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BUCKLING BEHAVIOUR OF THIN WALLED ANGLE SECTION BEAM SUBJECTED TO PURE BENDING MOMENT

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May, 2006

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ABSTRACT

This thesis presents buckling behaviour of thin walled angle section beams subjected to pure bending moment. Under certain condition, usually involving compressive stresses, a structural member may develop large distortions under critical loading conditions. This condition is described as buckling. Buckling may be demonstrated by pressing the opposite edge of a plate towards one another. Forty cold formed galvanized mild steel angle sections were tested in four-point bending with the unstiffened flanges in compression. Effective width method according to British Standard specifications, BS5950 (British Standard Institution BS5950-Structural use of steelwork in building, Part 5: Code of practice for design cold-formed sections BSI, 1998) were used considering both simply supported and partially fixed boundaries to predict the moment capacity and resulting midspan deflections and to compare with experimental results. In this project detailed explanation on how the rig experiment, which is used to run the experiment, is shown. As a result the maximum moment and centered deflection is observed and recorded. Results show that the flange of thin-walled specimens was more stiffened when the value of angle and thickness increased. Graphs were plotted clearly show the existence of two phases which is linear and non-linear based on graph shape. From the entire graphs that have been plotted, the graphs of effective-width method value is lesser than the experimental method. Graphs also show that when angle value increase, maximum moment also increase.

ABSTRAK

Tesis ini menerangkan tentang perlakuan ledingan ke atas rasuk dinding nipis bersudut subjek terhadap momen lenturan. Di bawah sesuatu keadaan, kebiasaannya dalam bentuk mampatan, herotan yang besar akn berlaku ke atas sesuatu bahagian dalam struktur apabila di kenakan daya kritikal ke atasnya. Keadaan ini di kenali sebagai ledingan. Ledingan boleh juga di praktikkan dengan memberi tekanan ke atas sesuatu bahan secara bertentangan. Empat puluh besi lembut yang disadur, dalam bentuk bersudut telah di uji dengan lenturan empat titik bersama dengan bibir yang lembut dalam keadaan mampatan. Kaedah keberkasanan lebar menurut spesifikasi Piawai British, BS5950 (British Standard Institution BS5950-Structural use of steelwork in building, Part 5: Code of practice for design cold-formed sections BSI, 1998) telah digunakan dengan mempertimbangkan kedua-duanya telah disokong dan pada bahagian batas yang tetap untuk meramalkan kapasiti momen dan menghasilkan defleksi pada bahagian tengah panjang dan untuk membandingkan dengan keputusan eksperimen. Di dalam projek ini, penerangan yang lebih mendalam bagaimana kelengkapan eksperimen yang digunakan untuk menjalankan ekserimen ditunjukkan. Hasil daripada eksperimen, momen maksimum dan defleksi pertengahan telah direkodkan. Keputusan menunjukkan bibir pada specimen dinding nipis lebih keras apabile nilai sudut dan momen bertambah. Graf-graf yang di plot jelas menunjukkan terdapat dua fasa pada bentuk graf yang mana linear dan tidak linear. Daripada graf-graf yang di plotkan, graf hasil daripada kaedah tebal efektif adalah kurang berbanding graf eksperimen. Graf juga menunjukkan nilai sudut bertambah, nilai momen maksimum juga bertambah.

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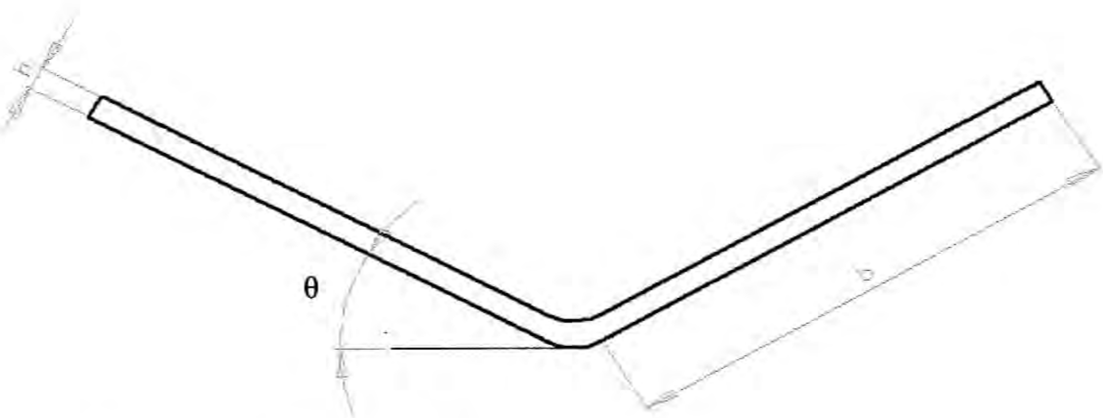

SYMBOL	**DEFINITION**
b	width of flange
b_e	effective width for stiffened plate
b_{eu}	effective width for unstiffened plate
D	Plate flexural stiffness
E	Young's Modulus of Elasticity
G	Modulus of Rigidity
h	plate thickness
I_R	Reduced second moment area about axis of bending
K	Dimensional buckling coefficient
L	Length of specimen between supports
M	Moment applied to beam
M_R	Moment subjected to effective width method

M_y	Yield moment
ϕ	Plate aspect ratio
θ	Angle of flange
σ	Compressive stress at load
σ_{cr}	Critical compressive stress or local buckling
σ_y	Yield stress
τ	Shear stress
δ	Centre deflection
v	Poisson's ratio
$x, y, z,$	coordinates of the plate

SUBSCRIPT	DEFINITION
No.	Number

SPECIMEN NUMBERING SYSTEM

Dog Bone Specimen

e.g. TT01/1.05

- 1.05 — Thickness
- TT01 — Specimen no.

Thin Walled Angle Specimen

e.g. 01A / 1.00 / 08

- 08 — Angle
- 1.00 — Thickness
- A — Indicate set of specimen
- 01 — Specimen no.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Under certain condition, usually involving compressive stresses, a structural member may develop large distortions under critical loading conditions. This condition is described as buckling. Buckling may be demonstrated by pressing the opposite edge of a plate towards one another. Buckling proceeds in manner which maybe either *stable* (in which case displacement increase in a controlled fashion as loads are increased) or *unstable* (in which case deformations increase instantaneously, the load carrying capacity nose-dives and the structure collapses catastrophically).

Buckling is characterized by two features:-

1. Compressive action, either overall or localized and,
2. The displacements are orthogonal to the direction of the compressive action, which is unlike more force/displacement situations.

Buckling of structural members has been investigated for over two centuries since the original work of Euler in the 18th century. In recent time, thin-walled members have been developed which use increasingly thinner material, now down to as low as 0.42 mm thickness in some cold-formed sections used for residential construction. Sections of this type can undergo sectional instability as well as overall modes of buckling.

Buckling has become more of a problem in recent years since the use of high strength material requires less material for load support structures and components have become generally more slender and buckle-prone. This trend has continued throughout technological history i.e. the dangers associated with over-slender build were tragically driven home by the collapse of the Tacoma Narrows road bridge over the Puget Sound in 1940. Although this failure was apparently due to wind-structure aerodynamic coupling rather than buckling.

In Kolej Universiti Teknikal Kebangsaan Malaysia, the fields of buckling problem are still new. So, there is no continuation and extension of previous projects from this college. In this project, the plane angle sections start with corner angles of 2.5°, 5°, 7.5°, 10°, 12.5°, 15°, 17.5°, 20° and 22.5°. The thickness of the thin-walled galvanized mild steel plate used was 1.00mm and 1.50mm.

The design of thin-walled beams traditionally involves the consideration of both plate stability (local buckling) and member stability (lateral-torsional buckling). Plate stability is considered by examining the slenderness of the individual elements that make up the member and the potential for local buckling of those elements. Member stability is considered by examining the slenderness of the cross-section and the potential for lateral-torsional buckling.

