KEJURUTERAAN AWAM
50 Tahun Selepas Kemerdekaan

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Moment Resistances of Extended Endplate Connections with Trapezoid Web Profiled Steel Sections as Beams

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Abstract

Conventionally, steel frames are designed either using the approach of simple construction or continuous construction. Apparently, there is another alternative approach that has been recognized and encouraged by the standards (BS 5950 and EC 3) called the semi-continuous construction, which is usually associated with the use of partial strength connections. The beam-to-column joints are generally formed using end-plate connections (either flush or extended), hot-rolled universal columns, and hot-rolled universal beams. In this investigation, Trapezoid Web Profiled (TWP) sections were used as beams and extended endplates were used as connections. A series of experimental test was set up to study the moment rotation relationships of extended endplate connections with TWP beams under monotonic loading. This paper presents findings on the behaviour of partial strength joints in term of the moment capacities of the extended endplate connections. The experimental results were validated by theoretical results establish based on the 'component' method suggested by Steel Construction Institute. The development of the component method was in line with the code of practice of EC 3 and BS 5950:2000 Part 1. The results indicate that the moment capacities, obtained from the experimental investigation using the conservative 'knee-joint' method, are higher than the theoretical values. Therefore, it can be concluded that the proposed extended end-plate connection has met the requirement of partial strength connection and suitable to be used in semi-continuous construction.

Keywords: Extended End-plate Connection, Beam-to-Column Connection, Trapezoid Web Profiled, Semi-Continuous Construction, Partial Strength Connection.

1.0 Introduction

Conventionally, steel frames are designed whether as pinned jointed or rigidly jointed. When designed as pinned jointed, the beams are assumed simply supported and the columns are assumed to sustain axial load and nominal moments (moments from the eccentricities of beam's end reactions). The connection is simpler but the size of the beams obtained is bigger. On the other hand, rigidly jointed frame results in bigger columns due to higher end moments and a more complicated connection.

An approach, which creates a balance between the two extreme approaches mentioned above, has been introduced. The approach is termed as the semi-rigid design. Here, the semi-rigid design offers a more realistic behaviour of steel frame. A certain degree of rotational stiffness is assumed but full continuity is achieved by the connections. By using this approach, the steel frame can therefore be designed economically.

The introduction of hybrid sections as beams contributes further to the economic aspects of steel frame. By the same token, a beam with trapezoidally corrugated web called Trapezoid Web Profile (TWP) is introduced with the semi-rigid design of connection in the semi-continuous construction.

1.1 Research development

The interest in the behaviour of connection has dated back to 1917 when Wilson and Moore conducted an experiment on riveted structural connection. The interest in semi-rigid action and behaviour started after 1970s of which noticeable works were reported. [Chen et. al.(1989), Abdalla et. al (1995), Davison et. al. (1988), Jaspart, (2000)].

One of the earliest experiments on corrugated web profiles was carried out in 1956 by Fraser who investigated the strength of multiweb beams. In 1969, Easley and McFarland made several experimental investigations on shear diaphragms of panel with trapezoidally corrugated webs. In Sweden, the studies on buckling behaviour of trapezoidally corrugated webs were carried out at Chalmers University of Technology by Luo et. al (1995). Beams and girders with trapezoidally corrugated webs have been investigated also in the United States. [Elgaaly et. al. (1996, 1997)]. In Malaysia, studies on the matter were mostly carried out since 1998, but similar to other previous works, concentrated only on the individual capacities such as shear, bending, local flange buckling, lateral beam buckling, stability of column, foundation pile capacity, fatigue and composite floor system [Osman (2001)].

A study on partial strength connections, which usage has been encouraged by BS 5950 (2000) and EC 3 (1992), were carried out by Md Tahir (1995) using hot rolled sections as beams. The study indicates that significant savings of the total frame weight could be achieved if partial strength connections are used. In this study, the behaviour of partial strength endplate connections with Trapezoid Web Profiled (TWP) sections as beams is studied.

2.0 Background

2.1 Type of connection

Extended endplate connection consists of an endplate welded to the cross-sectional face of a beam in the workshop, and bolted to the column on site. The endplate is usually extended above the top flange of the beam to accommodate another row of bolts, though the bottom part could also be extended if the joint is expected to sustain reversal of moment. This type of connection can provide some 30% to 50% the capacity of the connected beam, which is suitable for the semi-continuous construction [SCI (1996)]. For this reason, the connection is also referred to as the partial strength connection. A typical extended endplate connection is shown in Figure 1.

