THE STUDY OF LATERAL TORSIONAL BUCKLING BEHAVIOUR OF BEAM WITH TRAPEZOID WEB STEEL SECTION BY EXPERIMENTAL AND FINITE ELEMENT ANALYSIS

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ABSTRACT

Experimental and numerical study on lateral torsional buckling behaviour of steel section with trapezoid web is presented in this paper. Comparison is made with conventional beams with flat web. In the experimental work, sections with nominal dimension 200 x 80 mm and 5 m length were loaded vertically while the lateral deflection were unrestrained to allow for the lateral torsional buckling. In the analytical study, eigen-value buckling analysis in the finite element method was used to determine the critical buckling load. It is concluded that steel beam with trapezoidally corrugated web section have higher resistance to lateral torsional buckling compared to that of section with flat web. The result shows that corrugation thickness influence the resistance to lateral torsional buckling.

1.INTRODUCTION

Economical design of structural steel sections normally requires thin webs to increase the shear buckling strength. The conventional method which uses intermediate stiffeners welded to web to allow the use of thin webs has two disadvantages i.e. high cost of fabrication and reduced service life of the element. The use of corrugated sheets (Figure 1) to replace flat sheets as webs of a girder eliminate both disadvantages [1,2,3]. In addition, it reduces the total weight of the structure, thus allowing longer spans and savings in foundation design. Previous researches have been carried out to study the performance of trapezoid web section in shear in web, secondary bending moment in flange, bending, and axial buckling [4,5,6].

When a beam is loaded , it will deflect vertically. If the beam does not have sufficient lateral stiffness or lateral support along its length, the beam will also deflect out of the plane of loading. The load at which this buckling occurs may be substantially less than the beam's in plane load carrying capacity. For an idealized perfectly straight elastic beam, there will be no out-of-plane deformations until the applied moment reaches the critical value M_b, when the beam buckles by deflecting laterally and twisting. These two deformations are interdependent: when the beam deflects laterally, the applied moment exerts a component torque about the deflected longitudinal axis which causes the beam to twist. This behaviour, which is important for long unrestrained I-beams whose resistances to lateral bending and torsion are low, is called elastic lateral torsional buckling.

Experimental and numerical study on lateral torsional buckling of steel section with trapezoid web is presented in this paper. The objectives of the study is to determine the lateral torsional buckling capacity of trapezoid web profile in comparison with normal flat web beams using experimental and finite element method.

