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Effect of Triangular Web Profile on the Shear Behaviour of Steel I-Beam

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Abstract: Shear buckling occurred in the instability modes of steel beams when it slender. This paper develops a three-dimensional finite element model using LUSAS 14.3 to study on the effect ofthe triangularsteel beamweb profile (T_{RI}WP) inshearbuckling behaviourof differentthicknesscompared to that of thenormalflatbeam (FW). All specimens are cantilever beam which are fixedat one ends. The flange is constant with variable web thickness. Eigenvalue buckling analysis was used in analysing the buckling load of the flat plate model and triangular web profile (T_{RI}WP). Results showed that the web thickness gave a significant impact on the shear buckling of the T_{RI}WP. In addition, the corrugation thickness of web was also effective in increasing the shear buckling capacity of the profile.

Key words: Triangular web profile · Finite element analysis · LUSAS · Shear buckling · Eigenvalue

INTRODUCTION

The study on the effect of corrugation angle to the bending performance of steel beam with triangular web profile (T_{RI}WP) has been studied by Hashim [1]. Figure 1 shows the T_{RI}WP as a built-up steel section made up of triangular web profile. The web profile is a modified section ofa trapezoid web profile steel section whichis the eccentric stiffeners of the trapezoidal section; that is eliminated and changed to the slanting stiffeners. Beam with triangular web profile steel sections are considerably increase the flexural strength and stiffness of the steel beams according to Hashim [1]. The flexural strength of the girder was also contributed by the girder's flanges. The flexural strength of a steel girder with a corrugated web plate is provided by the flanges with almost no contribution from the web and with no interaction between flexure and shear behaviour [2, 3].

Luo [4] has proposed three types of shear buckling patterns that has been named as local buckling, global buckling and zonal buckling. Luo[5] also has recommended a formula to predict the ultimate strength of trapezoid web under patch loading using non-linear finite element method. Several factors that influence the ultimate strength were investigated; which includes strain-hardening models, initial imperfections, variation of yield stress and strain-hardening degree due to corner effects, loading position, load distribution length and variation of geometric parameters. While, Osman et al. [6] have conducted a series of experiments to study the shear behaviour of trapezoid web profile. Three series of tests on trapezoid web plate girder were conducted on 5 metres beam which was identified as TS 400-2, two beams with 1.7 metres length and six square web panels with 380 x 380 mm. From the results of the tests, it was concluded that local buckling failure modes were observed in most of the test girders, which stretched over one cycle of the trapezoidal form. The ultimate shear capacity of trapezoid web plate girder is higher than the elastic design capacity, which only accounts for the web shear buckling limit. Usman [7] also carried out finite element analysis to study the critical shear by using the Eigenvalue-buckling analysis. In this work, a new formula for critical shear stress was proposed and the new proposed equation was compared to the experimental data collected in UniversitiTeknologi Malaysia (UTM). The formula of critical shear stress that was proposed is Q_0 (design shear capacity) which is calculated based on the proposed design formula. It was derived while neglecting the contribution of the flanges. The calculation of the shear force capacity were derived from the following equations and based on the support arrangement for each test:

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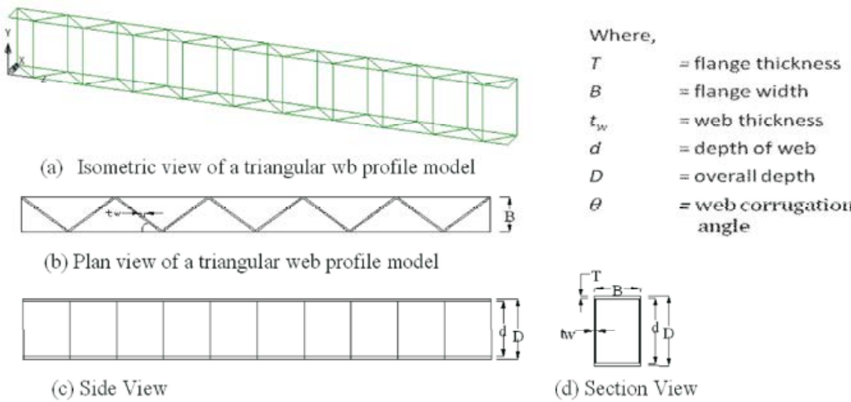


Fig. 1: A typical shape of T_{RI}WP web section

$$Q_0 = 0.6\times0.65p_{yw}.d \quad (1)$$

where:
Q_0 is the design shear capacity
p_{yw} is the design strength of the web
d is the depth of web
t is the thickness of the web

Apart from that, the following expressions of the shear buckling resistance V_{cr} of a stiffened or unstiffened panel was proposed:

$$V_{cr} = q_{cr}.dt \quad (2)$$

The value of the shear buckling resistance for flat web (FW) can be obtained with the application of the above equation.

