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# BEHAVIOR OF CONNECTION ROTATIONS COMPOSITE STEEL BEAM WITH PARTIAL STRENGTH USING TRAPEZOID WEB PROFILED

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## ABSTRACT

In steel structures, the connections will be designed whether simple, semi-continuous, or continuous construction, either using non-composite or composite connections. Many constructions are usually designed as simple which associated with simple construction or rigid which is associated with continuous construction. However, the actual behaviour between these two extreme cases is taken placed between simple and rigid, which is semi-rigid connection. The use of partial strength or semi-rigid connections for composite has been adviced by codes and studies doe to few researches doing on this field. The matter known as semi-continuous construction have proven that substantial savings in steel weight of the overall construction using non composite or composite connections. The objective of this paper is to present the behaviour of partial strength connections flush end plate full of composite steel beam with partial strength connections using Trapezoid Web Profiled (TWP) steel sections and Universal Beam (UB). The composite TWP steel section, built up section with the flange designed using S355 steel section and the web is designed using S275 steel section. Four full scale tests have been carried out for composite beams with flush and extended end-plate connections as partial strength composite connections. The use of partial strength composite connections will also reduce the deflection of the beam as suggested by the Steel Construction Institute (SCI). The moment resistances and the deflection of the composite beam presented in this paper, and the behaviour of end-plate connections showed extremely good agreement between experimental values and the predicted values. The results have shown that the partial restrained of the composite connections has contributed to the reduction in the deflection, the increase in the moment resistance of the beam, and the the restrain of rotation on the composite connections of the design of TWP steel section as a beam.

**Keywords:** Behaviour, Connection Rotation, Composite Steel Beam, Trapezoid Web Profiled Section.

## INTRODUCTION

Composite Steel and Concrette is widely used right now for building structures. The using of technology for composite steel and concrete either for cmposite beams or composite connections is widely used. The study of composite connections between the composite beam and bare steel column in a frame is also studied qiute significant. In General, the connections can be assumed as pinned, where only nominal moment from the beam is transferred to the column, rigid or full strength, where full continuity of moment transfer exists, or partial strength connection where the the connection behave between simple and rigid connection. However, in composite, the connections can only assumed as either full strength or partial strength . BS5950 and EC 3 allow building frames of bare steel or compsite steel to be designed as semi-rigid using the partial strength connection. The types of composite construction using partial strength composite connections is assumed as semi-rigid or semi-continuous construction. In semi-rigid design for composite design, the moment-rotation relationships of partial strength connection which includes the moment resistance and rotational stiffness (rigidity), is to be established prior to its usage in design. In this research, the behaviour of composite partial strength connections with TWP sections as beam and UC section as column has been analized. The purpose of using TWP section is an alternative beam which has some advantages offered by the sections in general.

### Background

**a). Trapezoid Web Profiled (TWP) Steel Sections c empared to Universial Beam.**

A trapezoid web profile is a built-up steel section made up of two flanges connected together by a thin corrugated web usually in the range of 2 mm to 8 mm. The web is corrugated at an angle of 45 degree and welded to the two flanges by using automated machine. Since the web and flanges may comprise of different steel grades, TWP section is also classified as a hybrid steel section. The steel grade of the flanges is usually designed for S355, so that the flexural capacity of the beam can be increased, whilst the steel grade of the web is usually designed for S275, so that the cost of steel material can be reduced since the shear capacity is usually not critical. The use of different steel grades in the fabrication of TWP section leads to further economic contribution in addition to the contribution from using partial strength connections. The thick flanges, thin web and deeper beam of a TWP section as shown in figure 2.1 in comparison to a hot-rolled section of the same weight lead to larger load carrying capacity and greater beam span.