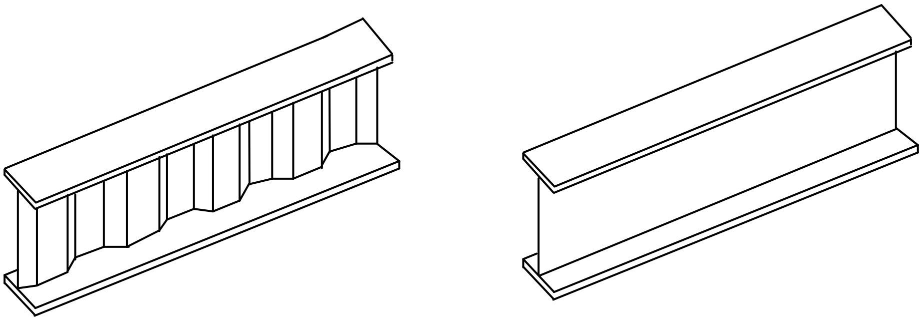


Figure 1 : Typical beam sections with trapezoid web and flat web

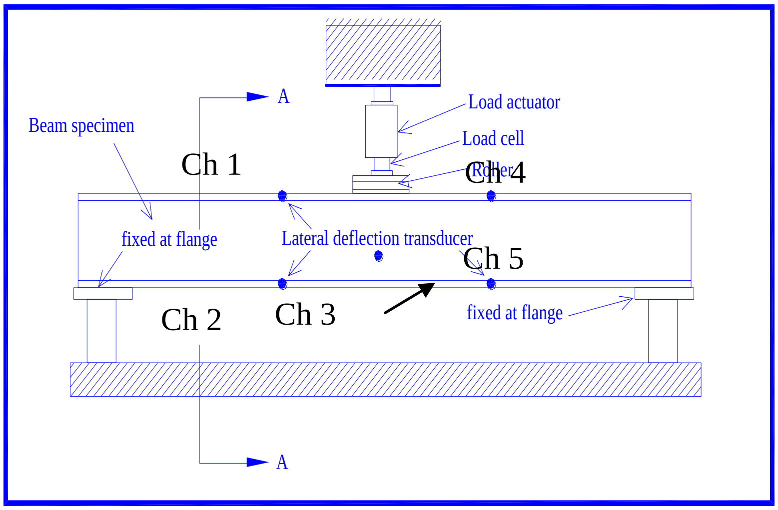
2. EXPERIMENTAL STUDY

2.1 Test procedure

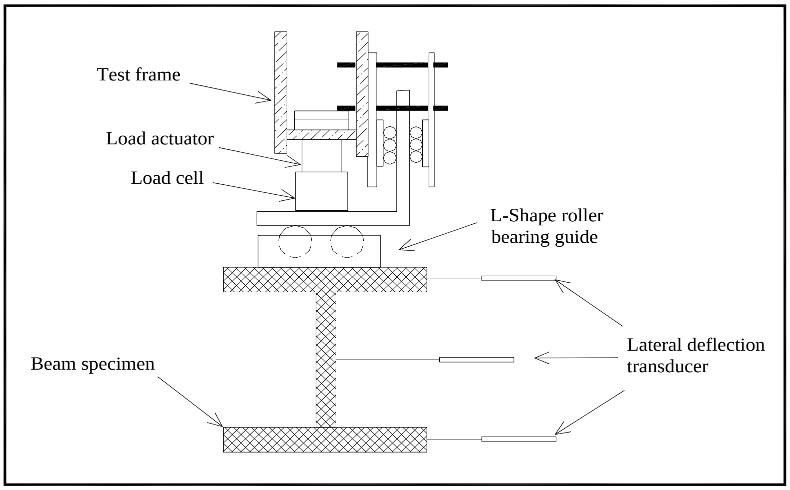
Lateral torsional buckling tests were conducted on three sets of beams, each set consists of two specimens i.e. sections with trapezoid web numbered as TWP3 (TWP3A and TWP3B), trapezoid web profile TWP4 (TWP4A and TWP4B) and flat web FW3 (FW3A and FW3B). The difference between TWP3 and TWP4 is in their web corrugation thickness, where TWP3 has full corrugation thickness (hr = B) while TWP4 has only half corrugation (hr = 0.5B).

The test was designed based on the test method by Dirk [7] and Salina [8]. Figure 2 shows the diagrammatic view of the test set-up. The photograph is shown in Figure 3. A point load was loaded at mid span of the specimen through a specially designed loading device. The L-shape roller bearing guide was used to ensure that the jack always seated on a horizontal surface so that the direction of the loading was kept vertical under increasing loading. The roller on the top flange under the loading was used to ensure that there was no horizontal restraint that might inhabit lateral buckling during loading.

Two types of lateral restraint at the support were used, i.e. type A and type B. For type A, the bottom flange of the beam at both ends were fixed, whilst for type B, the bottom flange and web which were both restrained from deflect laterally. It is shown in Figure 4.



