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Parametric Study of Bonded Connection in Composite Structures through the FE Modeling of Push-Out Test

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Abstract

This paper investigates bonded connection in steel-concrete composite beams and presents the 3D modeling of push-out tests by the Finite Element Method. The exact three dimensional geometry of the problem is considered; the whole elements of the connection are taken into account. The mesh is optimized in order to ensure accuracy and convergence. The concrete is assumed to follow a damaged plasticity model. This model states that the two main failure mechanisms are tensile cracking and compressive crushing of the concrete material. The contact between the steel connector and the concrete is either perfect or described by a Coulomb law (friction with sliding).

The effect of reinforcement and spacing of the connector on the structural behavior of the connector is presented and analyzed by comparison with results of push-out experiments, using load-slip curve. The importance of the contact nature and the friction coefficient as well as the concrete behavior and the exact geometry of the connection are put into evidence.

The final aim is to develop a modeling able to reproduce the main features of the behavior of connections in composite structures but simple enough to be used in the modeling of real structures like beams or columns.

Keywords: Headed stud connector, Push-out test, Finite element modeling, Composite connection.

1. INTRODUCTION

The steel-concrete composite beams have been widely used because of the benefit of combining concrete and steel. Concrete is used for compression where steel is prone to buckling, while steel is used...
for tension where concrete can be easily cracked. The association between concrete and steel beam is ensured by connectors. Generally, connectors are headed shear connectors or stud connectors. The behavior of such a connection depends on many factors including strength and dimension of stud connector, spacing between stud connector and concrete strength.

The standard experiment used to study shear connection in steel-concrete composite beams is presented in Eurocode 4. A schematic view of the push-out test is proposed in figure 1: it is the reference sample studied by Lachal during an experimental campaign presented in (Lachal 2005). In a push-out test, a uniform load or displacement is applied to the upper end of the steel beam. Slip between the steel beam and the two slabs is measured at specified load or displacement increments and the load is typically plotted against the average slip to obtain load-slip curve.

Figure 1: Reference specimen for Push-out test (dimensions in mm), used in (Lachal 2005)

Figure 2: FE mesh used in this work for push-out specimen.
The steel profiled beam used in push-out test is of type HEB 260 with a yield stress equal to 355 MPa. The concrete is supposed to be of class C40/50 with a measured mean compressive strength of 56 MPa. The steel rebar has a diameter of 10 mm and is of type FeE500. The 19x100 mm headed studs are welded through the profiled steel beam. Their yield stress is 355 MPa and their ultimate stress is ranging between 510 and 780 MPa.

To study all parameters affecting the behavior of headed shear stud connectors in composite beams with profiled steel beam, push-out tests become a costly and time consuming option. Then Finite Element modeling can provide an efficient alternative to these experiments. Figure 2 shows a mesh of the sample. To reduce the cost of the calculation, two symmetrical planes are used and only a quarter of the specimen is presented.

2. IDENTIFICATION OF CALCULATIONS ASSUMPTIONS

To obtain an accurate modeling of push-out tests, it is necessary to identify at first the main assumptions of the computation such as optimal mesh, material behavior, interactions between stud and concrete. This identification has been performed on a simplified model where only one stud is embedded into a concrete block. Figure 3 presents the simplified model and the mesh used.

The investigations show that the optimized mesh has 32 elements in circumference of the hole and an aspect ratio of elements close to 1:1. These results are in accordance with the conclusions of (Siebert 2003) and (Maniatis 2006).

For all the identification studies, steel is supposed to be elasto-plastic with yield and ultimate stresses respectively equal to 355 and 510 MPa, a Young’s modulus of 200 GPa, a hardening modulus of 3500 MPa and a total strain at the beginning of the hardening equal to 0.01. The evolution of the stress-strain curve in the hardening zone corresponds to Gattesco model as described in relation (1):

$$\sigma = f_y + E_h \left( \varepsilon - \varepsilon_h \right) \left[ 1 - E_h \frac{\varepsilon - \varepsilon_h}{4(f_u - f_y)} \right]$$

(1)

The mechanical behavior of concrete is simulated with various models more or less complex: elastic behavior, a smeared cracked model with a tensile damage alone (it could be sufficient for applications in which the behavior is dominated by tensile cracking (Hillerborg et al. 1976)), a damaged plasticity model (Lubliner et al. 1989) with and without compressive damage. In this last case, the model proposed by Sima (Sima et al. 2008) has been used for the concrete damage evolution. Carreira and Chu model as defined by the relation (2) has been used for the definition of the stress-stain curve of concrete (Carreira et al. 1985). This model needs only the compressive strength (fc=56 MPa) as input data.

$$\sigma_c = \frac{f_c \gamma (\varepsilon_c / \varepsilon_{cs})}{\gamma - 1 + (\varepsilon_c / \varepsilon_{cs})^\gamma}$$  \text{where}  \gamma = \left[ \frac{f_c}{32.4} \right]^{3} + 1.55 \text{ and } \varepsilon_{cs} = 0.002

(2)
Figure 4 presents and compares the main results obtained in terms of load-slip curve of the stud. For the same concrete behavior, the use of tied contact overestimates both initial stiffness and strength of connection compare to a sliding contact. The small sliding contact formulation is particularly well adapted for three dimensional problems, as already explained in (Bernard et al., 2009). Considering a compressive damage leads also to a decrease of both initial stiffness and strength of connector. On this last point, we can also add that the damage definition is important. This last conclusion represents a new result: in problems with such localized damage, the definition of the plastic strain and then of the unloading slope of the curve is necessary even if the applied loading is not cyclic. Damage models without plasticity need a refinement.

