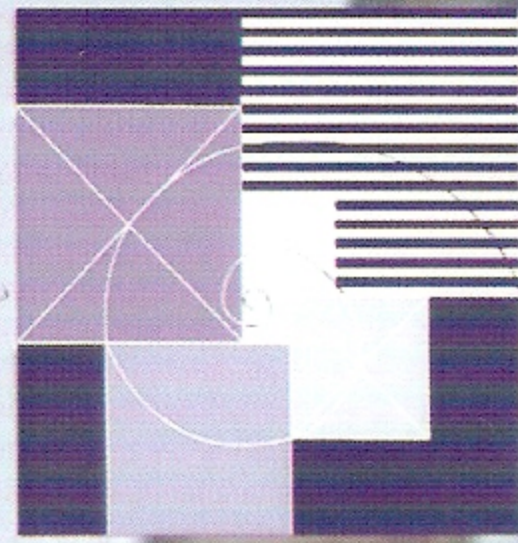# PROSIDING

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ECONOMIC ASPECTS OF PARTIAL STRENGTH CONNECTION IN THE DESIGN OF BRACED STEEL FRAME USING TRAPEZOID WEB PROFILED STEEL SECTIONS

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ABSTRACT

Eurocode 3 offers the opportunity to design steel frames as 'semi-continuous' by including the moment resistance of 'partial strength' connections in plastic hinge analysis of the frame. Compared to conventional pinned-jointed simple construction, semi-continuous construction with partial strength joints offers the benefits for braced frames such as shallower and lighter beams, standardized connections with less complicated geometry, and more robust frame than simple construction. It is expected to result in significant savings in frame weight. This paper presents findings on a series of two-bay and four-bay braced frames of two, four, six and eight storey with span ranging from 6m to 9m by comparing between simple construction design with semi-continuous construction design using trapezoidal web profiled steel section as a beam. The aim of this parametric study was to obtain the economical sizes for the beams, based on the minimum weight or lightest section of beams in particular, and columns. The aspect of economical in term of the total weight of frames was accounted only for the weight of the beams and columns. The weights of other components, for example the fittings, were assumed to be marginally small to affect the total weight of frames and were identical for all of the frames designed using either construction method. Trapezoidal Web Profiled (TWP) sections were adopted in both construction methods. However, the TWP section is only used for the design of the beam; the column section was designed using the universal column of British sections. Flush end-plate connections were used as partial strength joints whereas for simple construction, partial depth flexible end-plate connections were used as pin joints. The connections used were based on the standardised tables established by the authors using component method proposed by Steel Construction Institute. The design of beam and column was based on BS 5950:2000 Part 1. The results of the percentage weight savings are analysed and discussed base on the effect of increasing the beam span from 6m to 9m, the effect of using Flush end-plate, and the effect of increasing the number of bays. From the study, it was concluded that the percentage of savings using partial strength connection was in the range of 6.97% to 16.34% depending on the design variables.

Keywords: Braced frame, Trapezoid Web Profiled (TWP), partial strength connection, semi-continuous construction, simple construction, Universal Column (UC) section.

I. INTRODUCTION

Eurocode 3 (1992) offers the opportunity to design steel frames as 'semi-continuous' by including the moment resistance of 'partial-strength' connections in plastic hinge analysis of the frame. This is potentially both an economical and straightforward method of design, particularly when applied to end plate type connections. The connections are termed 'partial-strength' because their moment resistance is less than that of the con-nected beam.

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The connections are designed to be ductile, and thus possess adequate rotation capacity to act as plastic hinges. Semi-continuous construction of braced frames is expected to result in significant savings in frame weight (Anderson 1993)(Bjorhovde 1992) but the extent of the savings has been questioned (Girrardier 1994). The objective of this study was to make economic comparisons in terms of savings of steel weight for braced steel frames, comparing use of pinned beam-to-column connections (SCI 1992) with partial-strength joints (SCI 1995), for design of steel grade S275 using TWP steel section. All designs were in accordance with the load factors in BS 5950 Part1 (2000) to determine design loads typical on an office building (BSI 1985).

