Third International Conference on Construction in the 21th Century (CITC
"Advancing Engineering, Management and Technology"
15-17, September 2005, Athens.

Economic Aspects of Composite Beam Using Trapezoidal Web Profiled Sections with Unequal Flange

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Abstract
This paper presents the analytical design method on Composite Trapezoidal Web Profiled (CTWP) as composite beam with full shear connection. Flange only method was adopted to determine the moment capacity of the beam as suggested in BS 5950-1:2000 and Steel Construction Institute. In this method the web of the CTWP beam is assumed not to contribute to the moment capacity of the beam as the web of TWP section is too thin and classified as semi-compact section. An unequal flange of TWP section is proposed for composite beam design. A series of parametric study has been carried out to compare the design of CTWP with the design of composite beam using hot-rolled British sections. The beam spans ranging between 6m to 12m were designed for both types of composite beam. The results showed that the percentage savings in steel weight by comparing CTWP sections with composite beam of hot-rolled section were in the range of 4% to 34% depending on the length of beam span. It can be concluded that the use of TWP section as composite beam contributed to the saving in steel weight by designing the beam as unequal flange.

Keywords
Composite Beam, Hot-Rolled, Trapezoidal Web Profiled, Service Limit State, Ultimate Limit State.

1. Introduction

To obtain more economical structural design against the bare steel beams, composite beam is one of the popular alternatives which incorporates the strength of concrete slab into composite beam 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 are further enhanced with the use of trapezoidal web profiled sections. TWP beam is generally a built-up steel plate girder where the web is corrugated at regular intervals into a trapezoidal shape along the length of the beam(Osman, 2004). The shape of the TWP is shown in Fig. 1. The introduction of TWP section as an alternative to traditional hot-rolled steel section is due to the use of thin corrugated web section that reduces the steel weight of the composite beam. As a result, the cost of construction can be reduced. This paper presents the analytical design method mainly on the moment capacity of CTWP beams in full shear connection by adopting the flange only method as proposed by code of practice(BS 5950 Part 1,2000) and also known as "composite truss method" by Steel Construction Institute(S. Neal and R. Johnson, 1992). The design aspects of the composite beam were checked for Ultimate Limit State and Service Limit State as required by the code of practice(BS 5950 Part 1 and 3:2000). The moment capacity and the deflection of the composite beam depend on the depth and the area of the bottom flange of TWP sections. The geometrical aspects of TWP sections are tailor made to the needs of the design engineers.

2. Geometrical aspects of TWP sections

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 Fig. 1(Mohomed Elgaaly and Anand Seshadri, 1998). The web and the flanges comprise of different steel grades depending on design requirements. TWP section is also classified as a prefabricated hybrid steel section as the section is comprised of two different types of steel grade. The size of flange and web could be varied as any conventional flat-web plate girder(Hussein, 2001). However, due to machinery constraint, the web thickness is only allowed to be 3mm to 8mm thick; the flange thickness can only be up to 60mm; flange width ranging from 100 to 500 mm; and the beam depth varies from 200mm to 1600mm. The steel grade of the flanges is designed for S355 steel whereas the web is designed for S275 steel. The use of S355 steel grade is intended to maximize flexural capacity of the beam. The steel grade of the web is designed for S275 so as to reduce the cost of steel material and the capacity of shear is not that critical in the design of the beam. The use of thick and high strength flanges, thin corrugated web and deeper beam for TWP section compared with hot-rolled section of the same steel weight leading to higher load capacity and greater beam span. Based on the configuration of the structure, TWP beam can offer substantial saving in the steel usage, and in some cases of up to 40% as compared to conventional rolled sections(Hussein, 2001),(Tan Cher Siang, 2004), (Hasni@Ihsan, 2000). It is more significant when there is a need for a column free, long span structural system, such as portal frames for warehouses, girders for bridges, floors and roof beams for high-rise buildings, portal frames for factory.

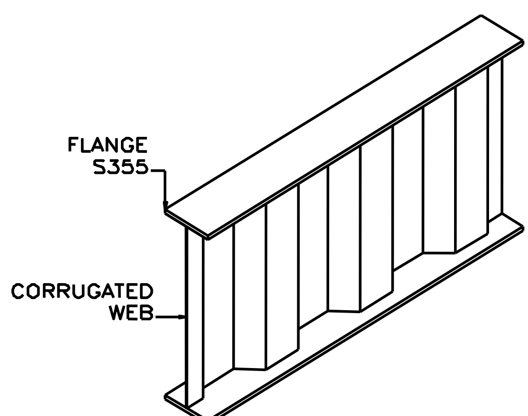

Figure 1: Shape of TWP section

3. Composite TWP Beam Design using "Flange Only Method"

The structural system of a composite beam is essentially a series of T beams with wide flanges. The orientation of the section is designed in such way that the concrete flange is in compression and the steel beam is largely in tension. In the ultimate limit stage, the bending strength of the beam is determined from its plastic capacity, with the assumption that the strains across the section are sufficiently great that the steel stresses are at yield throughout the section and that the concrete stresses are at their design strength. However, this is only applicable under certain limitation of beam size to avoid local buckling of web or of steel flange. Beyond these limits, the 'plastic moment capacity' may be subjected to certain reduction, or, the moment capacity is determined elastically(S. Neal and R. Johnson, 1992). By incorporating the TWP beam in composite system, the corrugated web is assumed not to contribute any moment resistance, as the web is very thin.

