The 1st International Conference of

European Asian Civil Engineering Forum EACEF

The future development in civil engineering based on research and practical experience.

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26 - 27 September 2007
at the Universitas Pelita Harapan,
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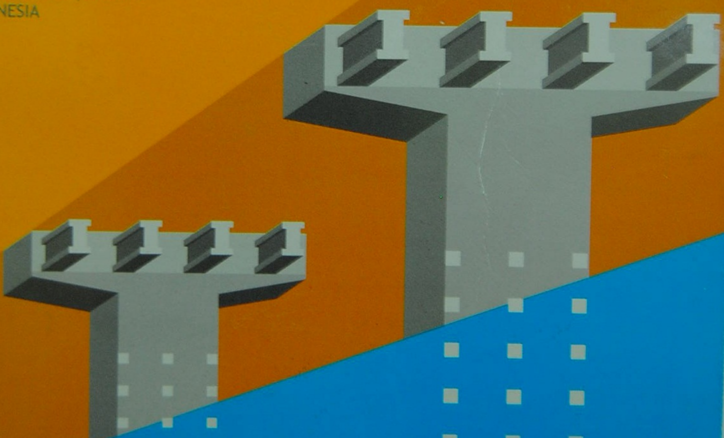
INDONESIA



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Abstract

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STANDARDISATION of PARTIAL STRENGTH COMPOSITE CONNECTIONS USING PRE-FABRICATED STEEL SECTIONS

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ABSTRACT: Connections are usually designed as pinned which associated with simple construction or rigid which is associated with continuous construction. In actual situation, the connections behaviour falls between these two extreme cases. The use of partial strength or semi-rigid connections has been encouraged by Eurocode 3 and studies on the matter known as semi-continuous construction have proven that substantial savings in steel weight of the overall construction. Composite connections have been introduced in this paper to improve the performance of partial strength connection. The objective of this paper is to present the behaviour of full scale testing on standardized partial strength flush end-plate composite connections using pre-febricated section known as trapezoidal web profiled steel (TWP) sections. A method known as "component method" was introduced by SCI to predict the moment resistance of the connection. The results also showed that the proposed composite connection for the Trapezoid Web Profiled Steel Sections has a ductile behaviour and the connections can be categorized as partial strength connections which is suitable for semi-continuous construction.

KEYWORDS: Composite Connections, Partial strength, Moment Capacity, Beam-to-Column connection, Trapezoid Web Profiled Section, Semi-Continuous Construction.

1. INTRODUCTION

The use of composite beam in buildings has known to increase the loading capacity and stiffness of the composite construction. The benefits of composite beam action result in significant savings in steel weight and reduce the depth of the beam. To obtain more economical structural design against the bare steel beams, composite beam was designed by taking the advantage of incorporating the strength of concrete slab by the use of headed studs. The composite action due to the interaction of steel beam and concrete slab with shear connectors increases the load-carrying capacity and stiffness of composite beam. These advantages of composite beam contributed to the dominance of composite beam in the commercial building in steel construction industry. The advantages of composite construction have been further extended with the use of composite connection. This composite connection enhanced further the stiffness of the connection and increases the weight saving of the design of composite beam (SCI 1996). Traditionally, steel frames are designed either as pinned jointed or rigidly jointed. The beams are assumed as simple supported with pin jointed connections and the columns are assumed to sustain axial and nominal moment (moment from the eccentricities of beam's end reactions) only. The connection is simple but the sizes of the beams obtained from this approach result in heavy and deep beam. On the other extreme, rigidly jointed frame results in heavy columns due to the end moments transmitted through the connection. Hence, a more complicated fabrication of the connection could not be avoided.

One alternative which creates a balance between the two extreme approaches mentioned above has been introduced. This approach, termed as partial strength composite connection is usually associated with a connection having a moment capacity less than the moment capacity of the connected beam (SCI 1996). Partial strength composite connection is the term used for connection in the design of semi-continuous construction for multi-storey steel frames by Eurocode 3 (CEN 1992) where the strength of reinforcement embedded inside the concrete slab was taken into account in improving the moment capacity and stiffness of the connection. In semi-continuous frame the degree of continuity between the beams and columns is greater than that in simple construction design but less than that in continuous construction design. The degree of continuity in the use of partial strength connection of beam to column can be predicted to produce an economical beam section that representing the section between pin joint and rigid joints (Chen and Kishi 1989). By adopting this approach, studies conducted on the use of partial strength connection have proven substantial savings in overall steel weight (Tahir 1995) (Couchman 1997). This is possible as the use of partial strength has contributed to the benefits at both the ultimate and serviceability limit states design. However, the use of partial strength composite connections for Trapezoidal Web Profiled sections has not been established yet. To establish the study of the use of TWP sections with partial strength connection standardized partial strength composite connections tables need to be established first. Therefore, this paper intends to establish the standardized tables for partial strength composite connections for TWP sections based on the proposed method by SCI (SCI 1996) (Husin (2000).