II. TRAPEZOID WEB PROFILED STEEL SECTIONS

Trapezoid Web Profiled steel sections is a built-up section comprised of two flanges made up of steel Grade of S355 and connected together by welding the thin corrugated web section (3mm to 8mm thick) made up of steel Grade of S275 to form an I-shaped section. This type of sections contribute to the steel weight savings of up to 40% compare with hot-rolled sections with the steel Grade of S275 as reported by Wail, (2001). Trapezoid Web Profiled (TWP) sections will be used as beam elements as the reports by Hanim (2001) have shown that TWP section was able to produce even more reduction in beam depths and steel weight. Figure 1 shows a typical TWP section, which is formed by welding the flanges to the trapezoidal corrugated web with thickness ranging between 3 mm to 8 mm thick.

Since the use of TWP sections in semi-continuous construction has not been utilized, studies on the connections and sub-assemblages of frames have to be conducted in order to understand the behavior and to incorporate the findings in the design of semi-rigid or partial strength connection in steel framing. This includes the aspects of moment resistance, rotational stiffness, and rotational capacity of the connections, and the overall structural behavior associated with the multi-storey braced frames construction. The shape of trapezoid web is designed to accommodate shear forces and to increase the crushing and buckling resistance of the TWP web. The size of the flange varies from 10mm to 60 mm thick with the width ranging from 100 mm to 500 mm.

The size of flange and the depth of beam will verify the moment capacity of the TWP beam. The depth of the TWP beam varies from 200 mm to 1600mm. The web and the flanges comprised of different steel grade depending on design requirements. The depth of the beam which can reach 1600mm deep is an added advantage to TWP section with greater moment resistance and longer beam span as compared with limited depth of hot-rolled section which can only reach up to 900mm deep.
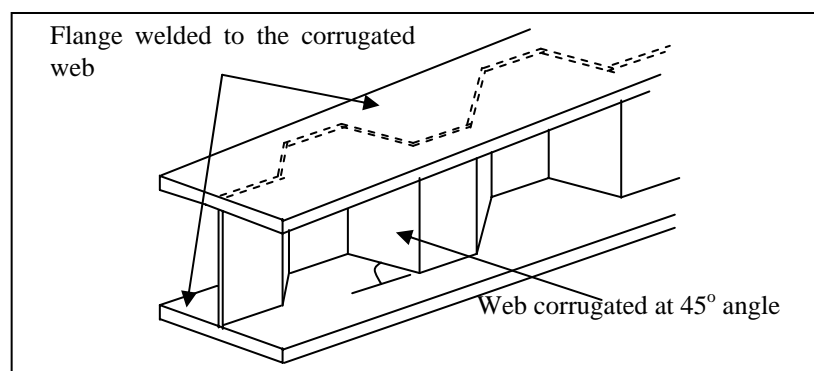

Flange welded to the corrugated web

Web corrugated at 45° angle

Figure 1. Cross section of trapezoid web profiled

III. SCOPE OF STUDY

A series of two-bay and four-bay braced frames, of two, four, six and eight storeys, was used to compare the two design approaches. The structure was assumed to comprise a series of plane frames at 6m centers. Floors and roofs were assumed to span this distance between the plane frames, and therefore the longitudinal beams were designed only to tie the frames together and to provide lateral restraint to the columns at each floor level. Figure 2 shows a general arrangement for a typical plane frame of two-bay, within a two-storey structure.
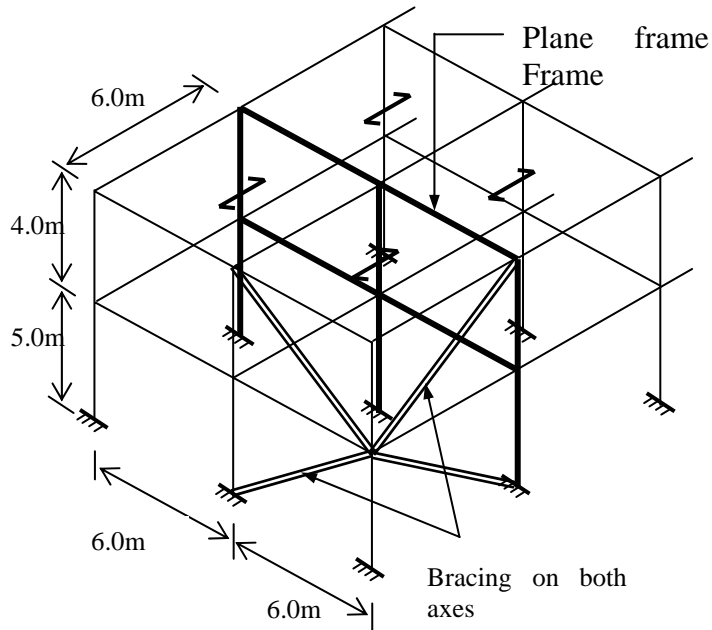

