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Experimental Study on the Lateral Torsional Buckling **Behaviour of the Triangular Web Profile Steel Section**

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Abstract. A triangular web profile (TriWP) section is a structural steel section that is made of two flanges connected to a web plate of triangular profile. Only certain research works have been carried out to study the characteristic, behaviour and the advantages offered by this section compared to the normal flat web (I-beam). An area that is not given full attention is the capability of this section to resist the lateral torsional buckling moment capacity compared to that of the normal flat web. The objectives of this thesis are to study the lateral torsional buckling behaviour of Triangular Web Profile (TriWP) steel section and compare to that of the flat web by experimental and to find the value of M_b, moment buckling resistance for TriWP. The scope of study covered the experimental work and theoretical investigation of triangular web profile steel section subjected to lateral torsional buckling moment resistance. The effect of the shape of the triangular web profile beam compared to that of the flat web beam was also be studied. For the buckling moment resistance, several factors were taken into account such as buckling parameter, torsional index, warping constant and torsional constant. All these factors are related to the second moment of area with respect to minor axis. The lateral torsional buckling test includes 8 specimens (4 flat webs and 4 TriWP). Each specimen was tested in two different sizes which is 200x100x6x3 and 180x75x5x3. Findings from the lateral torsional buckling tests were compared to the manual calculation using BS 5950: Part 1:2000. The lateral torsional buckling test shows that the moment buckling resistance of the triangular web profile steel beam section is better than that of the flat web in smaller size while in bigger size flat web beam has better moment resistance than that of triangular web profile steel beam. The section properties such as width (B), depth (D), thickness of flange (t_f) and thickness of web (t_w) affect the buckling moment resistance, Mb of the steel section

1. Introduction

1.1 Background of Study

Since before the Renaissance steel had been produced by various inefficient methods. Throughout 17th century, the steel production had developed better. Steel is an alloy, which is a combination of iron and other elements, most commonly carbon. Others are manganese, chromium, vanadium and tungsten. The presence of carbon and other elements acting as a hardening agent and preventing dislocations in the iron atom. Varying the amount of alloying element cause a different hardness, ductility and tensile strength. The variety percentage of carbon content can increase steel hardness or tensile strength.

A beam is a horizontal structural element that is capable of withstanding load primarily by resisting bending. One of the most common types of steel beam is the I-beam or wide-flange beam. It is also known as a universal beam. This is commonly used in steel-frame buildings and bridges. Other common

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beam profiles are the C-channel, the hollow structural section beam, the pipe, and the angle (McCormac, 1981). There are two type of beam, one is laterally supported beam and other is laterally unsupported beam. In laterally supported beam, full lateral support is provided by reinforcement concrete slab. But in some cases it is not possible to provide this ideal condition. When a beam lacks in lateral support over its length, lateral torsional buckling may occurs. The reduction in bending strength depends on cross-sectional dimensions, length of compression flange, type or restraint support and type of cross-section. If the laterally unrestrained length of compression flange of beam is relatively longer, then lateral torsional buckling may take place therefore the beam would fail before it can attain its full moment capacity.

Recently, several researchers have attempted to use corrugated plates in the web of I-girders. This is to overcome the disadvantages of conventional stiffened flat webs such as web instability due to bending stress and fatigue failure. The use of corrugated web is a potential method to achieve adequate out-of-plane stiffness and shear buckling resistance without using stiffeners. Therefore, it can considerably reduce the cost of beam fabrication and the weights of superstructures. Moreover, the efficiency of prestressing is enhanced because the corrugated web carries only shear forces and flanges carry moment due to the accordion effect (Moon et. al., 2009).

Besides, there were researcher focused on the vertically corrugation. Based on the observer, the lower corrugation profiles of web (exchange from trapezoid to triangular to flat web) shows I-girder phenomenon of lateral torsional buckling of the inelastic I-girder with corrugation profiles of the web has been taken into consideration. The results increased the critical moment to 40% using corrugation profile of web (Kazemi et.al, 2010). In addition, the researchers mentioned that the high flexural strength and stiffness of corrugated web in bending provides great resistance to lateral torsional buckling. They developed a simplified procedure to calculated torsional constant for beams with trapezoid corrugated webs (Johnson and Cafolla, 1997).