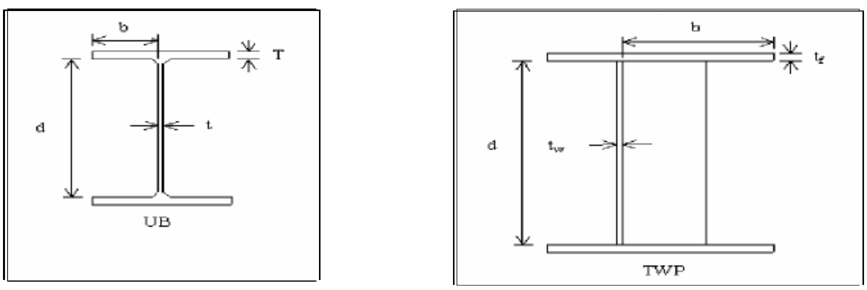


Figure 2.1: Dimension for Classification of UB and TWP Sections

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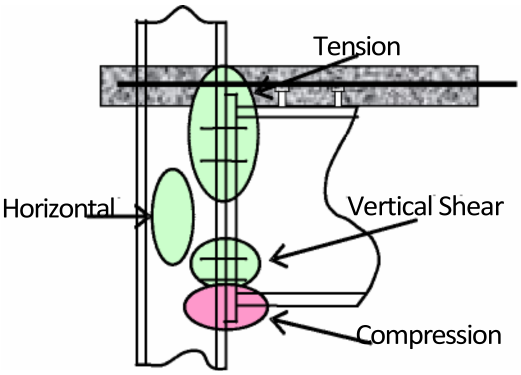
**b). Flush End-Plate with Concrete Composite**

Classically, flush endplate semi-continuous braced frames are the most suitable for composite connections because of the advantages that they possessed. The methods and procedures of design is adopted for beam-to-column composite connections. In Composite design, A triangular distribution is modified to acquire a more accurate distribution of bolt forces using a plastic distribution approach. In the component method, a particular connection is divided into three critical areas or zones. These zones are:




| Zone | Ref | Failure mode |
|---|---|---|
| Tension | a | Bolt tension |
| | b | End plate bending |
| | c | Column flange bending |
| | d | Beam web tension |
| | e | Column web tension |
| | f | Flange to end plate weld |
| | g | Web to end plate weld |
| Horizontal shear | h | Column web panel shear |
| Compression | j | Beam flange compression |
| | k | Beam flange weld |
| | l | Column web crushing |
| | m | Column web buckling |
| Vertical shear | n | Web to end plate weld |
| | p | Bolt shear |
| | q | Bolt bearing (plate or flange) |

Figure 2.2: Arrangement for Composite isolated tests

The resistance of these zones will determine the moment resistance of a beam-to-column connection. Figure 2.2 shows an Arrangement of composite flush-end plate connection with the critical zones affected during loading.

**c). Composite Partial Strength Connections**

There are two types of Composite partial strength connections that are commonly used are the flush endplate connection and extended endplate connection. These two connections are made of a plate, which is welded to the beam‘s end in the workshop, bolted to the column on site, and then associated with reinforced concrette as composite with the reinforcement tighted in the unversal column. For the composite connection wth flush-end plate, the analysis fo the connection is similar to an extended endplate, the reinforement tighted in the column will work similar to the bolt row of extended endplate connection. If the moment resistance or moment capacity of a connection is lower than the moment capacity of the connected beam, the connection is referred to as the partial strength connection.

The adavantage of designing steel frames in composite are that the steel weight of the connections account fewer than bare steel design for less than 25% of the frame weight which will affect the cost of the fabrication with the range of 45% to 60% of the total cost. The fabrication of partial strength connections may be marginally more expensive since some degree of rigidity has to be provided. However, by using partial strength connections in composite, beam sizes could be reduced and significant overall savings of frame weight could be acquired compared with simple connection design. The use of the proposed composite connections has been reported that the savings in steel weight of using partial strength connection alone. In composite connection, the moment rotation has also shown some advantages, that the angle of rotation is smaller than non-composite which will influence rigidity of of the construction.

