A PARAMETRIC ANALISYS OF COMPOSITE BEAMS WITH T-PERFOBOND SHEAR CONNECTORS

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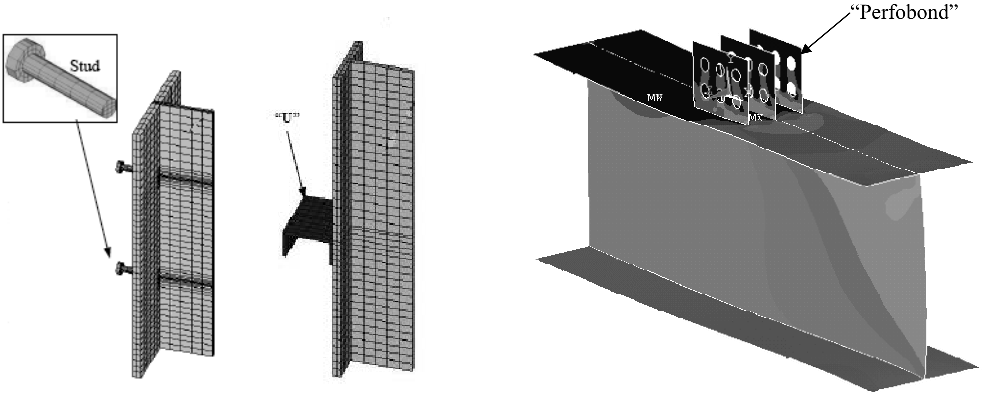
***Abstract**. This paper presents the design and push-out test results of T-Perfobond connectors. The shear connectors were made with two different geometries by varying the connector flange thickness. The T-Perfobond connectors presented two web holes and were immersed into 120mm thick concrete slabs. Reinforcing steel bars were used inside the web holes to increase its structural performance. A numerical study was also made to aid the shear connector design aiming to increase its associated deformation capacity. The results indicate that the developed T-Perfobond connector possessed an appropriate structural behaviour and was also able to achieve the Eurocode 4* [1] *ductility requirements.*

1 INTRODUCTION

Composite beam investigations are not new and continues to motivate the search for new technologies that meet not only improvements in the structural point of view, but also meet economic needs in composite construction. Several authors have presented numerical and experimental works in this line of research, specifically around the development of new alternative shear connectors. Various existing types can be cited like the widely used stud bolts, C profiles and Perfobond, Figure 1, Vianna et al. [2].

Ferreira [3] developed the T- Perfobond rib connector for use in beam to column connections of external columns, Figure 2. Its main function was to transmit the reinforcing bar tensile forces to the columns flanges in composite semi-rigid joints present in hogging moment regions.

This work presents alternative geometries for the T-Perfobond connector to be used in composite beams under positive moments. It is widely known that the Perfobond connector geometry is made of a rectangular steel plate with holes welded to the steel beam to be later immersed to the concrete slab. Alternatively the T-Perfobond connector is made from an I profile section, incorporating to the original Perfobond connector the contribution of an additional flange, that can provide additional anchor capacity, [4]. Perfobond connectors may be even more efficient with the use of additional reinforcing steel bars inside the connector holes. The Perfobond was developed by Leonhard and was investigated by various authors like: Machacek e Studnika [5], Valente e Cruz [6], Vellasco et al. [7], Ahn et al. [8], Martins [9], Vianna et al. [2] focusing on their structural capacity determined by push-out tests. Various geometrical and material parameters can influence the structural behaviour of the connector like: concrete compressive strength, number of holes, plate geometry, among others.



(a) Studs [10] (b) C profiles [10] (c) Perfobond [11]

Figure 1: Examples of shear connectors.