Figure 3: Mesh used for the simplified problem (a) and boundary conditions (b)

Figure 4: Comparison of the various simulations (serie 1: model with tensile damage and tied contact; serie 2: model with tensile damage and sliding contact (friction coefficient \(\mu=0.4\)); serie 3: damaged plasticity model with definition of tensile and compressive damage and sliding contact (\(\mu=0.4\)); serie 4: serie 3 with viscoplastic regularization; serie 5: plasticity model with definition of tensile damage coefficient and sliding contact).
The use of a viscoplastic regularization leads to a small difference on the results. It appears interesting in order to solve some problems of convergence.

These results prove that few simplifications can be used in the modeling of push-out tests: the mesh has to be sufficiently fine, the behaviors of steel and concrete have to be known accurately, and furthermore the contact between the stud and the surrounding concrete has to be taken into account in a realistic way, the sliding and friction contact model should be used.

3. PUSH-OUT TEST MODELING AND COMPARISION WITH EXPERIMENTS

The starting computational assumptions being identified, the modeling of the push-out tests has then been performed in order to obtain the behavior of the headed stud. In this mesh, only reinforcement bars near to the connector have been considered with an equivalent square section. Considering that no identification has been made, the results predicted by the modeling shown in figure 5 are in good agreement with experimental ones. From the result shown on this figure, the effect of the presence of reinforcement on load-slip curve is minor for this class of concrete.

![Graph](image.png)

Figure 5: Load-slip curve per connector obtained by the modeling of Push-out test

4. STUDY OF THE INFLUENCE OF THE SPACING BETWEEN STUDS

In this part, the influence of spacing between studs on load-slip curves and shear strength of the studs will be determined numerically. The further effect of the spacing of stud connector on behavior of a whole composite beam will be studying using load-slip curves obtained in push-out tests.

4.1. Push-out tests with grouped connection of 100mm spacing

The finite element modeling of the Push-out test for grouped connection with 100mm spacing between stud connectors is realized with the same material properties and model than for standard Push-out test. In this model, 60,876 elements and 72,054 nodes corresponding to 206,697 variables have been used. The load-slip curves are shown on figure 5 along with comparison with the curve from standard Push-out test and experiment conducted by Lachal (Lachal 2005). The ultimate shear strength of the connector with
grouped connection shown in figure 6 is of about 4% less than ultimate strength of the standard connection, where experimental test value is about 7%.

![Force-sliding curve per connector obtained by the modeling of Push-out test](image)

Figure 6: Force-sliding curve per connector obtained by the modeling of Push-out test

4.2. Up-scaling to the whole steel-concrete composite beam

Two composite beams have been modeled, one with uniformly distributed stud connector and other with grouped stud connector. The configuration of these beams is shown in figures 6(a) and (b). In these modelings, the steel beam is 500mm height, its flange is 200mm width and its web is 10mm thick. The concentrated load is applied at the mid-span of the beam. The finite element mesh is shown in figure 6(c). At the composite beam scale, shear studs are thus replaced by nonlinear translational springs as shown in figure 7. These springs act in the longitudinal direction of the beam and connect two coincident nodes of the mesh, the first one belonging to the girder and the second one to the slab. In order to be as realistic as possible, it is necessary to add a new kinematic constraint on the width of the beam: in this direction, the displacement of two points connected by a spring is assumed to be the same. The damaged plasticity (Lubliner model) and elasto-plastic model have been used for concrete and steel respectively.

The maximum deflection at mid-span of the beam and the maximum slip at both end of the beam are plotted in function of the load as shown in the figure 9. There are no real differences in the load-deflection and load-slip curves of the composite beams with uniform spacing of connector and with grouped connection; even if the beam with grouped connector has a lower stiffness in the plastic branch of the curve. The beam with uniform spacing connectors presents also a slightly higher strength than the beam with grouped connectors. The vertical displacement along the connector line is still under investigation for both configurations of composite beams.

Headed stud connector, Push-out test, Finite element modeling, Composite connection
Figure 7: Composite beam with standard spacing of stud connector (a), grouped stud connector of 100mm spacing (b) and corresponding FE mesh (c)

Figure 8: Kinematic constraints imposed between two coincident points.

5. CONCLUSIONS

From all these studies, the following conclusions can be proposed:

- The perfect contact between connector and concrete tend to overestimate the stiffness and the strength of the shear connector. The friction contact should be used with suitable value of friction coefficient. The material model should include the compressive damage evolution for the concrete damage plasticity model of concrete.
• The reinforcement has no impact on the load-slip curve of the shear connector for concrete of class C40/50. Further investigation should be made to check if the presence of reinforcement has any effect on load-slip curve for composite beam with lower class of concrete.

• The grouped connection has a slightly lower strength than standard connection. When applied to the composite beam, the initial stiffness is approximately the same for both beams using grouped connection or standard one, while the ultimate strength of the composite beam with standard connector is higher.

The multi-scale approach presented in this section enables thus to obtain results useful for structural design as well as for constructive provisions.

Figure 9: Load-deflection curves (a) and Load-slip curves (b).

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