In this project, two sets of 20 specimens (total of 40 specimens) of cold form thin walled angle were prepared for the test. Buckling behavior at various loading stages was then observed and examined carefully. The experimental results from the investigation were then compared with the theoretical analysis. Results from first set of 20 specimens were also compared with the second set of 20 specimens for the consistency of the beam buckling behavior.

1.2 Objective of the Project

The project concerned with forty numbers of cold-formed steel plain angle beams of various corner angles, thicknesses had been subjected to pure moment. The objectives of the test are as follows:-

1. To built a test rig
2. To study the load deflection behavior of the beams.
3. To observe the phenomena of local buckling.
4. To obtain the maximum moment.
5. To compare the experimental results with theoretical results.

1.3 Scopes of the Project

The scopes of project are as follows:-

1. To built an experimental rig
2. To fabricate specimen
3. To conduct experiment on angle section galvanized mild steel beams with fixed span and variable thickness, angle and width.

CHAPTER 2

LITERATURE REVIEW

2.1 Thin-Walled Sections

Al-Mosawi (2000) found the algorithm treats the cross-sectional dimensions such as width, depth and wall thickness as design variables and considers the displacement as well as stress limitations. The presence of torsional moments causes warping of thin-walled sections. The effect of warping in the calculation of normal stresses is included using Vlasov theorems. These theorems require the computation of sectorial properties of cross-sections. A general numerical procedure is presented for obtaining these properties. The optimum design problem of thin-walled open sections subjected to combined loading turns out to be a highly nonlinear problem. It is shown that optimality criteria method can effectively be used to obtain its solution.

To design thin-walled columns with unstiffened flanges, Rasmussen (1994) found that it is not necessary to limit the axial capacity of channel, single angle and Z-section columns with unstiffened flanges to the load causing local buckling of the flanges, as is required in the AlSl Specification. Rules are proposed which greatly improve the AISI rules for concentrically and eccentrically loaded channel section columns with unstiffened flanges. The proposed rules allow the local buckling coefficient of the unstiffened flanges in bending to be determined on the basis of a rational buckling analysis when bending causes compression at the free edge of the unstiffened flanges. When bending causes tension at the free edge of the flanges, the proposed rules allow the flanges to be treated as stiffened elements.

There are two type of thin-walled where is stiffened and unstiffened. Turning the free edge of an unstiffened flange inwards or outwards to form a lip can substantially improve the local buckling resistance of a member. The lip is the most common type of edge stiffener used in cold-rolled, thin-walled sections. In order to improve the local buckling characteristics, edge stiffeners are widely used to stiffen the flat compression elements of thin-walled structural members. Seah (1993).

Cold-formed steel beams have open sections where centroid and shear center do not coincide. When a transverse load is applied away from the shear center it causes torque. Because of the open nature of the sections, torsion induces warping in the beam. B.P. Gotluru (2000).

The buckling of plate panels was investigated for the first time by Bryan in 1891, in connection with the design of a ship hull. The assumptions for the plate under consideration are those of thin-plate theory (Kirchhoff's theory):

a) The material is linear elastic, homogeneous and isotropic.

b) The plate is perfectly plane and stress free.

c) The thickness "t" of the plate is small compared to its other dimensions.

d) The in-plane actions pass through its middle plane.

e) The transverse displacements w are small compared to the thickness of the plate.

f) The slopes of the deflected middle surfaces are small compared to unity.

g) The deformations are such that straight lines, initially normal to the middle plane, remain straight lines and normal to the deflected middle surface.

h) The stresses normal to the thickness of the plate are of a negligible order of magnitude.

2.2 Buckling

Ilyushin (1947) has treated the stability of plates. Stressed above the-elastic limit with consideration of three possible zones that might result from buckling as shown in graph 2.1. A purely elastic zone, a zone in which part of the material is in the elastic and plastic state which called 'elasto-plastic" zone and a purely plastic zone in which all of the plate is stressed beyond the elastic limit. All three zones may exist simultaneously if the plate is not entirely in the plastic state before buckling or if the buckling is allowed to proceed beyond the initial stages.