Finite Element Analysis: Some characteristic cases of the above studies also were validated via the Finite Element (FE) Method. For that purpose, LUSAS 14.3 has been employed to do the buckling linear analysis. Detailed of the FE model of the triangular web profile beam built up is shown in Figure 1. The model consists of size 1000 x 600 mm with various thickness, oriented quadilateral thin shell element (QSL8) employed to both of the flanges and the web of the beam. The dimensions and geometric characteristics of the analyzed girders are listed in Table 1.

The pure shear loading condition is modeled by applying distributed load on one side vertical stiffener. For shear model support condition, line AD is restrained in each translation and rotational direction as shown in Figure 2. Lines AB, BC and DC are restrained on x and z translation's directions. Concentrated load is applied only on line BC as shown in Figure 2.

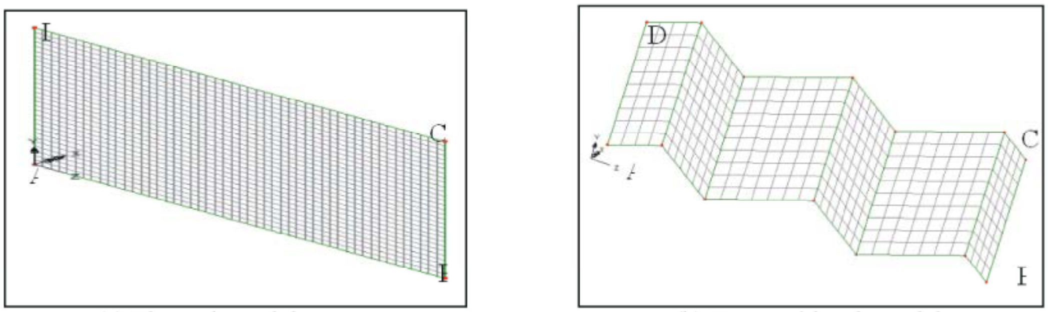
Table 1: Dimension of TRIWP and FW steel sections in finite element analysis

FEA model index	E kN/mm^2	τ_y N/mm^2	t_w mm	h_w mm	h_w/t_w	L mm	O
TriWeb Plate-1	205	275	1	600	600	1000	45
TriWeb Plate-2	205	275	2	600	300	1000	45
TriWeb Plate-3	205	275	3	600	200	1000	45
TriWeb Plate-4	205	275	4	600	150	1000	45
TriWeb Plate-5	205	275	5	600	120	1000	45

The main objective of an eigenvalue analysis is to obtain the critical shear. Without considering membrane tensile and flange capacity, the modelling techniques used in the eigenvalue buckling analysis were employed. This technique is reliable to be used in the study of shear capacity of triangular web compared to normal flat web. Eigenvalue buckling analysis is a linear analysis, that may be applied to relatively stiff structures in order to estimate the maximum load that can be supported to structural instability or collapse [8].