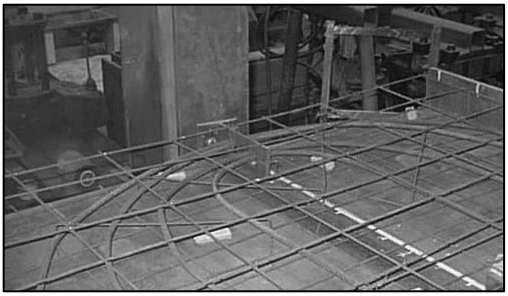


Figure 2: *T-Perfobond rib* connector by Ferreira [3]

This paper presents the results of tests carried out in two experimental programs to evaluate the performance of the T- Perfobond connector. The results of a numerical modelling of the flange connector is also presented aiming to determine the best configuration to increase the shear connector ductility. The first experimental program was held at the Department of Civil Engineering, University of Coimbra while the second was held at the Pontifical Catholic University of Rio de Janeiro. In the first program, the T- Perfobond connector was made from IPN 340 profiles, Figure 3a, made of S275 steel grade, Vianna et al. [12], (web thickness equal to 12.2 mm and average flange thickness equal to 18.3 mm). This particular connector presented a rigid block like behaviour during the performed push-out tests. In order improve the connector ductility, a new geometry was investigated reducing the flange thickness to 11.3mm while keeping the original web thickness to enable a comparison with the first set of tests. The present paper also presents and numerical investigation of the deformation capacity of the connector flange that was accomplished before the second experimental programme.

The new T- Perfobond connector geometry adopted in the second experimental programme is presented in Figure 3b and Figure 4. The connector was made from a HP200x53 profile equivalent to American Profile HP8x36, using a ASTM A572 Grade 50, equivalent to a S355 steel grade.

a) IPN 340 – University of Coimbra tests b) HP 200x53 – PUC-Rio tests

Figure 3: Adopted *T-Perfobond* connectors.

The T-Perfobond connectors were used in 120mm thick concrete slabs designed to reach a class C30/37 compressive strength.

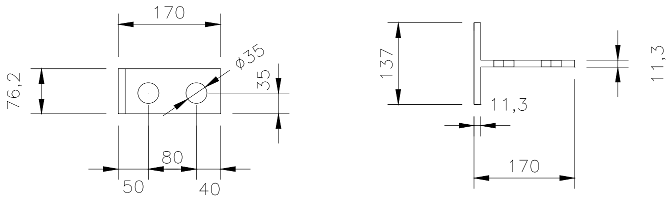


Figure 4: Geometry of *T-Perfobond* connectors the second stage

2 NUMERICAL MODELING

The proposed numerical models were developed using Shell 63 elements, available in the ANSYS program library, to represent the T- Perfobond connector flange. This is a plane finite element with four nodes and six degrees of freedom per node, three translations and three rotations, Figure 5, being capable to take into account the material nonlinearity.

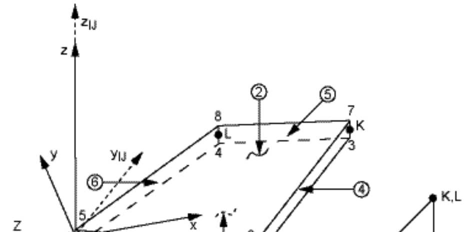


Figure 5: Elemento Shell 63, Manual do Ansys

In order to verify the deformation capacity of the connector flange a simplified model layout taking into account the symmetry conditions was adopted. The nodes corresponding to the supports, representing the part of the connector welded to the beam flange, and the nodes along the symmetry line of the flange, had all their degrees of freedom restricted. The load was applied by means of a pressure (around 48.85 MPa) applied at the entire flange area to simulate the push-out test transfers of forces that occurs from the concrete slab to the shear connector flange, Vianna [13]. The modelling layout is depicted in Figure 6 where its highlighted region is shown in detail in Figure 7 were the flange adopted mesh is illustrated. A linear elastic analysis was performed assuming an isotropic behaviour with a 205GPa Youngs Modulus and a 0.3 Poisson's ratio.