**d). Failure Mode of the Connections**

There are three kinds of failure of the connections during loading applied to the structures as shown in figure 2.3;

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1. Complete flange yielding mode; the strength of the flange is weaker than to the strength of the bolts. The flange will yield but the bolts are still intact shown in figure 2.3 (a)
2. Bolt failure with flange yielding; the strengths of the flange and the bolts are about the same. As a result, both the flange and the bolts will yield together upon failure. This mode of failure is shown in figure 2.3 (b).
3. Bolt failure; the strength of the bolts is weaker than the strength of the flange. Upon failure, the bolts will yield (or even break), the flange is still intact, shown in figure 2.3 (c)

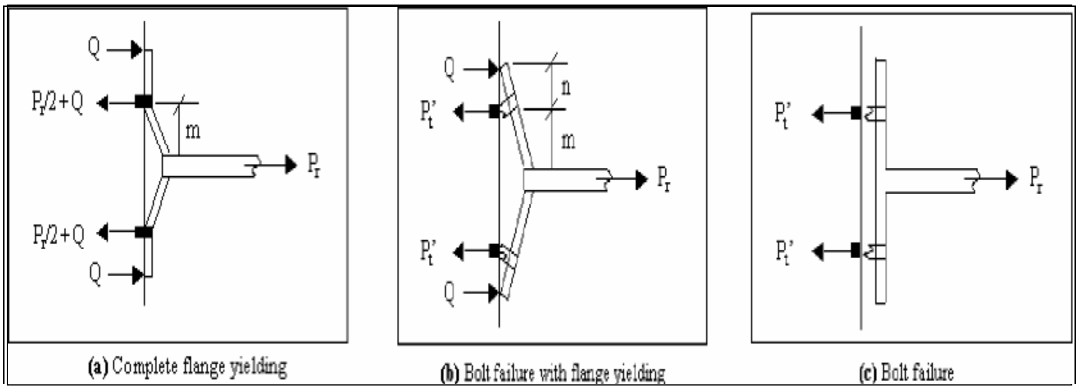


Figure 2.3: Modes of failure of equivalent T-stubs (Adapted from SCI (1995)

In designing steel frames as bare steel, the steel weight may account for less than 5% of the frame weight and the cost of the fabrication is in the range of 30% to 50% of the total cost. The fabrication of composite partial strength connections could be more expensive since some degree of rigidity has to be provided. However, by using composite partial strength connections could affect the reducing of beam sizes with significant overall savings of frame weight. The use of the proposed composite connections will be an added advantage. It has been reported that the savings in steel weight of using partial strength connection alone in multi-storey braced steel frames using British hot-rolled section was significantly give the overall saving of the construction cost.

## 1. Experimental Procedure For Composite Connection

The encouragement of this experimental work is to study the effects of partial restraint provided by the composite partial strength connections on the ultimate and serviceability of the TWP beam. A series of four isolated composite steel beam-to-column joints and two steel sub-assemblage composite beam-to-column joints were tested on a full-scale basis. A purpose-built test rig was designed and erected to accommodate a column height of 3 m and a beam span of up to 6 m. The rig consists of channel sections pre-drilled with 22 mm holes for bolting purposes. The sections were bolted to form loading frames, which were subsequently secured to the laboratory strong floor as shown in Figure 3.1 for the composite isolated tests. The column height was at 3 m to represent the height of a sub-frame column of multi-storey steel frame. The column was restrained from rotation at both ends whilst the beam was restrained to avoid lateral movement as shown in the figures. In the isolated tests, the load was applied using a hydraulic jack at a distance of 1.3 m from the face of the column. This distance was deemed adequate to cover the distance of the contra flexural point between the negative end moment of the joint and the positive moment of the beam. This distance was still within the standard distance of one fourth of the length of the beam so that a bending situation was assured.