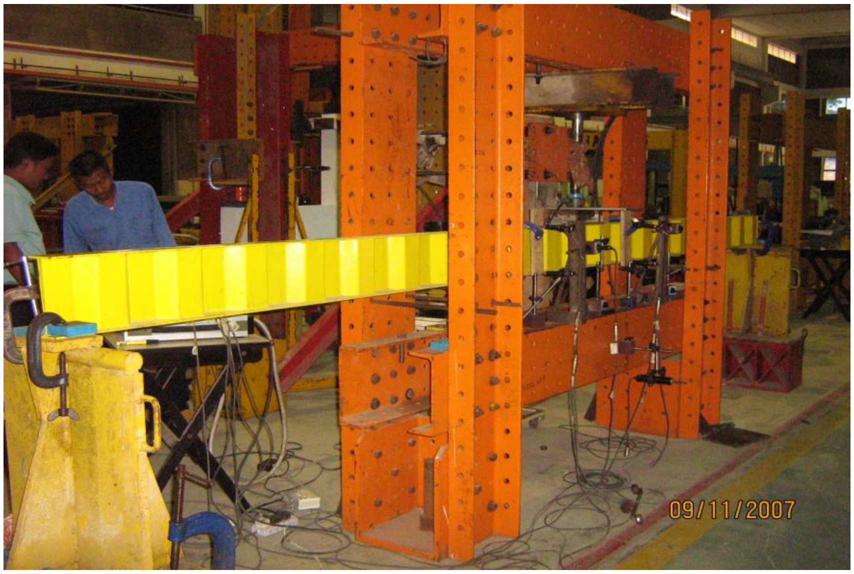
(a): The overall view of the test set up



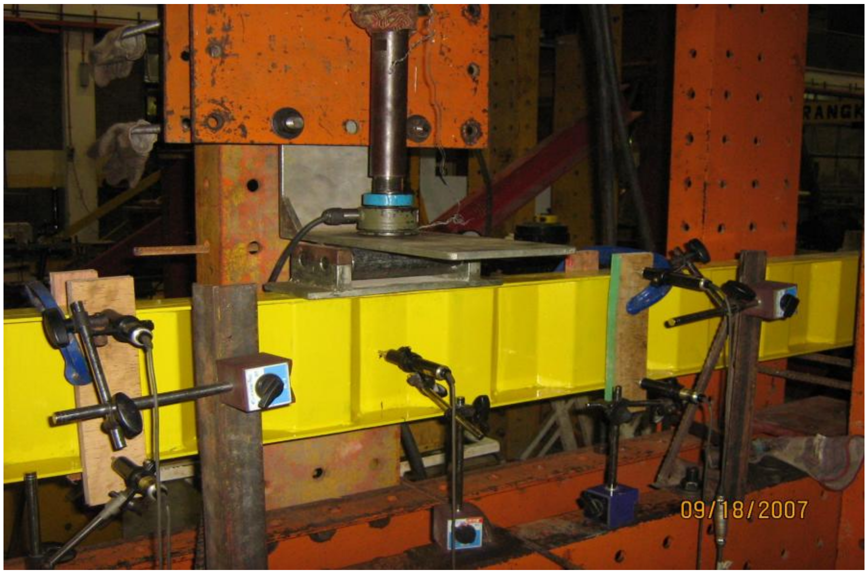
(b): Details of the loading device

Figure 2: Test set-up and the loading device

For each type of beam, two different spans were used i.e 4000 mm and 5000 mm. Displacement transducers were placed at five different locations to measure the lateral deflection of the beams. Loads were applied gradually, with the increments of 1.0 kN. The displacement was recorded at each increment. The lateral displacements of beam specimens were measured at 400 mm (left and right) from mid span of the beam (for top and bottom flange) and also at the centre of the web.

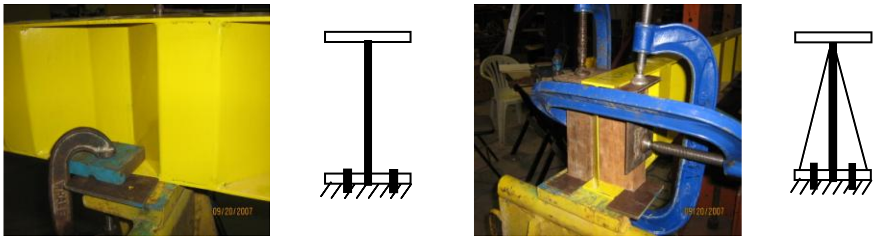


(a) : The overall view of the test beam



(b) Positions of vertical and lateral transducers

Figure 3 : The testing rig and loading at mid span



Fixed at flange only (Type A) Fixed at flange and web (Type B)

