Parametric Study of steel-concrete composite beams

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Abstract— *In this paper a numerical model is developed to predict the behaviour of steel-concrete composite beams with circular openings up to failure. The numerical model takes into account both material and geometric non-linearity and nonlinear behavior of the connection. Calibration with experimental data obtained from previous work shows that the model is able to predict, with relatively good accuracy, the ultimate load. A parametric study is then followed to study the influence of post dimensions and the shape and spacing of the openings on the behavior of such beams under the action of three types of static loading*

Keywords— Composite beam, concrete, steel, nonlinear behaviour, shape opening, spacing openings.

I. INTRODUCTION

Use of cellular composite beams is become very popular now a days due to its advantageous structural applications. Considering the high usage of cellular composite beams with web openings, particularly in high-rise buildings, study of their behavior is essential. Many investigations have been conducted regarding the behavior of these beams [1], [2], [3]. The information available on beams with web openings does not cover some points for circular openings. Different research studies are carried out for analysis and design of cellular steel beams with and without the presence of slab concrete. Ehab Ellobody [4] studied the interaction of buckling modes in castellated beam with hexagonal opening analytically as well as experimentally. 96 models of castellated beam were developed with all non linear material properties in ABAQUS Finite Element programming software. The parametric study was extended in order to study the effects on the beam when the geometries of the specimen is changed also the length of the beam was considered. It was observed that normal strength castellated beam generally fails in lateral torsional buckling, while high strength castellated beam fails by web distortional buckling. B. Anupriya and Dr. K. Jagadeesan [5] studied analytically shear strength and deflection properties of castellated beams with hexagonal openings using ANSYS14. Study shows that, as the depth of castellated beam increases, the stress concentration at corners as well as at the loading point increases. Konstantinos Daniel Tsavdaridis and Cedric D'Mello [6] studied the performance, modes of failure and the load carrying capacity of various types of cellular beams analytically as well experimentally, providing web openings at close spacing. Ehab Ellobody analyzed the castellated beam with circular openings by nonlinear analysis, where the combined modes of buckling of these beams were considered. The behavior was checked for high strength of beam by considering the parameters like imperfection of geometry, remaining stresses and also non linear material properties of material were considered. The non linear finite element method helped in predicting deflection, failure modes and also the loads causing failure. Wakchaure M.R. and al. [8] carried out experimental investigation on simply supported hexagonal castellated beam under two point loading. Modes of failure of the castellated were examined for different depths of openings. From the experimentation, researchers conclude that the castellated beam behaves satisfactorily up to a maximum depth of 0.6 times the depth of opening (0.6D). Siddheshwari. A. and al. [9] presented a review existing literature in which he explains the parameters that were considered and the numerical and experimental results.

The use of composite steel-concrete structures results in optimal performance of the two materials (the steel in tension and the concrete in compression) but in design process it is necessary to evaluate the influence of the connection between the two materials on the overall behavior of the structure. Consequently, slippage between the steel beam and the concrete slab cannot be neglected as suggested by the European Code of steel-concrete composite construction EC4 [10].

In cellular composite beams discontinuity in the cross section of steel beam, due to the presence of web opening, can have an impact on their flexural capacity (transverse rigidity discontinued) and modeling is a the key issue in the analysis of this type of structures. The purpose of this article is the influence analysis of the partial interaction behavior of this type of composite beams in presence of openings in the web, taking into account the geometric and material nonlinearity of various components of the beam. A numerical modeling in 3D finite element was made to study simply supported cellular composite beams subjected to positive bending due to concentrated loads at mid-span. A parametric study is then followed to study the influence of post dimensions and the shape and spacing of the openings on the behavior of such beams under the action of three types of static loading.

II. 3D NUMERICAL MODELING OF the BEAM

Numerical modeling in 3D allows most often representing the exact geometry of the beam and providing a better understanding of its behavior. Practically, the three-dimensional numerical model requires considerable computing cost and requires an efficient electronic support. The choice of the finite elements used in this modeling is guided by the findings of the literature search and by means of calculation associated with the code "ANSYS" we use [11]. We used in this study, a representative model that requires geometrical and material data necessary to make a reliable study. For this, the study is based on the results of the composite beam made experimentally by K. Abdul Aziz in 1986 and numerically by Fabbrocino and all in 1998 [12]. The composite beam tested by K. Abdel Aziz named PI4, with a range of 5.0 m and simply supported at the ends is subjected to a concentrated load at mid-span "Fig. 1".

