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# Shear behaviour of innovative connectors in partially encased column

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## ABSTRACT

This paper is concerned with the shear performance of an innovative shear connectors in partially encased H-section columns. Finite element (FE) analysis has been employed to investigate the ultimate shear capacity and maximum slip of the connectors. The bond between steel section and concrete in partially encased composite (PEC) column relatively weak. To overcome this, rectangular hollow steel (RHSS) were welded through steel web as innovative connectors which allow the interaction between two sides of the concrete. The RHSS models were compared to perforated column web connector (RWO). Results obtained are presented in the form of load-slip response, ultimate shear capacity and failure modes. Experimental results show that the RHSS connectors significantly increase the interaction between the steel section by showing an increase about 50% in shear capacity compared to RWO type connectors.

## 1. INTRODUCTION

A partially encased composite (PEC) column is a type of composite column that generally consist of an H-shaped (or I-shaped) steel section with concrete caste between the flanges. Typical cross-sections of composite columns with fully and partially encased steel sections and concrete filled tubular sections. Extensive experimental research has been performed on a small-scale and large-scale PEC column specimens under various loading conditions by many researcher. The results of these experimental investigations indicated that the behavior of this composite column is significantly affected by the local instability of the thin steel flanges (Begum 2007, Ellobody 2011). The eccentric axial load-carrying capacity and the deformation capacity of full and partial concrete-encased columns also were tested and also include the effect of lateral reinforcement (Ellobody, 2011). In particular the bond between steel and concrete is usually completely neglected in the design, where the stress transfer is

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entrusted to mechanical devices (connectors). In composite columns the contribution of the bond at the steel-concrete interface can be taken into account in the calculation because the contact surface is wider and the concrete is completely or partially encased in the steel profile, which gives a beneficial confinement effect (Begum 2013). Key to the satisfactory structural response of PEC is the effective shear stress transfer from one material to the other (i.e. composite action) particularly in regions of geometric discontinuity of the structural members, where bond stress demand is the greatest (Roeder 1999). Composite action may be achieved via the natural bond between steel and concrete, similarly to the bond between steel reinforcing bars and surrounding concrete, or with the aid of shear connectors of various forms, including structural bolts (Shakir 1993), Hilti nails, threaded bars, self-taping screws and tab stiffeners (Xiushu 2013).

The most commonly used shear transferring device, or shear connection, in both building and bridge constructions is the headed shear studs. Many research works were carried out on the behavior of stud shear connectors both experimentally and numerically all over the world from different angle of views (Nakajima 2003, Spacone 2004, Miah 2005). A study conducted by Baran (2012) used a channel as a perfobond shear connector. However, the shear transferring mechanisms of the innovative connectors are different with the headed shear studs, are formed innovatively by the web openings of the steel section (Bing 2013). The concrete-infill-only shear connection also is formed as the in-situ concrete completely fill the web openings without any additional element, i.e. hollow sections or stud shear. The concrete infill elements interact with the web post transferring the longitudinal shear force.

In this study, rectangular hollow steel sections (RHSS) was proposed as shear connectors to increase the bond between steel and concrete in PEC. This shear connectors innovatively designed to combine the shear resistance of steel hollow sections and confine concrete as infill material inside of the sections. RHSS was installed passed through web openings and the contact between RHSS and the column web was welded. The voids in RHSS connectors are filled by the in-situ concrete. In order to predict the bond behaviour of proposed shear connector for PEC column, numerical analysis has therefore been carried out.

## 2. DESCRIPTION OF THE SHEAR CONNECTORS

The brief details of the models developed are summarized in Table 1. The push-out model which were designed to investigate the proposed shear connectors were used as shown in Fig. 1. RHSS with 5mm in thickness and 130 mm in length were used in the numerical model. There were two sizes of the RHSS shear connectors in PEC: 75 x125 mm and 100 x150 mm. Furthermore, web openings connectors with the same sizes of RHSS were modeled in order to make a comparison of their behaviour. The setup of the push-out models were designed to create desired loading conditions and also to be in compliance with Eurocode 4 (EN1994-1-1:2004).