2. PRE-FABRICATED TRAPEZOIDAL WEB PROFILED (TWP) STEEL SECTION

A trapezoid web profile plate girder is a built-up section made up of two flanges connected together by a thin corrugated web as shown in Figure 1 (Osman 2001) (Hussein 2001). The introduction of corrugated web is to eliminate the use of stiffener along the beam due to load bearing and point load (Luo 1995). However, further checks need to be carried out for heavier load bearing. The web is corrugated at an angle of 45 degree and welded to the two flanges by automated machine. The web and the flanges comprised of different steel grade depending on design requirements. TWP section is also classified as a hybrid steel section as two different types of steel grade were used in the development of the section. The steel grade of the flanges is designed for S355 and the steel grade of the web is designed for S275. The flanges are purposely designed for S355 so that the flexural capacity of the beam can be increased and the web is designed for S275 so as to reduce the cost of steel material. The capacity of shear is usually not that critical in the design of the beam (Hussein 2001). The use of different steel grades in the fabrication of TWP section leads to further economic contribution to steel frames design besides the use of partial strength connection. The use of thick flanges, thin corrugated web and deeper beam for TWP section compared with hot-rolled section of the same steel weight leading to heavier load capacity and greater beam span that can be achieved.

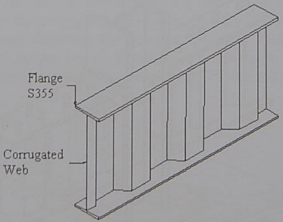

Figure 1 The drawing of TWP section.

2.1. Advantages of TWP Section

The advantages of TWP section as compared to the conventional plate girder or hot rolled steel section include the following (SCI 1998):-

- Utilization of very thin web with minimum thickness of 3mm reduces the weight and the tonnage of the steel.
- Elimination of the need of stiffeners as a result of corrugated shape reduces the fabrication cost.
- The use of high strength steel S355 for flanges and deep beam leads to higher flexural capacity, wider span and less deflection.

Based on the configuration of the structure, TWP beam can offer substantial saving in the steel usage, and in some cases up to 40% as compared to conventional rolled sections (Osman 2001) (Hussein

2001). The advantages of use of TWP sections are more significant when there is a need for a column free, long span structural system, such as portal frames for warehouses, girder for bridges, floor and roof beam for high-rise buildings, and portal frame for factory.

3. ASPECT OF PARTIAL STRENGTH CONNECTIONS

In the design of braced multi-storey steel frames, the steel weight of the connections may account for less than 5% of the frame weight; however, the cost of the fabrication is in the range of 30% to 50% of the total cost (SCI 1996). The increase in the fabrication of the connections is due to the difficulty in selecting the type of connection, the grades and sizes of fittings, bolt grades and sizes, weld types and sizes, and the geometrical aspects. For composite connection, the size of reinforced bar and the capacity of moment and shear should be established in the standardized tables to ease the design engineers to use the proposed connection. Therefore, a standardized partial strength composite connections tables should be available with details of the geometrical aspects to cater for the problems arise due to so many uncertainties in the fabrication of the connections. Although the advantages or benefits of using the partial strength connections are quite significant, the disadvantages of this approach should also be addressed. The disadvantage in this approach is that it may be marginally more expensive, depending on the cost of labour paid which varies between Europe and Asian countries to fabricate partial-strength connection rather than simple connections. In Malaysia where the cost of labour is relatively low compare with the Europe, the use of proposed connections will be an added advantage. The benefits of overall cost saving of the partial strength connections have proven to be more than simple connections (Tahir 1995) (Couchman 1997). It is reported that the savings in steel weight of using partial strength connection alone (non-composite) in multi-storey braced steel frames using British hot-rolled section was up to 12% (Tahir 1995). The overall cost saving was up to 10% of the construction cost which is quite significant (Tahir 1995) according to the cost of labour in the United Kingdom. However, further percentage savings are expected with the use of partial strength composite connection as the moment capacity and stiffness of the connection increases. Figure 2 shows the TWP section with shear connectors that are typically used in the design of composite beam and composite connection.

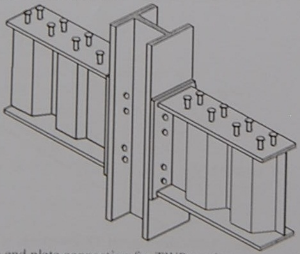

Figure 2 Typical flush end plate connection for TWP section connected to hot-rolled column

4. DESIGN OF COMPOSITE CONNECTION

The design philosophy presented in this paper was adopted from 'component approach' described in SCI (SCI 1996) (CEN 1992) (Husin 2000). The moment capacity of the connection was determined by considering the capacity of each relevant component such as the tensile of the top bolt row and the tensile capacity of the reinforcement bar anchored inside the concrete slab. The composite connection capacity was also checked to meet the requirement of BS 5950:2000 Part 1 (BSI 2000). The moment resistance of the connection was developed by coupling tension force in the reinforcement and the upper bolt with the compression of the beam flange to the column at the lower part of the beam. The lever arm to calculate the moment capacity was established by considering the distance between the components of the tension zone and the compression zone.

4.1. Tension Zone

The tension zone comprised of three components that govern the magnitude of the tensile force which contributed to the moment capacity of the connection. These three components are listed as the reinforcement bar, the upper row of bolts and the longitudinal shear force.

4.2. Compression Zone

The strength of the compression capacity of the connection relied on the flange and web of the lower beam and on the resistance of the column web. The failure modes on compression zone are due to crushing or buckling of the column web or on the flange or web of the lower beam. This compression zone however, did not design for the use of stiffener at the web of the column so as to reduce the cost of fabrication. Therefore, the calculated value of moment resistance in the tables developed for TWP section is only for unstiffened column web.

5. STANDARDISED TABLE FOR COMPOSITE FLUSH END-PLATE CONNECTIONS

The use of partial strength connection for hot-rolled British sections has well established by SCI (SCI 1996). A series of tests at the University of Albertay, Dundee was successfully been carried out to verify the predicted moment and shear capacity with the experimental tests capacities (Bose 1993). The results confirmed with the predicted values and the standardized tables for the connection have been published by SCI (SCI 1996) (Jaspart 2000). However, these tests were carried out for hot-rolled steel section and the connection is a non-composite connection. In this paper, the connection is categorized as composite connection and the sections used were TWP sections. In the development of standard flush end-plate composite connections tables for TWP sections, only one table is presented in this study. Other tables with different geometrical configuration are published elsewhere (Saggaff, 2006).

Figure 3 shows a typical composite flush end plate connection for TWP section as composite beam with steel decking and reinforcement bar connected to British hot-rolled section as column. British section is selected for the column as it is very good in compression which is not the case for TWP section as the web of TWP is too thin to sustain crushing force from the flange of the beam. TWP section is proposed for beam as the corrugated web section is very effective to cater for buckling and bearing resistance. The minimum thickness for corrugated web is 3mm for shallow beam and the maximum thickness is 6mm for deeper beam. The ratio of beam depth versus web thickness is kept not to exceed the limit for compact section as described by BS5950:2000 Part 1 (BSI 2000).

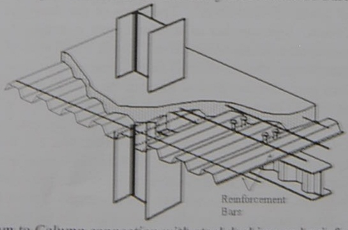

Figure 3 TWP section Beam to Column connection with steel decking and reinforcement bar embedded in the web

5.1. Notation Used In the Proposed Capacity Tables

A spread sheet has been developed to calculate the moment and shear resistance of the standardized connections, based on the critical zones checks as in Fig. 4 and method proposed by SCI as described earlier. Details of formulation and calculation are described elsewhere (SCI 1996) (Husin 2000). The development of the standard tables for the connections is tabulated in Table 1. Compression zone at bottom flange of beam was found to control the failure mode of the connection. The compression value at the bottom flange (P_c) is equal to the area of cross section of the bottom flange of the connected beam multiplied by $1.2p_y$ as explained earlier. This calculated compression value should be bigger than the summation of forces in the tension zone so that premature failure can be avoided. These forces came from the reinforcements noted as (F_{reinf}) and forces of bolts noted as (F_{r1} + F_{r2}) in the tables. The moment resistance from the proposed table was calculated from the summation of each reinforcement and bolt row multiplied by the lever arm of the connection. The lever arm for the first tension bolt row which is defined as distance measured from the centre of compression capacity to the tension reinforcement bar noted as 'A_r' in the tables. For the tension bolt row it is measured as a distance from first tension bolt row to the centre of compression beam flange noted as 'A' in the tables. The moment that form from the tension reinforcement and the tension bolt row is added together to establish the moment resistance of the partial strength composite connection. This moment resistance is designated as M_c in the tables. If the summation of the tension forces is greater than the compression forces, the moment resistance of the connection was designated as dashed (-) in the tables, meaning that the moment resistance for stiffen connection is not available.

