BUCKLING BEHAVIOUR AND INSTABILITY OF TAPERED COLUMN MADE OF ALUMINIUM ALLOY

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Report of
Projek Sarjana Muda II

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JUNE 2017

SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor Mechanical Engineering (Structure and Materials)"

Signature: ……………………………

Supervisor: …………………………….

Date: …………………………….

DECLARATION

"I hereby declare that the work in this report is sufficient in term of scope and quality for the award of the degree of
Bachelor of Mechanical Engineering (Structure and Materials)"

Signature: ……………………………

Author: ……………………………

Date: …………………………….

Dedicated specially for

My beloved family

ACKNOWLEDGEMENT

There were too many people who involve in helping me to complete this report. First of all I would like to express my gratitude to the people that help me a lot in completing this report either directly or non-directly.

To my supervisor for this Projek Sarjana Muda (PSM), Prof. Madya Abd Salam bin Md Tahir, I would like to thank him for his guidance and commitment in giving guidance and advice while undertaking this PSM. Thank you for your guidance, encouragement, and the inspiring words in motivating me to keep developing myself and also the kind words which enlighten me to the right path or direction.

To all of the laboratory assistant and technician of FKM-UTeM, I would like to express my sincere gratitude for welcoming me and my other friends wholeheartedly and for giving us the opportunity to experience the friendly working environment in the laboratory. I'm feeling grateful also because of their undying support and patience in giving us guidance.

My greatest thank you goes to my beloved family, for being my inspirations and motivation to always do my best in everything I do without giving up. I would also like to thanks for their undying support and for always being there every time I need, to overcome any difficult circumstances or conditions.

ABSTRACT

Compressive members are typically found in most structural members. It is important to know the limits of material used since it can failed in two ways. In this study, the mode of buckling failure being investigated is limited to the elastic mode. Buckling only happens in long slender structural member well before experiencing plastic deformation. Before the plastic deformation, elastic failures such as yielding or crushing can also occur. The purpose of this study is to determine the critical buckling load of tapered column with different aspect ratios and how the end support conditions is influencing the buckling load and to compare with the analytical result. In this study, the material used for the specimen is Aluminium Alloy 6061 bar with square and round cross-sections. In preparing the specimens or columns, specified machining process need to be done to fulfill the required dimension of the specimen. The specimen tapered ratios used are 0.84 and 0.66 with length of 0.16m, 0.19m and 0.22m respectively. The buckling test is conducted by using INSTRON 5585 floor mounted material testing machine. The graph of buckling test obtained had been plotted in Load (kN) against Extension (mm). The loading rate used for the test is constant at 0.75/mm/min or equivalent to 0.0125/mm/sec. From the overall result, the critical buckling load for pinned-ended support is lower than pined-fixed support. The increase of buckling load also affected as the tapering ratio and effective length increases. Besides, different cross-sectional area give different reading of buckling load which is, square column have higher buckling load compared to circular column. However, there are significant differences between the experimental and theoretical results which is mainly affected by the surface condition of the column.

ABSTRAK

Ahli mampatan adalah ahli yang sering dijumpai dalam bidang penstrukturan. Had bahan yang digunakan haruslah diketahui kerana ia boleh gagal melalui dua kaedah. Dalam kajian ini, cara kegagalan lenkokan yang diujikaji adalah lengkokan secara elastik. Lengkokan hanya berlaku bagi ahli struktur yang langsing sebelum melalui perubahan plastik. Sebelum itu, kebarangkalian untuk kehancuran dan penghasilan juga boleh berlaku. Tujuan kajian ini adalah untuk menentukan beban kritikal lengkokan bagi struktur yang berbeza nisbah tirus dan bagaimana ia akan terjejas dengan menggunakan sokongan yg berbeza dan dibandingkan dengan keputusan analisis. Pancalogam Aluminium 6061 dengan keratan rentas segi empat sama dan bulat adalah jenis bahan yang digunakan dalam kajian ini. Proses pemesinan tertentu adalah diperlukan dalam menyediakan spesimen bagi memenuhi keperluan dimensi yang sepatutnya. Nisbah tirus yang digunakan dalam ujikaji ini adalah 0.84 dan 0.66 dengan masing-masing mempunyai panjang bernilai 0.16m, 0.19m dan 0.22m. Ujian lengkokan dijalankan dengan menggunakan mesin “INSTRON 5585 floor mounted material testing system”. Kadar kelajuan yang dihunakan semas berlakunya ujikaji adalah dimalarkan bagi semua specimen iaitu pada kadar 0.75/mm/min ataupun bersamaan dengan 0.0125/mm/sec. Berdasarkan hasil keseluruhan keputusan eksperimen dan teori, beban kritikal lengkokan bagi keadaan yang menggunakan sokongan pin kedua-duanya adalah lebih rendah daripada pin-tetap. Peningkatan beban lengkokan juga adalah disebabkan nisbah tirus dan panjang specimen. Selain itu, keratin rentas juga memberi bacaan beban lengkokan kritikan yang berbeza, yang mana,beban lengkokan lajur segi empat adalah lebih tinggi berbanding lajur bulat. Walaupun, terdapat perbezaan dari segi bacaan teori dan eksperimen yang mana kemungkinan dipengaruhi oleh faktor keadaan permukaan.