Table1. Test specimens

| Specimens | Shear connection | Variable of specimens | Web opening | Thickness | Length |
|---|---|---|---|---|---|
| RWO1 | Concrete-infill-Only | Dimension | 75x125 | - | - |
| RWO2 | Concrete-infill-Only | Dimension | 100x150 | - | - |
| RHSS1 | Confine concrete | Dimension | 75x125 | 5mm | 130mm |
| RHSS2 | Confine concrete | Dimension | 100x150 | 5mm | 130mm |

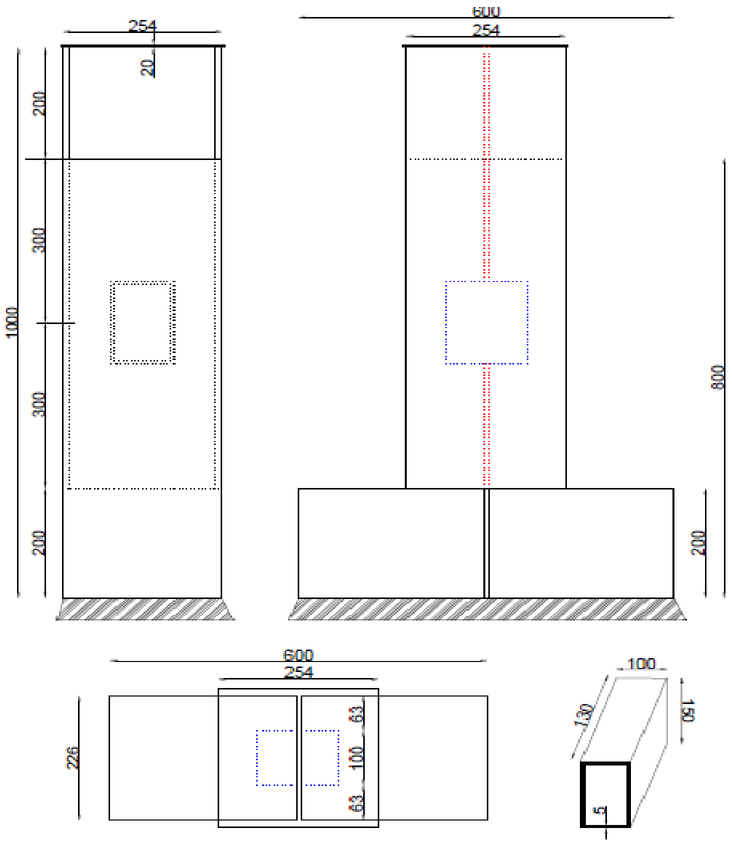


Fig.1.Typical layout of push-out test considered for numerical analysis

## 3. FINITE ELEMENT MODELING

3.1. Type and mesh

Element types for the steel and concrete of the columns were chosen from the element library of the finite element software ABAQUS 6.9 in this study. The 3D solid element was utilized to model the steel and concrete. The elements can be employed for linear and complex non-linear analyses involving contact, plasticity and large deformations. Different finite element mesh sizes were examined to find a reasonable mesh size which can achieve accurate results. As a result, the mesh size corresponding to 24373 elements was revealed to obtain exact results. A typical finite element mesh used in this study is illustrated in Fig. 2.

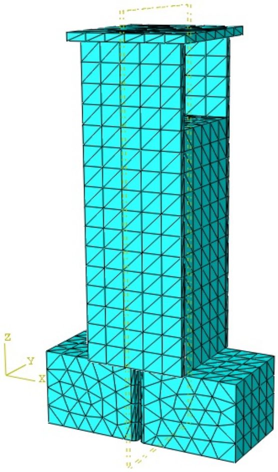


Fig.2.Typical finite element mesh used in this study

3.2. Boundary conditions and load application

The fixed symmetry boundary conditions have been considered in the 3D finite element modeling in this study. Therefore, the rotations of the top surface of the columns in the X, Y and Z directions were considered to be free but in bottom it's assumed to be fixed. Also, the displacements of the bottom and top surfaces in the X and y directions were restrained. On the other hand, the displacement of the bottom surface in the Z direction was restrained while that of the top surface, in the direction of the applied load and where the load is applied, was set to be free.

The load application on the column in the modeling was on the basis of the loading arrangement in the corresponding experimental test of the column. The axial load of the experimental test was exactly modeled by incremental displacement load with an initial increment of 1 mm in the negative Z direction acting axially to the top surface of the column. Increment is a step in a non-linear analysis where a portion of the total load is applied. The increment change was 0.1 mm in the analysis. Iteration is a step within a load increment where the analysis solver attempts to converge to an acceptable solution. The iterations per increment were 10 in the analysis. Incremental loading adds displacements to a previous increment (ABAQUS 6.9). Each step in the non-linear analysis was a small amount of the displacement of the column and it was continued up to the failure of the concrete material.

