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Numerical analysis of composite slim-floor beams

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ORIGINAL RESEARCH PAPER

ABSTRACT

In this research work existing laboratory tests of slim floor beams with solid monolithic concrete slab were modeled and analyzed using GID and Atena software. After validating the advanced finite element model with the test results of the international literature, structural parameters were analyzed with the aim to study their influence on the load bearing and deformation capacity of the beams. The parameters were related to the geometric of the beam: size of web openings and top concrete cover. With these results conclusion can be noticed that focusing on the optimal arrangement of the geometrical parameters of the composite beam could lead to better structural behavior with more economical solutions.

KEYWORDS

composite, slim-floor, composite slim floor beams, dowels

1. INTRODUCTION

The composite structures can be defined as a structure consisting of two or more materials, with distinct boundaries and conditions between them, the composite structures are made up with the interaction of the different structural elements [1].

1.1. Types of composite floor systems

Steel-concrete composite structures contain different types of structural systems like composite beams, columns, slabs and joints, which are considered as a good economical solution especially for buildings and bridges. Analytical and experimental tests were evaluated on these types of structures to achieve more developed and improved composite work which can be achieved by using shear connectors, and to overcome the disadvantages [1–5].

In the case of normal composite floor systems, any increase in the span causes a higher beam section depth (larger structural depth) and heavier sections than expected. This is the reason why Composite Slim Floor Beams (CoSFBs) have been developed to overcome this problem with many other advantages [6–8].

The main supporting element is the steel beam, which has been integrated into the concrete slab. The slab is supported directly on the lower flange of an asymmetric steel sections, or on welded plate to the lower flange in a double symmetrical I sections [8–10].

The advantages of the slim-floor systems can be detailed as follows: reduction of floor thickness, light structures, built-in fire resistance because covering the steel section by concrete will insulate it [6, 11], long spans, the concrete surrounding the steel beam section supports the slender steel plates, which is translated into a reduction of the risk of local instability of the element, easy and fast to build [10, 12].

1.2. Shear connections of slim-floor beams

The most popular type is the headed stud, which are welded on the upper flange of the steel beam. Using normal types of shear connections in CoSFB (headed studs) requires a reduction

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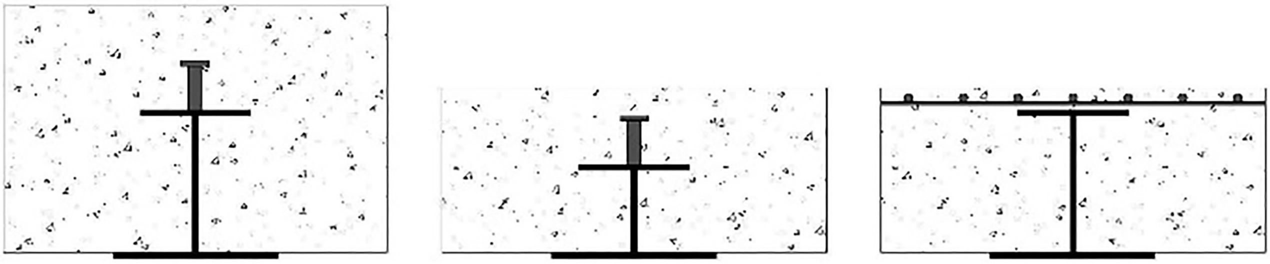

Fig. 1. Slim floor beam with shear studs-design problems with the size of the section

in beam height or increasing in slab thickness (Fig. 1), which will lead to increase the thickness or decrease the resistance or the span, and these are not the required results from using CoSFB. Due to all these reasons the usage of innovation shear connections was improved [6, 12–14].

In order to enlarge the application range of CoSFB and maintain its economic and technical advantages, an innovative composite slim-floor beam has been developed. CoSFB is a deep-embedded concrete dowel with transversal reinforcement connecting in-situ concrete with the steel section, ensuring a composite action without an increase in the floor thickness. Concrete dowels are defined as drilled openings through the web of a steel section and standard reinforcement bars placed transversally to the beam span through the web openings, while they are filled with in-situ concrete (Fig. 2) [5, 6, 8, 15].

The shear transferring mechanism enables the steel beam and concrete elements to interact with each other. The composite behavior of the beams will be the result of this interaction [16].