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FIGURE 1: STATIC DIAGRAM OF THE BEAM (PI4).

III. DESCRIPTION OF STEEL BEAM

Steel section profile used by the authors is an IPE400, with elastoplastic law. Steels of the profile and reinforcement of slab details are shown in "Fig. 1" and the mechanical properties of the steels are shown in "Table 1". The walls of the steel profile (web and flanges) are modeled by shell elements with four nodes called SHELL43; the proposed height of the steel profile is based on the approach to define the mesh of the shell in the center line of the flanges. Which gives a height calculation $h = h_t - t_f = 386{,}5$mm.

TABLE 1
CHARACTERISTICS OF BEAM COMPONENTS.

Elements	f_y [MPa]	f_u [MPa]	ε_y [‰]	ε_t [‰]	ε_u [‰]
Web	260	372	1,238	22,28	99,0
Flanges	245	361	1,167	21,0	93,36
Reinforcement ϕ=8 /10	370	375	1,76	31,68	140,8
Studs ϕ=19	350	450	1,67	30,0	133,3
$E_s = 2{,}1\text{x}10^5$ MPa			$\upsilon=0.3$		

IV. DESCRIPTION OF THE REINFORCED CONCRETE SLAB

The concrete slab of 800mm width and 100mm thickness is connected to the IPE400 profile, the behavior law was adopted under traditional regulatory form "parabola-rectangle" according to Eurocode 2 with a compressive strength $f_c = 35$ MPa and the modulus of elasticity $E_{cm} = 33.5$ kN/mm² with the strain at maximum compressive stress of concrete, $\varepsilon_{c1} = 2.2$ ‰. We chose this behavior law because the slab is fully compressed.

The concrete slab is modeled as a conventional reinforced concrete element, so that its analysis is based on two assumptions:

- No slip between reinforcements and concrete is allowed,
- The strength of concrete in tension is neglected in the calculation.

For the modeling of the slab, the volume elements are used "CONCRET65", these are reserved specifically for the concrete material in the library software. This type of modeling can introduce differences hardware characteristics (if any) in different layers through the thickness of the slab. The reinforcements were modeled by unidimensional elements bar called "LINK8", the mechanical properties of the steel used are shown in "Table 1".

V. DESCRIPTION OF THE CONNECTION

The connection is discretized at the slab-upper flange interface at each node by a connector that is loaded in bending and shear. The law of behavior of this connector is defined by a law called "load-slip" to reproduce the real behavior of the connector. In this model, the connection is provided by 18 headed studs (2x9 pair) Nilson type ϕ = 19mm diameter and 75mm height with a spacing of 650mm. Note that the spacing "p" connectors must be adapted to shear flow in the beam. In this study where the shear force is constant, we adopt a constant spacing. The diagram "shear force F-slip s" of connector i is defined by the relationship of Olgaard [12], which relates the shear force F_i and slippage s_i at the contact interface by formula: $F_i=P_{max}.(1-e^{-\beta.Si})^{\alpha}$. Control parameters α and β of the initial slope of the curve and its shape are defined taking into account typical values of the two coefficients found in the literature [13], while the value of P_{max} was measured by testing push out. In our case: α =0.4 et β=0.709mm^{-1}, avec P_{max}=130 kN. Studs are modeled by nonlinear spring elements called COMBIN39, this type of spring used allow introducing non-linear curves in several points "Fig. 2".

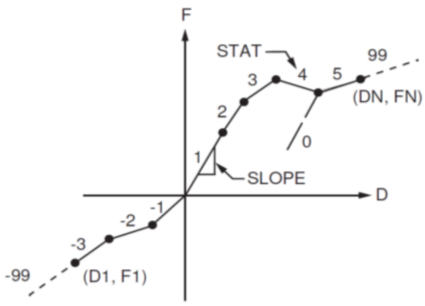

FIGURE 2: FORCE-DÉPLACEMENT COMBIN39 [11].