Figure 4 : Lateral restraint Type A and B at the beam end support

The test was stopped when buckling occurred, as determined in the graph of moment versus lateral displacement. In the test, all beam specimens were found to be still in elastic state after the tests. Relationships between bending moment and lateral deflection were plotted. In general, the lateral deflection increase linearly with the vertical bending moment. Then, the increase becomes non-linear, followed by a stage when the deflection increase monotonically.

The value of lateral torsional buckling moment resistance was determined from the intersection of tangent of the first and second curve. The intersection method was known as "knee joint" which has been used by other researchers [9,10] to determine the moment resistance of connection. The values of lateral torsional buckling resistance, M_b for all specimens were determined when a "knee" shape was observed. In each graph, two tangent lines were drawn and the intersection of these two lines gives the M_b value.

The deflection from the midspan was used for the determination of M_b. The M_b value for each beam was indicated in each graph (Figure 5). The result of the experiment is presented in Table 1.

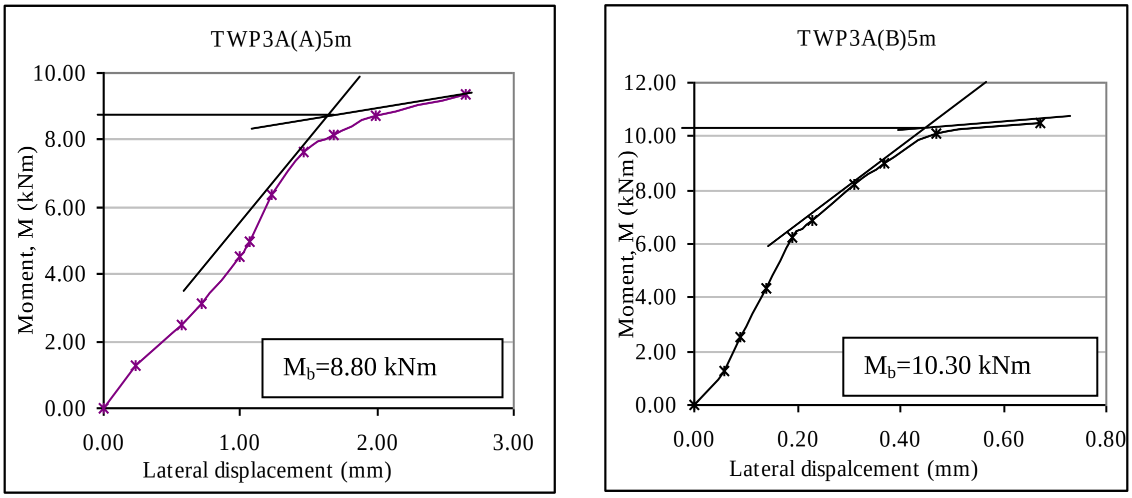


Figure 5: Typical graphs for the determination of M_b

Table 1 : Test results of M_b for beams with normal flat web and beams with trapezoid web profile

Span of beam (mm)	Beam mark	Support type 'A'		Support type 'B'	
		M_b kNm	Average M_b kNm	M_b kNm	Average M_b kNm
5000	TWP3A	8.80	9.00	10.30	10.80
	TWP3B	9.20		11.30	
	TWP4A	8.00	8.20	9.00	9.25
	TWP4B	8.40		9.50	
	FW3A	7.10	7.05	8.20	8.55
	FW3B	7.00		8.90	
4000	TWP3A	9.50	9.65	11.00	11.20
	TWP3B	9.80		11.40	
	TWP4A	8.90	9.10	9.20	9.60
	TWP4B	9.30		10.00	
	FW3A	8.10	8.30	8.50	8.65
	FW3B	8.50		8.80	

From the table, it is observed that :

(i) Beams with flat webs and 5 m have the average of lateral torsional buckling moment, M_b lower than that of beam 4 m, for each of the Type A and B support. The same finding for TWP3 and TWP4 was obtained.