Figure 2 General arrangements for a typical plane frame of two-bay two storey

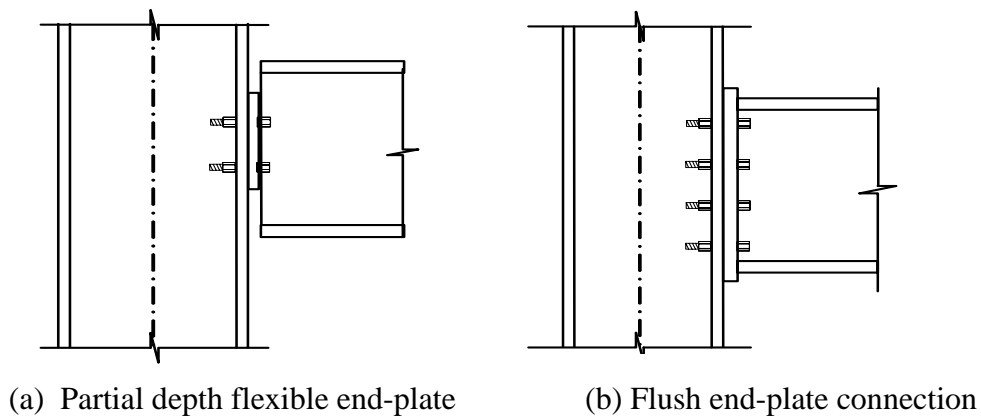(a) Partial depth flexible end-plate   (b) Flush end-plate connection

Figure 3. Typical connections for TWP beams

Figure 3 (a) and (b) show typical arrangements of partial depth flexible end-plate and flush end-plate connections. The selection of flush end plate is considered as it provides the benefit of maximum stiffness of the connection within the ductility constraint (SCI 1995). The flush end plate also provides a moment resistance in the range

30-50% of that of the connected beam. Only S275 steels were considered for the designed sections.

In general, there are three principal types of loading that need to be considered in the design of multi-storey framed buildings namely; dead loading, imposed loading and wind loading. However, in this study, the wind loading is assumed too small to affect the outcomes of the designs as most of the load is carried out by the bracing system. Described below is the derivation of the dead load and imposed load values that were subjected to the frames.

a) Dead load (for floor and roof)
      i) 150 mm thick
         Precast hollow core slabs   = 2.5 kN/m^2
      ii) Finishes   = 1.5 kN/m^2
    Total dead load   = 4.0 kN/m^2

b) Imposed load
      i) For floor (including partition)   = 4.0 kN/m^2
      ii) For roof   = 1.5 kN/m^2

For the ultimate limit state, loads should be multiplied by the appropriate load factors and combined with other loads to form load combinations. Typical load factors of 1.4 and 1.6 were used for the dead load and imposed load respectively. For the serviceability limit state, only the unfactored imposed load was considered in the calculation of beam's deflection as specified by the design rule (Clause 2.5.2) of BS 5950:2000 Part 1. Reduction in live load was made when a column supported more than one level, according to BS 6399 (1985).