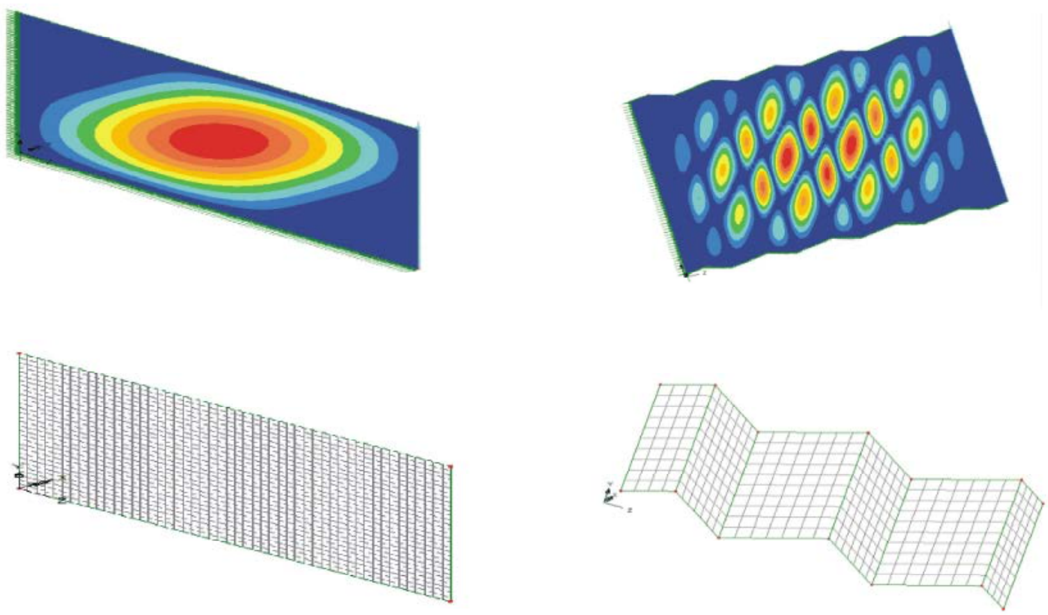
RESULT AND DISCUSSION

Five finite element models of triangular web were developed. Each model has the dimension of 1000x600 mm with 1, 2, 3, 4 and 5 mm web thickness. Eigenvalue buckling analysis was used to analyse the buckling load of the flat plate model of various thicknesses. Results of the analysis on flat plate were then compared to that of the established theoretical formula for critical shear buckling in BS 5950:2000 part 1 without considering membrane tensile and flange capacity. The result of eigenvalue buckling analysis for the model with the dimension of 1000x600 mm had high accuracy and error of less than 5%, as listed in Table 2.



(a) Flat web model (b) Trapezoid web model

Fig. 2: The finite element meshing on the model



(a) (b)

Fig. 3: The Finite Element contour shear buckling (a) normal flat web (b) triangular web properties.

Table 2: Comparison between eigenvalue analysis results of Flat Plate and Triangular Web Plate models

Model Index	Thickness t (mm)	d/t	Flat Plate model FEA (kN)	Triangular Web Plate model FEA(kN)
TriWeb Plate-1	1	600	2.12	2.15
TriWeb Plate-2	2	300	16.93	17.18
TriWeb Plate-3	3	200	57.15	858.89
TriWeb Plate-4	4	150	135.47	2022.15
TriWeb Plate-5	5	120	264.58	3915.59

The buckling pattern of the normal flat web and triangular web profile are shown in Figure 3. The global buckling has occurred in the web for normal flat web while for the triangular web profile has occurred as a zonal buckling on each of its web (Figure 3). For that reason, it can be concluded that the shear flow is uniformly distributed over the web. In addition, the web thickness also contributes to the shear buckling of the beam. It can be seen that when the thickness of the web increases, the shear buckling capacity also increases and similar results were reported by other researcher [7]. From present work; it can be concluded that thickness of web gave an effect of increasing the ability to maintain a greater percentage of its buckling load as also it has been mentioned by Elgaaly [9,10].

The triangular web profile has a higher ultimate shear strength due to its web configuration compared to the normal flat plate of the normal size as shown in Figure 4. From the eigenvalue buckling analysis, it shows that at web thickness of t=1 mm, there is a small difference between the normal flat web and the triangular web profile. However, when the web thickness is increased,

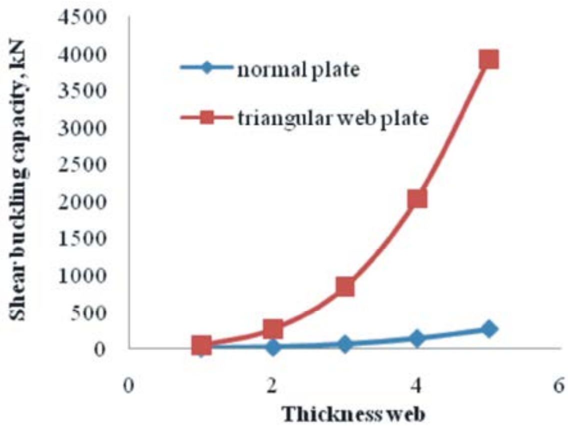


Fig. 4: Graph comparisons between finite element analysis result for triangular web and shear capacity of normal plate based on BS 5950.

the value of shear buckling capacity also increases rapidlyas shown in Figure 4. Therefore, it can be concluded that one of the factor that contribute to this performance is the thickness of the web. Meanwhile for flat web the value of shear buckling capacity was not much different with the increasing of the web thickness.

CONCLUSION

It can be concluded that the triangular web profile section had higher shear capacity compared to that of normal flat web profile section. The thickness of web is one of the factors that contribute to theperformance of the web itself. The modelling technique using the eigenvalue analysis is reliable to be used in studying the shear capacity of triangular web profile.

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