(ii) As expected, the beams with Type B support has higher M_b value that those with Type A support for both spans.

(iii) TWP section perform better than that of flat web in terms of lateral torsional buckling moment resistance.

(iv) The beam with trapezoid web profile section with full shape corrugation ($h_r = B$) are better than the beam with trapezoid web profile section with half shape ($h_r = 0.5B$) and flat web in their lateral torsional buckling moment resistance.

The higher resistance to lateral torsional buckling is due to the higher moment of inertia about minor axis, I_y for the section with trapezoid web profile. The minor axis moment of inertia was studied by the author [11], and the formulation for the I_y value has been developed based on experimental and analytical study.

3. Finite Element Study On Lateral Torsional Buckling By Finite Element Method

In this study, all models were assumed to buckle under perfect conditions, where there is no initial imperfectness and eccentric load. The buckling moments were then compared with result obtained from testing . Eigenvalue analysis of LUSAS Modeller was used to determine the buckling loads.

A linear buckling analysis is a useful technique that can be applied to relatively stiff structures to estimate the maximum load that can be supported prior to structural instability or collapse. The assumptions used in linear buckling analysis are that the linear stiffness matrix does not change prior to buckling and that the stress stiffness matrix is simply a multiple of its initial value.

3.1 Modelling

LUSAS models are defined in terms of geometric features that must be subdivided into finite elements for solution. This process of sub division is called meshing. Mesh datasets contain information about element types, element discretisation and mesh type. The I-beam models were assigned ungraded mild steel for its material property with Young's modulus, E= 209×10^3 N/mm^2 , shear modulus, G = 79×10^3 N/mm^2 and Poisson ratio of 0.3. The beams are simply supported and unrestrained laterally.

The convergence of the mesh was established by independently increasing the mesh density in each part of the model beam section. The model was also analysis with increased mesh density in all parts of the section simultaneously, and with higher-order elements (QSL8).

3.2 Eigenvalue Buckling Analysis

The main objective in the eigenvalue buckling analysis is to obtain the critical buckling load, by solving the associated eigenvalue problem. In LUSAS, there are two methods to obtain information regarding buckling loads and their respective deformation mode i.e. The linear eigenvalue buckling analysis and the full geometrically non-linear analysis. Figure 6 show a typical buckling shape in Mode 1.

