WARPING BEHAVIOUR OF
CANTILEVER STEEL BEAM WITH OPENINGS

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"The journey of a thousand miles begins with a single step.

A Man without dream is nothing at all.

Dare to dream!! "

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ABSTRACT

This project presents a short study on warping behaviour of cantilever steel beam with openings subjected to coupled torsional force at the free end. Thus far there has not been any research regarding the relationship between warping and web's openings. Finite element software, LUSAS 13.6, was used to perform analysis on seven groups of modelling. The analysis of the results showed that opening has a close relationship with warping since opening can reduce web stiffness. When warping resistance decrease, warping displacements and warping normal stress will increase. Opening with bigger size, installed at the free end and central of the web will induce greater warping and vice versa. Simple approximation of installing stiffeners is proposed in this study to provide section's warping resistance effectively.

ABSTRAK

Projek sarjana ini mengkaji kelakuan ledingan (*warping*) pada rasuk julur keluli berlubang yang mana hujung bebasnya dipiuhkan terhadap paksi membujurnya. Hingga kini, tiada sebarang kajian mengenai hubungan antara kelakuan ledingan dengan lubang pada web rasuk. Perisian LUSAS 13.6 digunakan untuk mengkaji 7 kumpulan model di dalamprojek ini. Keputusan yang diperolehi menunjukkan lubang boleh mempengaruhi kelakuan ledingan rasuk dengan mengurangkan kekukuhan web rasuk. Anjakan dan tegasan paksi akan meningkat berikutan dengan pengurangan kekukuhan ledingan. Lubang berbentuk lebih besar yang dipasang pada hujung bebas dan tengah web akan membentuk piuhan yang lebih ketara dan sebaliknya. Fahaman ringkas terhadap pemasangan pengukuh turut dikaji bagi meningkatkan keupayaan ledingan rasuk dengan berkesan.

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NOTATIONS

B - Width of flange

D - Overall depth of girder

t - Thickness of web

T - Thickness of flange

E - Young's modulus

H - Warping Constant

I_w - Waripng Constant

J - Torsional Constant

G - Shear modulus

ϕ - Angle of twist

L - Length of the section subject to T

T - Applied torque

σ_w - Warping normal Stress

τ_w - Warping shear stress

W_{ns} - Normalized warping function at the particular point 'S' in the cross Section

W_{ws} - Warping statical moment at the particular point 'S' in the cross section.

a - Distance of effective flange restraint

M_E - Elastic critical moment

M_p - Plastic moment capacity of section

M_b - Buckling resistance moment

P_b - Bending strength

S_x - Plastic section modulus

n	-	Slenderness correction factor
u	-	Buckling parameter
v	-	Slenderness factor
x	-	Torsional index
p_y	-	Design strength
A	-	Cross-sectional area of a member
λ	-	Slenderness of a beam
λ_1	-	Constant for a particular grade of steel
λ_{LT}	-	Equivalent slenderness
$\bar{\lambda}_{LT}$	-	Non-dimensional effective slenderness, ratio of λ_{LT} / λ_1
h	-	Distance between shear centre and the flanges
K	-	Global stiffness matrix

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CHAPTER I

INTRODUCTION

1.1 Introduction

Steel was first produced in the Middle Ages, but it was just used for structural engineering over a century ago. Steel is one of the most important construction materials available in Malaysia's market due to its strength-to-volume ratio, wide range of possible applications, availability of many standardized parts, reliability of the material and its ability to give shape to nearly all the architectural wishes. Numerous researches had been carried out to study various strength properties of steel sections. BS 5950 for example has been introduced to provide a guideline in designing steel structures. The main reason of using standard in design work is structural safety.

In design of beam, various strength properties of steel beam need to be taken into consideration. One of them is lateral-torsional buckling strength of beam. In order to understand the lateral-torsional buckling (LTB), it is essential to develop the knowledge about torsional behaviour of the section including the torsional properties i.e. torsional constant (J) and warping constant (H). A general idea of lateral-torsional buckling including the torsional properties i.e. torsional constant (J) and warping constant (H) can be obtained through Appendix B BS5950: Part 1: 2000.

Frequently torsion is a secondary, though not necessarily a minor effect that must be considered in combination with the action of other forces. The shapes that make good columns and beams, i.e. those that have their material distributed as far from their centroids as practicable, are not equally efficient in resisting torsion. Thin-wall circular and box sections are stronger torsionally than sections with the same area arranged as channel I, tee, angle, or zee shapes. When a simple circular solid shaft is twisted, the shearing stress at any point on a transverse cross-section which is initially planar remains a plane and rotates only about the axis of the shaft.

The development of cellular beams was initially for architectural application, where exposed steelwork with circular openings in the webs was considered aesthetically pleasing. It was recognized that their application could be extended to floor beams and that, due to the high price of curtain walling, savings in the total building cost were attainable through the use of long span cellular beams. They would allow floor zones to be kept to a minimum, without increasing the cost of the steel frame, and enable services to pass through the circular openings, obviating the need for underslung services.