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LISTS OF ABBREVIATION

FE	Finite Element
ASTM	American Society for Testing and Materials
AA	Aluminium Alloy
m	Metre
kN	Kilo Newton

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CHAPTER 1

INTRODUCTION

1.1 Background

There are various types of mechanical failures. Their importance varies from a minor nuisance to a major disaster. Sometimes, such failure can cause injury, lost of human life or property damage.

Failure is defined as the inability of an engineering component to carry out its specific function. According to the International Electrotechnical Commission (IEC), failures mean the termination of the ability of an item to perform a required function. There are various type of mechanical failures and buckling is one of them. Buckling is a sudden failure of a member subjected to compressive stress (or load) where at point of failures, the actual compressive stress is less than the ultimate compressive stress (σ_{ult}) of the material.

Column in a building is an architectural invention which allowed for the support of ceiling without the use of solid walls, thereby increasing the space which could be spanned by a ceiling, allowing the entrance of light and offering an alternative aesthetics to building exteriors, particularly in the peristyles of temples and on colonnades along stoats (Cartwright, 2012). Column can be differentiated by its different cross-sectional area. The two category of column is uniform and non-uniform cross sectional area.

For column that have uniform cross sectional-area, it's usually called as straight column. Meanwhile, for non-uniform cross-sectional column, they falls into three types which is stepped column, tapered column and double tapered column. Non-uniform column also can be known as non-prismatic column. Figure 1.1 shows the different type of column visually.

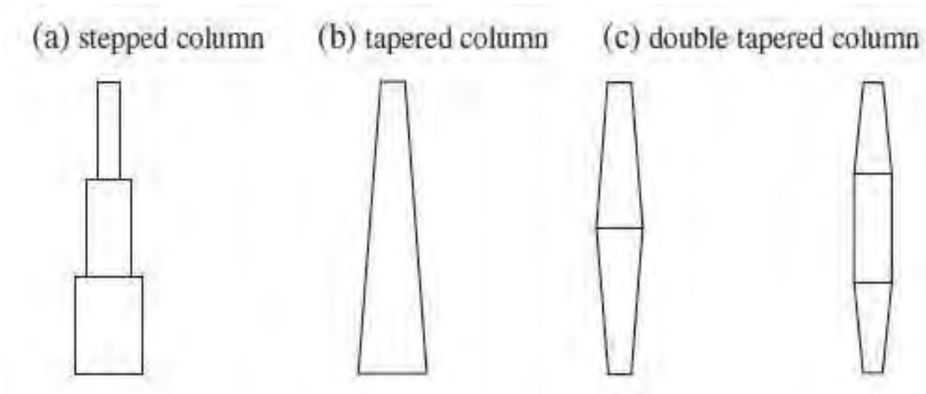


Figure 1.1: Steel column with non-uniform cross-section

(Source: Zhang, Guo & Dou, 2013)

Column with different cross-section give their own advantages and disadvantages. Straight column are easier to make and manufactured. In this research, we only covered about the tapered column to be defined its buckling behaviour. Tapered column or also known as tapered members are important in structural engineering because of their reduced weight compared with uniform or straight column for the same axial load carrying performance (buckling load) (Iremonger, 1980). This is due to the rational sectional distribution of stiffness to reduce weight or to satisfy architectural and functional requirements (Saetiew & Chucheepsakul, 2012).