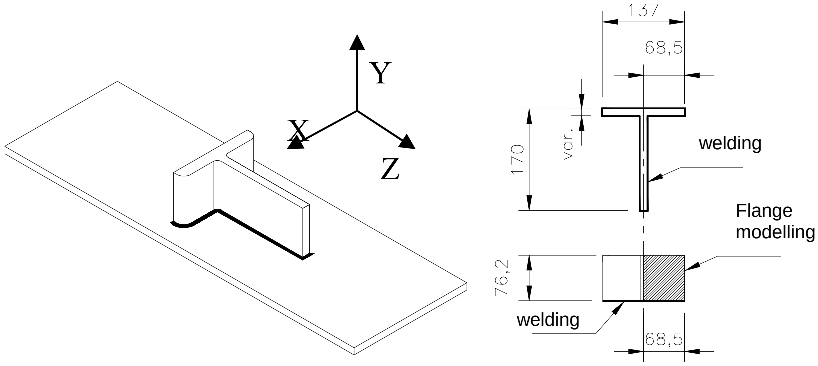


Figure 6: T-Perfobond connector

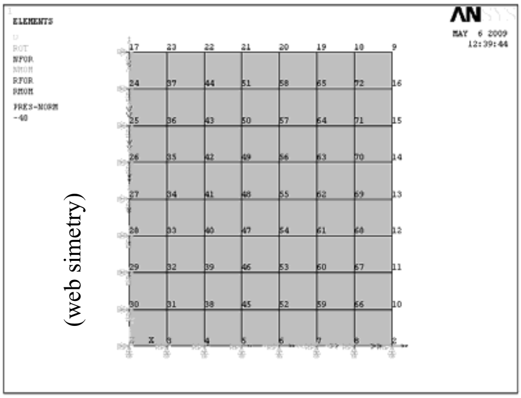
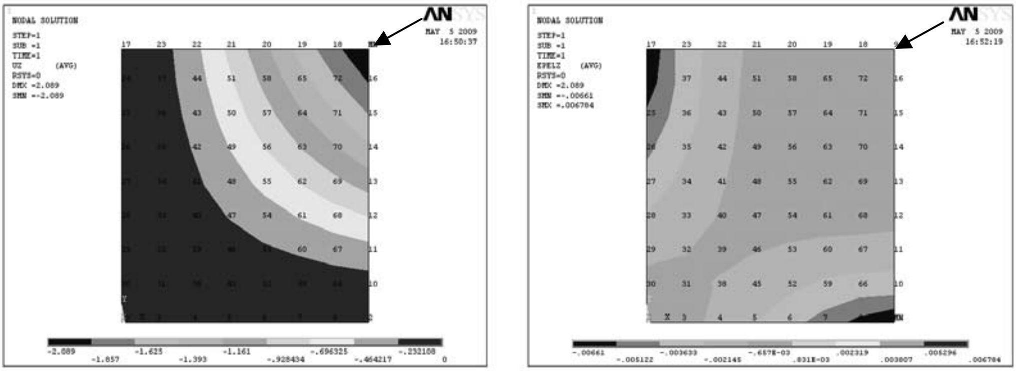


Figure 7: Connector flange model: mesh and boundary conditions.

Table 1 presents the results of the elastic deformation capacity and associated displacements related to node 9, shown in Figure 8, determined in the present investigation. The 18.3 mm thickness is associated to the flange adopted in the T-Perfobond connectors used in the first push-out tests. The thickness of 12mm was chosen as an initial try to increase almost 3 times the 18.3 thick connector deformation capacity. The 11.3 mm flange thickness corresponds to the flange and web thickness of the HP200x53 profile adopted in the second set of push-out tests. Figure 8 graphically presents deformation and displacement distribution along the 11.3 mm thick flange.

Table 1: Numerical modelling results

Thickness of plate (mm)	Z Axis Displacement (mm)	Z Axis Elastic deformation (με)
18.3	0.49	203
12.0	1.74	574
11.3	2.09	657



(a) Z- Axis displacement distribution (mm) (b) Z- Axis deformations distribution (με)

Figure 8: HP200x53 connector results (11.3mm thick).

This simple model of T-Perfobond connector flanges indicated that if a reduction of the flange connector thickness from 18.3 mm to 12mm was made a significant gain was achieved in the shear connector deformation capacity. This was the main direction for choosing the HP200x53profile, that presents a 11.3 mm flange and web thickness in the second set of Push-out tests.

3 PUSH-OUT EXPERIMENTAL PROGRAM

The performed push-out tests followed the Eurocode 4 [1] procedures. These tests can used to obtain the relationship between applied forces and associated deformations of the shear connectors being more simpler and direct than traditional flexion tests, Vianna et al. [4].