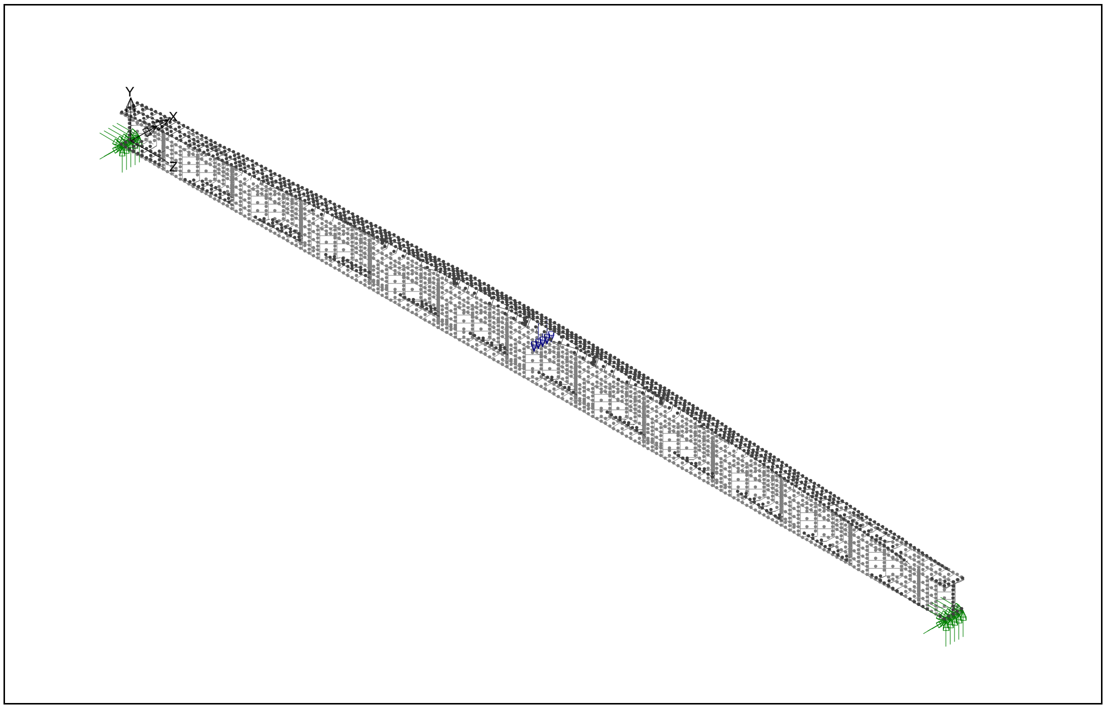


Figure 6 : The buckling shape mode 1

Modes 1,2, and 3 represents the buckling shape of the element. In this study the result of mode one would be considered; because it was found that all the beam specimen failed in the tests due to this mode. This is also because mode one is the least value. It will be unrealistic to choose the higher modes 2 and 3 to get the critical buckling load. The resulted eigenvalues are actually the load factors to be multiplied to the applied loading, to obtain critical buckling load. The eigenvalue buckling analysis in LUSAS Modeller will provide both local and global buckling modes. Engineering judgment is necessary to determine which buckling mode is the most critical in order to select the appropriate buckling load factor. It is, of course possible to visually examine the resultant modes in LUSAS Modeller.

3.3 Result and Discussion.

The results of M_b are summarized in Table 2. In addition, the M_b value derived from the design calculation is given for each beam. The method of calculating the design M_b value is also given in BS 5950:Part1:2000, by neglecting the contribution of web. It can be summarized as follow:

The critical buckling loads and the lateral torsional buckling moments results of eigenvalue analysis theory calculation for trapezoid web profile and flat web are presented in Table 4, for both type A and type B support. It is shown that, as expected, as the lengths of the two beams with trapezoid web profile increase, the lateral torsional buckling moment decreases. It is found that, trapezoid web profile sections need higher load to buckle compared to flat web. This is because of the higher value of I_y for the TWP section compared to the flat web section [11].

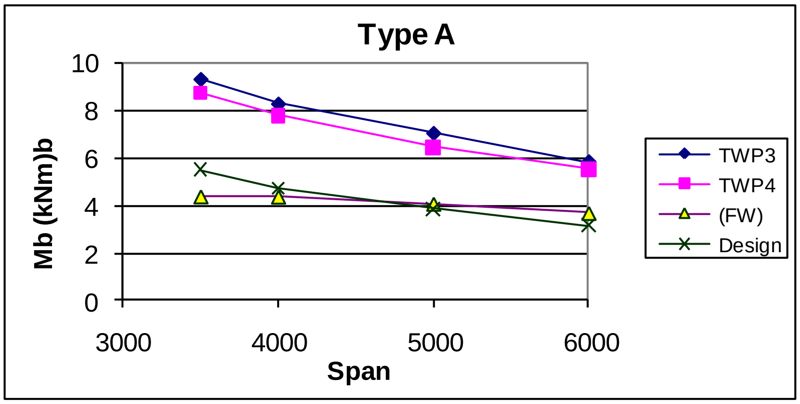
In terms of the effect of corrugation shape, the results show that web with full corrugation (TWP3 ; $h_r = B$) have a higher resistance to lateral torsional buckling compared to that of the half corrugation shape (TWP4 ; $h_r = 0.5B$) . As a conclusion, trapezoid web profile section have higher resistance in lateral torsional buckling behaviour and hence suitable for structural applications.

