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Simulation Behaviour of Precast Concrete Connection with Embedded Box Section under Static Loading

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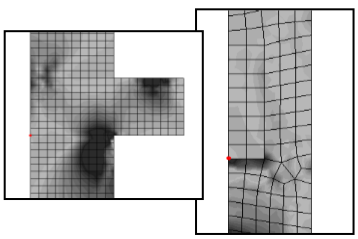
Graphical abstract



Abstract

This study is concerned with 18 precast concrete beam-column connections incorporating embedded steel box-section using Finite Element (EF) modelling. The variables considered were: length and width of the embedded steel member. The results indicate that connection containing a wider flange of the embedded member can resist more vertical loading. Also, the deflection at ultimate load increases as the width of the embedded steel section increase. Generally, there are a few design methods available in the codes; this study also evaluates the available design formulas using FE simulation results and the data from other researchers. From the evaluation and the analysis it was shown that twice the width of the embedded width should be taken as the effective width of the connection when the PCI (Precast Concrete Institute) design equations are used.

Keywords: Precast concrete connection; embedded steel box section

Abstrak

Kajian ini adalah berkenaan dengan dua siri terdiri daripada sejumlah 18 pratuang konkrit sambungan rasuk-tiang menggabungkan terbenam keluli kotak seksyen menggunakan Unsur Terhingga (EF) pemodelan. Pembolehubah dipertimbangkan ialah: panjang dan lebar ahli keluli tertanam. Keputusan menunjukkan bahawa sambungan bebibir yang mengandungi lebih banyak ahli terbenam dapat menahan beban menegak lebih. Juga, pesongan pada beban muktamad meningkat di mana lebar seksyen keluli peningkatan terbenam. Secara umumnya, terdapat beberapa kaedah reka bentuk yang terdapat dalam Kod; Kajian ini juga menilai formula reka bentuk boleh didapati menggunakan keputusan simulasi FE dan data dari penyelidik lain. Daripada penilaian dan analisis yang telah ditunjukkan bahawa dua kali lebar lebar terbenam perlu diambil sebagai lebar berkesan sambungan apabila PCI (Precast Concrete Institute) persamaan reka bentuk digunakan.

Kata kunci: Sambungan konkrit pratuang; seksyen kotak keluli tertanam

■1.0 INTRODUCTION

In many parts of the world, precast concrete is considered by architect engineers and contractors as an alternative method to cast-in-place concrete and steelwork construction for medium rise buildings of between two and twelve stories. The design and analysis of precast skeletal structures is greatly influenced by the behaviour of beam-column connections, where patented designs have led to a wide range of types with different structural qualities. An embedded steel connection, which includes a structural steel member, is a beam-column connection with steel section embedded into a precast column in order to transfer shear and axial forces, and sometimes bending and torsion moments as shown in Figure 1. The strength of these connections depends on the width of the structural steel member, the embedded length of the steel member, the compressive strength of concrete, and the eccentricity of load. The most widely used method of designing these connections is presented in the Prestress/Precast Concrete Institute (PCI) Design Handbook. The design method was first developed by Marcakis and Mitchell in 1980. The given equation by PCI is based on some assumptions such as spreading stress distribution in a width equal to the width of embedded member. There is possibility that in the connection, the load is able to spread in greater width of the embedded member. Marcakis and

Mitchell in1980 assumed that the effective width for this connection is equal to the width of the concrete confined by the column ties measured to the outside of the ties.[1,2]

This phenomenon sometimes causes spalling of the concrete cover. But in conditions where effective width would be very large compared to the width of the embedded member (e.g. in a wide RC column), a maximum effective width of 2.5 times the width of the embedded member is taken. The proposed analytical model assumes that the stiffness of the steel member is sufficiently greater than that of the concrete surrounding in which it may be treated as a rigid member. Mattock and Gaafarin 1981 carried out analytical and experimental studies to attain a better understanding on the behaviour and strength of embedded steel sections as bracket. The strength and ductility of tilt-up concrete wall panel connections were investigated analytically and experimentally by Lemieux *et al*. (1998) in a series of monotonic and cyclic tests. In their research the presented equations by PCI was used. In their work, most of the tested connectors did not show sufficient ductility. Therefore, it can be concluded that the connection should be treated as a pin connection.[3,4]

