams with both solid and composite slabs. Material nonlinearities are considered for all components, i.e., steel beam, concrete solid slab, steel reinforcement in the slab and shear connectors. The main idea is to make use of the computer program ANSYS, which is based on the Finite Element Method. It is widely known that laboratory tests require a great amount of time, are very expensive and, in some cases, can even be impractical. On the other hand, the finite element method has become, in recent years, a powerful and useful tool for the analysis of a wide range of engineering problems. In order to obtain reliable results up to failure, finite element models must properly represent the constituent parts, adopt adequate elements and use appropriate solution techniques. As the behaviour of composite beams presents significant Nonlinear effects, it is fundamental that the interaction of all different components should be properly modeled, as well as the interface behaviour. Once suitably validated, the model can be utilized to investigate aspects of behaviour in far more detail than is possible in laboratory work. A three-dimensional model is proposed, in which all the main structural parameters and associated Nonlinearities are included (concrete slab, steel beam and shear connectors) as used.

II. GEOMETRY OF PUSH OUT TEST SPECIMEN

The geometry of the push-out test specimen is shown in Fig. 1. was investigated in this study. This specimen is in accordance with the standard push-test specimen in Eurocode-4. The width and thickness of the concrete slab is 390 and 120 mm, respectively. The thickness of the steel beam is 7.6 mm. The rebar diameter is 10mm. The thickness of three embossed steel plates is 8mm, 10mm and 12mm and the yield strength of plate is 270MPa. The pattern is DIN 59220: 2000 teardrop pattern as shown in Fig 2.



(a) Front view



(b) Side view

Fig. 1: Push-out test specimen (Embossed steel plate)

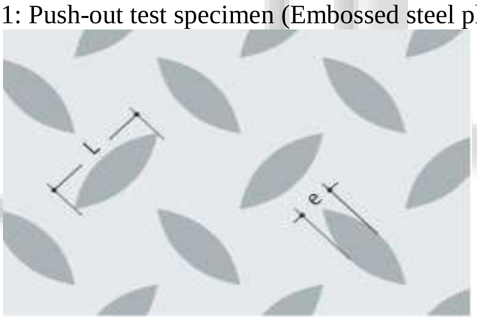


Fig. 2: DIN 59220:2000 teardrop pattern

L: approximately 30 mm

e: approximately 10 mm

III. FINITE ELEMENT MODELING

A. *Finite Element Type and Mesh*

The push-out specimen is composed of six components. They are the concrete slab, steel beam, embossed steel plate, cohesive layer, reinforcement bars and rigid base. The concrete slab part was meshed with solid element. This element can be used for nonlinear analysis including of contact, large deformation, plasticity and failure. The steel beam and the connector were modeled in the same part and meshed with solid element. The cohesive layer was meshed with the 8-node three-dimensional cohesive element. The rebar part was modeled by the truss element. In order 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 connector, the mesh size was also reduced at the joint between plate and steel beam where the stud would fail under shear force. The overall mesh size was 25 mm and the smallest size was about 3 mm.

B. *Loading and Boundary Conditions*

The rigid base was assumed to be immovable so all DOF of the reference node of the rigid base were restricted. In this analysis displacement control was applied. Loading was downward enforced displacement applied to the top surface of the steel beam as shown in Fig. 3. The applied displacement was linearly increased by amplitude function. The loading rate can be varied by using different amplitude functions. The slip was measured as the relative displacement between the nodes on the steel flange and on the concrete slab near by the connector plate. The load was measured as the total reaction acting on the loading surface.

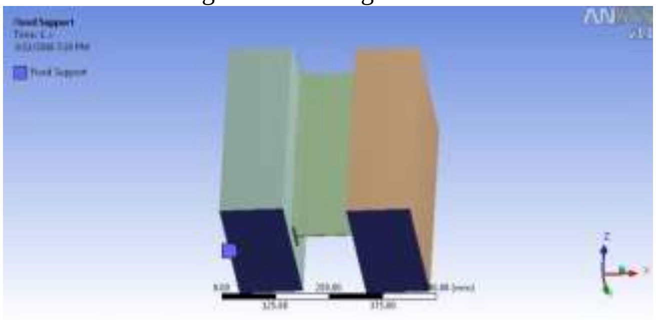


Fig. 3: Support condition

C. *Material Property*

S. No	Material	Property	Value
1	Structural steel	Yield stress(MPa)	250
		Ultimate strength(MPa)	410
		Young's modulus Es(MPa)	$205x10^3$
		Poisson's ratio µ	0.3
		Ultimate strain e	0.25
2	Reinforcing bar	Yield stress(MPa)	415
		Ultimate strength(MPa)	450
		Young's modulus Es(MPa)	$200x10^3$
		Poisson's ratio µ	0.3
		Ultimate strain e	0.25
3	Concrete	Compressive strength(MPa)	34.2
		Tensile strength(MPa)	3.553
		Young's modulus Ec(MPa)	32920
		Poisson's ratio µ	0.15
		Ultimate strain e	0.045
4	Embossed steel plate connector	Spacing (mm)	110
		Number of rows	2
		Numbers of connectors	4
		Yield stress(MPa)	435
		Ultimate strength (Mpa)	565
		Young's modulus Es(MPa)	$200x10^3$