Table 2 : Percentage difference of M_b for beams with normal flat web and beams with trapezoid web profile (finite element analysis).

Support	Span (mm)	M_b			Mb (design)
		TWP3	TWP4	(FW)	
Support Type A	6000	5.84	5.54	3.70	3.15
	5000	7.05	6.45	4.09	3.85
	4000	8.30	7.81	4.39	4.73
	3500	9.35	8.75	4.40	5.51
Support Type B	6000	11.62	9.75	7.23	3.32
	5000	14.35	11.28	8.87	8.60
	4000	15.41	13.79	11.50	10.96
	3500	15.66	15.05	13.43	13.08

Figure 7 shows the comparison between the TWP3, TWP4 and FW in their lateral torsional buckling resistance for Type A support. Both set of results show a similar trend i.e as the beam length increases, the buckling moment decreases. In all beam cases, the finite element prediction are more than that of the test .

For support Type B, the beam length increases, the buckling moment decreases. For all specimens, the buckling moment results from the finite element predictions are bigger than that of the test results for all lengths of beams.



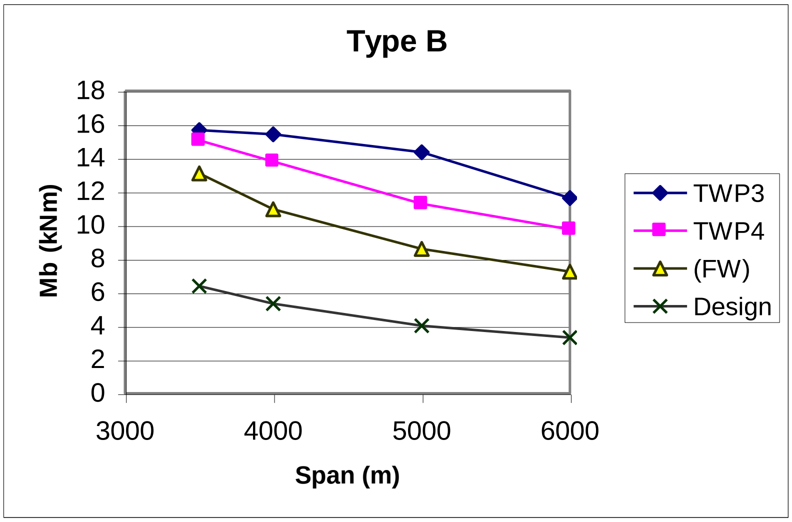


Figure 7 : Buckling moment resistance for different span

Figure 7 show that as length increased the value of M_b decreased. In both figures, comparison between different corrugation ratio shows that the value of M_b for TWP3 (half-corrugation) is higher than TWP4 (full-corrugation). The overall observation shows that the result from the finite element analysis is higher than the test for support Type B but not for the Type A support. In comparison, in all cases, the value of M_b for finite element analysis and testing are more than the value M_b from the design formula. In finite element analysis, the value of M_b at Type A support was less than M_b value from design formula. From both figures, comparison between different types of restraint shows that Type B gives extra value than Type A support. This is in accordance to the theory, i.e.Type B support is supposed to get higher value of M_b than Type A. This is because of the specimen was more difficult to move in Type B support. Therefore, the value of M_b will be higher for Type B.

4.0 CONCLUSION

From the experimental and analytical study on the lateral torsional buckling on trapezoid web section, it can be concluded that :

(1) Steel beam with trapezoidally corrugated web section have higher resistance to lateral torsional buckling. compared to that of section with flat web.
(2) The result shows that corrugation thickness influence the resistance to lateral torsional buckling. Sections with thicker corrugation have higher resistance to lateral torsional buckling.
(3) Higher value of moment of inertia about minor axis for the section with thicker corrugation contributes to the higher resistance to lateral torsional buckling.
(4) Finite element can be used to determine the elastic lateral torsional buckling moment of the section.

5.0 ACKNOWLEDGEMENTS

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M_b=10.00
kNm