For loading on columns, self-weight was approximated to be 5kN/storey. Self-weight from minor axis beams was taken as 25kg/m or 2.0kN for 6m frames. Load from brickwork and glazing was taken as 50kN, which is in accordance with the earlier SCI studies on savings in weight (Chung 1993), and was only applied to external column. A parapet 0.75m high was assumed at roof level.

IV. DESIGN APPROACH

Full-scale tests with the test rig was designed and erected with using columns 3 m height Computer software were prepared by the authors to analyse and design for both simple and semi-continuous construction. Two sets of computer programming were prepared. The first set was prepared to analyse and design simple construction frames with pinned joint. The second set was prepared to analyse and design semi-continuous construction frames with partial strength joint

1. Simple construction

This followed usual practice according to BS 5950:2000 Part 1. Hence, although the connections were de-signed for shear only, external column were designed for a nominal moment due to an assumed eccentricity in the application of beam end reactions. This was taken as 100mm from the face of the column. If a beam was not a roof beam, the moment was divided equally between the columns above and below (clause 4.7.7).

The effective length for both major and minor axes was taken to be 0.85L. All beams were subjected to uniformly distributed load, and the design moment in simple construction was therefore wL2/8 as shown in Figure 4. The effective span for beams was taken from centre of column to centre of column. The connections were flexible end plates selected to resist the design shears (SCI 1992). According to the code, the following stability check needs to be satisfied in 'simple' construction:-

$$\frac{F_c}{P_c} + \frac{M_x}{M_{bs}} + \frac{M_y}{p_y Z_y} \leq 1.0$$

(1)

where

Fc = axial force in column,

Pc = compression resistance of column,

Mx = maximum end moment in column on major axis,

My = maximum end moment in column on minor axis,

Py = design strength of steel

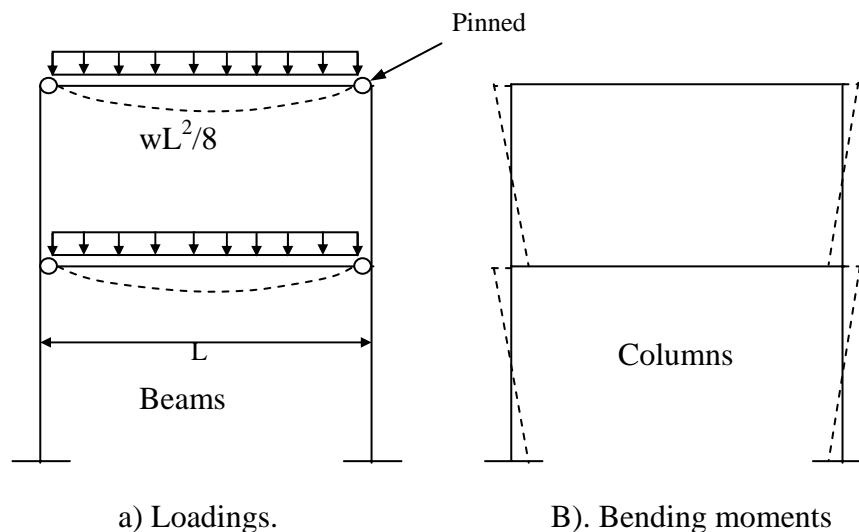Zy = the elastic modulus on minor axis.

Mbs = buckling resistance moment.

a) Loadings.   B). Bending moments

Figure 4. Simplifying assumptions of simple design

2. Plastic design for Semi-Continuous braced frames

For ultimate limit state, plastic design provides as attractive approach, particularly if linked with partial-strength joints providing a moment resistance 30-50% of that of the connected beam. As will be shown, such resistance still provides worthwhile reductions in beam weight or depth, and overall frame cost. The advantages of this approach are as follows:

a. The moment resistance required at the connections is readily determined from a beam-type plastic hinge mechanism.

b. Ductility can be provided through the use of relatively thin end plates (12 – 15mm) in mild steel, in con-junction with appropriately strong bolts and welds (Bose 1995). Such end plates will usually be independent of column size; thereby assisting the preparation of concise design tables for standard connections and permitting beam design to be completed before the column are considered.