In a structural design, when a beam is loaded in flexure, the top side is under compression and the bottom is under tension. Laterally, stable steel beams can only fail due to (a) flexure, (b) shear or (c) bearing, assuming the local buckling of slender components does not occur. These three conditions are factors for limit state design of steel beams. Due to excessive flexure, shear and buckling, steel beams become unserviceable. Lateral Torsional Buckling (LTB) happens when a laterally unsupported compression flange is behaving like a column and tend to buckle out of plane between points of lateral support. However because the compression flange is part of a beam section with a tension zone that keeps the opposite flange in line, the section twists when it moves laterally. This mean that the beam section buckles, twits and moves laterally sideways due to lateral torsional buckling.

1.2 Objective of the study

The objectives of this research are stated as below:

- i) To study the lateral torsional buckling behaviour of Triangular Web Profile (TriWP) steel section and compare to that of the flat web by experimental.
- ii) To determine the value of Mb, moment buckling resistance for TriWP.

2. Methodology

2.1 Introduction

Lateral torsional buckling occurs in unrestrained beams because the compression flange will try to buckle laterally about the beam's more flexible minor axis. A beam is unrestrained when its compression flange is loose to displace laterally and rotate. When I sections are used as beams or beam columns the compression flange is under compressive stress and has a bent to buckle. This torsion twists and warps the unrestrained part of beam leading to lateral torsional buckling. The section then will twist because of the other flange is in tension and it is reluctant to buckle. Figure 1 shows the lateral deflection, the vertical deflection and the twisting.

2.2 Manual design calculation based on BS 5950

The design for this section is a basic working tool for users of BS 5950: Part 1 for designing steelwork buildings using triangular web section (TriWP). The design guide was published in June 2001 as a draft of 1st edition by M.H. Osman. Below is the calculation step involved in a design check for lateral torsional buckling resistance on triangular web section.



Figure 1. The lateral deflection, the buckling and the twisting.

Class 1 Plastic:

Cross section are those in which a plastic hinge can be developed with significant rotation capacity. If the plastic design method is used in the structural analysis, all members must be of this type too (Arya, 2009).

Class 2 Compact:

Cross section with plastic moment capacity developing but local buckling may prevent production of a plastic hinge with sufficient rotation capacity to permit plastic design.

Class 3 Semi-compact:

Cross section in which the stress at the extreme compression fibre can reach the design strength but not developing the plastic moment capacity.

Class 4 Slender:

Cross section contain slender elements subject to compression due to moment or axial load. Local buckling may prevent the full elastic moment capacity from developed.

In the calculation only flange is considered. Elgaaly (1997) indicated that the contribution of the web to moment capacity of the beam could be neglected.

Second moment of area (the thickness of the web is negligible)

About x-x axis:

$$I_x = 2\left[\left(\frac{(B)(t_f)^3}{12}\right) + (B)(t_f)\left(\frac{D-t_f}{2}\right)^3\right]$$
(1)

About y-y axis:

$$I_{y} = 2 \left[\frac{(t_{f})(B)^{3}}{12} \right]$$
(2)
$$\gamma = \left(1 - \frac{l_{y}}{l_{x}} \right)$$
(3)

A factor,

Radius of gyration (the thickness of the web is negligible)

$$\mathbf{r}_{\mathbf{x}} = \sqrt{\frac{I_{\mathbf{x}}}{A_f}} \tag{4}$$

(3)

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$$\mathbf{r}_{\mathbf{y}} = \sqrt{\frac{I_{\mathbf{y}}}{A_f}} \tag{5}$$

Elastic Modulus (the thickness of the web is negligible)

$$Z_{\chi} = \frac{l_{\chi}}{\binom{D}{2}} \tag{6}$$

$$Z_{y} = \frac{I_{y}}{\left(\frac{B}{2}\right)} \tag{7}$$

Plastic Modulus (the thickness of the web is negligible)

$$S_x = B \times t_f \times \left(D - t_f \right) \tag{8}$$

$$S_y = \left[\frac{B}{2} \times t_f \times \frac{B}{4}\right] \times 4 \tag{9}$$

Warping constant, H and Torsion constant, J

$$H = \left(\frac{l_y \times h^2}{4}\right) \tag{10}$$
$$I = \sum_{i=1}^{n-1} \frac{1}{2} h t^3 \tag{11}$$

$$J = \sum_{3} b t^{3}$$
(11)

Buckling parameter, u and Torsional index, x

$$u = \left(\frac{4(S_{\chi})^{2}\gamma}{A^{2}h^{2}}\right)^{\frac{1}{4}}$$
(12)

$$x = 0.566h \left(\frac{A}{J}\right)^{\frac{1}{2}}$$
(13)

The moment capacities M_{cx} and M_{cy} are given as:

$$M_{cx} = p_y Z_x \tag{14}$$

$$M_{cy} = p_y Z_y \tag{15}$$

The equation for buckling resistance moment, Mb is decided based on the section classification (clause 4.3.6.4 BS 5950:Part 1).