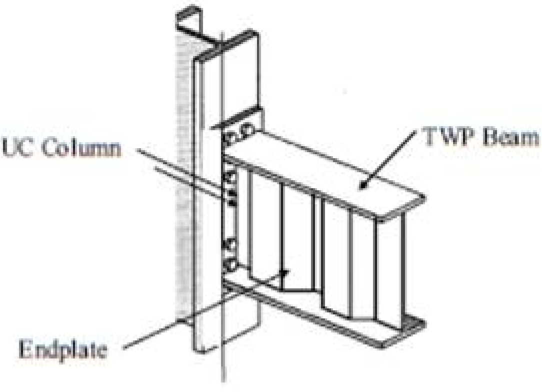


Figure 1: Extended endplate connection with TWP section

2.2 Theoretical behaviour

The moment transmitted by an extended flush end plate connection is through the coupling action between the tension forces in bolts and compression force at the centre of the bottom flange. Each bolt above the neutral axis of the beam produce tension force whereas the bolts below the neutral axis are dedicated to shear resistance only. EC 3 suggests that the bolt forces distribution should be based on the plastic distribution instead of the traditional triangular distribution. Figure 2 shows the forces in the connection and the corresponding plastic distribution.

According to SCI's (1996) publication, the capacities of each critical zone must be checked. The process involved can be considered iterative. In tension zone, the resistance of each bolt is calculated one row at a time and the lesser of the force will be chosen. These checks are: beam and column web tension, and endplate and column bending and bolt strength. As for the compression zone, typical web bearing and buckling are checked. The horizontal panel shear forces are then checked for shear zones. As for vertical shear on bottom bolts, the effect is not critical and assumed adequate.

2.3 Theoretical moment capacity

The moment capacity of connection is calculated by multiplying each bolt forces with the lever arm measured from the centre line of the bottom flange of beam.

$$M_c = \sum \left(F_{ri} \times h_i \right) \quad \text{Eqn.(1)}$$

3.0 Experimental works

The experiment is designed to study the behaviour of extended endplate connection in term of the moment-rotation relationship. A series of four arrangements of extended endplate connection were tested. Depending on the size of the beam, two sizes of endplates were used which are 200 mm x 12 mm and 250 mm x 15 mm. The thinner plates, which are for smaller beams, were connected using M20 8.8 bolts whilst the thicker plates, which are for larger beams, were connected using M24 8.8 bolts. The thickness of the weld connecting the flange and the web of beam to the end plate are 10 mm and 8 mm respectively. The details of the four arrangements are given in Table 1. Figure 2, on the other hand, shows the configuration of the extended endplate connections.

Table 1: Details of specimen

Elements	Specimen Name	Size
TWP Beam	E2R20P1	400x140x39.7/12/4
	E3R20P1	450x160x50.2/12/4
	E2R24P2	500x180x61.9/16/4
	E3R24P2	600x200x80.5/16/6
UC Column	All	305x305x118
End-plate/Bolt	E2R20P1	200 x 12/M20 8.8
	E3R20P1	200 x 12/M20 8.8
	E2R24P2	250 x 15/M24 8.8
	E3R24P2	250 x 15/M24 8.8
Weld	All	12 mm to beam's flange and 10 mm to beam's web

With the exception of the rotational inclinometer, all of the other devices were connected directly to the data logger. The rotational values of the beam and column were recorded manually from the digital display unit of the rotational inclinometers. One inclinometer was mounted midway at the web of the beams at a distance of about 100 mm from the face of the column flange. This inclinometer provided the rotational values of the beam, ϕ_b, upon loading. The other inclinometer was placed at the centre of the column panel shear thus provided the rotational values of the column, ϕ_c. The overall rotation of the joint, ϕ, was then taken as the difference between ϕ_b and ϕ_c.