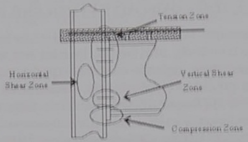

Figure 4 Critical zones that need to be checked for failures

5.2. Geometrical configuration of the connection

The dimensions of the end-plate are noted as B_p for width and T_p for thickness of the end-plate. All flanges and web of beam attached to the end-plate are to be fully welded with minimum fillet weld of size 10mm for flange and 8mm for web. This is to ensure that the mode of failure does not occur at the welding. The design strength of the flange and web of TWP section is designated in the bracket (as F_t – Web – F_b) where F_t and F_b is S355 steel grade and Web is S275 steel grade. The size of TWP sections is designated as D for depth, B for width, W for weight per metre length, T_f for thickness of flange, t_w for thickness of web. For the reinforcement use in the tables, the design strength of the steel is noted as T460 for steel grade of 460N/mm^2. The sizes of the diameter of the reinforcement are given as T12mm and T16mm. The number of reinforcement is assigned as 4D-12 meaning that 4 number of reinforcement is used with the diameter of 12mm. The area of the reinforcement is also given and converted to percentage of area of steel in concrete as shown in the tables. Beneath this percentage row is the values given for the tension force of the reinforcement. The tension force of the bolts is noted as F_{r1} and F_{r2}. The number and size of reinforcement will determine the moment resistance of the connection. Therefore, the tables are divided into column from A to H to differentiate the moment resistance of the connection due to the change in the size and number of reinforcement. If the column has a smaller capacity, the reduction of bolt force is shown in the table. A modified moment resistance is calculated by using this reduction value which result in smaller value. A bracket ( ) in compression zone indicates that the column web has a greater compression capacity than the sum of the bolt row forces. The values given in the tables were the moment resistance of composite connection where no stiffener needed for the column web.

6. CONCLUSIONS

This study concluded that it is possible to determine the moment capacity of 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 and size of column. For the size of column, the reduction of moment capacity is due to the effect of compression of the beam flange to the column flange without the need of stiffener. The suggested weld size for flange and web is strong enough to prevent any failure at the weld. It can be concluded that the proposed composite connection for the Trapezoid Web Profiled Steel Sections has a ductile behaviour and the connections can be categorized as partial strength connections which is suitable for semi-continuous construction.

7. ACKNOWLEDGEMENT

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8. REFERENCES

Bose, B. (1993), "**Tests to verify the performance of standard ductile connections**", Dundee Institute of Technology.

British Standards Institute BS 5950-1, (2000), "**Structural Use of Steelwork in Building Part 1: Code of Practice for Design – Rolled and Welded Sections**", British Standards Institution, London

British Standards Insitution, (1997), "**BS 8110: Structural use of concrete. Part 1: Code of practice for design and construction**", BSI, London.

British Standards Insitution, (1994), "**DD-ENV 1994-1-1: 1994 Eurocode 4: Design of composites steel and concrete structures Part 1.1 General rules for buildings**", CEN, Brussels.

Couchman, G.H. (1997), **Design of Semi-continuous Braced Frames**, Steel Construction Institute Publication 183, Silwood Park, Ascot, Berkshire SL5 7QN, U.K

Eurocode 3, (1992), "**Design of Steel Structures: ENV 1993-1-1: Part 1.1: General Rules and Rules for Buildings**", CEN, Brussels.

Husin, A. (2000), "**Performance of steel joints on major axis for steel frames using locally produced steel sections**", Civil Engineering Faculty, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia, M.Phil. Thesis.

Hussein, W.Q. (2001), "**Design Guide for Steel Plate Girder with Corrugated Webs (TWP)**", Presentation in Design of Steel Structure Short Course, TWP Sdn Bhd.

Jaspart, J.P. (2000), "**General Report: Session on Connections.**", Journal of Constructional Steel Research, Vol. 55, pp 69-89.

Luo, R. (1995), "**Load Carrying Capacity of Steel Girders and Panels with Thin-Walled Trapezoidally Corrugated Webs.**", Compilation of Papers. Chalmers University of Technology, Sweden.