However, the effect of warping due to openings is not stated in BS 5950. The purpose of this study is to assess the warping behaviour of the cantilever steel beam with web openings using finite element modeling. Warping normal stress, displacements on longitudinal axis and angle of twist obtained through finite element analysis were used as comparison parameters between section with and without openings.

1.2 Background of Study

The aim of structural design should be to provide a structural capable of fulfilling its intended function and sustaining the specified loads during its service life. Any features of the structure that have a critical influence on its overall stability should be identified and taken account of in the design. In structural design, torsional moment may, on occasion, be a significant force which provision must be made because the stability of a flexural member is very often a function of its torsional stiffness. The theory of torsion would be considerably simpler if the planar surfaces assumed to be remained plane after twisting. In fact, only cross-sectional surfaces of round shapes remain planar after twisting. In 1853, the French engineer Adhemar Jean Barre de Saint-Venant showed that when a noncircular bar is twisted, it will not remain plane. The original cross-section plane surface becomes a warped surface.

Warping is a difficult phenomenon to visualize. A variable shear flow will occur around the perimeter of a square bar if the shear stress distribution postulated by using membrane analogy as illustrated in Figure 1.1. This variation in shear stress in terms of magnitude and direction induces flexural stresses provided the member subjected to torsion was constrained from warping. If the plate is not constrained, the induced flexural stresses cause warping.

For closed sections such as tubes and box sections, the sections remain plane after twisting within practical limits of accuracy, and the torsional resistance contributed by the parts of the cross-section is proportional to the distance from the centre of twist. While I-section member under uniform torsion such that flange warping is unrestrained, the pattern of shear stress is shown in Figure 1.2. Open sections are substantially less rigid torsionally than sections of the same overall dimensions and thickness with flanges restrained against warping [1].

The development of cellular beams was initially for architectural application, where exposed steelwork with circular openings in the web is considered aesthetically pleasing. Furthermore, this application will allow floor zones to be kept to a minimum, without increasing cost of the steel frame, and enable services to pass through the circular openings, obviating the need for underslung services. But there is no reference available for the warping effect due to the openings. Therefore, this project is carried out.

1.3 Problem Statement

Nowadays, the use of steel beams with openings is commonly used since it makes ducting and services work much more easily. Despite the advantages of flexibility in construction or better outlook, the introduction of opening may reduce the strength of the section if it was not properly designed. Ward (1990) [2] shows that the overall flexural capacity is assessed by considering the plastic moment capacity of the cross section through the centre line of the opening. This reflects that opening can influence the web's strength properties. Hence, it is essential to carry out a study to determine the warping behavior for the steel beam with web opening. Cantilever steel beam was chosen in this research since the nature of cantilever steel beam which restrained at one side makes it vulnerable for torsion.

1.4 Objectives of Study

The objectives of study are as below:

1. To determine the warping behaviour of cantilever steel beam with openings
2. To observe the effect of installing intermediate stiffeners.
3. The use of finite element method in the study of warping behaviour.

1.5 Scope of Study

The scope of study can be divided into several areas which stated as below:

1. Verification of the FEM modal by analytical method.
2. To identify the warping displacement.
3. To identify the angle of twist
4. To identify the warping normal stress.
5. Two types of stiffeners was studied

.

1.6 Research Significance

The significance of the study is that the establishment of warping behaviour of cantilever steel beam with openings and guideline for installing intermediate stiffeners on cantilever steel beam with openings with respect to warping behaviour. This new understanding will then pave way to the development of accurate use of transverse stiffeners on cantilever steel beam with openings as a fundamental engineering problem-solving methodology.