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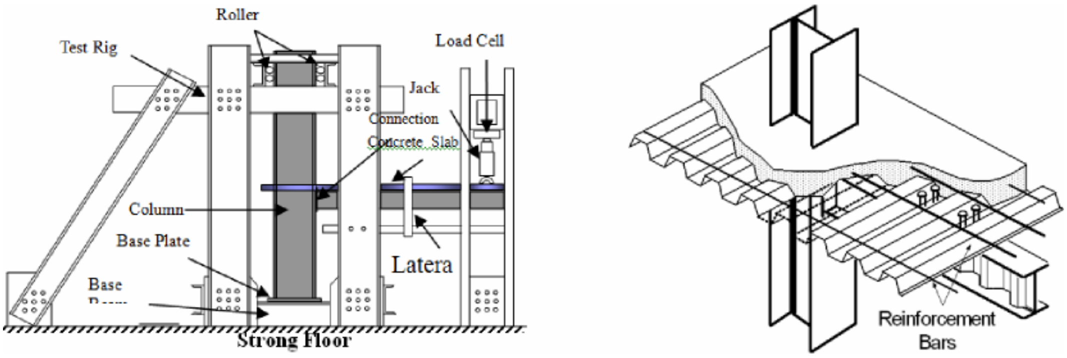


Figure 3.1: Arrangement for composite Isolated Test

After the instrumentation system had been set-up and the specimen had been securely located in the rig, the data collection software in the computer was checked to make sure that all channels connecting to the instruments on the specimen indicated a properly working condition. Correction factors from calibration and gauge factors from manufacturer were input into the software prior to each test. A 5 kN increment was adopted in order to have a gradually applied loading condition. Each specimen was then loaded until a substantial deflection of the beam was observed. The load application was continued at this point but adopting a 2 mm increment in the deflection instead of the load as before. This procedure was continued until the specimen had reached its failure condition. The failure condition was considered to have been reached when an abrupt or significantly large reduction in the applied load or when a large increment in the deflection of the beam has been attained.

**Description of Specimens.**

In the isolated composite joint tests, four sets of compositbeam-to-column joints with consisting of a 1.5 m composite concrete and steel beam were tested. Each of the composite beam specimens was connected to the column flange using flush endplate connection (FEP) type of partial strength connections. The arrangement was a flush endplate connection (FEP) as shown in Figure 3.1. The geometry of the connections was identical of the endplate connection. Details of the specimens for the arrangements in the isolated joint tests are as shown in Table 1.

Table 3.1: Details of specimens

| Speciment | Bolt Rows | Bolts | End Plates W | End Plates D | End Plates T | Size of TWP Beam | Size of Column |
|---|---|---|---|---|---|---|---|
| C5 | 1 | M20 8.8 | 200 | 440 | 12 | 400x140x39.7 | 305x305x118 |
| C6 | 1 | M24 8.8 | 250 | 540 | 15 | 500x180x61.9 | 305x305x118 |
| C7 | 2 | M20 8.8 | 200 | 490 | 12 | 450x160x50.2 | 305x305x118 |
| C8 | 2 | M24 8.8 | 250 | 640 | 15 | 600x200x73.3 | 305x305x118 |

## RESULTS AND DISCUSSION

The experiments were stressed on the behaviour characteristics of the composite connections using flush endplate in isolated tests with the applied loads of the composite TWP beam in the tests. The deflection of beam was compared with the deflection limit suggested by BS5950: 2000, Part 1. On the other hand, the moment resistance and rotation of the composite connections

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that associated with the deflection and load were also considered. As The results, the behaviour of endplate in composite in term of the moment-rotation relationship of the connections was obtained from the isolated tests results.

**a). Modes of Failure of Endplate.**

At the early beginning stage of loading there were definitely no apparent visual deformations observed in all the tests. This was expected since the application of loads was intended for all components of composite joint in the arrangement prior to the commencing of the actual test. In addition, this stage was also meant for checking all of the instrumentation system prior to the actual commencement of the tests.

After re-initialising, each specimen was then loaded until there was an indication that a =failure‘ has been attained, and so the test was brought to a stop. During the tests, there was no occurrence of any vertical slip at the interface between the endplate and the column. This was mainly due to the adequate tightness of the bolts carried out during the installation and after the initial loading.