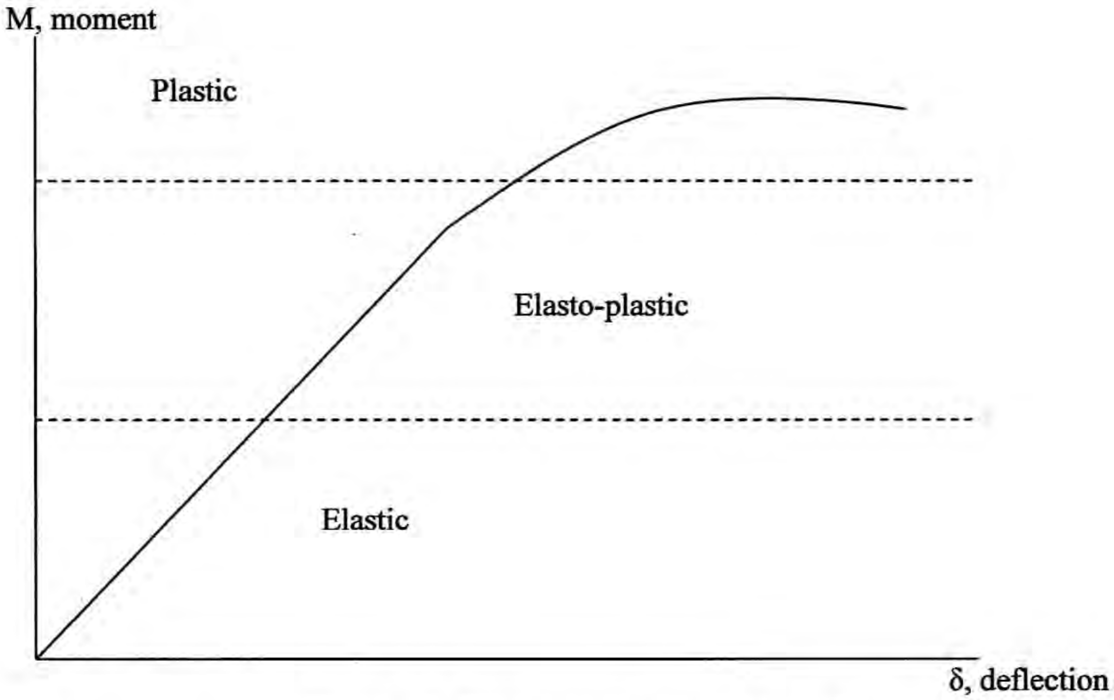

Figure 2.1: Graph moment versus deflection

Katsuki Takiguchi (1996) obtained basic empirical data on the shearing behavior of thin steel plates attached to concrete, especially to understand the relationship between the shear strain of the plate and its lateral displacement, as fundamental research on the safety of lining plates. A new apparatus for measuring the lateral displacement of a lining plate by continuously scanning its surface is tested. The apparatus proves to be quite effective for understanding the buckling wave of the lining plate and the essential behavior of a thin steel plate attached to a concrete wall subject to a shear force is clarified.

The investigation by Zbigniew Kolakowski (1998) is concerned with open cross-section columns under an axial compression or/and a constant bending moment. The beam-columns are assumed to be simply supported at the ends. His aimed is to improve the study of the equilibrium path in the post-buckling behavior of imperfect structures with regarding the second order non-linear approximation and the effect of cross-sectional distortions. The principal goal of numerical analysis is to investigate the influence of the wall orthotropic factor of columns upon the all buckling modes from global (flexural, flexural-torsional, lateral, distortional and their combinations) to local and upon the coupled post-buckling state. In the solution obtained the transformation of buckling modes with the increase of load up to the ultimate load and shear lag phenomenon is included.

