Numerical Simulation Of FPCB Shear Connectors For Thin Sheets

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Abstract. In this work, experimental investigations were conducted, and a numerical model was proposed to analyze the behavior of circular openings with transverse bars as steel-concrete shear connectors (FPCB). Although the effectiveness of these connectors for thick plates has already been proven by previous works, the application of circular openings with transverse rebar shear connectors to thin sheets has not been widely evaluated yet. This paper presented the development of the numerical model for the analysis of circular openings with transverse bars as steel-concrete shear connectors. The three-dimensional model of the plug-in test adapted for the analysis of these connectors was performed in the finite element program ABAQUS. The C3D8R solid element was used to simulate the concrete block, the steel sheet, and the steel rebar. For the steel stirrups, T3D2 truss elements were used. To simulate the concrete the Concrete Damaged Plasticity (CDP) model was adopted and for the steel elements the bilinear simplified curve was implemented. The aim of this paper was to compare it with experimental tests performed by the author and to demonstrate its capacity to efficiently represent the behavior of the circular openings with transverse rebar shear connectors to thin sheets observed in the experimental test.

Keywords: Shear connector, Composite dowel, Slip capacity, Ductility, Thin sheet.

1 Introduction

The circular opening with transverse bars as steel-concrete shear connectors (FPCB) is applied to be a load transfer device in composite structural elements. The FPCB constitutes holes in steel sheets filled with concrete and transverse bars. Initially, the FPCB connectors were only used in composite beams as a part of the shear connector Perfobond (see Fig. 1) proposed by Andrä [1] in the 1980s, however, due to its mechanical characteristics and ease of execution, this shear connector configuration has been improved and adopted in several structural applications.

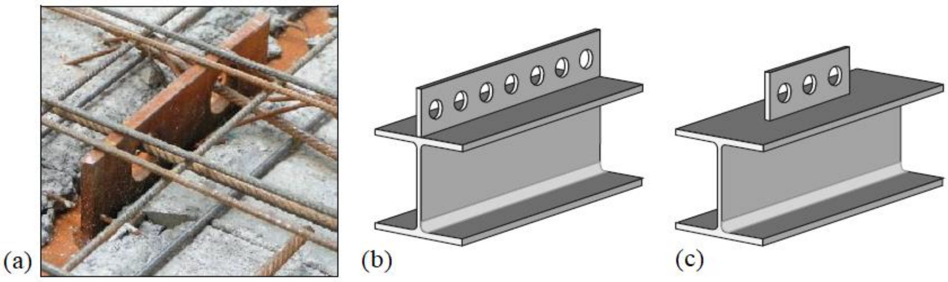

Figure 1. (a) Perfobond shear connector applied to composite beam (Vianna *et al* [2]: (b) continuous and (c) discontinuous (Veríssimo [3])).

Over the years, the FPCB shear connector (Fig. 2) has become more popular because shows satisfactory mechanical behavior (high strength, stiffness, and good sliding capacity), it also has the constructive advantage of being able to use the composite element's own (steel sheet, rebar, and concrete) to load transfer between the materials, it that is not required an additional element to be welded to the structure for this function.

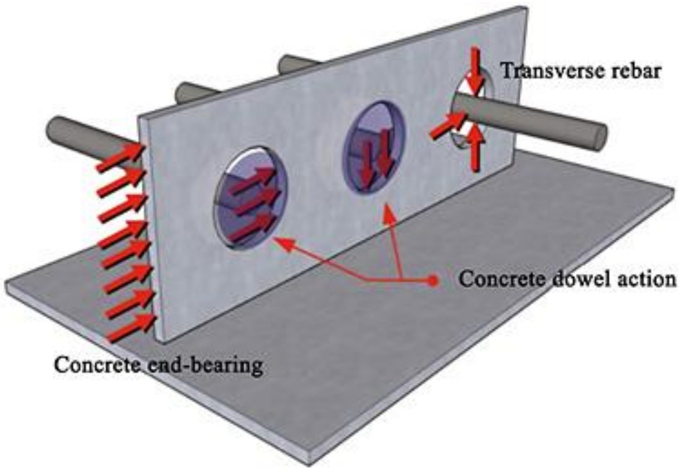

Figure 2 - Loads applied on connector in pull-out test (Cho *et al* [4]).

A model nomenclature follows the pattern described in Fig. 3, where each part describes one of the parameters defined in the models. The sheet thickness (t), the hole diameter (D), the diameter of the transverse bar (d), the compressive strength of concrete (f_c), the position of the transverse bar (e_0), the yield strength of steel (f_y), and the ultimate tensile strength of steel (f_u).

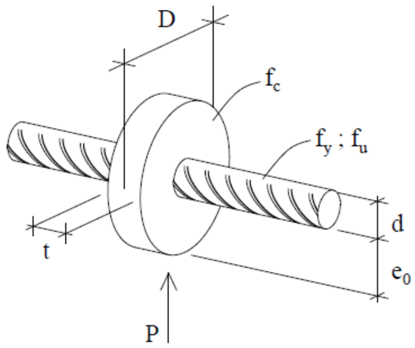

Figure 3 - Connector configuration.

Despite the FPCB shear connector showing potential applications, most of the studies in the literature about the FPCB connector were developed from tests in an unconfined situation, resulting in conservative analytic models. In view of this, Aguiar [5] developed an experimental and numerical study with the aim of analyzing the isolated hole of the FPCB shear connector in a confined situation. This study resulted in a satisfactory analytical model, capable of representing the entire force-slip curve and predicting the strength capacity of the FPCB shear connector in a confined situation.

Although the analytical model developed by Aguiar [5] for the FPCB shear connector was validated for a wide range of geometric and material properties, this study was limited to connectors with thick sheets (thickness > 6mm). In view of this, the present paper aims to carry out a set of experiments to investigate the FPCB shear connector with thin sheets. In the end, intend to develop a numerical model from the experimental results and a parametric study with the objective to analyze the features and behavior of the FPCB shear connector with thin sheets.

2 Experimental Program

The experimental shear tests performed in this work were designed in a pull-out configuration, consisting in applying an upward tension load to a steel plate that is inserted and connected to a reinforced concrete block through a circular opening with or without a transverse bar. The concrete block stays rigidly restrained by a thick steel plate, which is anchored to a reaction slab, and the slip between the steel plate and the concrete block is monitored by displacement transducers, as shown in Fig. 4. This test configuration was based on the “plug-in” test of He *et al.* [6], which has very similar geometry but has the load applied downwardly in the steel plate, in the form of compression. The reasons for adopting the pull-out configuration in this work are: 1) to avoid instability on the thinner steel plates and 2) to prevent the result to be affected by minor misalignments and initial imperfections, which, under compression, would tend to increase and cause friction between steel plate and concrete. The aim of this work is to perform an in-depth study of circular openings with transverse bar shear connections (FPCB) with thin sheets in a confined situation.

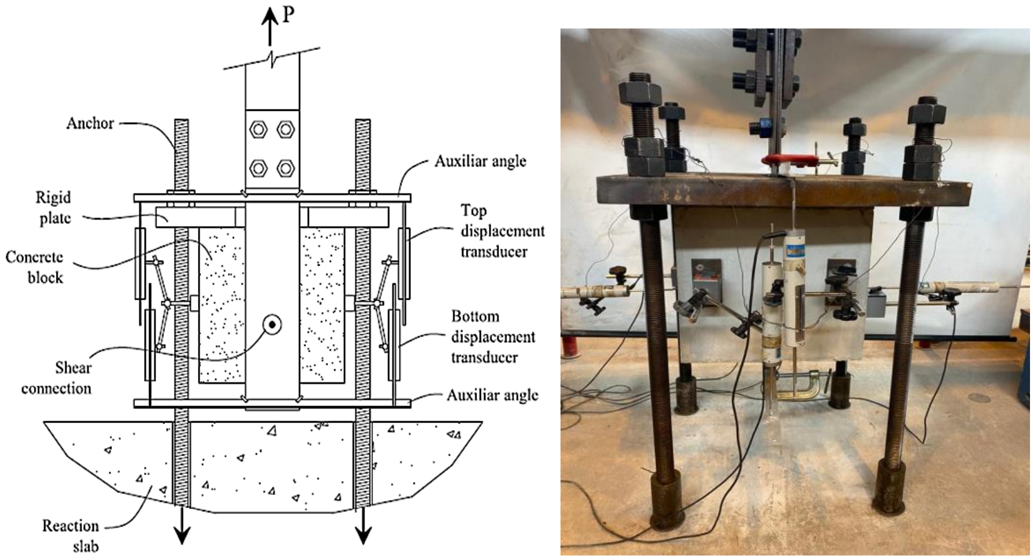

Figure 4 – Test setup

Therefore, all specimens tested in this work contained one single opening in the steel plate and had the steel plate treated with grease and after painted to eliminate the bond between steel and concrete. The reason for restricting the study to such a specific specimen configuration is to isolate and focus only on the connection’s fundamental behavior, removing secondary effects that would interfere with the result, such as group effect, the bond between steel plate and concrete, and load eccentricity, which can vary in magnitude depending on each specific structural application, and thus are not objects of investigation in this study.

The overall geometry of this work’s specimens is shown in Fig. 5.

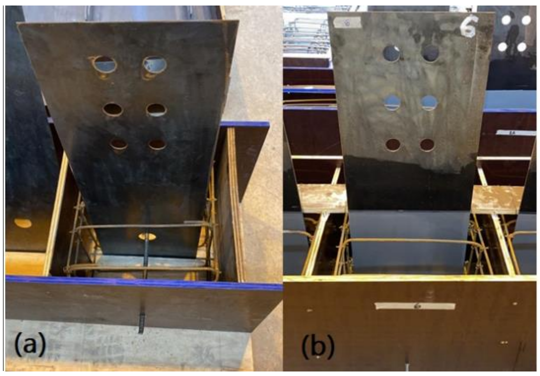

Figure 5 – (a) Model setup without grease and ink before concreting. (b)Model setup with grease and ink before concreting.

3 Numerical model

The 3D numerical model of finite elements (FEM) was developed using the ABAQUS software [7], aiming to obtain a simulation of the experimental performed tests. The models are composed of a steel sheet with a hole, transverse bar, concrete block, and rebar. (see Fig. 6).

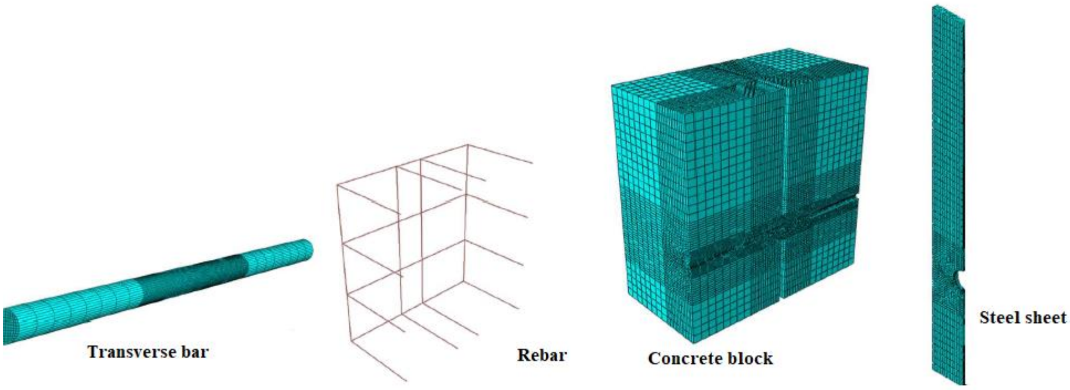

Figure 6 – Numerical model

The steel sheet, the transverse bar, and the concrete block were modeled using C3D8R solid elements and the rebar was modeled using T3D2 one-dimensional elements (see Fig. 7).

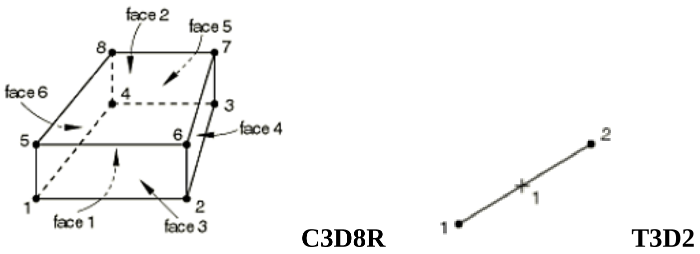

Figure 7 – Finite Elements used in the model - C3D8R e T3D2 (ABAQUS [7]).

The top of the steel sheet was connected to a reference point to which a vertical displacement of 30 mm was applied in the direction of the sheet's pullout. Contact pairs were defined between the rigid surface and the top of the concrete block, and between the steel sheet and the concrete.

A coefficient of friction of 0.1 was attributed to these contacts between steel surfaces in the tangential behavior and the normal behavior was defined as Hard. A Tie type constraint was defined between the passing bar and the concrete. An Embedded Region type constraint was defined between the rebar and the concrete.

The analysis method used was the Dynamic, Explicit method, as this made it possible to reach higher levels of deformation in relation to the Static General method, allowing to obtain the force x relative slip curve up to a higher level of slip. To ensure that the model behaved as a quasi-static problem, a load application time of 1500 s was defined and the Smooth amplitude function was applied to apply a displacement of 30 mm. To reduce the model processing time, the Mass Scaling device provided by ABAQUS [7] was used. At the end of processing, a negligible level of inertial forces was verified, as desired.

The behavior of concrete was simulated using the constitutive model Concrete Damaged Plasticity where curves were provided for the behavior in compression and for the behavior in tensile. These curves were defined from the results of the concrete characterization tests, using the formulation of the EN 1992-1-1:2004 [8] standard. The behavior of the steels in the model was defined from stress x strain curves.

In the FPCB shear connector (the concrete pin formed inside the hole, in the transverse bar, and in the steel sheet), the region of high-stress gradients, a fine mesh of finite elements was adopted, with dimensions of up to 3.0 mm. As it moved away from the hole region, was adopted mesh with the largest dimensions (from 8.0mm to 20.0mm), because these are regions that do not significantly influence the results to be analyzed.

The overall mesh feature of this work's specimens is shown in Fig. 8.

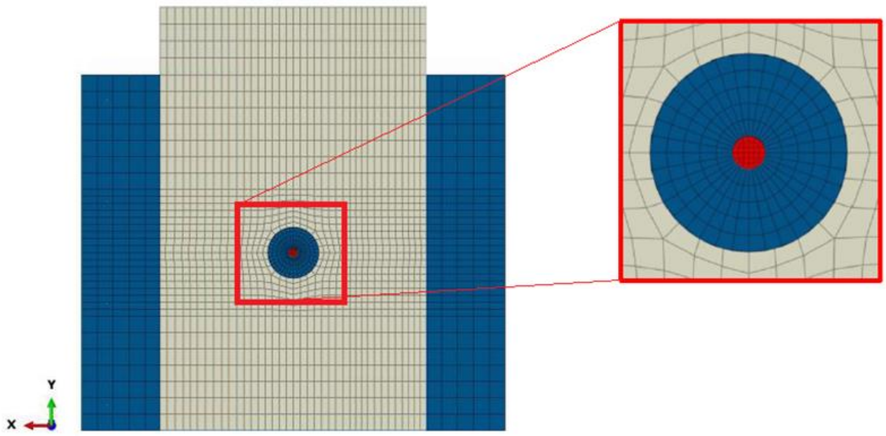

Figure 8. Finite element mesh

3.1 Comparison between the experimental results and calibrated FEM-model

In order to obtain a good approximation between the numerical and experimental results, it is being carried out a work of the calibration of the numerical models where several internal parameters of the model's constituents of the materials are being varied, seeking the most appropriate combination of values for simulation of the prototypes.

Until now, an acceptable approximation of the results of the prototypes has been achieved. Model-01(Fig.9) and Model-07 (Fig.10) using the following set of parameters for Concrete Damaged Plasticity: Dilation Angle = 30; Eccentricity = 0.1; fb0/fc0 = 1.16; K = 0.9; Viscosity Parameter = 0.00025. The overlapping numerical and experimental curves of prototypes P01 and P07 are presented in Fig. 9.The same calibration process will be extended to the other prototypes.

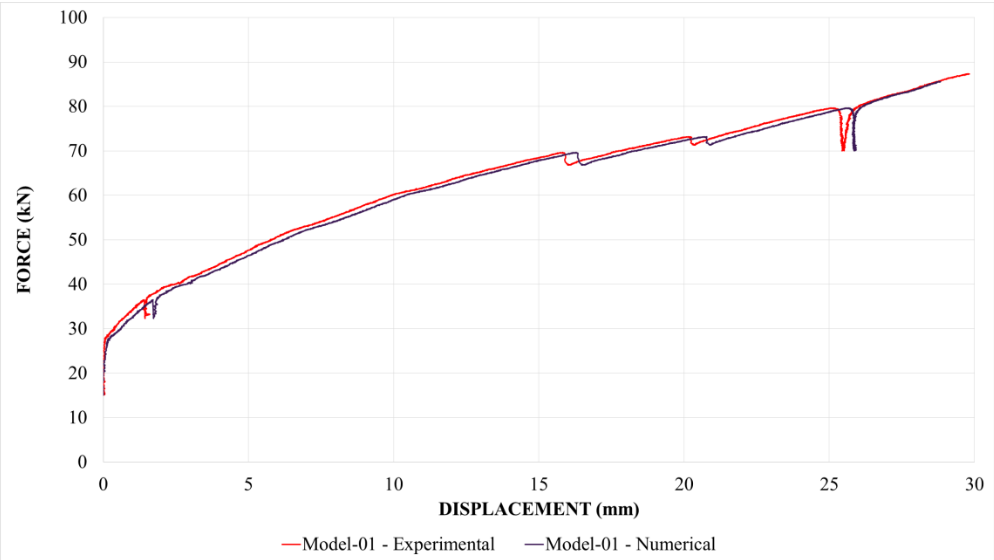

Figure 9. Model-01

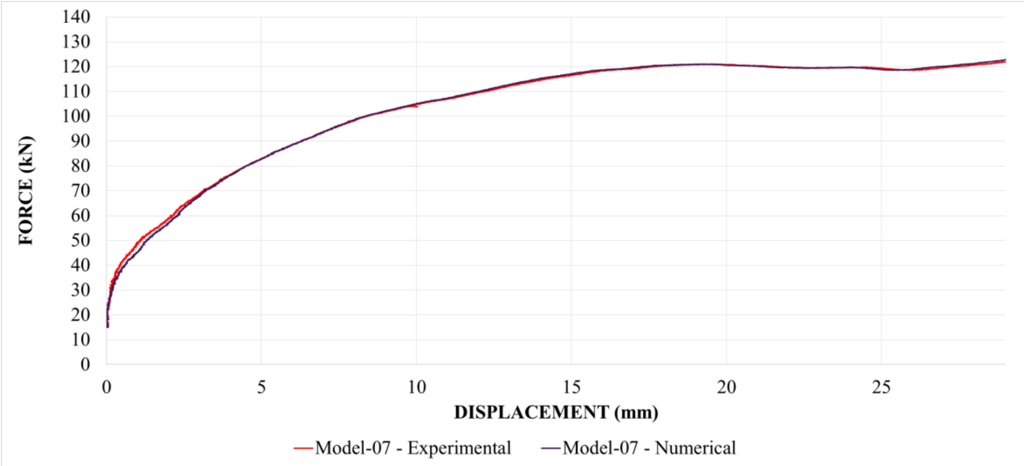

Figure 10. Model-07

3.2 Analytical parametric analysis

Having developed and validated an analytical model capable of generating whole load-slip curves for circular openings with transverse rebar shear connectors (FPCB), the model will be applied to perform a parametric analysis in which the parameters D, t, d, e0 and fc that will be varied within the model's validation limits. This work will be carried out using programming in the Python language.

4 Conclusion

This work presents the development of a numerical model to simulate the behavior of a FPCB Shear Connectors For Thin Sheets. Although analytical models for determining the axial strength of FPCB already exist, studies on the shear connectors to thin sheets are not conclusive. Fifteen experiments were carried out, expanding the datasets used for the development of the presented numerical model and demonstrating the applicability of this new solution, and two were presented in this paper.

From the experimental results, it was possible to observe that the FPCB shear connectors with thin sheets show good structural behavior. The numerical model developed in ABAQUS [7], although still in calibration, has already been able to simulate with good approximation the FPCB shear connectors with thin sheets behavior in pull-out tests. This will allow, varying some geometric parameters of the connection evaluate its resistance capacity and ductility. This parametric study will be very useful for proposing a new and more comprehensive calculation model for FPCB shear connectors with thin sheets.

Acknowledgements. This research has been supported by the Brazilian research agency CNPQ.

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