Class 1 plastic or Class 2 compact cross-sections:

$$M_b = p_b S_x \tag{16}$$

Class 3 semi-compact cross-sections:

$$M_{b} = p_{b}Z_{x}; or alternatively$$

$$M_{b} = p_{b}S_{x,eff}$$
(17)

Class 4 slender cross sections:

$$M_b = p_b Z_{x,eff} \tag{18}$$

In which *pb* is the bending strength allowing for susceptibility to lateral torsional buckling and Zx is the elastic modulus, *pb* can be obtained depending on the particular values of $\lambda_{LT} = \sqrt{\beta} u v \lambda$

Ratio $\sqrt{\beta}$ is taken as follows:

Class 1 plastic or Class 2 compact cross-sections: $\beta w=1.0$;

Class 3 semi-compact cross sections:

- If
$$M_b = p_b Z_x$$
 $\beta_w = \frac{Z_x}{S_x}$;

- If
$$M_b = p_b S_{x,eff}$$
 $\beta_w = \frac{S_{x,eff}}{S_x}$

Class 4 slender cross-sections:

$$\beta_w = \frac{Z_{x,eff}}{S_x}$$

For slenderness, λ is equal to L_E / ry which according to Table 13 in BS 5950: Part 1, LE for compression flange laterally unrestrained and both flanges free to rotate is given by: $L_E = 1.0L_{LT} + 2D$

The slenderness factor, ν formula for an I-, H-section with unequal flanges is given by:

$$\nu = \left[\left(4\eta (1 - \eta) + \frac{1}{20} \left(\frac{\lambda}{x} \right)^2 + \psi^2 \right)^{\frac{1}{2}} + \psi \right]^{\frac{1}{2}}$$
(20)

(19)

Using all the parameters, from Table 17 BS 5950:Part 1:2000, value of pb and Mb is determined.

2.3 Laboratory Testing

This study is about carrying the testing process on real specimens and compare the results. The eight specimens, four flat web as control specimens and other four triangular web profile are tested. The specimen of 2.5 m long is set up on the testing machine and loads are applied slowly until failure. Each displacement increment of load and deflection is recorded. The set up for the lab testing can be review in figure 2. The position of the loading, supports and LVDTs can be seen in figure 3.



Figure 2. Schematic drawing of testing set up.



Figure 3. Position of loading noses, supports and LVDTs.

The beam specimens of normal flat web beams and triangular web profile beams are identified as FW and TriWP respectively. In this study, there were four models each for FW and TRIWP steel sections. The depth (D), breadth (B), web thickness (tw), flange thickness (tf) and corrugation angle (θ) are shown in table 1. Total number of the specimens are eight specimens, four for FW and four for TriWP. The angle of the corrugated web profile is 45° following normal practice. Two sizes of specimens are used which the 200x100x6x3 and 180x75x5x2. Each set of the size consists of two flat web as control specimens and another two triangular web profile steel sections.

Case			Type of section
FW1	200×100×6×3 mm	L=2.5m x 2	
T _{RI} WP1	200×100×6×3 mm	L=2.5m x 2	
FW2	180×75×5×2 mm	L=2.5m x 2	
T _{RI} WP2	180×75×5×2 mm	L=2.5m x 2	

Table 1. The dimension properties of models.

Table 2. List of TriWP and flat web (200x100x6x3 mm).

Set A (200x100x6x3)			
$\theta = 45^{\circ}$	$\theta = 0_0$		
TriWP 1A	FW 1A		
TriWP 1B	FW 1B		

Set B (180x75x5x2)			
$\theta = 45^{\circ}$	$\theta = 0_0$		
TriWP 2A	FW 2A		
TriWP 2B	FW 2B		

Table 3. List of TriWP and flat web (180x75x5x2 mm).

Based on previous literature review, several methods known for lateral torsional buckling testing is used. In simple way, the methods can be assigned to two types, involving cantilevered and simply supported beams. In this thesis, the lateral torsional buckling test is carried out using simply supported beam type setting. This is adopted from the method used by Du' (1977) which was carried out in an experimental study on the lateral torsional buckling of the end notched steel beams. A roller bearing guide is placed to ensure that the line of load action remained vertical. Another set of roller was placed between the plates to ensure that there was no horizontal restraint would inhabit lateral torsional buckling during loading.

3. Results and Discussion

This chapter is dedicated to present, compare and discuss the series of results obtained from the testing processes. Table 4.1 and 4.2 show the specimens sizing for the beams with triangular web profile (TriWP1A, TriWP1B, TriWP2A, TriWP2B) and beam with flat web section (FW1A, FW1B, FW2A, FW2B). Experimental investigations on the behaviour of beams with triangular web profile section and flat web section subjected to point loading had been carried out. These tests had been done in the heavy structure laboratory of Universiti Sains Malaysia (USM). The objectives of the experimental work were to study the lateral torsional buckling behaviour of Triangular Web Profile (TriWP) steel section and compare to that of the flat web section. For this set of specimens, the other main objective is to find the value of lateral buckling moment resistance, Mb.

3.1 Lateral Torsional Buckling Behaviour of Triangular Web Profile Beam Section

The first objective is to study the behaviour and determine the value of moment buckling resistance, Mb of the TriWP beam sections subjected to lateral torsional buckling moment by experimental method. Results from all the testing show that the value of Mb for the triangular web profile steel sections were found to be lower than that of the flat web section. However in set A, the flat web steel sections do have greater moment resistance than the triangular web profile steel section but in set B the value of buckling moment resistance, Mb of the triangular web profile steel section is higher than that of the flat web. In the experimental study, beam specimens were tested under bending moment induced by a point load at mid span. Plots of the applied moment, M versus the lateral deflection, δ for all the specimens are presented before. The test was stopped when the beam reach its failure. The result of Mb are summarized in table 4(a) and 4(b)

 Table 4(a). Average Mb for section properties of 200x100x6x3 mm.

Type A (200x100x6x3)

Span (mm)	Beam mark	M _b (kNm)	M _b (kNm) average	
2100	FW1A	25.90	28.20	
	FW1B	30.70	28.30	
	TriWP1A	18.20	10.70	
	TriWP1B	21.20	19.70	

Type B (180x75x5x2)				
Span (mm)	Beam mark	M _b (kNm)	M _b (kNm) average	
2100	FW2A	11.90	11.50	
	FW2B	11.10	11.50	
	TriWP2A	12.20	12.05	
	TriWP2B	13.70	12.95	

Table 4(b). Average Mb for section properties of 180x75x5x2 mm.

Nevertheless, TriWP1A and TriWP1B have better moment resistance than TriWP2A and TriWP2B since the sizes are different. The TriWP1A and TriWP1B are of size 200×100×6×3 mm while TriWP2A and TriWP2B are of size 180×75×5×2 mm.

3.2 Test Results and Observations

The lateral torsional buckling moment resistance, Mb, value was determined from the intersection of two straight lines developed from a linear behaviour of the connection with a straight line. Another line on the non-linear region should be drawn as a curve started to form a plateau. This intersection method is known as the "knee joint" method which has been used by many researchers to determine the moment resistance of the connection from the moment rotation curves (S. Jamali, 2002). For this study the same method is used to determine the buckling resistance moment, Mb. In each graph, two tangent lines were drawn and the intersection of these two lines gives the Mb values.



Figure 4. The "knee joint" method to determine the buckling resistance moment, Mb.

3.3 Discussion of the results

In the test, lateral torsional buckling occurred due to the combined lateral displacement and twisting of an unrestrained member subjected to bending about its major axis. Lateral torsional buckling occurs in unrestrained beams because the compression flange tries to buckle laterally about the more flexible minor axis of the beam. The section then twists because of the other flanges is in tension and it is reluctant to buckle. For the corrugated web profile section, TriWP1A and TriWP1B have higher lateral torsional buckling resistance than that of the TriWP2A and TriWP2B sections.

In general, the behaviour of lateral torsional buckling resistance of the flat web beam section is better than triangular web profile beam section due to some properties such as the width, depth, thickness of flange and thickness of web. During the test, almost 25% of the specimens were cracked when it received high loads. This is due to the poor welding done to the web section making the corrugated web profile is not a continuously steel section. In figure 5, the cracked web is obviously can be seen after unloading the hydraulic jack.



Figure 5. Cracks of the web at point of loading.

For triangular web profile steel section (TriWP), the average for TriWP1A and TriWP1B is 19.70 kNm and for the flat web section, FW1A and FW1B the average moment capacity, Mb is 28.30 kNm. The percentage difference is calculated by minus the experimental value with the design value and divided it with experimental value. In manual calculation using BS 5950: Part 1: 2000, for section properties of 200x100x6x3 of the TriWP moment capacity is 18.08 kNm which is 8.22% difference while for the flat web section is 19.62 kNm which gave the percentage difference of 30.67%. For section 180x75x5x3, the percentage difference for TriWP is -17.99% and for the flat web is -1.47%. The table 5 shows the summary of the experimental Mb, design Mb and the percentage difference.