Zhi-ming Ye (2002), restraint provided by the sheeting to the purlin is modeled by using two springs representing the translational and rotational restraints. The analysis is performed using finite strip methods in which the pre-buckling stress is calculated based on the same model used for the buckling analysis rather than taken as the 'pure bending' stress. The results obtained from this study show that, for both local and distortional buckling, the restraints have significant influence on the critical loads through their influence on the pre-buckling stress rather than directly on the buckling modes. While for lateral-torsional buckling, the influence of the restraints on the critical loads is mainly due to their influence on the buckling modes rather than the pre-buckling stress.

Jaehong Lee (2002) has studied the lateral buckling of a laminated composite beam with channel section. A general analytical model applicable to the lateral buckling of a channel-section composite beam subjected to various types of loadings is derived. This model is based on the classical lamination theory, and accounts for the material coupling for arbitrary laminate stacking sequence configuration and various boundary conditions.

Sándor Ádány (2004) had proposed a new approach to the problem, by developing a method which may enable general numerical methods to directly calculate critical loads for pure buckling modes. The proposed method can also be applied for the modal decomposition of a general (interacted) buckling mode.

Two cases were considered by Cheng Yu (2004), buckling of a plate simply supported on all four sides and buckling of a plate simply supported on three sides with one unloaded edge free and the opposite unloaded edge rotationally restrained. These two cases illustrate the influence of stress (moment) gradient on stiffened and unstiffened elements, respectively. The axial stress gradient is equilibrated by shear forces along the supported edges.

Xiao-ting Chu (2004) investigated on the buckling behaviour of cold-formed steel channel section beams when subjected to a uniformly distributed load. The focus of the study is on the local and distortional buckling, for which existing results are only for sections subjected to pure compression and/or pure bending. The results obtained from this study have shown that, for local buckling, there is no practical difference in the critical loads between pure bending and a uniformly distributed load. For distortional buckling, however, remarkable difference exists. The critical load for a uniformly distributed load is generally higher than that for pure bending by about 10% for beams between 3 and 6 m in length.

Teter (2004) was concerned with interactive buckling of thin-walled beam–columns with central intermediate stiffeners under axial compression and a constant bending moment. The columns are assumed to be simply supported at their ends. The paper's aim is to expand the study of the equilibrium path in the post-buckling behavior of imperfect structures with regard to the second order non-linear approximation. In the solution obtained, the transformation of buckling modes with an increase of the load up to the ultimate load, the effect of cross-sectional distortions and the shear lag phenomenon were included.

Vodenitcharova(2005) employed Airy stress-function method to analyze the deformation of the matrix, and the cross-sectional change of the single-walled carbon nanotube (SWNT) in bending. A particular consideration was given to the effect of the SWNT radial flexibility on the strain/stress states and buckling. It was found that in thicker matrix layers the SWNT buckles locally at smaller bending angles and greater flattening ratios. This causes higher strains/stresses in the surrounding matrix and in turn degrades the strength of the nanocomposite structure.

2.3 Effective-width method

The lateral-load stiffness of the slab-column frame is often represented using an equivalent slab-beam to account for the flexural stiffness of the slab. One approach, commonly referred to as the effective beam width method, provides a simple and reasonably accurate means to model the lateral-load stiffness of slab of the slab-column frame Hwang (1989).

Effective-width formula was derived from the numerical results of an elastic postbuckling analysis of plates subjected to eccentric loading in its plane. The plate is assumed to possess initial out-of-flatness as well as welding-type residual stresses. Based on an extensive numerical study, a set of new effective-width formulas have been derived as functions of both the magnitudes of initial out-of-flatness and compressive residual stress. Thus, the formulas could be used to predict the strength variations of various plate-assembled members in combined compression and bending. Tsutomu Usami (1993).

Rasmussen (2002) presents a design method for calculating the effective width of these elements, based on plate test results of unstiffened elements under strain gradients varying from pure compression to pure bending. It is shown that both elastic and plastic effective widths may be derived from the test results, and effective width methods based on both principles may be used for design.