$$\phi = \phi_b - \phi_c \qquad (2)$$

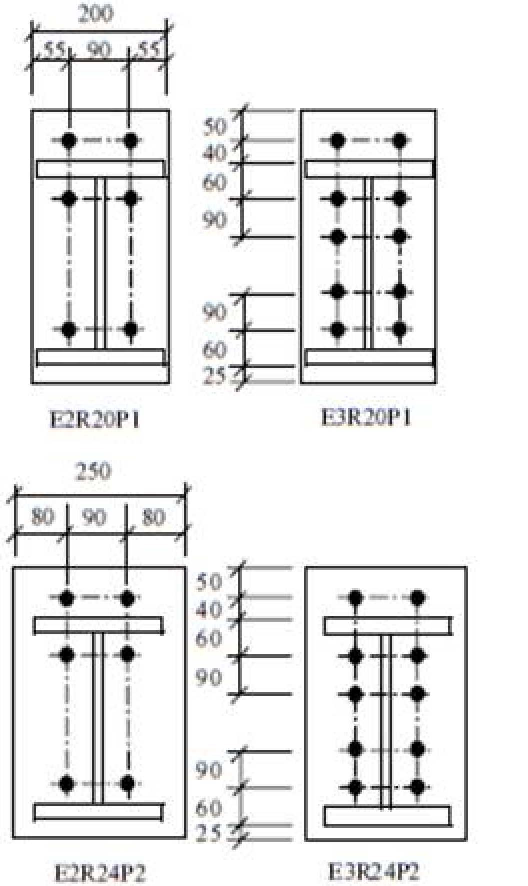


Figure 2: Configurations of endplate connections

Linear variable displacement transducers (LVDTs), which are used to measure the linear displacements along the beam and the column, were placed at several specified locations. Besides measuring the deflections of the beam and the translations of the column, measurements obtained from LVDTs can also be used to determine the rotations of the joint. The loads were applied on the beam by using a single inlet hydraulic jack and measured by a load cell. Figure 3 illustrates the set-up and layout of the arrangement adopted for the experiment showing the locations of the column, beam, inclinometers, LVDTs, hydraulic jack, and load cell. The load was applied at a distance of 1.3 m from the face of the column with an increment of 5 kN for all tests. Figure 4, on the other hand, shows the test rig devised to carry out the experiment.

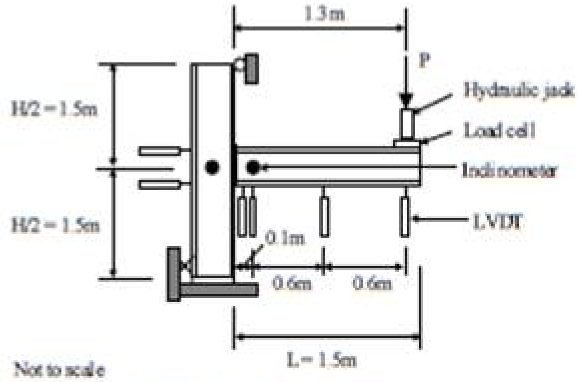


Figure 3: Test set-up

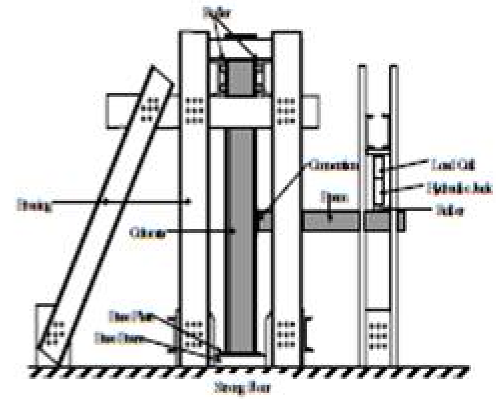


Figure 4: Test rig

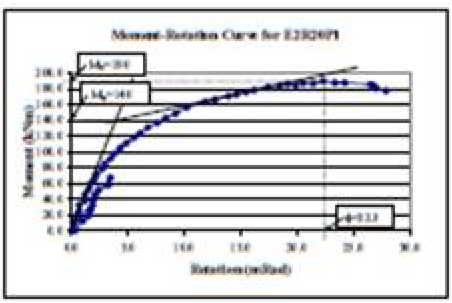
4.0 Results and Discussion

A computer program was designed using excel spreadsheet to determine the moment resistance for each connection. All steps involved and procedures for checking capacities in each critical zone were based on the 'component' method as described in the SCI's publication (1996).