3.3. Modeling of concrete-steel interface

The contact between the concrete and the steel H section and shear studs was simulated by surface. The surface to surface attributes was be used to model contact surfaces. The surface contact facility is non-linear. Slave and master surfaces was selected to provide the contact between two surfaces, steel and concrete. Although, the steel material is stiffer than the concrete material, the steel H section may have less stiffness than the volume of the concrete in this study. Consequently, the concrete and steel surfaces were respectively selected as the master and slave surfaces. Dabaon (2013) has also presented this process of choosing master and slave surfaces. The surface to surface has the capability of defining properties such as friction coefficient. The friction between two surfaces, the steel H section and concrete, is considered so that they can remain in contact. The Coulomb friction coefficient in surface-surface was selected as 0.45. The surface-surface allows the concrete sides and steel section to separate or slide but not to penetrate each other.

*3.1.3. Accuracy of modeling*

The finite element modeling result was compared with the experimental test result reported by Bing (2013) to reveal the accuracy of the 3D modeling in this study. According to Fig. 3, the curves obtained from the modeling and corresponding experimental test agree well with each other. The difference between the ultimate axial load capacity obtained from the modeling 141 kN, and that from the experimental test 119 kN is about 18.5%. This acceptable difference demonstrates that the behaviour up to failure, failure mode and ultimate capacity of push-out models could be predicted with sufficient accuracy.

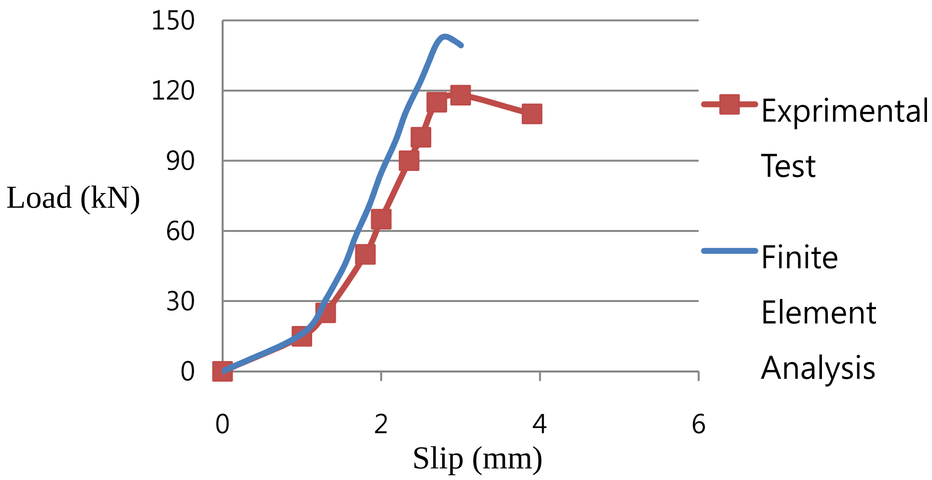
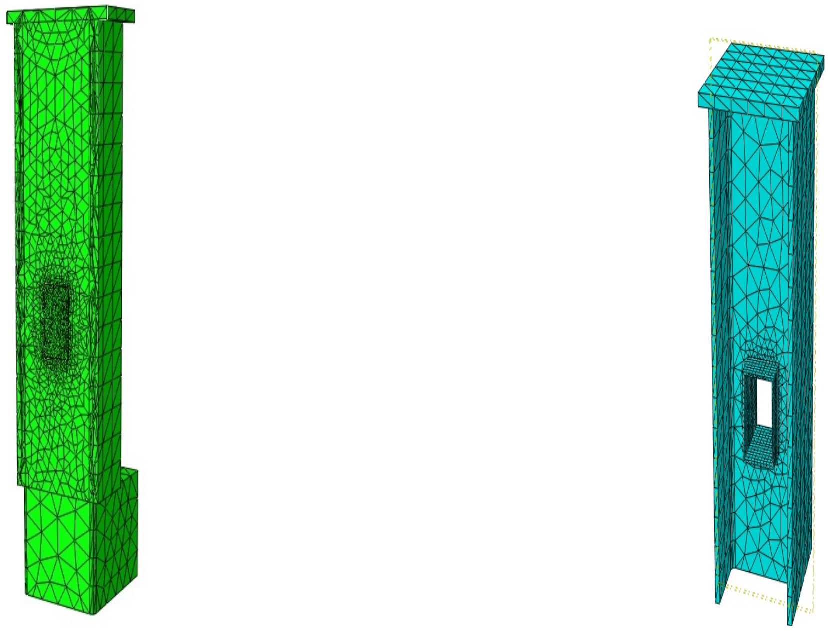



Fig.3. Load-slip curves of FE and experimental (Bing 2013).