VI. LOADING AND SUPPORTS CONDITIONS

The beam considered in this model is simply supported at the ends and maintained laterally, subject to a concentrated load at mid-span; the load was applied as a distributed pressure on a surface from 200x200mm to avert the concentration of stresses on the slab.

VII. MODEL VALIDATION

The model in 3D is certainly very detailed "Fig. 3", but the computational cost can be excessive and may penalize its practical application for engineers. We will first validate the model of the composite beam and the calculation results obtained are compared to those of the experimental PI4 beam tested by K. Abdel Aziz and calculated by Fabbrocino and al. [11]. Then, based on this model, we present a new model for cellular composite beam.

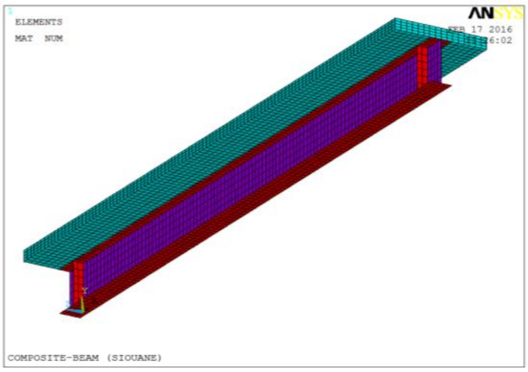

FIGURE 3: FEM MODEL OF BEAM PI4.

VIII. LOAD-DEFLECTION BEHAVIOR VALIDATION

The comparison of our results and those of the authors are shown in "Fig. 4". It is found that the experimental collapse of the beam "PI4" has been reached for P_{exp} = 490 kN, with deflection 157mm, and the ultimate load calculated by Fabbrocino and all. P_{EF} = 488 kN with a deflection equal to 182mm [11]. For the same collapse experimental load P_{exp}, we found 171.7mm f deflection, with a relative error equal to 9.4%. Therefore, a slight difference of the elastoplastic area curve is found, it is highly dependent behavioral relationships both materials and shear studs.

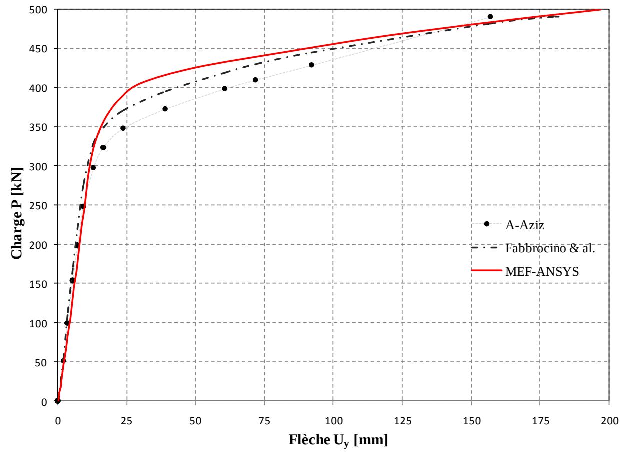

FIGURE 4: LOAD-DEFLECTION AT MID SPAN.

IX. SLIP VALIDATION

To validate this model to slip, we use the results of K. Abdel Aziz and Fabbrocino and all. The results are shown in "Fig. 5". The results show good agreement with the results of tests particularly for landslides at the end of the beam, with a difference of no more than 2.5% for the elastic limit load.