3.1 Moment Capacity of CTWP Beams (Full Shear Connection)

Since the corrugated web is flexible in longitudinal direction of the beam, the moment resistance of the beam is merely contributed by the concrete slab and the flanges of beam as shown in Fig. 2, where the web depth is the gap between the top flange and bottom flange. This discontinuity of top flange and bottom flange due to this gap should be the concern in the plastic section analysis.

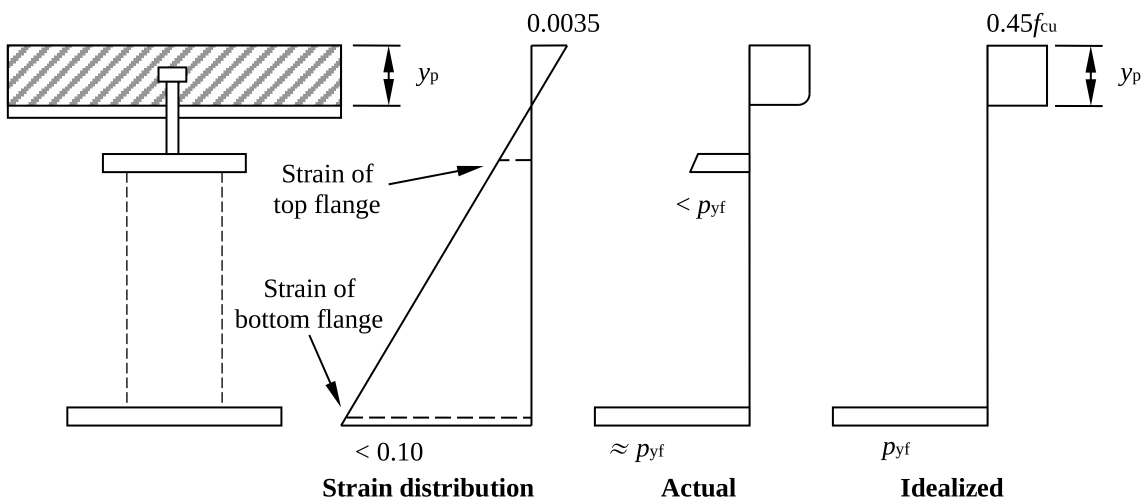

Figure 2: Plastic analysis of composite section

Consider both flanges located underneath the plastic neutral axis whereas the resistance of concrete R_c is larger than the resistance of the sum of both flanges R_s. Both flanges are subject to tension force while the top portion concrete subject to compression. The strain distributes linearly from the top of beam, crossing the vertical neutral axis, to the bottom of beam as shown in Fig. 2. The strain in bottom flange was found to be proportionally larger than the strain in the top flange. Fig. 2 shows that the deeper the gap between the flanges, the larger will be the strain. This implies that the bottom flange may have exceeded its safe strain limit that is 0.10mm or even failed before the top flange reaches its yielding strain. Beyond the safe strain limit, all forces which previously were taken by the whole system will immediately be transferred to the concrete slab and top flange, and will result to a sudden failure of the beam. Therefore, the safe failure mode should be taken as the point where the bottom flange completely yields.

Since the top flange does not contribute in moment resistance (also in flexural stiffness), it is suggested that the only top flange of the beam is considered in the design during construction stage. The size of the top flange is therefore suggested to be smaller than the bottom flange for composite stage loading. As a result an unequal flanges section is therefore suggested for CTWP. Details of the reaction of forces and notation used are given in Fig. 3. For $R_c \geq R_b$, and assuming full shear connection ($R_q \geq R_b$), the bottom flange yield first the position of plastic neutral axis should lie in concrete flange(S. Neal and R. Johnson, 1992). The equation of moment capacity of the CTWP beam is as follows:-