3.2. Numerical analysis

Since the proposed 3D finite element modeling of this study was demonstrated to be acceptable, the method was utilized for the non-linear analysis of partially encased columns of same size of H section and top plate as that of Bing (2013) but with different concrete cross section and variable web opening size and hollow steel section. The previously explained modeling specifications were exactly employed for simulating each of PEC column. First series include two models simulated as perforated column web connectors. Whereas in second series, two different shape of rectangular hollow steel section were employed in PEC column as innovative shear connector. The FE models of PEC columns are illustrated in Fig. 4. Half scale FE model are used for a better mesh distribution around shear transfer parameters.



a) RWO model b) RHSS models

Fig.4. Finite element model of the PEC columns.

## 4. RESULTS AND DISCUSSION

The finite element analyses provided detailed output in terms of forces, slip and stresses. However, for brevity only the most relevant results are presented herein for discussion. In Fig 5 plotted is end column displacements against load applied at the top column plate for RHSS and RWO connectors. For RHSS models, an elastic behaviour is observed up to ultimate load and beyond that the load start to drop. The loads drops with the increase of slip. Whereas, for RWO connectors, it is observed that the slip suddenly increase at loads 15 kN to 20 kN and loads keep incresing with the increase of slips until it reaced the ultimate load capacity. So a larger slip are obtained for RWO models compared to RHSS models at ultimate shear capacity. Table 2 summarized the predicted maximum shear capacity and slip of the models. The ultimate load for RHSS models are about 50% higher than those RWO models. This shows that the proposed connectors in PEC column has better interaction compared to RWO connectors. RHSS1 connector which has a wider flange, 100 mm, has 15% higher in shear capacity compared to RHSS1 which has 75 mm in flange width. RHSS type connector also has higher stiffness compared to RWO type connector. In RHSS models, high stresses are observed in concrete distributed surrounding the connectors area which caused the models reach the ultimate shear capacity as shown in Fig. 6a.

Whereas for the RWO type, the high stresses in concrete occurred at top area of web openings as shown in Fig. 6b.