c. Stiffness calculations, which would necessarily include contributions from the column section, are avoided.

d. For typical relative values of dead and live loading, pattern loading need not be considered because each joint will attain its design resistance MRd under the factored dead load.

e. Although the beam's compression flange is unrestrained near the supports, the limited joint's resistance will reduce the likelihood that lateral buckling will occur.
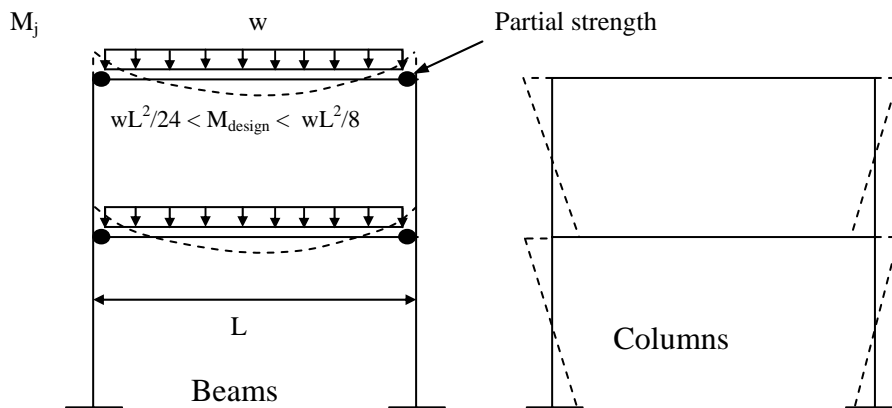
Bending moments in members of a semi-continuous frame

Figure 5. Simplifying assumptions of semi-continuous design

Distribution of moment from beam to column and possible pattern of curvature for intermediate column

Distribution of moment from beam to column and possible pattern of curvature for bottom column
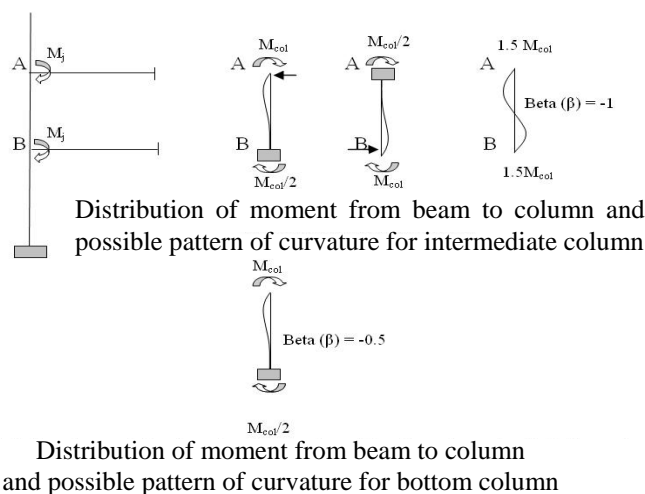
Figure 6. Justification of moment factor m = 0.40

3. Design of Semi-Continuous constructions

In semi-continuous construction members were designed for a local plastic hinge mechanism, taking into ac-count the design moment resistance of the joints. Beams were assumed laterally restrained by the floor or roof units. Unlike conventional simple design, the beam was taken to span between the flanges of the columns, assuming the column sections obtained in simple design. This was because accurate account was being taken of the moment developed in the partial-strength connection at the face of the column. The total load on the beam was not reduced though in comparison with simple design. The end moments were selected from the standardized tables prepared by the authors by adopting "component method" proposed by SCI. This end moment is actual the moment resistance of the connection noted as Mj. The beam section selected had to be at least "compact" as described by BS 5950:2000 Part 1 to enable its plastic moment to be developed; a restriction to only "plastic" sections was unnecessary as the plastic hinge in the beam section is always the last to form due to the limited resistance of the connections. The design moment of the beam was determined by taken into account the reduction of the moment due to partial restrained of the connection. As a result, the design moment M design is equal to $wL^2/8$ minus by Mj as shown in Figure 5. Beam sizes were selected from the list of Trapezoidal Web Profiled steel section to provide adequate resistance and stiffness. The deflections of the beams were calculated by taking into account the partial restraint of the connection; the limit was checked according to BS 5950:2000, Part 1.