An efficient structural system for seismic resistance can be achieved if opening in structural walls can be arranged in a regular pattern. In this manner, a number of individual wall piers are coupled together to produce a system having large lateral stiffness and strength. The beams that connect individual wall piers are referred to as coupling beams. Reinforced concrete coupling beams may have conventional reinforced, diagonal reinforced, or hybrid reinforcing steel arrangement. Coupling beams may also be fabricated from rolled or built-up steel shapes, or have a composite steel concrete design (Harries and Gong 2000).[5]

An analytical and experimental research study considering cyclic response of steel-composite coupling beam was carried out by Gong and Shahrooz (2001).They showed that the embedded steel section equations presented by PCI can be used for coupling beams. They also found that the embedment length has a major influence on the performance of steel-composite coupling beam. A considerable amount of studies were carried out on coupling beam using PCI equation. The reported studies indicated that when cyclic loads are applied, the required embedment length may be conservatively determined from the equations proposed by PCI. Since the connection can be used in many applications and a few design methods are available; therefore, there is a need to evaluate the methods. This paper is concerned with embedded box section in which the lengths and widths of the embedded member are varied. These connections are analyzed under vertical loading using the finite element modelling software package ABAQUS. This study also aims at evaluating the available design methods and suggesting the effective width using the data from the FEM results and previous work.[6,7,8,9,10,11,12,13,14]

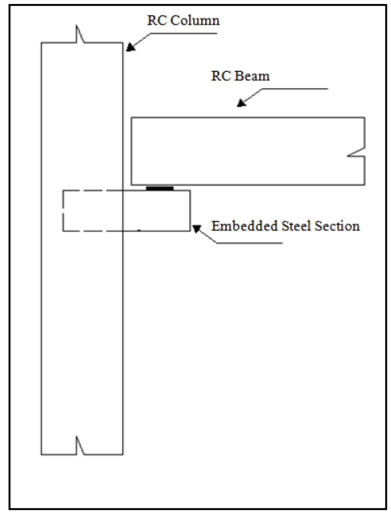


Figure 1 A Typical reinforced concrete connection with embedded steel section

2.0 FINITE ELEMENT ANALYSIS

Finite element software ABAQUS version 6.9 has been used in this study. The models included 3-D solid having geometric and material non-linearities. The reinforcement was modelled as rebar elements embedded in the solid element. The incremental load was applied using Riks method. Solid elements are volume elements, which are composed of a single homogeneous material. Concrete was modelled using solid element (3D Stress). Line mesh (3-node quadratic, 3-D truss) was used to model the behaviour of reinforcement. This is a technique used to have embedded node(s) at desired locations with the constraints on translational degrees-of-freedom on the embedded element by the host element. The reinforcements are modelled as embedded region in concrete using constraints in interaction module, and making the concrete the host. Thus, reinforcement element can only have translations/ rotations equal to those of the host elements surrounding them. The typical parts used in the FEM of this study are presented in Figure 2, which consist of reinforcements, concrete column, steel section.