Size (mm)	M _b for Flat web (kNm)	M _b for TriWP (kNm)	M _b design (kNm)		Percentage different (%)	
			Flat Web	TriWP	Flat Web	TriWP
200x100x6x3	28.30	19.70	19.62	18.08	30.67	8.22
180x75x5x2	11.50	12.95	11.67	15.28	-1.47	-17.99

 Table 5. The experimental Mb, designed Mb and percentage difference

Based on the results, the large percentage difference in buckling moment resistance, Mb for the flat web is caused by the technical problem which is the specimen is not properly clamped during the first time of setting up the equipment. While for the TriWP for section properties 180x75x5x2 mm, the value of designed Mb is higher than the test result can be explained as follows; during the experiment, the TriWP steel section had cracked at the welded web before reaching the maximum buckling moment resistance capacity.

Figures 6 and 7 below show the different of maximum buckling moment for triangular web profile and flat web section of 200x100x6x3 mm. The graph clearly defined that flat web section had higher buckling moment than that of the TriWP steel section.



Figure 6. Graph of Moment versus Lateral displacement for FW1A and TriWP1A.



Figure 7. Graph of Moment versus Lateral displacement for FW1B and TriWP1B.

Figures 8 and 9 below show the difference of maximum buckling moment for triangular web profile and flat web section of 180x75x5x2 mm. The graph clearly defined that TriWP steel section has higher buckling moment than that of the flat web steel section.



Figure 8. Graph of Moment versus Lateral displacement for FW2A and TriWP2A



Figure 9. Graph of Moment versus Lateral displacement for FW2B and TriWP2

4. Conclusions

From the study, the following conclusions can be made:

• Lateral torsional buckling test shows that the moment buckling resistance of the triangular web profile steel beam section is better than that of the flat web in smaller size while in bigger size flat web beam has better moment resistance than that of triangular web profile steel beam.

• The section properties such as width (B), depth (D), thickness of flange (tf) and thickness of web (tw) affect the buckling moment resistance, Mb of the steel section.

• The way of producing the steel section (rolled of welded) for the test is found to affect the buckling moment resistance, Mb. The steel section cracked at the welded web showing the section is not properly welded.

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References

- [1] Atan H 2001 *Flexural Behaviour Of Trapezodial Web Profile* (Universiti Teknologi Malaysia)
- [2] Bailey C G, Burgess I W and Plank R J 1996 J. of Construct. Steel Res. 36 101
- [3] De'nan F 2008 Lateral Torsional Buckling Behaviour of Trapezoid Web Profile Section, (Universiti Teknologi Malaysia)
- [4] De'nan F, Saad S and Osman M H 2009 Determination of the Second Moment of Area of Trapezoid Web Profile (Universiti Sains Malaysia) p 51
- [5] De'nan F, Osman M H and Saad S 2010 Inter. J. of Recent Res. And Applied Study 2 1
- [6] Du Plessis D P 1977 Int. Colloqium on Stability of Struct. under Static and Dyna. Loads. Struct. Stability Res. Council **563**
- [7] Elgaaly M, Seshadri A and Hamilton R W 1997 J.of Struct. Eng. 123 1
- [8] Korchar H R and Kulkarni S K 2012 Inter. J. of Computational Eng. Res. 2
- [9] Hashim N S 2011 Comparison on Bending Performance Between Triangular Web Profile Steel Beam Section (TRIWP) and I-beam Steel Section (Universiti Sains Malaysia)
- [10] Hashim N S and De'nan F 2011 Inter. J. of Energy Eng. 2 1
- [11] Hassan A 2011 Finite Element Analysis of Shear of Triangular Web Profile Beam Section. (Universiti Sains Malaysia)
- [12] Moon J, Yi J, Choi B H and Lee H 2009 Thin-walled Struct. 47 21
- [13] Osman M H, De'nan F and Mirasa A K 2008 Australiasian Struct. Eng. Conf.70 2
- [14] Pasternak H and Kubieniec G 2010 J. of Civil Eng. and Mngment. 16 166
- [15] Sayed-Ahmed E Y 2004 Proc. of the Inst. of Civil Eng. Paper Struct. and Build. 158 53
- [16] Tan C S 2004 *Buckling Analysis Of Compression Member With Trapezoid Web Profile* (Universiti Teknologi Malaysia)