For partial strength connections, columns were checked against overall buckling using the simplified approach outlined in BS 5950:2000, Part 1 clause 4.8.3.3.1 with moment factor taken to be 0.40 for both the intermediate and bottom column. Bending moment diagrams are assumed to form at least partial double curvature on the column as shown in Figure 6. The beam end moment M beam is assumed to be divided equally between the upper and lower column lengths. A further check on the local capacity was made using equations in BS 5950: Part 1 clause 4.8.3.2. All column members were Universal Columns of British Steel sections.

4. Total Weight Savings

The results of the parametric study on the two cases of the multi-storey braced frames (simple and semi-continuous construction) are tabulate elsewhere. Comparison of the percentage steel-weight saving between simple construction and semi-continuous construction are given in Table 1.

For all cases, the semi-continuous construction using TWP sections resulted in significant savings of the total frame weight. The percentage of savings as compared to the simple construction using TWP sections was in the range of 8.09% to 11.83% for 6m span and in the range of 2.48% to 5.70% for 9m span. The result shows that as the span of beam increases the percentage weight saving decreases. This is because the design moment in semi-continuous construction increases as the span increases. Therefore, to increase the percent-age saving for longer span, a stiffer connection which has greater moment resistance of the connection should be provided. According to the previous study done by Mahmood Md Tahir (1997), the percentage of savings between the semi-continuous and simple construction using Universal Beam (UB) ranged from 2.38% to 11.95%, which is in good agreement with the result obtained from this study ranging from

2.48% to 11.83%. Hence, by adopting TWP sections, it is clearly seen that the contribution of TWP sections to the savings of the total weight of frames can be quite significant in the design of semi-continuous construction.

Table 1: Percentage of steel weight saving by comparing between simple and semi-continuous construction

Frame	6 m Span			9 m Span		
	Semi-continuous TWP	Simple TWP	%	Semi-continuous TWP	Simple TWP	%
2Bay 2Storey	2.189	2.389	-8.37	4.237	4.484	- 5.51
2Bay 4Storey	5.171	5.626	-8.09	9.955	10.436	- 4.61
2Bay 6Storey	8.646	9.467	-8.67	16.097	16.871	- 4.59
2Bay 8Storey	12.368	13.519	-8.51	23.112	23.832	- 3.02
4Bay 2Storey	3.964	4.364	-9.17	8.177	8.671	- 5.70
4Bay 4Storey	9.498	10.767	11.79	19.233	20.248	- 5.01
4Bay 6Storey	15.960	18.102	11.83	31.057	32.654	- 4.89
4Bay 8Storey	23.703	26.066	-9.07	45.180	46.327	- 2.48

IV. DISCUSSION OF ANALYSIS OF THE RESULTS

The scope of study focused on the percentage weight savings which depend on the number of storeys, the beam span of each frame, the compactness of available sections, and the depth and deflection limit of the beam selected. The overall percentages of weight savings in steel are ranging between 2.48% to 11.83% for S275 steel. The results of the percentage weight savings and an additional increase in percentage savings due to effect of increasing the number of bays from two to four are shown in Table 2(a and b). In Table 2(a) the increase in percentage savings are in the average of 9.19% for 2 bays and 9.75% for 4 bays. This increment is very significant as the average is more than 9%. However, for 9m span, the percentage increase has dropped to less than 7%. The use of stiffer connection such as extended end-plate connection with greater stiffener could increase the percentage weight saving. The increase in the number of bay from 2 to 4 bays has result to a marginal increase of not more than 1%. Therefore, the increase in the number of bay did not have significant impact to the percentage increase in steel weight.