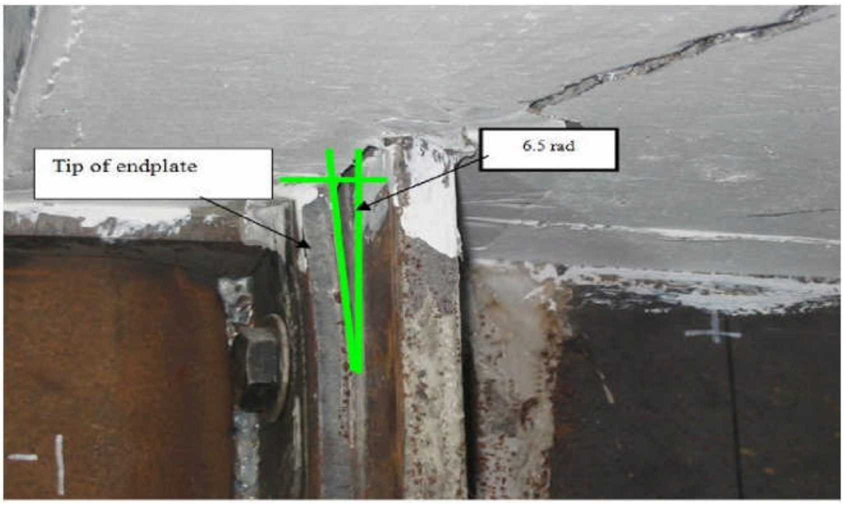


Figure 4.1: Deformation of flush end plate connection specimen C-5

Started with yielding of the reinforcement bars, and then followed by bending the end plate. Further increase of the applied load had not only deformed the end plate more until the region of the rows of bolts above and below the top flange of the beam. The applied load was then released at about one third of the predicted load for all specimens to ensure that the behaviour of the connections was in a linearly elastic state at that particular range. It was found out that the recovery of the loads in all specimens was in a linearly elastic manner, which corresponded to the initial stiffness of the connections. Even after failure, when releasing the applied loads, the slope of the drop of the loads was still corresponded to the initial stiffness of the connections as shown in figure 4.1. If the loading continues, the connection become failure following the failure of concrete as shown in figure 4.2.

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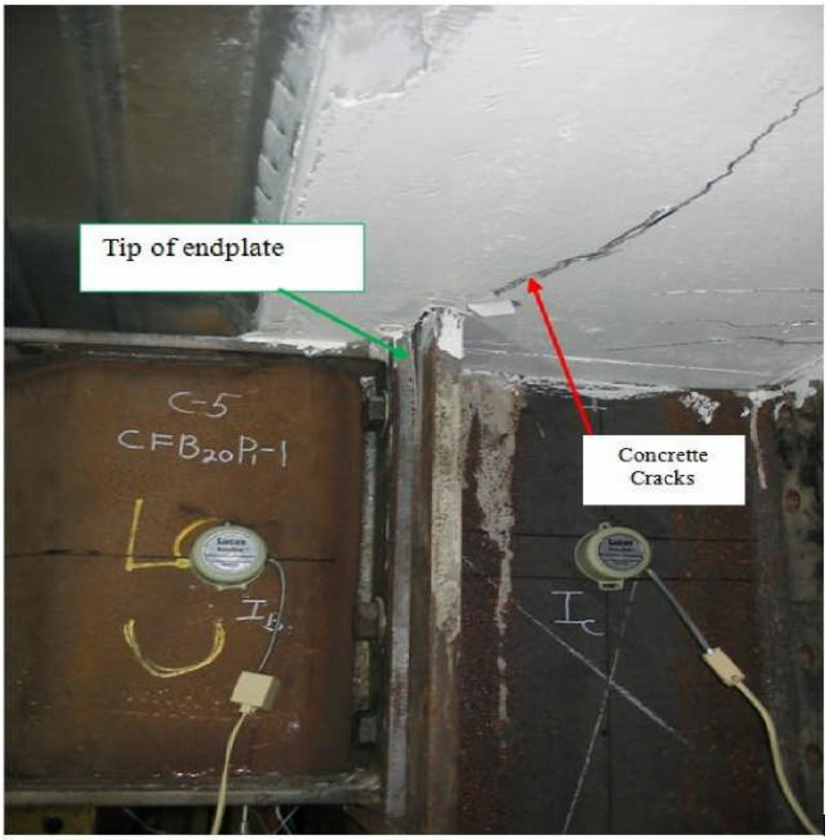