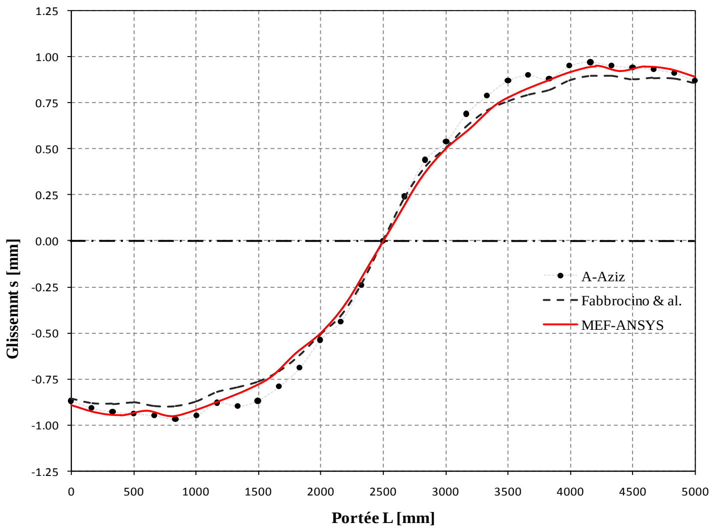

FIGURE 5: SLIP BETWEEN STEEL AND CONCRETE (P=344 KN).

X. VALIDATION OF THE CURVE

The comparison of curvature results ψ along the length of the beam and the moment-curvature relationship are shown in "Fig. 6" and "Fig. 7". When the failure load is reached, there is a good agreement between the curves "Moment-Curvature", the registered difference is of the order of 17%. The peak observed in Figure 5.9 is the result of the algebraic sum of the values from each side of the middle of the beam.

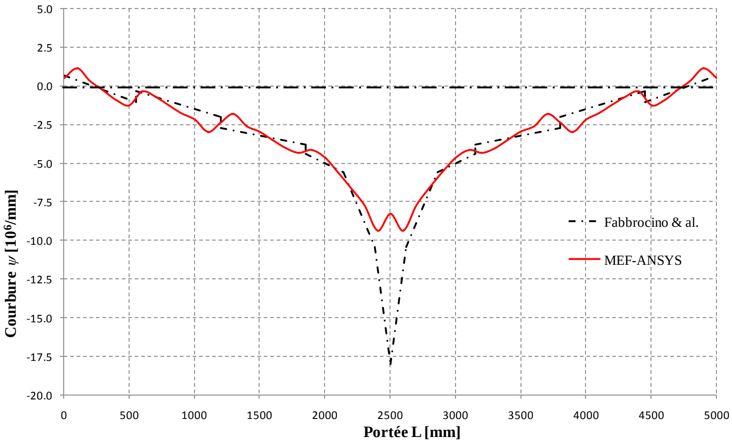

FIGURE 6: CURVATURE VARIATION ψ (P=344 KN).

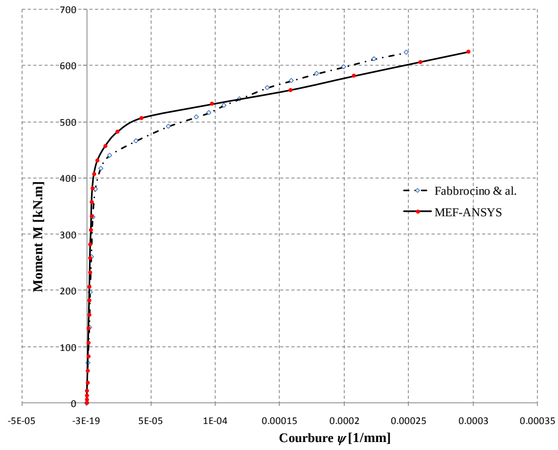

FIGURE 7: MOMENT - CURVATURE ψ (n_{cnt}=18).

XI. CONCLUSION

The modelization of the structural behavior of steel-concrete composite beams subjected to concentrated static load at mid-span was developed in this study. The 3D numerical model presented here, allows provide a better understanding of the relationship between the slip and shear connectors. We can notice that the estimate of the deflection and curvature seems to be more influenced by the constitutive relations introduced to materials and shear connectors. The difference between the results of linear analysis and analysis by FEM can be explained by a misinterpretation of the connection behavior in the analytical method. As regards the sliping, the results show good agreement with the results of tests particularly for landslides at the end of the beam, with a difference of no more than 2.5% for the elastic limit load. When the failure load is reached, a good agreement between the curves "Moment-Curvature" is found, the registered difference is of the order of 17%.

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