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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 outlined in BS 5950-1:2000. In this method the web of the CTWP beam is assumed not to contribute the moment capacity of the beam as the web of TWP section is too thin and classified as semi-compact section. Normally, the top flange of TWP beam is neglected due to the effect of discontinuity between top flange and bottom flange. As a result, the steel area of top flange is not necessary be the same as the bottom flange. Therefore 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 1.01% to 23.09% 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, Composite Web Profiled Sections, Hot-Rolled Sections, Service Limit State, Ultimate Limit State.

1. INTRODUCTION

To obtain more economic structural design against the bare steel beams, composite beam is one of the popular alternatives which incorporating 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 trapezoidal shape along the length of beam. 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 BS 5950 Part 3[2]. The elastic section properties of the composite section are adopted to check for the stress limit in concrete and steel. The deflection of the composite section was also checked according to the limit as stated BS 5950 Part 1:2000[3]. The moment capacity and the deflection of the composite beam are very much depends on the geometrical aspects of TWP sections. The geometrical aspects of TWP sections are tailor made as 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[4][5]. The web and the flanges comprised of different steel grade 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. However, due to machinery constraint, the web thickness is allowed to be 3mm to 8mm thick; the flange thickness could 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[5]. 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 [4][5]. It is 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, portal frame for factory.

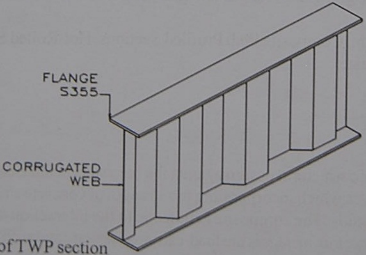

Figure 1. Shape of TWP section

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 ultimate limit stage, the bending strength of the beam is determined from its plastic capacity, which assumed 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. But, 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 subject to certain reduction, or, the moment capacity is determined elastically [1]. 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. The lateral torsional buckling resistances of bare TWP beam during erection stage and the corrugated web shear capacity may be determined using methods employed in normal TWP beam design [4, 5]. The deflection limits, serviceability criteria and natural frequency limit are the same as the conventional composite beam [2, 3]. Attention is needed to determine the ultimate moment capacity and elastic section properties in the design.

4. 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 concerned in the plastic section analysis.

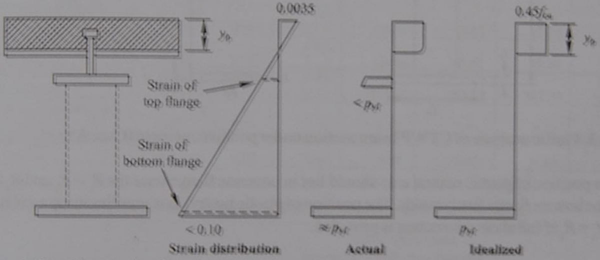

Figure 2. Plastic analysis of composite section

Consider both flanges are 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 and the top portion concrete subject to compression. The strain distributes linearly from top of beam, crossing the vertical neutral axis, to the bottom of beam (see Figure 3 – strain distribution). The strain in bottom flange was found to be proportionally larger than the strain in top flange. The deeper the gap between flanges, the larger the strain is. This implies that the bottom flange may exceed 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 taken by the whole system will immediately transferred to the concrete slab and top flange and result to the sudden failure of the beam. Therefore, the safe failure mode should be taken as the point where the bottom flange is completely yields.

Since the top flange did not contribute in moment resistance (also in flexural stiffness), it is suggested that the top flange of the beam is only considered in the design during construction stage. Since the top flange size required for these loading is relatively smaller than the bottom flange size required for composite stage loading, an unequal flanges section is therefore suggested.

$R_c \geq R_b$, the bottom flange firstly yield and full shear connection ($R_q \geq R_b$)

$$M_c = R_b(D_s + D - 0.5T_b - 0.5x) \qquad (1)$$

where

x $= (D_s - D_p)R_b/R_c$, is the concrete yield depth
R_b $= B_b T_b p_{yf}$, 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

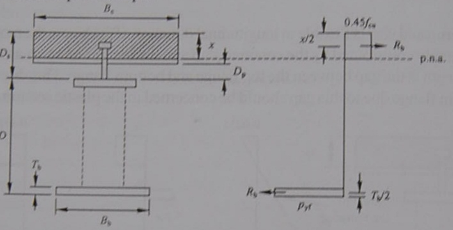

Figure 3. Plastic analysis of CTWP beam section under positive moment (Case A1)

The position of plastic neutral axis should lies in concrete flange once the $R_c > R_b$ and $R_q > R_b$, when the bottom flange firstly yields. The position of plastic neutral axis may lies in top steel flange when $R_c < R_b$ if full shear connection is provided.

5. PARAMETRIC STUDY.

The parametric study carried out in this paper was based on the comparison on 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 publication[][]. Computer programming has been established to carry out the calculation of CTWP and CUB. The computer program was designed base on the optimization of section which take into account the minimum 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.

6. 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 showed that the increase in percentage savings was in the range of 4% to 34% depending on the length of 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 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
Total deflection (L/200 in mm)	26.96	31.62	39.53	44.89	46.67	49.86	52.77
Stress in bottom flange (fs in N/mm²)	353.36	350.32	353.43	351.58	353.81	347.22	338.81
Stress in concrete (fc in N/mm²)	3.00	2.81	2.79	2.66	2.51	2.38	2.30
Natural frequency limit (Hz)	6.79	6.22	5.63	5.29	5.02	4.84	4.66

Table 2

Comparison of Steel Mass for CTWP and CUB and percentage of steel weight.

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%

7. CONCLUSION REMARKS

A series of analytical formula to determine flexural behavior of the composite trapezoidal web profiled beam has been shown in this paper. The determination of moment capacity of composite beam design can be calculated by adopting the flange only method. The strain difference between flanges due to the effect of the absence of limits the plastic moment capacity not taken into account the contribution of top flange in normal cases. The approach of calculating the moment capacity of CTWP is merely similar to composite truss design. Due to the over-flexibility nature of the TWP beam, the elastic deflection of CTWP beam may be increased by 10% from the normal deflection determination formula. 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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