Figure 4.2: Deformation of flush end plate composite connection and the cracks of the concrette

The prediction of moment resistance and the lost in stiffness is very much dependent on the stiffness of the connected members, types of joints, and orientation of the column axis. Beam-to-column connections generally have non-linear moment-rotation curves. Initially, the connections have a stiff initial response which is then followed by a second phase of much reduced stiffness. This second phase is due to in-elastic deforP rt1RQIIR1IItK1IIFRQQeFtIRQA'IIFRP SRQeQtAIIRLIItKRAIIIRI members of the frame in the immediate vicinity of the joint. These deformations need to be accounted for because they contribute substantially to the frame displacements and may affect significantly the internal force distribution. The structural analysis needs to account for this non-linearity of joint response to predict accurately both stiffness and resistance for a semi-continuous frame in case the joint behaviour exhibits a form of material non-linearity. The examples of shape of the experimental results for the M-01) curve are shown in figure 4.3 a to figure 4.3 d. The experimental values of moment resistance MR listed in Table 4.1 was determined by estimating Z KEQIIrII—I•QeH IIfRrP BdIIiQIIErFKIIRlIItKeIIO -O curves.

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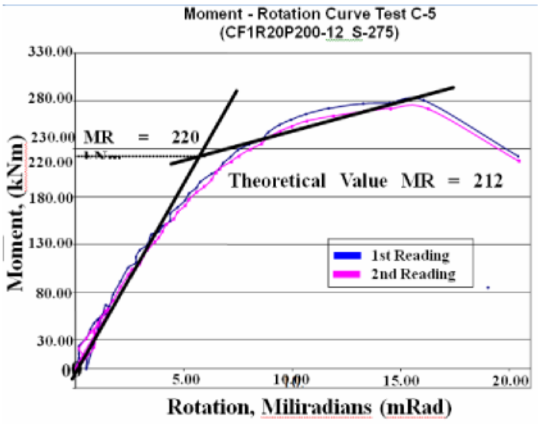
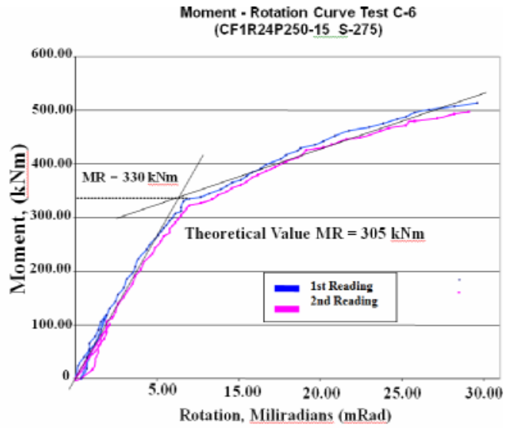
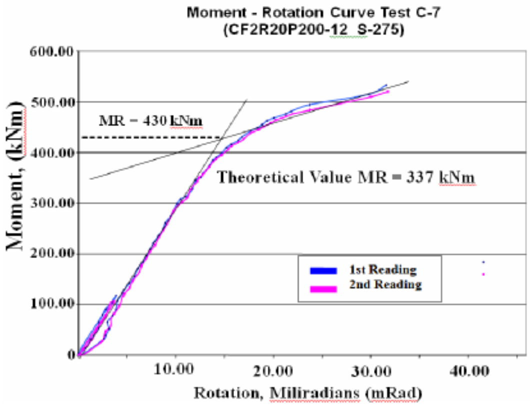
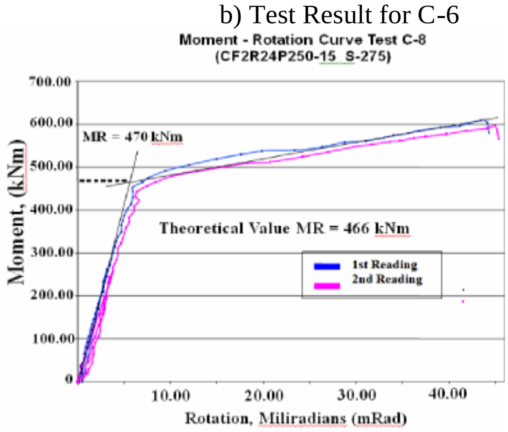



