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*Full Length Research Paper*

# Investigation of channel shear connectors for composite concrete and steel T-beam

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**This paper evaluates the behavior of channel shear connectors, embedded in a concrete slab, with different concrete materials. The results of a series of limited push-out specimens were presented and discussed. The push-out tests comprise of channel shear connectors in different types of concrete. Reinforcement was included in some specimens, as well. The results showed that using reinforcements in concrete slab, enhances the ductility and shear capacity of the composite system and using channels embedded in unconfined normal concrete, has a brittle performance. The channel shear capacity is less in the lightweight aggregate concrete, compared to the normal ones. Adequate ductility was reported for the channel shear connectors in most of the concrete types. In addition, it was verified that the channel connector presents a very rigid behavior, during the primary phase of loading. Using channel connectors with longer length can increase the ductility of the system. In general, the channel shear connector showed a ductile behavior. The results verified using channel shear connectors, embedded in tested concrete, in composite structures. The results also discussed the effect of different concrete types, on the ductility and load–displacement performance of the specimens.**

**Key words:** Shear connector, push-out test, load-slip curve, composite.

## INTRODUCTION

Composite steel-concrete beams, especially formulti-storey frames and bridges, have achieved a high global market (Dogan and Roberts, 2010a, b). This is mostly due to savings in steel weight, reduction in construction depth, thus providing an important economy through reduced material and faster construction. Shear connectors are used in composite beams, to provide the composite action (Ahn et al., 2008; Viest et al., 1952). Channel shear connectors nowadays are used extensively in composite beams and bridges (Shariati et al., 2011, 2011, 2010, 2010, 2011). Push-out test is a common test, which is used to evaluate the load-slip curve of the shear connectors, and the capacity of the shear connectors is determined (Maleki and Bagheri, 2008; Maleki and Mahoutian, 2009). The main objective of the research is establishing the modes of failure and ultimate strength of the channel shear connectors, fixed in different types of materials, to check the availability of using them in steel-concrete composite beams.

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## PUSH-OUT-TEST

Figure 1 shows the typical schematic view of push-out specimens. The channel shear connectors were welded to the steel beam flanges and two concrete slabs were connected. The channel flanges were welded on all four sides. One channel had been provided, in each slab.

The channel sections have different heights and lengths. In the steel bars' reinforced specimens, in each slab there were four hoops steel bars, with 10 mm diameter, in the two perpendicular directions. The slabs of all the push-out specimens were cast horizontally. For the concrete mix design, air-dry condition aggregates were used, in all mixes. Fine aggregate was graded silica sands and a maximum nominal size of 4.75 mm, and coarse aggregate was crushed granite, with maximum nominal size of 10 mm. The cement used in all mixes was Ordinary Portland Cement (OPC). To attain acceptable workability, super plasticizer (SP) was used in both mixes. The mix properties of concrete materials are