Osman, M.H. (2001), "**Performance Test and Research on Trapezoid Web Profile**", Presentation in Design of Steel Structure Short Course, Universiti Teknologi Malaysia.

Saggaf, A. (2006), "**Economic aspects of composite partial-strength connection in semi-continuous construction for multi-storey braced steel frame using TWP sections**", Ph.D Thesis, to be submitted 2006, Civil Engineering Faculty, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia.

Steel Construction Institute and British Constructional Steelwork Association, SCI P213 (1998), "**Joints in Steel Construction Composite Connections**", Silwood Park, Ascot, Berks SL 7QN, London.

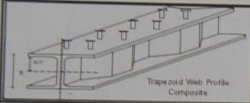
Steel Construction Institute and British Constructional Steelwork Association, (1996), "**Joints in Steel Construction. Volume 1: Moment Connections**", London.

Tahir, M.M. (1995), "**Structural and Economic Aspects of The Use of Semi-Rigid Joints in Steel Frames**", PhD Thesis. University of Warwick, United Kingdom.

Table 1 : Standardised Table for CFEP-1BRM20-EP200-12

STANDARDISED TABLE – TWP STEEL COMPOSITE CONNECTIONS
(CFEP-1BRM20-EP200-12)

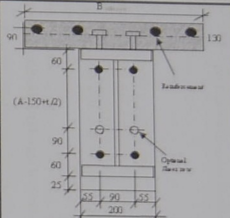
Beam Side



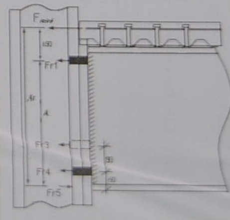
Moment Resistance of Composite Connection (Mcc)

1 ROW M20 8.8 B0LTS
FLUSH END PLATE 200 X 12
GRADE S-275

$A_{bolt} = 585\ mm^2$
$f_y = 355\ N/mm^2$
$\sum Fr_1 = 208\ kN$
$\sum Fr_2 = 0\ kN$



Vertical Shear Capacity
without shear row = 258 kN
with shear row = 442 kN



TWP - Beam Size (F_t – Web – F_b) (355 – 275 – 355)			Flush End Plate		Dimension		Reinforcement T12 f_y = 460				Concrete Grade 30	Reinforcement T16 f_y = 460				Bottom Flange Comp Capacity
							A	B	C	D		E	F	G	H	
							4 D-12	6 D-12	8 D-12	10 D-12		4 D-16	6 D-16	8 D-16	10 D-16	
							452 mm	679 mm	905 mm	1131 mm		804 mm	1206 mm	1608 mm	2011 mm	
							0.35 %	0.52 %	0.70 %	0.88 %		0.62 %	0.94 %	1.25 %	1.57 %	
							198 kN	297 kN	396 kN	495 kN		352 kN	528 kN	705 kN	881 kN	
D x B x W	T_f	t_w	B	T_p	'A'	'Ar'	M_{cc}	M_{cc}	M_{cc}	M_{cc}		M_{cc}	M_{cc}	M_{cc}	M_{cc}	$P_c=Fr_5$
mm x mm x kg	mm		mm		mm											kN
300 x 120 x 26.3	10	4	200	12	235	385	125	163	201	240		-	-	-	-	511.20
300 x 140 x 33.7	12	4	200	12	234	384	125	163	201	239		184	-	-	-	715.68
350 x 120 x 27.6	10	4	200	12	285	435	145	188	232	275		212	-	-	-	511.20
350 x 140 x 35.1	12	4	200	12	284	434	145	188	231	274		212	-	-	-	715.68
400 x 140 x 39.7	12	5	200	12	334	484	165	213	261	309		240	-	-	-	715.68
400 x 160 x 48.4	14	5	200	12	333	483	165	213	261	308		239	324	409	-	954.24
450 x 160 x 50.2	14	5	200	12	383	533	185	238	291	344		267	361	455	548	954.24
450 x 180 x 60.1	16	5	200	12	382	532	185	237	290	343		267	360	454	-	1226.9
500 x 160 x 52.0	14	6	200	12	433	583	205	263	321	379		295	398	501	602	954.24
500 x 180 x 61.9	16	6	200	12	432	582	205	263	320	378		295	397	500	495	1226.9
550 x 200 x 73.3	16	6	200	12	482	632	225	288	351	413		323	434	545	657	1363.2
600 x 200 x 80.5	16	6	200	12	532	682	246	313	381	448		351	471	591	711	1363.2