a) Test Result for C-5 b) Test Result for C-6




a) Test Result for C-7 b) Test Result for C-8

Figure 4.3: Moment – Rotation (M-$\phi$) of composite connection using flush end plate

By adopting this technique, the experimental values of MR for the overall composite joint for the tests were established. For curves which do not clearly show a linear region, an assumed straight line was drawn parallel to the unloading region traced from the exact M-$\phi$ curves.

The results of the moment resistance of composite connection were also compared with the moment resistance of composite partial strength connection. The moment resistance of composite connection was established by applying the component method proposed by Steel Construction Institute. The comparison of the results was shown in Table 4.1. From the results, the use of proposed composite connection for TWP section has shown an increment of the moment resistance of the connection.

The graphs showed that the connections behaved linearly in the first stage followed by non-linear behaviour and gradually losing the stiffness with the increase in rotation. The overall results showed that the experimental values of moment resistance were giving the values with the ratio ranged in between 1.01 to 1.23 as shown in Table 4.1.

The specimens C-5, and C-8, the form of deformation was the translation of the tip of the endplate away from the face of the column followed by a slight elongation of reinforcements bar pn the top and a slight buckling of the web around the tension region of the connections. This failure mode is usually referred to failure mode. Figure 4.1 dan Figure 4.2 has shown the failure mode of composite connection. Bigger beam of specimen might have caused the small deformation around

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the endplate.

Table 4.1: Test result based on the moment versus rotation plots

| Specimen Name | Moment, $M_U$ (kNm) | Rotational, $q_C$ (mRad) | | Failure Mode |
|---|---|---|---|---|
| C-5 | 220 | 6.5 | 1.04 | Concrette Cracks, Reinforced Concrete Yielding |
| C-6 | 330 | 9.2 | 1.08 | Concrette Cracks, Reinforced Concrete Yielding |
| C-7 | 430 | 16.8 | 1.23 | Reinforced Concrete Yielding then Slight Endplate Yielding |
| C-8 | 470 | 5.7 | 1.01 | Reinforced Concrete Yielding then Slight Endplate Yielding |

All the results of the all test are shown in Table 4.1 shows the plots of moment versus rotation for composite connections using the FEP, while Figure 4.1 show the plots of moment versus rotation for the four composite isolated tests using Flush Endplate connections. It was noticed that all the fourth specimens of the composite isolated tests failed due to the elongation of reinforcement bar that casuses failure of the connectins. The moment capacities, on the other hand, are 220 s/d 470 kNm. These values $\frac{M_U}{M}$ are between the 1.04 and 1.23, which categorise the connections as partial strength connections.

## CONCLUSIONS

This study concluded that it is possible to determine the moment resistance of composite flush end plate connections connected to a column flange by adopting the method proposed by SCI, even for different geometric parameters such as TWP section. The capacities of the connection depends on the geometrical aspects of the connection such as the size of bolt, number of bolt, size of end-plate, thickness of end-plate, size of beam, size of column and the size and number of reinforcement. Based on the results obtained, several observations have been made which lead to the following conclusion:

1. The Compote flush endplate connection gives a significant value of initial stiffness, however the bigger beam with more bolts of the connection has more moment capacity of the connection.
2. The failure mode for the composite flush endplate in the isolated tests has shown that endplate yielding after the failure of concrete rebar.
3. The deflection of the composite connection specimens has shown that the rotation of the failur is small due to the composite connection.

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