The second experimental program was divided into two parts with two tests in the first set, followed by three more tests on second. All connectors were made with a height and length of 76.2 mm and 170mm presenting two web holes, as shown in Figure 4. Table 2 presents the test results where it is easy to observe that 10 mm, 12mm, and 16mm S500 reinforcing steel bars were adopted in experiments.

Vertical and horizontal displacement transducers were installed in the two slabs to measure the relative slip between the concrete slab and steel profile as well as the uplift. In the first stage, held at the University of Coimbra, the tests were conducted in a 5000kN hydraulic jack system. In the second stage, held at PUC-Rio, the test system comprised the use of a reaction steel frame with two 1000kN hydraulic jacks. The adopted layout also comprised the use of a transition beam to transfer the loads from the two jacks to a single application point located at the steel beam push-out test configuration. thus meeting the EUROCODE 4 [1], recommendations' Vianna et al. [4]. A hinge was also used to ensure a smooth load transfer between the transition beam and the push-out test steel. The Figure 9 presents the push-out test configuration and details of reinforcement bars adopted.

Since the results of each series had different compressive strength of concrete, the value of force per connector was normalized by using Eq 1, proposed by Oguejiofor & Hosain [14].

$$P_{rkNormaliz} = P_{rk} \cdot \sqrt{\frac{f_{ckmean}}{f_{ck}}} \tag{1}$$

where:

$P_{rkNormaliz}$ connector characteristic shear capacity (kN).

f_{ckmean} mean concrete cylinder compressive strength (MPa).

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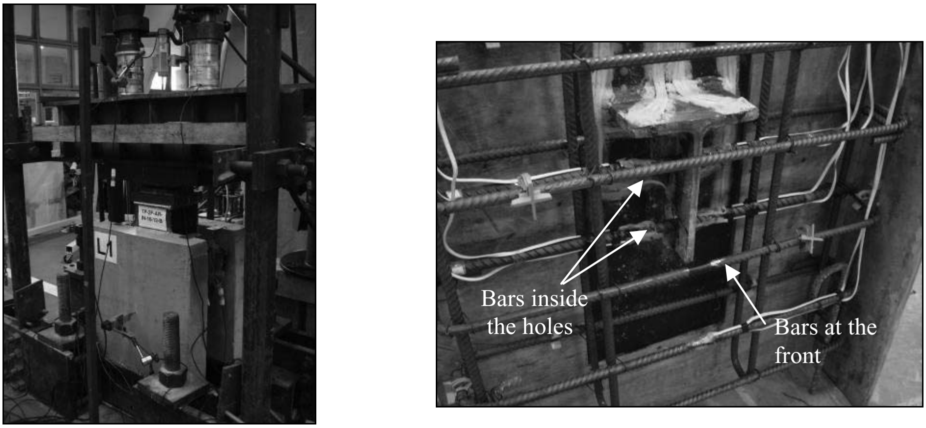

(a) Push-out test at PUC-Rio (b) Reinforcing bars at the front and inside the connector holes

Figure 9: Push-out test at PUC-Rio and reinforcing steel bars

The graph illustrated in Figure 10 shows the first and second set of test results made to evaluate the structural performance of the more flexible shear connector adopted at the second experimental programme. From these curves it it is possible to observe that the HP 200x53 T- Perfobond connectors had a better ability to deform being therefore, more ductile connectors. The connector with the best load capacity was made from a HP 200x53 profile with 12mm and 16mm reinforcing bars at the front and inside the connector holes, ie. TP-2F-AR-120-A-IN-12-16. If a comparison with the TP-2F-AR-120-IN-A-10 connector results , used in the first set, is made a gain of 13% and 137% in the load carrying and deformation capacities can be observed. The first experimental programme shear connectors that were manufactured from the IPN 340 profile had higher load carrying capacities when compared to the two second set of tests of the second experimental programme but on the other hand showed a limited ductility capacity. Table 2 summarises the Push-out tests characteristics and results:

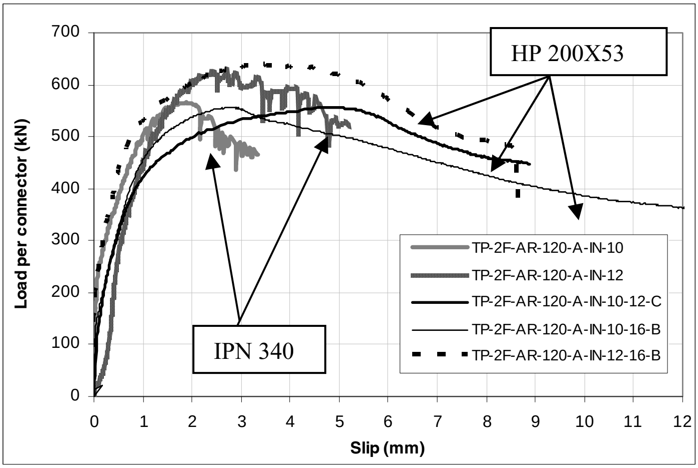

Figure 10: Comparison of T-Perfobond shear connectors made with IPN 340 and HP 200x53 profiles.

Table 2: Push-out tests characteristics and results.

	Specimen	Slab	T-Perfobond		Results				
		f_{ck}	ϕ Hole	ϕ Front	$q_{u,test}$	P_{rk}	P_{rkNorm}	δ_u	δ_{uk}
		MPa	(mm)	(mm)	kN	kN	kN	mm	mm
First	TP-2F-AR-120-A-IN-10	33	10	10	585.30	526.77	509.22	2.54	2.29
set	TP-2F-AR-120-B-IN-12		12.5	12.5	649.10	584.19	564.72	4.19	3.77
Second	TP-2F-AR-IN-10-12-C	35.15	12.5	10	594.62	535.16	501.26	6.75	6.08
set	TP-2F-AR-IN-10-16-B	29.18	16	10	541.97	487.77	501.44	5.15	4.64
	TP-2F-AR-IN-12-16-B	26.02	16	12.5	585.86	527.27	574.01	6.03	5.43

where:

Reinf. Hole	reinforcing bars diameter used inside the connector holes
Reinf. Front	reinforcing bars diameter used at the front of the connector
$q_{u,test}$	shear connector test strength
P_{rk}	shear connector characteristic strength
δ_u	test ductility capacity
δ_{uk}	ductility characteristic capacity

4 CONCLUSIONS

The push-out test indicated that varying the reinforcing bar diameter from 10 to 12.5 mm a significant gain in both load carrying and ductility capacities were obtained. The tests also indicated that only increasing the reinforcing bars diameter used inside the shear connector no significant gain in load carrying or ductility capacities was observed, contrary to what was initially expected. The test that used the 12mm diameter reinforcing bars used inside the connector holes presented a 31% ductility capacity increase when compared to the test with 16mm bars at the same location. At this point it is fair to observe that this result may have been masked due to lack of an effective load application control since this was manually made.

Only increasing the reinforcing bars diameter used at the front of the shear connector from 10 mm to 12.5 mm, gains of 14.5% and 17% were observed in the load carrying and deformation capacities. When both diameters were increased (10mm to 12.5 mm, for bars used at the connector front and inside its holes) a 14.8% increase and a 10.7% reduction were observed in the load carrying and deformation capacities. This result can also be explained by the manual load control previously explained. The test results indicated that reinforcing bars used at the connector front and holes had the same key influence over the connector load carrying and deformation capacities.

The second set of tests made with the 11.3 mm thick profile were able to meet the minimum slip limit of 6 mm required by Eurocode 4[1], which ensures the ductile connection behaviour. This type of behaviour could be confirmed with the aid of the simple numerical model results.

The investigation also confirmed that T-Perfobond connectors have high load carrying and stiffness capacities. Since this shear connector can be fabricated by readily available rolled profiles leftovers a significant economy can be achieved when compared to other commoly adopted shear connectors like the studs. The T-Perfobond connectors produced in Portugal, from the IPN340 profile did not present a ductile behaviour in 120mm thick slabs, indicating the adoption of an elastic distribution of shear along the beam length for composite beam design. Alternatively the T-Perfobond connectors, produced in Brazil, from a HP200x53profile, with proper reinforcing bars in 120mm thick slabs showed aductile behaviour, thus allowing a plastic design approach to be performed.

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