The 1st International Conference of

European Asian Civil Engineering Forum EACEF

The future development in civil engineering based on research and practical experience.

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26 - 27 September 2007
at the Universitas Pelita Harapan,
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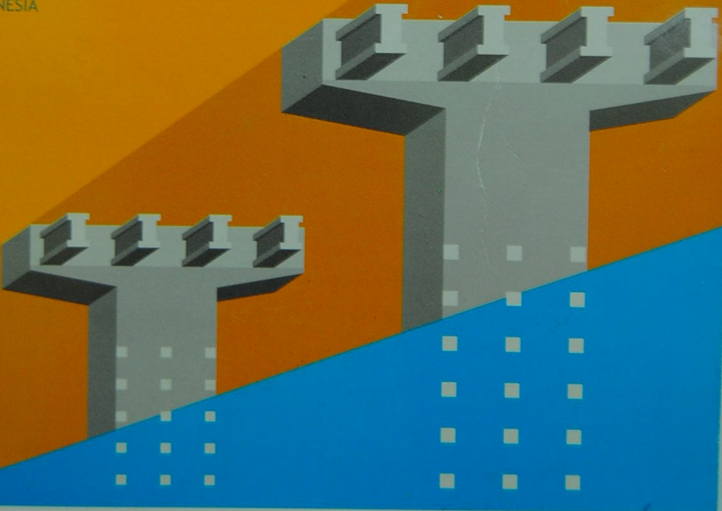
INDONESIA



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UPH
Civil Engineering Department

Universität Stuttgart
Germany

Program Book Abstract

ISBN 978-979-1053-01-3

PROGRAM BOOK and ABSTRACT

The 1st International Conference of EACEF
(European Asian Civil Engineering Forum)

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26-27/09 07
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Publisher : UPH - Press 2007

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BUCKLING ANALYSIS of CRUCIFORM COLUMN USING UNIVERSAL BEAM SECTION

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ABSTRACT: This paper describes the buckling behaviour of cruciform column section using universal beam sections. The initial imperfections and material properties of the cruciform column section have been measured experimentally and reported in this paper. A finite element model was developed to carry out the buckling analysis. The finite element analysis was performed on cruciform column sections compressed between pinned ends for different column lengths, and column curves ware obtained. The linear finite element model was verified against recent experimental results. An extensive parametric study was carried out using the finite element model to study the effects of cross section geometries on the strength and behaviour of cruciform column sections. The column strengths predicted by the finite element model were compared with the design strengths calculated using BS 5950-1: 2000. The results show that the design rules accurately predicted the column strengths for cruciform column sections using universal beam sections.

KEYWORDS: cruciform column, finite elements, buckling, steel structures, structural design.

1. INTRODUCTION

The use of hot-rolled steel structural member in construction is applied as a result of the superior strength to weight ratio and ease of construction. The compound cruciform column using universal beam section is recommended to be used as a column section other than conventional H-section due to its symmetrical shape. The capacity of a column is mainly governed by the second moment of inertia and slenderness ratio. Therefore, the symmetrical cruciform column sections have same value of second moment of inertia on both axes which will increase the axial capacity of a column. The stability of cruciform column is a current research area where it is still not widely apply in construction field. Many studies need to be carried out especially the buckling behaviour of cruciform column to predict the actual behaviour of the column.

The advantages of cruciform column using universal beam section can be used for multi-storey steel frame especially unbraced frames due to its characteristic. The symmetrical shape of cruciform column increases the axial capacity and stiffness of a column. Their wide flanges on both axes enable the builders to have more types of beam-column connections flexibility. Research has been carried out for the comparison of cruciform column and conventional H-section in the design of multi-storey unbraced frames. The results show that cruciform column able to achieve the required strength with less steel weight compare to conventional H-section. The percentage of steel weight savings is up to 45% for minor axis frames. The design recommendations for cruciform column were based on BS 5950-1: 2000 and Steel Construction Institute. For cruciform column, the Robertson constant of 2.0 is assumed as the same value used for universal beam sections in major axis. This value applied for both axes of the cruciform column where no flange is greater than 40mm thick. The reason for using 2.0 as Robertson constant is that the formation of cruciform column is by the use of universal bean and the bending on major axis in universal beam is stronger than the minor axis. Therefore, the assumption of using 2.0 as the constant for cruciform column in consistent with the constant suggested by BS 5950-1: 2000.

The design of cruciform column also correlated with four experimental tests. The column were selected from various slenderness ratios and tested with pinned ended condition. It was observed that the column failed beyond the predicted value and the failure mode is governed by flexural - torsional buckling. Many researchers showed that combining experimental investigation with numerical modeling provides better understanding for the buckling behaviour of a column. Therefore, a finite element model is needed to understand the buckling behaviour of cruciform column using universal beam section.

The objectives of this paper are to measure the initial imperfections, material properties and axial capacity of the cruciform column section experimentally. Second, a finite element model simulating the behaviour of cruciform column section is developed. The results obtained from the finite element analysis are then verified against the test results and theoretical results carried out earlier.