		Poisson's ratio μ	0.15
		Ultimate strain e	0.045

Table 1: Characteristics of the beam and material properties

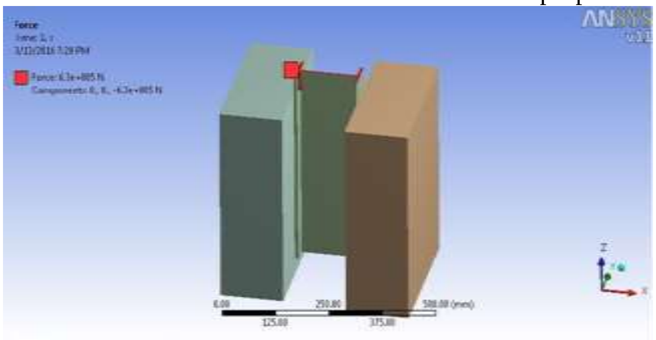


Fig. 4: Force Applied

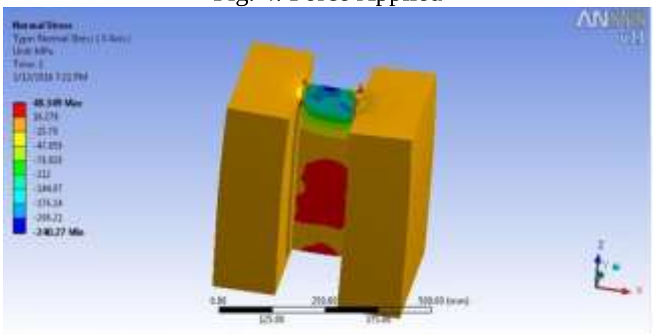


Fig. 5: Normal stress

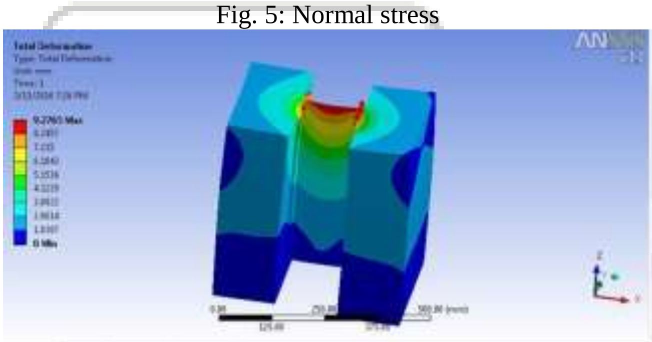


Fig. 6: Total deformation

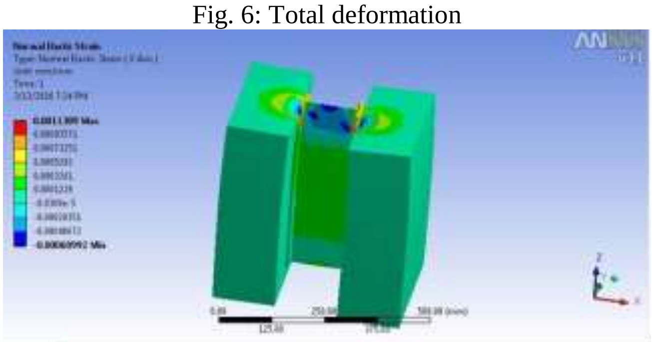


Fig. 7: Normal elastic strain

IV. CONCLUSIONS

Accurate nonlinear finite element models of push-out specimen have been developed to investigate the capacity of Embossed steel plate shear connectors embedded in a solid slab. The models took into account the nonlinear material properties of the concrete, steel beam, reinforcement bars and embossed steel plate shear connectors.

The initial cohesion was included to properly determine the stiffness of the connections. The capacity and ductility of the connection, the load_slip behaviour and failure mode of the embossed steel plate shear connectors were predicted from the finite element analysis and compared well with the experimental results from other researches. The Embossed steel plate shear connection capacities and ductility obtained from the finite analysis were compared with the design rules specified in EC4. The comparison showed that, the EC4 specifications overestimated the capacity of the embossed steel plate shear connectors up to 25%. This model was used to compare the three-dimensional stress state occurring in the slab concrete around the shear connector in the push-out test specimen. The comparison showed that the slab concrete around the shear connector developed different stress states. Considering the load transfer mechanism of the shear connector, this difference in the stress state was verified to be one cause of the difference in the horizontal shear behavior. Therefore in this work we have considered variation in thickness of shear connectors. By computations, it has been observed that height of the shear connectors does not influence much the deflection of the composite beam. However, increase in thickness of the shear connectors decreases deflection in composite beam.

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