In the slim floor composite beams with tie-bar as shear connections, the combination of the dowel reinforcement bars and the infill concrete is the main reason for the shear connection, which is responsible for the composite work. Due to the activation of composite dowel work, an increasing in the loadbearing resistance and stiffness of the beam is caused. The dowel reinforcement is mainly subjected to shear forces, and at larger deformations of the tie bar, to tension. By fixing the diameter and the strength of the tie bar, so at high concrete strength, the tie bar will be subjected to shear forces and its failure will occur due to shear, this phenomenon could be explained as the tie bar is not able to damage the concrete in the load direction and the axis of the tie bar cannot deform. However, at lower concrete strength, the tie bar will crush the concrete in the load direction which will create a space that will allow the tie bar to deformed, at this stage the tie bar is subjected to shear and to tension which is related to the increasing deformation of the tie bar. So, the load bearing behavior is controlled by the concrete component, the dowel action of the tie bar and the friction. [8, 17, 18].

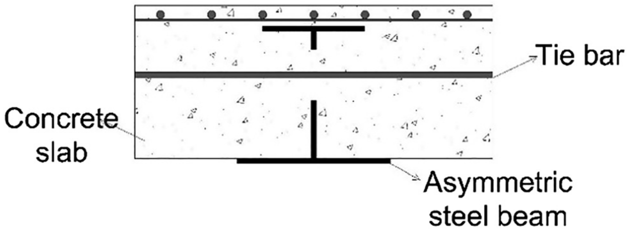

Fig. 2. Composite shallow cellular floor beam

2. EXPERIMENTAL TESTS

Many experimental tests were completed from many researchers with the aim to understand the details of the structural behavior and to provide results for the qualification of the numerical model. The details of two of the experimental program are summarized in this chapter, more details can be found in [16].

Two flexural tests were done on a full scale composite slim floor beam specimen. One four-point bending test and the other is a three point bending test, which is the failure test. The concrete slab is flat with a 1 m width supported on the bottom flange of the steel beam; with a tie bar with 16 mm diameter used as shear connections on half of the beam only [16], as it is shown in Figs 3 and 4.

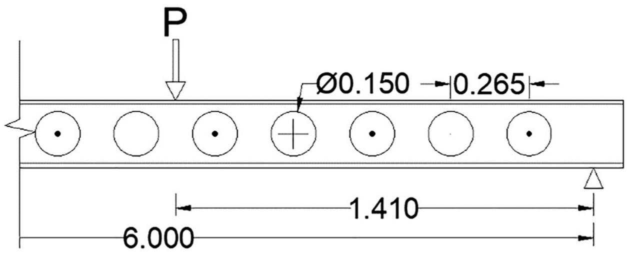

Fig. 3. Composite slim-floor beam specimen

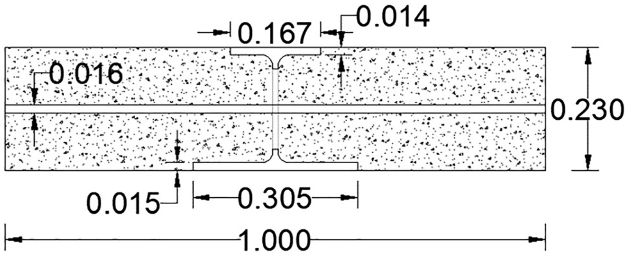

Fig. 4. Composite slim-floor beam section

3. NUMERICAL MODEL

For this research the Advanced Tool for Engineering Nonlinear Analysis (ATENA) software was used to build the model.

The numerical model is based on the specimens that could be found in Huo work [16].

3.1. Details of the numerical model

Material properties as shown in Tables 1 and 2 coming from material test.

Concrete is inhomogeneous, that is why concrete will show the main problem with Finite Element (FE) modeling. In concrete modeling in ATENA, six variable parameters out of 21 could be approximately determined experimentally: the compressive and tensile strength, modulus of elasticity, and density of the material, thermal expansion coefficient and the Poisson's ratio [19].

Assuming that the concrete specimen has lower properties than a cube or cylinder one, the parameters could be reduced in the FE model between (70–100%), because of different variables like: the construction process, the geometry of concrete and reinforcement, etc., so lower properties could be used in the Finite Element Model (FEM) (Table 2) with the value provide good accuracy with the experimental test [19].

The finite element model is presented in Figs 5 and 6.