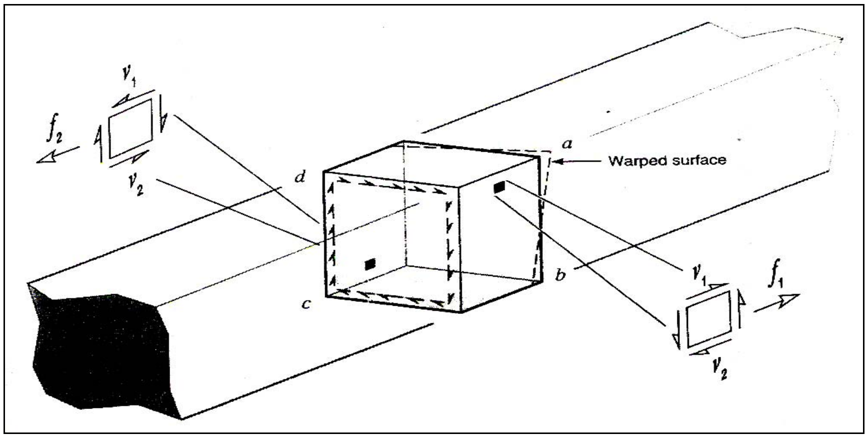

Figure 1.1: Torsional shear flow in a solid bar by Englekirk

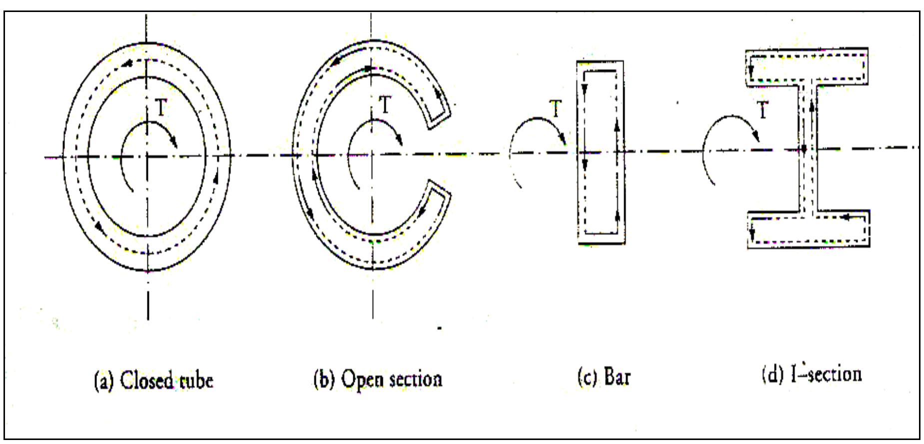

Figure 1.2: Torque induced shear flow by Gorenc, Tinyou & Syam

in the study of warping behaviour of cantilever steel beam with openings.

5.2 Suggestion

For future researches, experiment test to study the warping behaviour of cantilever steel beam with various location, sizes and numbers of openings should be carried out. Anyway, only cantilever steel beam studied in this project, further researches should be carried out to study the effect of opening to the uniform warping behaviour of simply supported steel beam. Besides, study on stiffeners in more detail should be conducted since this project only studied on two types of stiffeners due to time constraint.

REFERENCES

1. Gorenc, B., Tinyou,R. & Syam,A. *Steel Designers' handbook (Sixth Edition).* Australia: University of New South Wales Press. 1996.

2. Ward, J.K. *Design of Composite and Non-composite Cellular Beams.* Silwood Park: The Steel Construction Institute. 1990.

3. Englekirk Robert. Steel Structures. *Controlling Behaviour through Design.* USA: John Wiley & sons, Ltd. 1994.

4. Vlasov VZ. *Thin Walled Elastic Beams.* English translation published for US Science Foundation by Israel for Scientific Translations. 1961.

5. Timoshenko, S. *Theory of Elasticity.* New York: McGraw-Hill Book Co. Inc. 1934.

6. W.Y. Lin and K.M. Hsiao. *More General Expression or the Torsional Warping of a Thin-walled Open-Section Beam.* International Journal of Mechanical Sciences, Vol. 45, Elsevier Ltd. 2003.

7. Mauro Schulz and Filip C. Filippou. *Generalized Warping Torsion Formulation.* Journal of Engineering Mechanics, Vol. 124, No.3, ASCE. 1998.

8. E.J. Sapountzakis and V.G. Mokos. *Nonuniform Torsion of Bars of Variable Cross Section.* Journal of Computers and Structures, Vol.82, Elsevier Ltd. 2004.

9. Trahair, N.S & Bradford, M.A. *The Behaviour and Design of Steel Structures*. 2nd edition. New York: Harper Collins College Publishers. 1988.

10. Salmon, C.G. & Johnson, J.E. Steel structures. *Design and Behaviour, Emphasizing Load and Resistance Factor Design.* 4th edition. USA: Harper Collins College Publishers. 1996.

11. Heins,C.P. *Bending and Torsional Design in Structural Members.* Canada: D.C. Health and Company. 1975.

12. Vince Adams & Abraham Askenazi. *Building Better Products with Finite Element Analysis.* Santa Fe, USA: OnWord Press. 1999.

13. Salman Ullah Sheikh. *Warping Behaviour of Trapezoidal Web Profile.* Master Thesis. University Teknology Malaysia. 2002

14. Yong Jitt Ching. *Warping Constant.* Master Thesis. University Technology Malaysia. 2003.

15. British Standard Institution. *Lateral Stability of Steel Beams and Columns – Common cases of restraint.* 1992.

16. British Standard Institution. *BS5950: Part 1: 2000, Structural Use of Steelwork in Building.* 2000.

BIBLIOGRAPHY

Tirupathi R. Chandrupatla and Ashok D. Belegundu (1997). "Introduction To Finite Elements in Engineering." New Jersey: Prentice Hall.

Wilson E. L. (1997). "An Introduction to The Analysis of Linear Elastic Structures by Finite Element Method." University of Colorado Online Technical Support, http://www.colorado.edu (20-8-2005).

L.P. Yong and N.S.Trahair (2000). "Distortion and Warping at Beam Supports." Journal of Structural Engineering, Vol. 126, ASCE.

P.A. Kirby & D.A.Nethercot (1979). "Design for Structural Stability." New York: John Wiley & Sons.

W.F. Chen and E.M.Lui (1987). "Structural Stability (Theory and Implementation)." New York: Elsevier Science Publishing.