$M_c \quad = R_b(D_s + D - 0.5T_b - 0.5x)$

where

$x \quad = (D_s - D_p)R_b/R_c$, is the concrete yield depth

$R_b \quad = B_b T_b p_{yf}$, is the resistance of bottom flange

R_q is the resistance of shear connectors

B_b is the width of bottom flange

T_b is the thickness of bottom flange

p_{yf} is the design strength of flange

D is the overall depth of TWP beam

D_s is the overall depth of slab

D_p is the metal deck profile depth

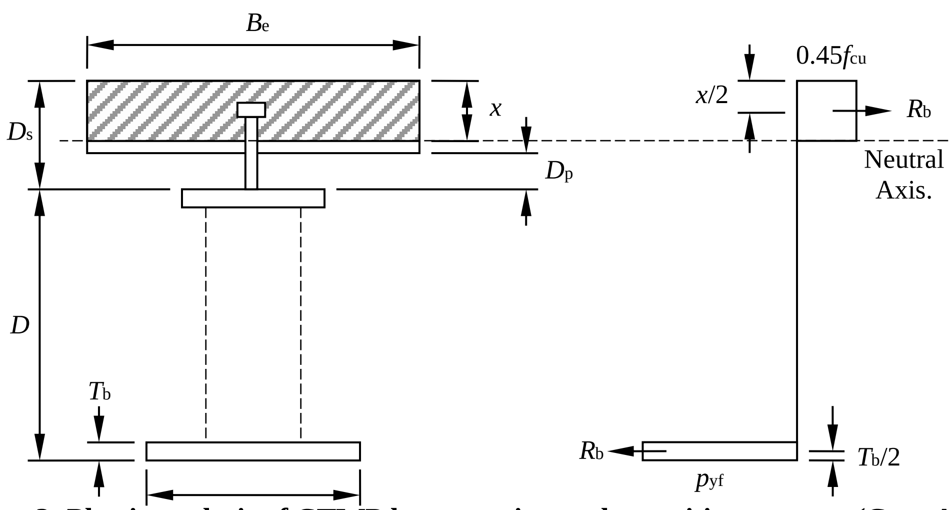

Figure 3: Plastic analysis of CTWP beam section under positive moment (Case A1)

The position of plastic neutral axis may lie in the top steel flange when $R_c < R_b$ if full shear connection is provided; or when $R_q < R_b$, if partial shear connection is provided. The top steel flange is neglected in the calculation of moment capacity of the composite beam, as the strain is small. In this paper, however, the parametric study of the comparison of CTWP and CUB is based on the position of plastic neutral axis which lie in the concrete slab.

4. Parametric Study.

The parametric study carried out in this paper was based on the comparison of the design of composite beam between composite trapezoidal web profiled section, and universal beam of composite beam. The geometrical aspects and the results of CTWP are listed in Table 1. The design of CUB are not shown in this paper as the design method has been established in Steel Construction Institute publications.(Lawson, SCI P078, 1990),(Lawson, SCI P055, 1993)

Since the size of TWP section is tailor-made, there is a variety of configuration that can fit the design criteria. As the design of the beam is usually based on the weight of the section, an optimization process of designing the beam has been carried out. Computer programming has been established to carry out the calculation of CTWP and CUB. The computer program was designed based on the optimization of section which take into account the lightest section for the size of top and bottom flanges of the CTWP section. In the design of CTWP and CUB, checks have been done on the aspect of Ultimate Limit State and Service Limit State as required by the code of practice.

5. Discussion of Results

The results of percentage steel weight saving by comparing the design of CTWP and CUB are presented in Table 2. The results show that the increase in percentage savings is in the range of 4% to 34% depending on the length of the span. The longer the span the higher the percentage saving. The percentage increment is relatively linear to the increase of the length of the span. The use of deep beam in TWP section has improved the moment capacity and the resistance of deflection of the beam. As a result the percentage saving of CTWP increases.

Table 1: Geometrical Aspects and Results of CTWP Sections

Span Length (L in m)	6	7	8	9	10	11	12
Overall depth of beam (D in mm)	280	340	380	440	510	580	640
Web thickness (t in mm)	3	3	3	3	3	3	3
Bottom flange width (Bb in mm)	105	120	140	155	165	180	200
Bottom flange thickness (Tb in mm)	10	10	10	10	10	10	10
Top flange width (Bt in mm)	100	100	100	100	130	135	150
Top flange thickness (Tt in mm)	11	11	11	11	10	10	10
Moment in composite (kN.m)	178.04	224.65	276.00	335.12	402.30	481.58	577.34
Shear force for corrugated web (kN)	128.21	157.91	177.71	207.41	242.55	277.20	306.90
Deflection in composite (L/360 in mm)	8.97	10.64	12.98	14.66	16.22	17.36	18.62

Table 2: Comparison CTWP and CUB for Percentage of Steel Weight Savings.

Span, *L* (m)	Extra steel mass against CTWP, d_{SM} (kg/m)			
	SM_{CTWP}	SM_{CUB}	SM_{CUB}-SM_{CTWP}	d_{SM}/SM_{CUB}
6	23.79	24.80	1.01	4%
7	26.56	28.20	1.64	6%
8	29.20	33.10	3.90	12%
9	31.98	39.00	7.02	18%
10	36.23	46.00	9.77	21%
11	39.66	52.30	12.64	24%
12	44.01	67.10	23.09	34%

6. Conclusions

A series of analytical formula to determine flexural behavior of the composite trapezoidal web profiled beam has been established in this paper. The determination of moment capacity of composite beam design can be calculated by adopting the flange only method. This method has been proven to increase the percentage savings of steel material in the design of composite beam. The concept of adopting unequal flange by using wider bottom flange has contributed to the savings of up to 34% in CTWP design. From the study it can be concluded that Trapezoidal Web Profiled section is suitable to be used in the design of composite beam.

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8. Acknowledgement

The authors would like to acknowledge special thanks and gratitude to CIDB for funding this project under Vot 73049. The support and fund given by CIDB to Steel Technology Centre, Universiti Teknologi Malaysia is very much appreciated.