The first approach and study regarding to buckling problem of column with different cross sectional is done by Dinnik in 1929 and 1932. In 1982, tapered box column under biaxial loading were analyzed by using moment curvature-thrust relationships and Horne's stability criteria (Theodore, Ioannis & George, 2012).

Laboratory test are essential in order to determine the critical load for column to buckle. Since buckling is due to compressive stress, a compression test had been conducted by using the INSTRON 5585 floor mounted universal testing machine. Compression tests were used in order to determine on how the material will react when compressed and determine the specimen behavior under a compressive load. For the compression experiment, the maximum load is limited to 200 kN which is equivalent to the maximum capacity of the Instron machine.. Figure 1.2 illustrates on how the column will be compressed by axial load to study the buckling behavior of the test columns.

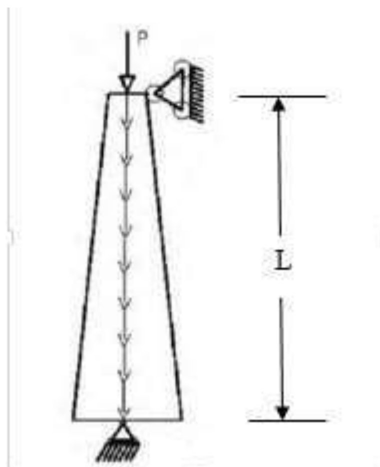


Figure 1.2: Illustration of compressive force applied to the tapered column or strut.

Tapered members are widely used in industry of automotive, aircraft component or aerospace structures, architecture and medical equipment. They usually used as slender structural member of high-rise building, long-span bridge, marine and offshores structures, aerospace, biomedical instruments and other machine parts.

1.2 Problem Statement

In this recent year, buckling had become a problem in structural engineering. Nowadays, most people doesn't know about buckling that actually happen around their surroundings. When said about buckling, it usually related to column structure. Column can be defined as the slender member that is relatively long and subjected to compressive axial load. Buckling instability can occur even by increasing in a small amount of load and it can lead to failure. As we can see, the column application had been used widely in structural of high-rise building, bridges, aircraft and aerospace structural members. From the two engineering application for example, it related to human safety. This study is important because it involve a large human safety factor. Therefore, to avoid the buckling instability the critical buckling load of the column need to be determined. The value of compressive load (P) supported by column must be less than the value of critical load (P_{cr}), in order to avoid buckling or instability.

$$\text{i.e} \quad P < P_{cr}$$

Besides that, this study is conducted due to limited number of literatures available that involve buckling of tapered column made from aluminum alloy especially. This is because, most of the research that had been conducted was about straight or prismatic column and mostly used steel as their material and as the test specimen.

1.3 Objectives

The objectives of this study is to determine the critical buckling load of tapered columns with different length, tapered ratio, cross-sectional area and how the buckling load is affected by the end support conditions and to be compared with the analytical result.

1.4 Scopes of Project

In order to conduct in-depth research of buckling problems, the study had been narrowed down to be more specific. The following scope had been suggested.

1. To design the fixtures to hold the test specimen or tapered column.
2. Fabricate square and round tapered column with solid cross section and used aluminium alloy as the material for the test column.
3. Tapered column will be designed with a three different length and two aspect ratios.
4. To conduct the compression or buckling test on the designed tapered column.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There are variety of ways that lead to failure in load-carrying structures. It depends on the structure's type, condition of support, loads supported and the material used. For example, an axle of vehicles that may fracture due to repeated cycles of load or beam that maybe excessively deflected that intend to make the structure unable to perform (Gere and Goodno, 2012). The maximum and minimum displacements are remained within the accepted limit during designing the structures to avoid the failure. In designing any structure or parts, the strength and stiffness are the most important factors.

2.1.1 Buckling

One of the structural failures is known as buckling. If the compression member is relatively slender, it may deflect laterally and resulting to bending. According to Gere and Goodno (2012), the column can be said buckled if lateral bending occurred. Phenomenon of buckling could be occurred in many types of structures and forms. The buckling occurrence does not limited to column only. For column that being compressed by axial force, column's shortening is the only deformation that occur to the column. Thus, it leads to buckling of column. