Numerical Simulation Of Pull Out Tests In Steel Checkered Plates

Orlando G. L. Almeida[1], Orlando M. L. Almeida[1], Lays R. A. Costa[2], Kildenberg K. F. Nunes[2], Hidelbrando J. F. Diógenes[2], Marília M. C. Araújo[3]

[1]MIMEE - Research Group on Building Information Modeling and Experimentation and Modeling of Structures, Federal University of Paraíba - UFPB
Campus Universitário, s/n, 58051-900, João Pessoa/PB, Brazil
orlandogabriel96@gmail.com, orlandomlalmeida@gmail.com
[2]PPGECAM, Federal University of Paraíba - UFPB
Campus Universitário, 58.051-900, João Pessoa/PB, Brazil
laysraianne@ct.ufpb.br, kildenberg@hotmail.com, hidelbrando@ct.ufpb.br
[3]Civil Engineering Academic Unit, Federal University of Campina Grande - UFCG
Rua Aprígio Veloso, 882, Universitário, 58428-830, Campina Grande/PB, Brazil
marilia.marcy@ufcg.edu.br

Abstract. Steel-concrete solidary behaviour in composite structures can be obtained through shear connectors. Most of the used connectors do not allow a uniform shear stress distribution between these materials, contributing to the stress concentration and the development of cracks, which can decrease the systems' durability. Connections by adherence (CA) appear as an alternative. In this type of connection, the steel-concrete interaction is achieved through a linear connector, which consists of a steel plate with checkered grooves, that favors the transfer of stress through the friction between the interfaces that will be in contact. In this way, the connection' performance is influenced by interfaces' behavior and steel-concrete interaction. In the case of CA, the resistance to pull a steel plate from a concrete element can be investigated employing Pull Out tests, in a similar way to that developed with bars. Therefore, this paper aimed to model Pull Out tests of steel plates, using ABAQUS®, which were calibrated from literature's experimental results. A parametric study was developed to investigate the influence of the steel-concrete contact area and the interface's stiffness in the adherence of the plates. The results showed that rougher interfaces, with greater stiffness and greater steel-concrete contact area, developed better results.

Keywords: Pull Out, Numerical Simulation, Connections by Adherence, Interface Steel-Concrete, ABAQUS.

1 Introduction

With advances in technology and the need to optimize space occupation, buildings have become increasingly taller, and their structure, therefore, more demanded. Nowadays, the use of steel and concrete as raw materials for structural systems is a reality, and their combination with the use of composite structures becomes more and more common. This type of structure has in its conception the use of the best characteristics of steel and concrete. But it does not have such an abundance of norms and experiments in its vast chain of parameters and variables.

One of the commonly used composite structure models is the steel-concrete composite beam, which, according to Yang et *al*. [1], consists of a steel beam connected by shear connectors to a prefabricated concrete slab.

According to Diógenes, El Debs and Valente [2], from structural support, the connectors are the most relevant components in composite structures, having a great influence on the final behavior of the structure, that is, on its final performance, so their study is essential to optimize the constructive processes safely and coherently.

One possibility to steel-concrete solidarity is the connections by adherence, which, according to Diógenes, El Debs and Valente [2], the solidarization of steel and concrete is through the friction between the connector, coupled to the steel part, and the concrete slab, distributing the efforts continuously along the element.

This type of connection, from a practical point of view, is simpler to perform on-site, because the connector consists of a ribbed, checkered or embossed steel plate, welded on the top of the steel beam, instead of using several shear stud connections. This last solution is commonly applied to composite structures. Besides not to favorize construction rationalization, stud-type connectors lead to crack formation, because shear stress is not continuously distributed in the connection.

Authors such as Veríssimo et *al*. [3], Vianna et *al.* [4] and Leonhardt et *al*. [5] have already studied some linear connections, but Diógenes et *al.* [6] point out that, even today, the connections between steel beams and prefabricated slabs are not fully adapted, which highlights the importance of deepening the study in this area. So, Connection by adherence can represent an alternative to this problem. Several authors, such as Diógenes, El Debs and Valente [2], Papastergious [7] and Thomann [8], have contributed to a better understanding of the Connections by adherence in the last decades, leveraging their study worldwide and being fundamental to the elaboration of this work.

In the Connection by adherence, as shear strength is due to the friction between the interfaces that will be in contact, Diógenes [2], Papastergiou and Lebet [9], and Thomann [8] mentioned that the connection behavior is strongly dependent to interfaces behavior.

Regarding the interface's performance, one parameter that should be analyzed is the resistance to pull a steel plate from a concrete block in order to evaluate the adherence (the resistance to sliding) between these materials. This parameter can be investigated employing Pull Out tests, in a similar way to that developed with bars.

Thus, based on the experimental research performed by Thomann [8], some Numerical analysis of Pull out tests for embossed-checkered steel plates embedded in a prismatic cementitious matrix were performed using ABAQUS® computer tool, based on the finite element method (FEM). The studied models were calibrated using parameters obtained from Thomann [8] experimental results.

After Numerical model validation, some parametric analysis were developed to evaluate the influence of the steel-concrete contact area on the model's behavior, as well as to verify the performance of the model by varying the stiffness of the interface between the two materials.

2 Methodology

The following methodological procedures were performed: Pull Out test Schema and Model Construction.

2.1 Pull Out Test Schema

As previously mentioned, the study consisted of the numerical analysis through the Finite Element Method (FEM) of connections by adherence between steel and concrete, submitted to the Pull Out test. In this test, which is similar to that performed with bar, an upward load that increases continually is applied to a steel plate that is partially embedded in a hardened concrete matrix. The test ends when the load necessary for the connection collapse is achieved (loss of adherence in the steel-concrete interface).

The model proposed and tested experimentally by Thomann [8], as well as the systematic of the Pull Out test, can be observed in Fig. 1a, and Fig. 1b:

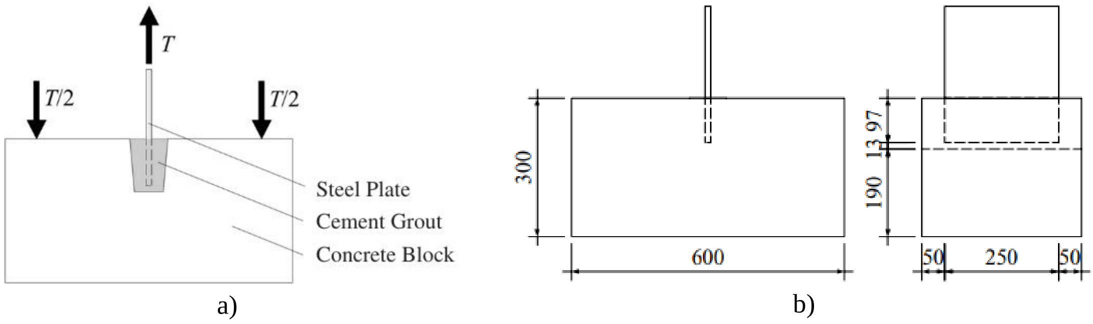

Figure 1. a) Pull Out tests Schema (Adapted from Thomann [8]); b) Specimens geometry and dimensions (mm)

2.2 Model construction

The specimens' geometry was based on Thomann [8]. This geometry was constructed in ABAQUS® using the extrusion technique for both the steel plate and the concrete block. For the Finite element choice, it was considered that elements with regular and symmetric shapes, such as square prisms of close dimensions, make the calculation process and interpolations of the model more coherent and less prone to large errors. So, the C3D8R element was used, an 8-node linear brick, ideal for stress and strain analysis.

Related to the boundary conditions, the concrete block had all of rotations and displacements restrained in all directions, and in the steel plate was applied a unitary upward load, increasing continuously to simulate the experimental test conditions.

Mesh size of 100 millimeters was considered to the concrete block, and 60 millimeters was considered to the steel plate. Some previous computational simulation was performed to define the mesh size, and bigger mesh element size presented poor results, while smaller, demanded much more simulation time. Figure 2a illustrates the numerical model's geometry, while Fig. 2b shows the finite element mesh obtained.

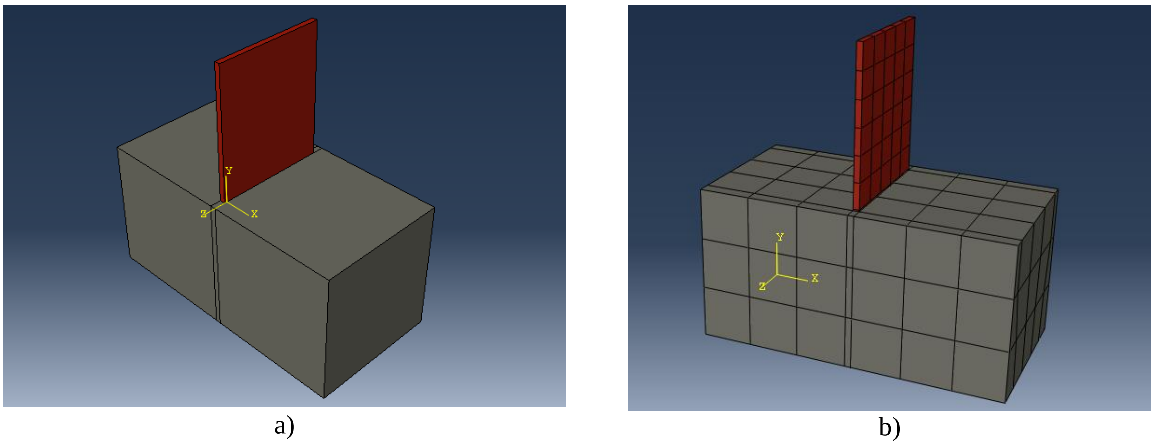

Figure 2. a) Numerical model's geometry; b) Mesh dimension

In order to define the interface's properties, the concept of cohesive interaction between the steel and concrete surfaces that are in contact was used, being necessary to incorporate stiffness values in the steel-concrete interface. For this, the parameters brought by Thomann [8] were used, as well as standard values for the characteristics of steel and concrete. The interface properties, as well as the materials in question, are listed in Tab. 1:

Table 1. Material parameters and interface (Adapted from Thomann [8]).

Steel	
Density (kg/m³)	7850
Elastic Modulus (GPa)	210
Concrete	
Density (kg/m³)	2400
Elastic Modulus (GPa)	30
Interface	
Knn (N/mm³)	81
Kss (N/mm³)	9
Ktt (N/mm³)	1.8

During the numerical simulation, step sizes of 0.1 mm were considered to a number maximum of 1000 increments, and the "Full Newton" technique was applied to the solution. Concerning the convergence strategy, "severe discontinuity iterations" was considered.

3 Results

3.1 Model calibration

In order to validate the model in ABAQUS®, the results that were obtained during this simulation were compared to those obtained by Thomann [8]. The comparison between the Maximum load – Displacement relation obtained numerically and experimentally is illustrated in Fig. 3a, and Fig. 3b, respectively:

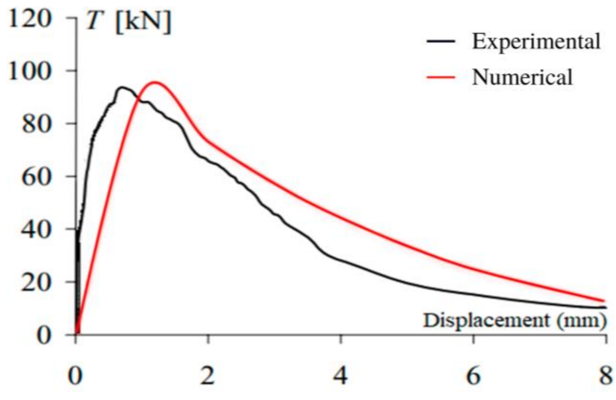

Figure 3. Numerical and experimental results (Adapted from Thomann [8]).

Fig. 4a, and Fig. 4b presents a comparison between the specimens' appearance obtained numerically and experimentally after rupture.

a) b)

Figure 4. Rupture surface. a) Numerical Model, b) Experimental Specimen (Adapted from Thomann [8]).

It was observed that by using the parameters brought by the author, the maximum load-displacement relation obtained numerically was similar to that obtained experimentally. In addition, in the numerical simulation, it was observed a shear stress concentration in the steel-concrete surface contact, in the rupture region observed experimentally, evidencing that the numerical model was coherent and valid for the parametric analysis process.

3.2 Parametric Analysis

The development of the parametric analysis took place through the variation of two parameters related to the steel-concrete bond: steel plate area (variation in length) and tangential stiffness at the interface.

In the process of variation in the plate's area, lengths of 100mm (21728 mm²), 125mm (26578 mm²), 150mm (31428 mm²), 175mm (36278 mm²), 200mm (41128 mm²), 225mm (45978 mm²), 250mm (50828 mm²) and 275mm (55678 mm²) were considered, while tangential interfaces' stiffness with the values of 0.5 N/mm³, 1.0 N/mm³, 1.5 N/mm³, 2.0 N/mm³, 2.5 N/mm³, 3.0 N/mm³, and 3.5 N/mm³ were considered. For both parametric studies, the maximum load value was verified until the connection rupture.

- **Contact Area Parameter**

By varying the length values of the steel plates, the area of the steel plate was varied, and it was possible to obtain the maximum load of the connection by adherence to various values of steel – concrete contact area. Fig. 5 illustrates the Maximum load – Contact area relation.

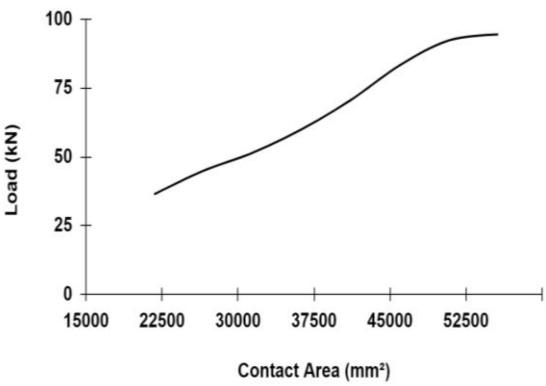

Figure 5. Maximum load – Contact area relation.

From Fig.5 it can be seen that for greater steel-concrete contact area, a greater load is necessary to separate the materials. And the same behavior is also observed by Souza, Tavares, and Fernandes [10] during Pull Out Tests with bars.

It was shown that the maximum load is almost linearly proportional to the contact area increasing. At the point 31428 mm² the graph presented a smooth inflection, with a small increase in the growth load rate, and at the point close to 50828 mm², a small decrease of the growth load rate was shown. That shows that by considerably decreasing in the contact area, the load value falls more quickly, while significant increases in the contact area would not necessarily mean important resistance gains.

Regarding the design of the composite beam, this can represent that taller shear connector, and so, the greater steel-concrete contact area can favorize a best structural performance of the beam, but some previous analysis, regarding all the structural parameters, must be considered.

- **Tangential Stiffness**

By varying the tangential stiffness on the steel-concrete interface, it was possible to obtain the maximum load of the connection by adherence to various values of rigidity between the steel and concrete.

Fig. 6 illustrates the variation of the maximum load to the interface's stiffness, showing that, as expected, with the increase of the stiffness of the region between the materials, the higher the load necessary to separate the objects.

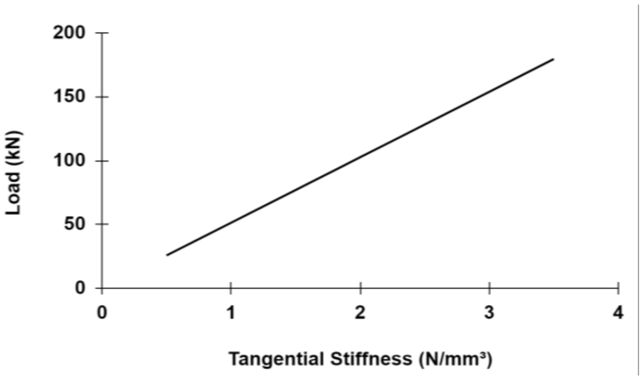

Figure 6. Maximum load for interface stiffness variation.

It was observed that the maximum rupture load varies linearly with the increase of the interfaces' stiffness. This can be understood by the fact that the interaction model used was based on the rupture when reaching a certain displacement between the materials, so the tangential stiffness is relevant only in the elastic-linear phase of the process, being coherent, for the adopted system, to return a linear relationship.

4 Conclusions

From Numerical analysis, it was found that a greater maximum load can be obtained by increasing the steel-concrete contact area and the stiffness of the interface.

It was possible to notice that the contact area between the steel plate and the concrete block exerts an interesting influence on the final load results, with behavior variations when increasing and decreasing the contact region.

Besides, it was noticed that the stiffness of the interface must be carefully determined to reach a certain result, due to its relevance in the resistive loads of the connection, that is, using materials and techniques that increase the stiffness of the interface is an interesting strategy in terms of reaching high levels of resistance.

From the results, some design parameters could be considered, such as the hight of the shear connectors in the composite beams: taller connector seems to improve the structural behavior of the beams.

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