The percentage weight increase of comparisons between simple and semi-continuous construction are also tabulated in Figure 7(a and b) in chart form. In Figure 7(a and b), the results show clearly the significant in-crease in the percentage steel weight savings by the use of flush end-plate connection to provide partial re-strain to the designed beam. The results also show that the percentage weight saving of steel increases as the number of storey increases from two to eight storeys.

Table 2(a) Braced frames; S275 steel; flush end plate partial-strength joints; 6m span.

		Number of Storeys			
		2	4	6	8
Flush end plate	2 bay	10.03 %	9.86 %	8.76 %	8.12 %
Average					9.19 %
(Min Weight)	4 bay	10.33 %	10.07 %	9.61 %	9.00 %
Average					9.75 %
6 meter span	Ad. Inc	0.30 %	0.21 %	0.85 %	0.88 %

Table 2(b) Braced frames; S275 steel; flush end plate partial-strength joints; 9m span.

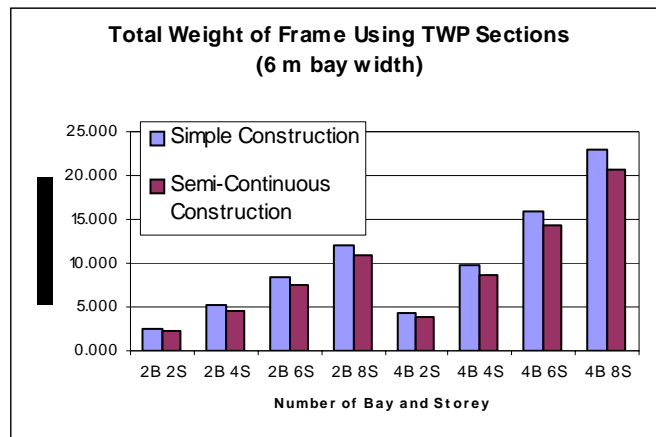|		Number of Storeys			
		2	4	6	8
Flush end plate	2 bay	08.15 %	06.27 %	08.17 %	04.85 %
Average					06.86 %
(Min Weight)	4 bay	08.43 %	06.57 %	06.87 %	05.08 %
Average					06.73 %
9 meter span	Ad. Inc	0.28 %	0.30 %	-1.30 %	0.23 %

Figure 7(a): Total weight of frame using TWP sections for simple and semi-continuous construction (6 m bay width)
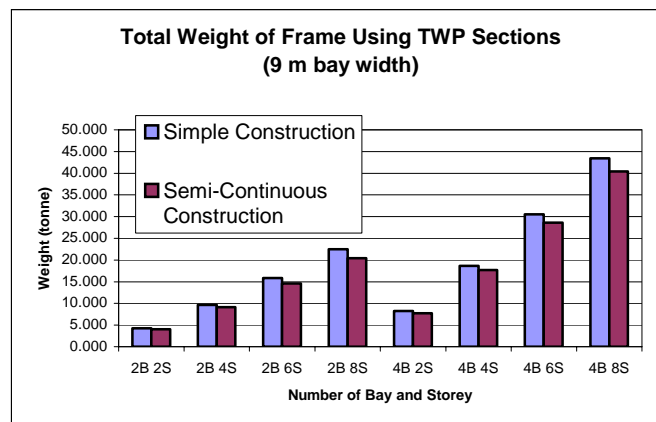

Figure 7(b): Total weight of frame using TWP sections for simple and semi-continuous construction (9 m bay width)

V. CONCLUSIONS

From the study, conclusions are made as follows:

1. The use of partial-strength connections results in shallower beams and worthwhile reductions in the cost of the structure.
2. Increase in the number of bays has contributed to a marginal increase in weight savings for most of the frames.
3. Increase the length of beam's span has contributed to a reduction in the weight savings
4. Increase in the number of strorey has contributed to a significant increase in the percentage weight saving.

The use of flush end-plate connection in the design of semi-continuous construction has contributed to an increase in the percentage steel weight saving in the range of 2.48% to 11.83% depending on the length of span, number of storeys, number of bays, and the type of connection used

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