Experimentally, the result obtained, in this case, the absolute rotation of the beam with respect to the column was plotted against the moment applied to the connection. Figure 5 shows the individual moment-rotation curves plotted for each of the extended endplate connections. The experimental value of moment resistance of the connection, M_R was determined using the so-called 'knee' method. In this method, a tangent line representing the linear elastic region is drawn on the curve from the origin. Another tangent line is also drawn on the curve to represent the non-linear region. The intersection of the two lines then can be taken as the value of the moment resistance of the connection as shown in the figures.

Each curve shows that the connection behaved linearly at first before changing into a non-linear behaviour. Then, gradually, the connection started losing the stiffness with the increase of rotation. Fig. 6 illustrates the moment-rotation relationships for all of the extended endplate connections. From this figure, it is clearly shown that the rigidity of an endplate connection increases as the number of bolts, the endplate size and the diameter of bolt increases. As for the moment resistances, the values obtained experimentally are higher than the theoretical values in the range of 1.14 to 1.46 when normalized. Table 2 list in details the results obtained.

The failure mode of the first and second specimen was endplate yielding. But, for the third and fourth specimen, besides the endplate yielding, a slight slipping of bolts at the top was noticed.



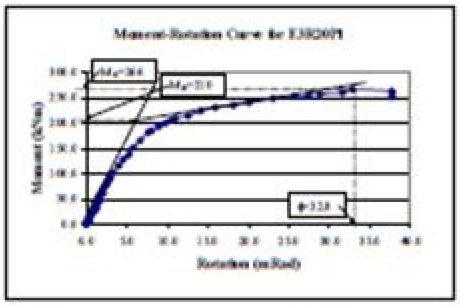
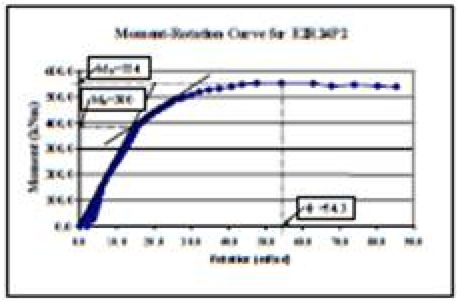


Figure 5: Individual moment-rotation relationships



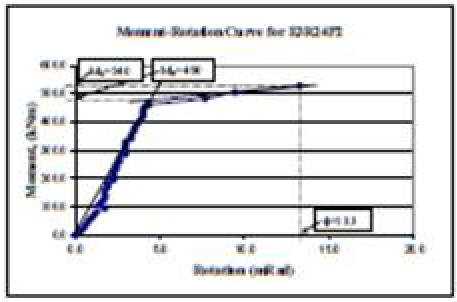


Figure 5 (Cont.): Individual moment-rotation relationships

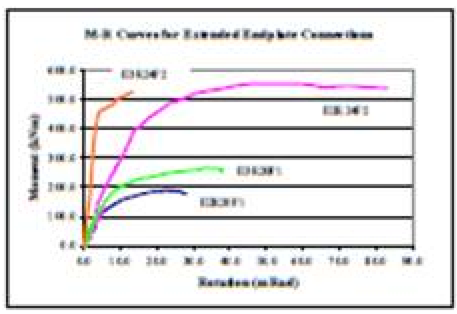


Figure 6: Moment-rotation relationships for all connections

Table 2: Summary of results

Specimen Name	M_R (T)	M_R (E)	M_U (E)	M_R(E) /M_R(T)	M_U(E) /M_R(T)
E2R20 P1	123	140	190	1.14	1.54
E3R20 P1	180	210	266	1.17	1.48
E2R24 P2	261	380	554	1.46	2.12
E3R24 P2	413	490	540	1.19	1.31

M_R – Moment Resistance, M_U – Moment Ultimate

T – Theoretical, E – Experimental

5.0 Conclusions

This study indicates that it is possible to predict the moment resistance, M_R of partial strength extended endplate connections with TWP sections as beams by adopting the method proposed by SCI (1996), even for different geometric parameters. Ductility was also assured based on the modes of failure observed and the amount of rotation recorded. The overall results of the moment resistances obtained experimentally in comparison to the theoretical values show an increase in the range of 14% to 46%. And if the values of moment ultimate are compared, the differences are even more.

Therefore, it can be concluded that the proposed extended end-plate connection has met the requirement of partial strength connection and suitable to be used in semi-continuous construction.

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