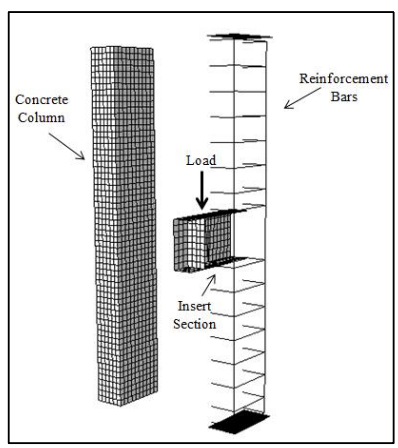


Figure 2 Parts showing concrete column, reinforcements, and steel section

Material properties of concrete and steel were defined using standard properties. Density, Modulus of elasticity, Poisson's ratio, elastic strain, and plastic strain of concrete and steel were incorporated. For concrete a density of 2400 kg/m^3, Modulus of Elasticity of 26000 MPa, Poisson's ratio 0.2, and total strain 0.0029 were used. For steel a density of 7850 kg/m3, Modulus of Elasticity 200,000 MPa, and Poisson's ratio 0.3 were used. The compressive strength of concrete and the yield stress of steel were assumed 30 MPa and 337 MPa, respectively. It is necessary to assess the accuracy of the proposed finite element modelling. Two specimens (SC5, SC11) tested by Marcakis and Mitchell (1982) were considered in this study to ensure the accuracy of the modelling by ABAQUS. The specimens were modelled and analyzed, and the results presented in Figure 3. It is clear from the figure that finite element results are close to the corresponding experimental values, maximum deviation being 4%. Since ABAQUS has been found to predict results with acceptable accuracy the software package was used for further analyses.

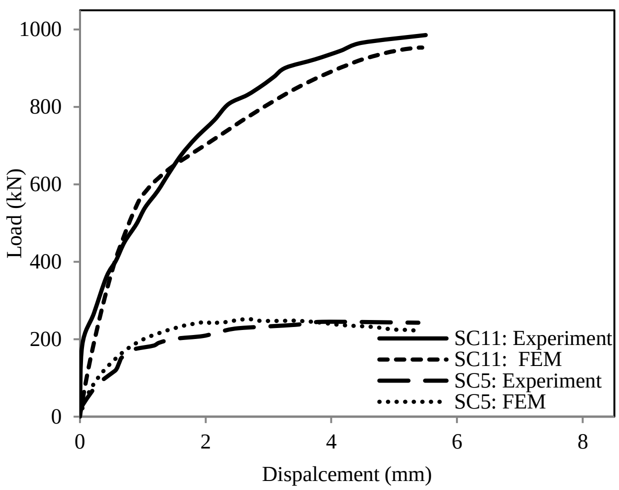


Figure 3 Comparison between finite element results and test results

In the analyses of all models, top and bottom of the column were assumed fixed as shown in Figure 4. Taking advantage of the symmetry in geometry, loading, and support conditions, only a half of the models were analyzed in order to reduce the computational time. A typical half model is shown in Figure 2. Mesh size of 20 mm × 20 mm was chosen based on convergence studies carried out to determine the optimal mesh that gives a relatively accurate solution and one that takes low computational time. All connections had an eccentricity of loading of 102 mm from the column ('a' in Figure 4). All connections incorporated hollow structural members that stick out from only one side of the column. The column was 203 mm × 203 mm in cross section and 1220 mm long. Column was reinforced with four 13-mm-diameter longitudinal bars and 10-mm-diameter stirrups spaced at 76 mm centre to centre. In order to achieve the maximum effective width, closely spaced column ties were provided. This reinforcement also controls cracking in the connection region. In order to prevent local buckling in the thin walled hollow structural section, the embedded connections were modelled and filed with concrete in order to prevent local buckling.

Two different series comprising a total of 18 embedded steel connections were analyzed. The embedded length and width of the steel members are given in Table 1. As it can be seen from the table the first ten connections are designated with L on which the embedment length are varied from 10% to 100% of the width of column. Whereas the rest of the connections designated with W represents connections with various width of the structural steel member. In series W, it was intended to have the same moment of inertia for all connections; on the other hand it is recommended that the minimum thickness of embedded steel member is taken 4mm [20]. Thus, the thickness of the hollow structural member was taken from 4 mm to 15.8 mm such the moment of inertia was kept constant.

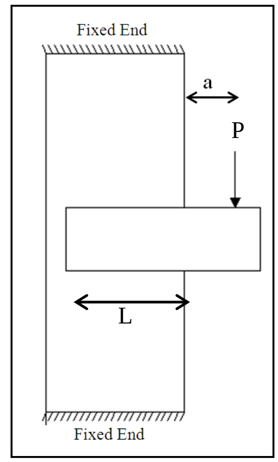


Figure 4 Boundary condition

Table 1 Details of connections

Designation	Length (mm)	Width (mm)	Thickness of the steel member (mm)
L10	17.7	88.5	10
L20	35.4	88.5	10
L30	53.1	88.5	10
L40	70.8	88.5	10
L50	88.5	88.5	10
L60	106.2	88.5	10
L70	123.9	88.5	10
L80	141.6	88.5	10
L90	159.3	88.5	10
L100	177	88.5	10
W30	177	53.1	15.8
W40	177	70.8	12.1
W50	177	88.5	9.6
W60	177	106.2	7.9
W70	177	123.9	6.6
W80	177	141.6	5.5
W90	177	159.3	4.7
W100	177	177	4

3.0 RESULTS AND DISCUSSION

3.1 Series L

Ten connections were modelled and analyzed. The load deflections responses are shown in Figure 5. The deflection of the embedded steel member relative to the column at the point of application of the load was measured. The figure shows that the load deflections curves remained linear up to about a load of 40 kN on the connections. At this point of the curves, right below the embedded steel member in the column begins to crack. After the load-deflections curves reaching the ultimate load, the curves become relatively flat. From the figure it can be seen that as the embedment length increases the strength of the connection increases It is apparent that all connections showed ductile behaviour. Figure 6 Shows concrete stress distribution of L100 at ultimate load. Crushing of the concrete below the corner of the embedded steel member is apparent. In the side view, it can be seen that the load is almost transferred diagonally from the point of applying load to the intersection of the column and the connection. In the front view, it is shown that the stresses are spread in greater than the width of the embedded steel section. It could be attributed to the confinement of the concrete in the connection region.

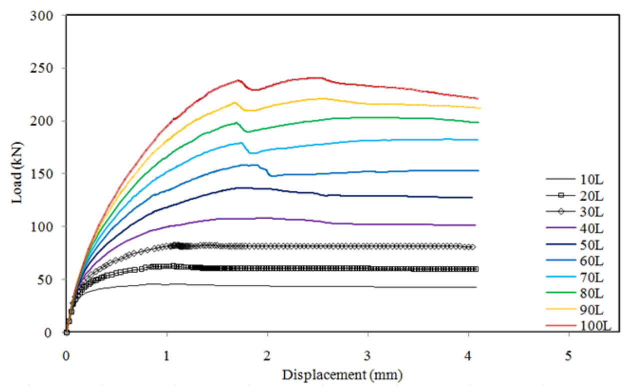


Figure 5 Load-deflection responses for Series L

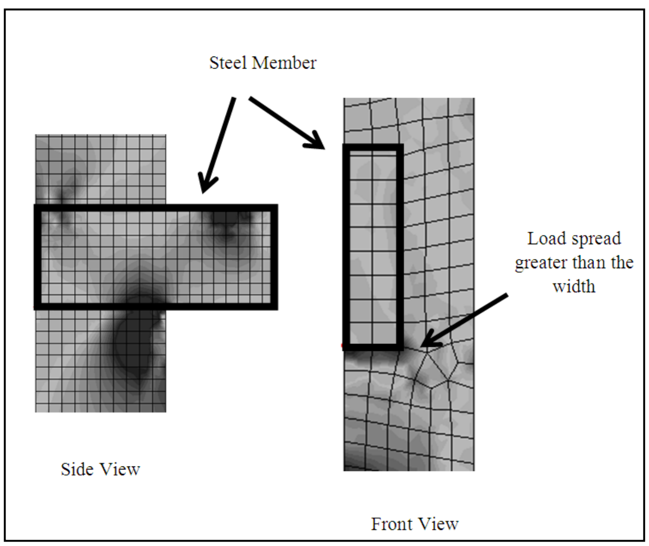


Figure 6 Stress distribution of L100

3.2 Series W

The second series comprised a total of 8 connections. All connections were modelled with the same moment of inertia in order to study the effect of the width of the connection. Load deflections responses are shown in Figure 7. The deflection of the embedded member relative to the column at the point of applying load was measured. The load deflection curves remained essentially linear up to about 60 kN and a deflection of 0.12 mm. From this point the stiffness of the connections gradually decreased. After reaching the ultimate load, the curves relatively become flat. The figure shows that the connections containing the wider flange embedded member is stiffer; and the deflection at ultimate load increases as the width increase. Since W30 had the narrowest width, thus it failed in brittle manner unlike the rest of the connections that show ductile behaviour. It is probably due to local crushing of concrete immediately below the embedded member. Therefore, it can be concluded that a minimum width should be provided. Since W40 shows a ductile behaviour, thus 40 percent of column width can be introduced as the minimum width for precast concrete connection with embedded box section. The stress distribution contour at failure load of connection W100 are shown in Figure 8. The figure shows that the cracks have been spread diagonally downward across the side faces of the column. There was no yielding stress in the bars, ties, and hollow structural member.