2. EXPERIMENTAL INVESTIGATION

The experimental program was divided into full-scale compression tests and material properties tests. The full-scale compression test consists of 4 cruciform column sections with pinned end condition subject to pure axial compression load. The columns are grinded at both ends to have a flat surface. The sizes of the specimens are selected from the section property tables developed earlier and the maximum axial load capacities are calculated based on the code of practice. The geometrical configuration of the specimen is shown in Figure 1 and their dimensions are given in Table 1. The distribution of 4 strain gauges at the position of half of the column length for each specimen is shown in Figure 2.

The material property for each cruciform column sections was determined by longitudinal tensile coupon tests. Three to five coupon specimens were cut from the flange and the web of the column section. The coupons were tested according to the British Standard BS EN 10002-1: 2001 in a 250kN capacity DARTEC testing machine. The measured material properties obtained from the coupon tests are summarized in Table 2.

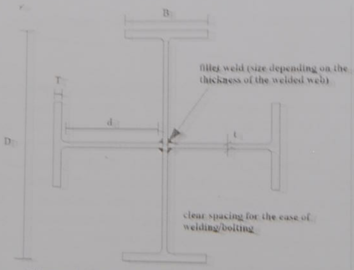

Figure 1 Cross Section of Cruciform Column

Table 1 List of Specimens

Specimen No	D	B	T	t	λ
254x102x44 CCUB1	201	100.5	8	5.8	28.17
203x133x50 CCUB2	202	134.3	7	5.5	26.50
203x102x46 CCUB3	198	100.2	7	4.9	28.19
152x89x32 CCUB4	155	90.8	7	4.8	35.24
63x38x13 CCUB5	73	37.5	4.4	2.4	76.36
76x45x16 CCUB6	86	38	4.2	1.8	64.05

*All units in millimeters

*λ is the slenderness ratio

Table 2 Steel properties

Property	Nominal Value	Measured Value	
		Mean	Standard Deviation
F_y (MPa)	332	358	27
E (MPa)	180000	207000	14000
t (mm)	6.0	6.1	0.04

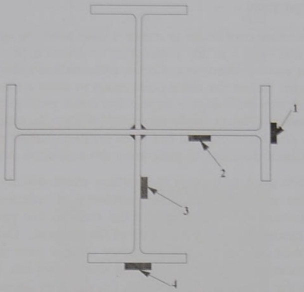

Figure 2 Distributions of Strain Gauges

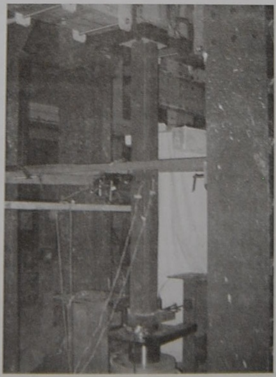

Figure 3 A View Of Typical Experimental Set-Up.

3. FINITE ELEMENT MODEL

The experimental specimens for cruciform column using universal beam section were implemented in the finite element model. The finite element program LUSAS 13.5 (2004) was used in the analysis for the simulation of cruciform column. The finite element model followed the same approach as detailed in the experimental columns. Two types of analysis were carried out. The first is eigenvalue analysis to determine the buckling modes and loads for the experimental specimens, where the second is eigenvalue analysis for cruciform columns with various effective lengths. The first analysis was carried out to validate the finite element results with theoretical prediction and experimental results. The second analysis was then use to develop a strut curve for cruciform column using universal beam section and compare with the existing strut curve as used in the Perry-Robertson formula.

The thin shell (QSL8) elements were used in the model. Units of kN, mm, kg are used throughout the example. The required output from the analysis consists of a deformed shape plot showing displacements caused by the imposed loading and the buckling load.

4. MODELING PROCEDURES

The modeling starts with entering coordinate to create a base point. Select the base point and enter a translation value of 120.8 and -120.8 in the y direction to create a line that will define part of the column web. Select the end point of the line and enter a translation value of 50.8 in the x direction to create the right column flange. Select the same point again to enter a translation value of -50.8 in the x direction to create the left column flange. Repeat the same process for minor axis but enter the same value in different direction (For example enters 120.8 for x direction and 50.8 for y direction). Finally a cross section of a cruciform column has been created. Select the whole model and enter a translation value of 1700 in the Z direction to generate a three dimensional model.