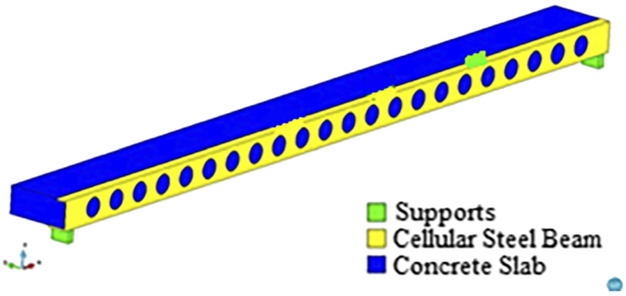

Fig. 5. Finite element model

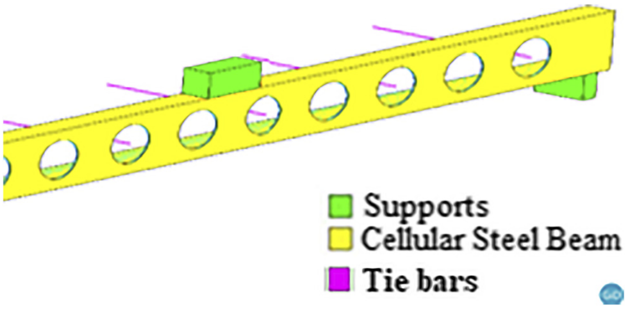

Fig. 6. Finite element model

A displacement has been applied on the upper supports with a value of (-0.001 m) in z direction, to simulate the applied force in the experimental test.

3.2. Verification of numerical model

The results of the experimental program and the FEM model were compared with the aim to validate the numerical model and to perform parametric analysis on structural details on the validated model.

The analysis had been done on the model under a three-point bending test, which was a failure test. It should be mentioned that the results for this test were affected with the previous four-point test silence both tests had been done on the same beam in a row.

Table 1. Cellular steel beam/reinforcement bars

Type	Elastic module E_s GPa	Yield strength f_y MPa
Cellular steel beam	210	414
16 mm	210	441.7

Table 2. Concrete slab/FEM concrete

Type	Elastic module E_c GPa	Cube compressive strength f_{cu} MPa	Tensile strength f_{ct} MPa
Concrete (test)	31	30	2.6
Concrete (model)	21.7	21	1.8

The result of the analysis of the finite element model is presented in (moment-deflection curve) in Fig. 7. The ultimate moment and the maximum deflection are 385 kN m, 80 mm for the experimental test and 397 kN m, 77 mm for the finite element model. The finite element curve and the test curve are in accordance, this means the FE model is validated for further parametric studies.

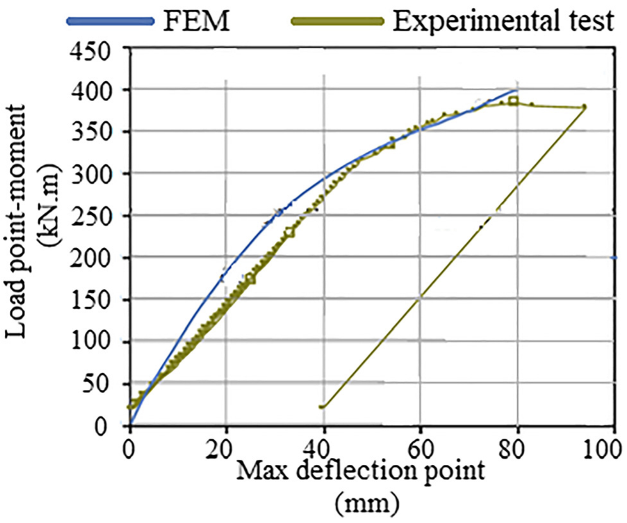

Fig. 7. Moment-deflection curve from the finite element model

4. PARAMETRIC STUDY ON FE MODEL

The aim of the parametric study is to evaluate the influence of the structural geometrical parameters (size of web openings, thickness of concrete cover) on the structural behavior.

4.1. Web openings size

Smaller web openings were modeled. The openings' diameter was decreased by 50% to be 75 mm instead of 150 mm (Fig. 8).

The moment - deflection curve of the modified FE model (with the modified openings) and the original FE model is shown in Fig. 9.

With decreasing the web openings by 50% the maximum deflection according to this research was decreased by 21.8% and the ultimate failure load was increased by 7.7%. According to these results, keeping the minimum size of the openings to create composite action could be the only requirement considering the slip behavior.

4.2. Concrete cover

5 cm concrete cover with a 10 mm reinforcement bars were created over the top flange of the beam (Fig. 10).