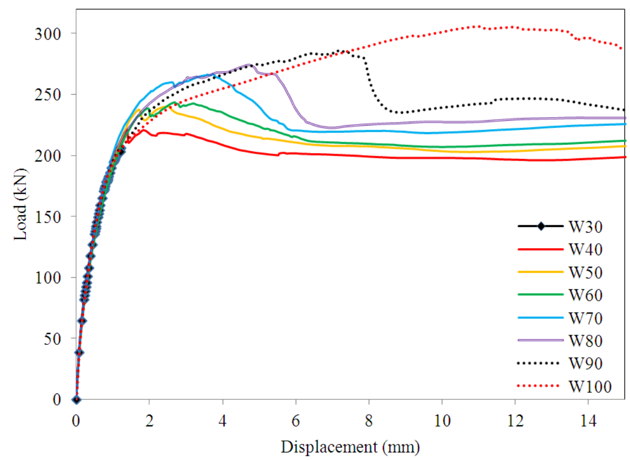


Figure 7 Load deflections responses for Series L

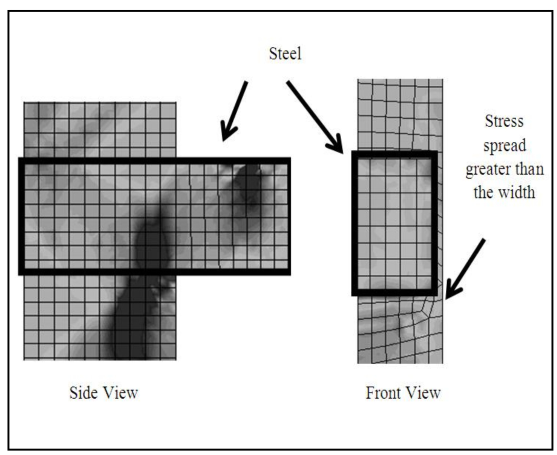


Figure 8 Stress distribution of W100

One of the main assumptions in the design equation of the connection is how the load is spread in the concrete. Based on the different stress distributions right directly below the embedded member three design equations are recommended (PCI 2004, Mattock and Gaffar1981, and Elliot 2002). The recommended design equations were assessed using the FEM results carried out in this study and the data from past research. It was found that the three design methods yield over conservative prediction of the ultimate strength of the connections. The PCI equation is about 50 per cent more conservative than Mattock and Gaafar's equation. In

PCI design method it is assumed that the load at below the embedded steel section is spread in equal width to the width of the embedded steel member which is known as effective width. Effective width shows how the load is spread as shown in Figure 9. Therefore, an attempt was made to determine the effective width of the connection using the results of FE modelling and the data from past research. Taking twice the width of the connection, regardless of the width of the column, into the PCI equation will yield a good agreement with the test results.[1,2]

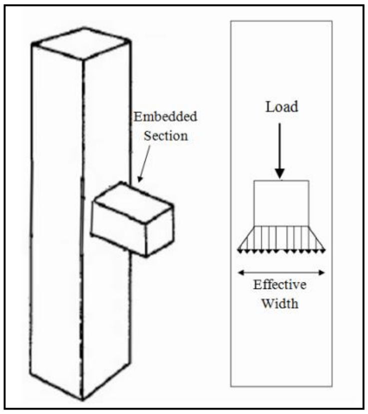


Figure 9 Effective width

4.0 CONCLUSIONS

The following conclusions can be drawn based on the results:

- As the embedment length increases, the strength of the connection escalates. The improvement in the strength of the connections is proportionally attributed to L20 to L50. Which does not support longer length will lead to stronger connection.
- Connections containing wider flange of the embedded member show more ductile behaviour.
- Minimum length of embedded member should be equal or greater than the width of the embedded member.
- Twice the width of the embedded width should be taken as the effective width of the connection when PCI equation is used.

Acknowledgment

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