The line mesh divisions were used to control the surface mesh density for the column. The Thin Shell, Quadrilateral elements with Quadratic interpolation was selected for the surface mesh. For simplicity, the automatic divisions were selected for the surface. For geometric properties, two steel thicknesses are required to model the flange and web of the column. Define the thickness of 6.8 mm for flange and 5.7mm for web then apply the geometry dataset onto the specified features. As for material properties, select material Mild Steel from the drop-down list, leave the grade as Ungraded and units kN mm t C. With the whole model selected, the material dataset Mild Steel Ungraded from the Tree view assigned on the selected features to all surfaces. In the finite element model, the ends of the columns were set to free for the translation in the Z direction and leave other translation as fixed. Apply this condition to the whole column except the major axis web at one end of the column. Defined another support condition where all directions are set to fixed at the translation and apply this dataset to the remaining column web. The load was applied to one end of the column in Z direction with the value of -10kN. After defining all the attributes to the model, the Eigenvalue Analysis was carried out. An eigenvalue analysis extracts the natural modes of vibration of a structure. It can also be used to solve buckling load analysis problems. The solution parameters for buckling analysis are specified using an eigenvalue control dataset.

After carried out the eigenvalue buckling analysis, the critical buckling load can be calculated by multiply the first load factor to give the value of loading which causes buckling in the first mode shape. The initial buckling load is equal to the load factor multiply with the applied load. The same method was then applied to the other cruciform column models.

5. VERIFICATION OF THE FINITE ELEMENT MODEL

In the verification of the finite element model, a total of 6 cruciform column sections using universal beam section were analyzed. A comparison between the experimental results and the results obtained from the finite element analysis is carried out. The main objective of this comparison is to verify and check the accuracy of the finite element model. The comparison of the ultimate loads and failure modes obtained experimentally and numerically is shown in Table 3. It can be seen that large variation has been observed between the experimental and numerical results for all the columns. A maximum difference in ultimate load of 222% was observed between experimental and numerical results.

The values of P_{exp} / P_{FE} ratio are 0.49, 0.31, 0.46, 0.41, 0.59 and 1.35. Two modes of failure have been observed experimentally and verified by the finite element (FE) model. The failure modes are twisting and overall buckling. Twisting was observed in stub column with a slenderness ratio of lesser than 80 while higher than that the overall buckling was observed.

Table 3 Comparison between Experiment and Finite Element Result

Specimen	Compression Resistance, Pc (kN)		Ratio of Experimental vs Finite Element	Difference Between Experimental and Finite Element
	Experimental	Finite Element		
CCUB1	1702	3484	0.49	-105%
CCUB2	1756	5654	0.31	-222%
CCUB3	1360	2955	0.46	-117%
CCUB4	1017	2496	0.41	-145%
CCUB5	205.5	346	0.59	-68%
CCUB6	227.5	168	1.35	26%

Figure 4 shows the deformed shape of the cruciform column observed experimentally and compared with the finite element analysis. It can be seen that the finite element model behave differently than the failure mode observed in the test.

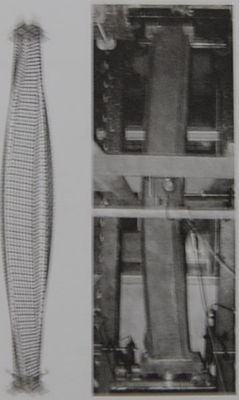

Figure 4 Comparison of Failure Mode between Experiment and Finite Element

6. COMPARISON OF COLUMN STRENGTHS

The column strengths (P_{FE}) obtained from finite element analysis in the parametric study is compared in Figure 5 with the strut curve obtained from the BS 5950-1: 2000. All column strengths are non-dimensional zed with respect to the nominal stub column design strength (section capacity) p_c. The design strength is plotted on the vertical axis, while the horizontal axis is plotted as slenderness ratio, where slenderness ratio is equal to the effective length, l_{eff} divided by r, the radius of gyration of the cross section.

The proposed strut curve (a) compared well with P_{FE} and accurately predicted the column strength for cruciform column section. The strut curve is quite conservative compare to the results obtained from experimental tests and finite element modeling.

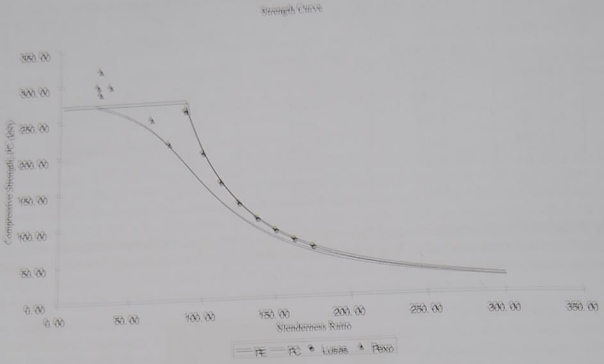

Figure 5 Comparison of Strut Curve with Experimental and Finite Element Results

7. CONCLUSIONS

A finite element model for the analysis of pinned-ended cruciform column section using universal beam section is presented. The axial capacity of the cruciform column section has been experimentally measured and modeled in the finite element analysis. It is shown that the finite element model predicted the strength and failure mode of cruciform column sections differently from the experiment results. The column strength obtained from the finite element analysis was compared with the strut curves predicted by BS 5950-1: 2000. It is shown that the strut curves in BS 5950-1: 2000 is generally conservative for cruciform column section.

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