The moment-deflection curve of the new FE model analysis (with the concrete cover) and the original FE model is shown in Fig. 11. At the ultimate failure (the maximum load level) with a bending moment 475 kN m, the maximum deflection was 64 mm.

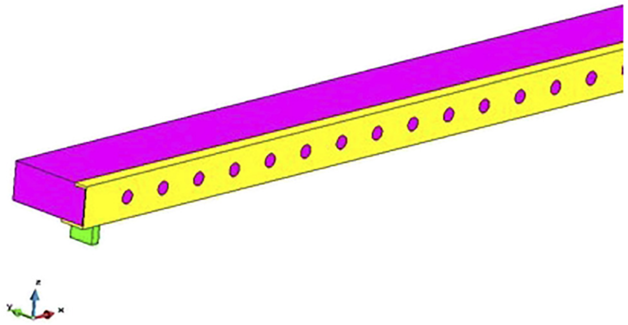

Fig. 8. Beam with openings smaller by 50%

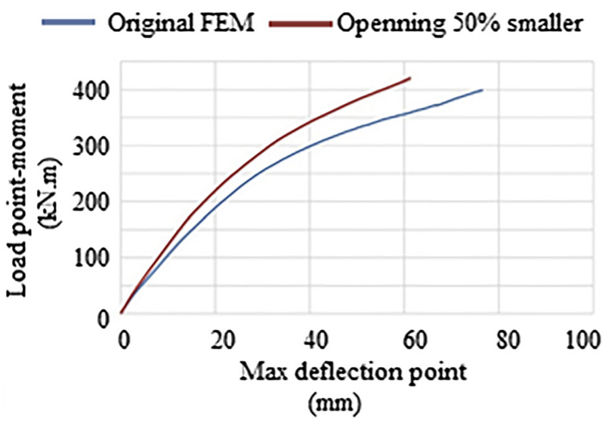

Fig. 9. Comparison between moment-deflection curve for the original and the modified finite element model

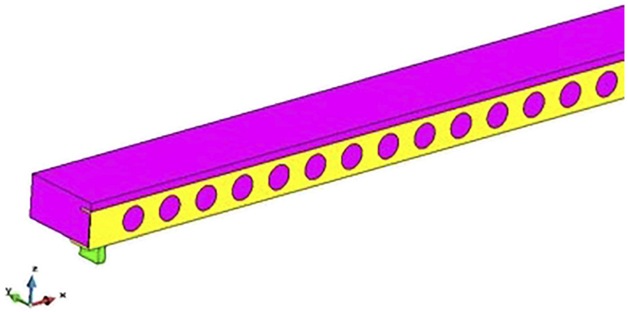

Fig. 10. Beam with 5 cm concrete cover

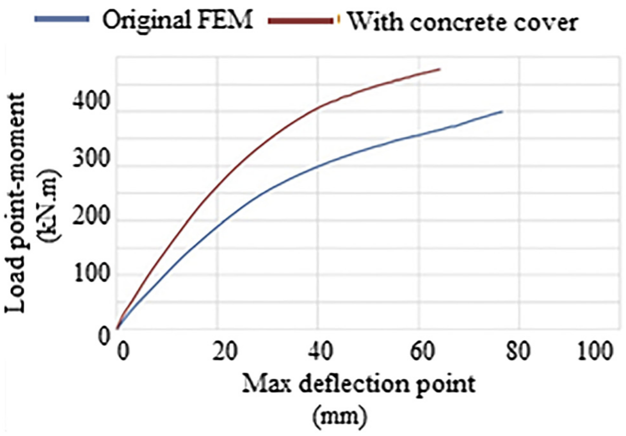

Fig. 11. Comparison between moment-deflection curve for the original and the modified FEM

The thicker concrete slab causes higher stiffness that is why the stiffness of the structure has increased.

5. CONCLUSION

An existing experimental test specimen was modeled as FE model to check the influence of different parameters on the behavior under the bending test.

In this research two parameters had been studied, the size of the web openings and the concrete top cover. Decreasing the web openings caused a stiffer section, which leads to the idea that drilling the steel web to create openings with small diameters could be done with no need to have a fabricated cellular steel beam, more tests should be done to find the perfect percentage for the openings size to have a stiffer section with the consideration of the size effect on the longitudinal shear resistance. Adding a top cover concrete would help placing the needed tube installations which will improve construction process, and will give a higher strength to the section, so focusing on the geometrical parameters could lead to better construction methods and ideas.

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