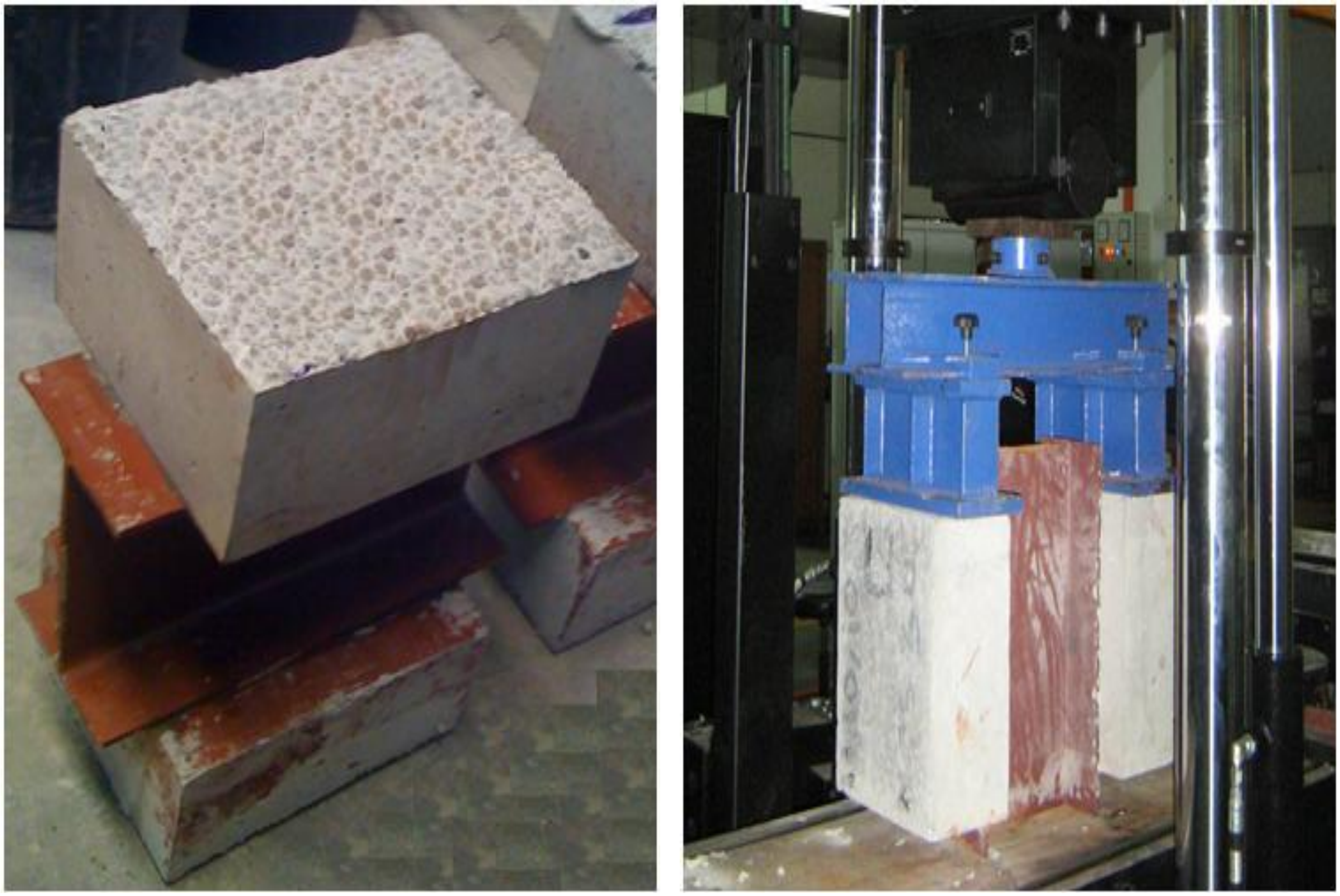

**Figure 1.** Typical push-out specimen.

presented in Table 1. All of the push-out specimens were cast in a horizontal position, similar to the site situations. A reliable quality of concrete for both sides of specimen slabs was assumed, as well. All specimens were cured in water, for 28 days, before testing. Use of a universal testing machine, specimens' loading was applied as shown in Figure 1. Displacement control was applied, throughout the universal testing machine, after laying concrete slabs on support of the machine. However, the ultimate capacities for all specimens were naïf, in the constant tests. A steadily increasing displacement was applied, until complete failure. The relative displacement between the steel beam and the concrete slabs versus applied load was recorded for each test. In the symbolization of the specimens, the first letter indicates the type of the concrete, referring to its series, the first two digits indicate the height and the last two digits indicate the length of the channel shear connector, in the concrete slabs.

## RESULTS AND DISCUSSION

The failure modes observed in all the push-out specimens can be broadly classified into two types. The first type of failure is the channel fracture. In this failure mechanism, generally, the channel webs were yielded and then there was a fracture close to the bottom flange fillet. The second type of failure is crushing-splitting of the concrete. In this failure mode, concrete crushing was occurred, followed by cracking and splitting of the concrete slab. The failure mode for all specimens is described in Table 2. Using the applied load per channel versus relative displacement between the steel beam and the concrete slabs, the peak load assigned as shear capacity of connector, under monotonic loading. These results are summarized in Table 2, as well. It is seen that the ductility of the reinforced specimens, with steel bars, were further increased. It can be concluded that in all reinforced specimens, there is an enhancement in displacement, according to the peak load. In other specimens, no obvious yield plateau is obtained. Figure 2 shows a typical view of these types of fracture failure, for channel connectors.

### Conclusions

In this paper, several channel shear connectors, fixed in different types of concrete slabs, were tested and push-out test results are presented. The failure modes observed in all the push-out specimens and shear capacity of the channel shear connector were reported.

**Table 1.** Mix proportions of concrete materials by weight.

| Concrete type | Cement (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Silica fume (kg/m$^3$) | Leca (kg/m$^3$) | Lime stone (kg/m$^3$) | SP (%) | W/C |
|---|---|---|---|---|---|---|---|---|
| HA | 460 | 910 | 825 | 40 | - | - | 0.5 | 0.37 |
| HB | 360 | 940 | 870 | - | - | - | 1.0 | 0.50 |
| LWA | 400 | 180 | 1100 | - | 147 | - | 0.5 | 0.37 |
| LWB | 400 | 180 | 1100 | - | 147 | - | 0.5 | 0.37 |
| NA | 400 | 700 | 1100 | - | - | - | 1.0 | 0.38 |
| NB | 400 | 700 | 1100 | - | - | - | 1.0 | 0.38 |
| ND | 460 | 910 | 825 | 40 | - | - | 0.5 | 0.37 |

**Table 2.** Failure load capacity and maximum slip and failure modes.

| Specimen | Failure load (kN) | Maximum slip (mm) | Failure mode |
|---|---|---|---|
| HA10050 | 197.7 | 9.0 | Connector |
| HA7550 | 196.1 | 8.0 | Connector |
| HB10030 | 115.5 | 6.5 | Connector |
| HB7530 | 111.1 | 4.0 | Connector |
| LWA10050 | 103.1 | 3.0 | Concrete |
| LWB10030 | 78.3 | 2.5 | Concrete |
| NA10050 | 128.3 | 6.0 | Concrete |
| NB10050 | 131.5 | 3.5 | Concrete |
| NB10030N | 92.7 | 5.0 | Concrete |
| ND10050 | 152.5 | 6.5 | Connector |
| ND7550 | 139.7 | 5.5 | Connector |
| ND10030 | 112.3 | 5.0 | Connector |
| ND7530 | 109.5 | 3.5 | Connector |

The results show that using reinforcements in concrete slabs enhances the ductility and shear capacity of the composite system. It means that, by using transverse steel in the concrete blocks of specimen, the shear capacity and ductility of the composite system are increased. The channel shear capacity is less in lightweight aggregate concrete compared to the normal ones. The composite system has a brittle behaviour, when channel shear connectors are embedded in unconfined normal concrete. The capacity of channel shear connectors in high strength concrete, showed adequate ductility. Specimens with higher channel connectors are more flexible and carried a slightly higher load, compared to specimens of a lower height.

It was verified that the channel connector presents a very rigid behaviour, during the primary phase of loading. Using reinforcement in concrete blocks of push-out tests increases the shear capacity and ductility of the composite system. Using channel connectors with longer length can increase the ductility of the system. In general, the channel shear connector showed a ductile behaviour.

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**Figure 2.** Typical types of failure for channel connectors (left: concrete crushing-splitting, right: channel fracture).

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