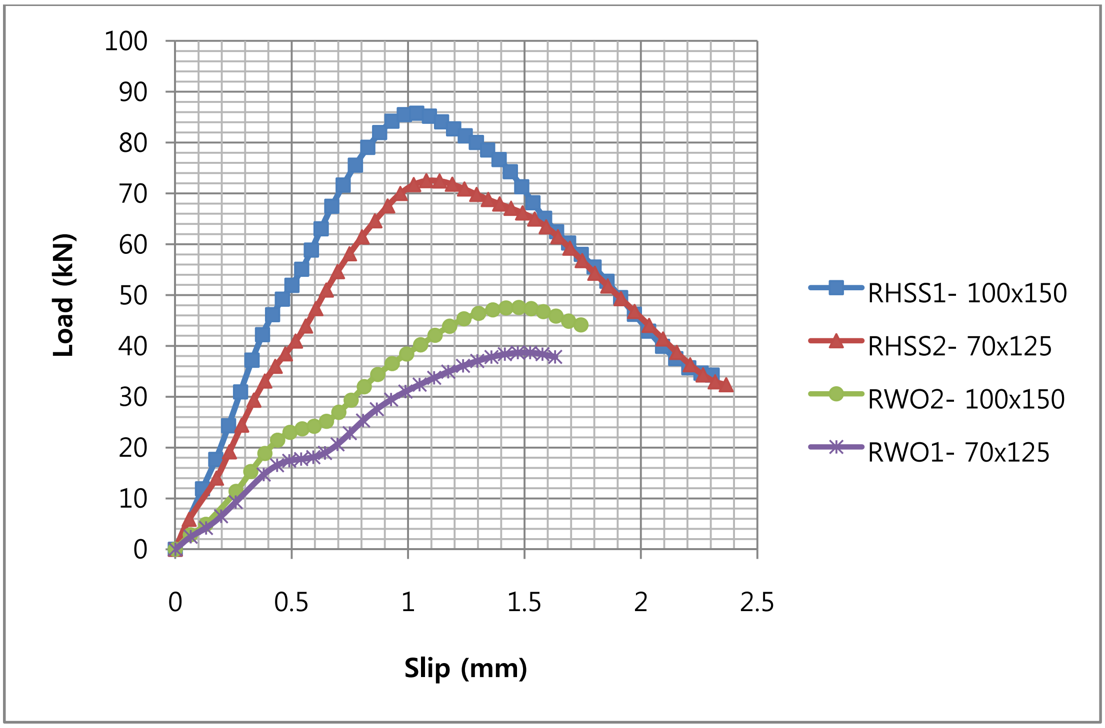
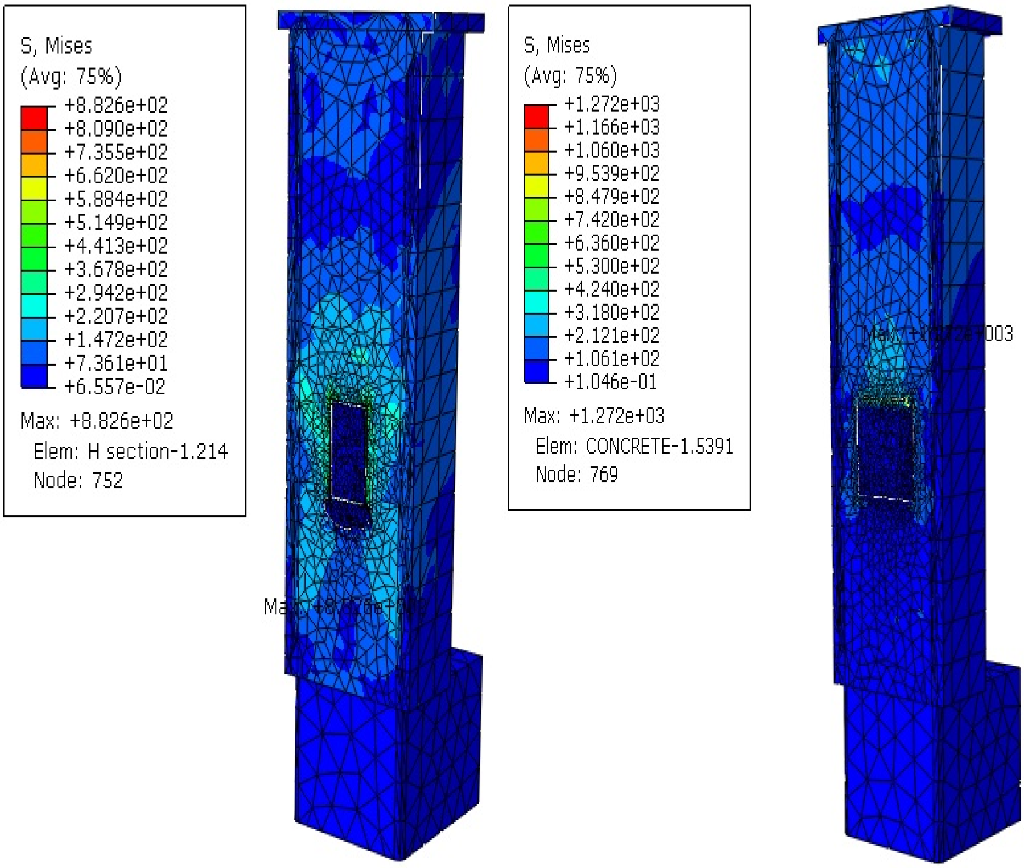



Fig.5. Load-slip plots for RHSS and RWO connectors

Table 2. Load and slip results of FE models

| No. | Specimens | Ultimate Load ( kN) | Slip at ultimate load (mm) |
|---|---|---|---|
| 1 | RWO1 | 44.27 | 1.53 |
| 2 | RWO2 | 47.97 | 1.47 |
| 3 | RHSS1 | 72.49 | 1.07 |
| 4 | RHSS2 | 85.75 | 1.03 |




a) RHSS model b) RWO models

Fig.6. Failure modes of the PEC columns 0f web opening only shear transfer, S1

## 5. CONCLUSION

Partially encased composite (PEC) columns with rectangular hollow steel sections (RHSS) connectors and perforated column web type connectors (RWO) have been investigated. The non-linear finite element software package (ABAQUS) was employed to simulate the push-out test in order to predict the shear capacity of the proposed connectors in PEC column. The accuracy of the analyses is based on the comparison of the experimental results of push-out test for web openings type connector. It was revealed that the proposed modeling can predict the behavior of the columns with a reasonable accuracy. The validated model then was used to investigate the RWO and extended to RHSS models. It is concluded from the results presented herein that RHSS connectors has shown significant increase in the shear capacity compared to RWO connector. It is also revealed that the wider RHSS flange produce higher shear capacity. Meanwhile, the failure modes of the push-out test were dominated by high stresses in concrete.

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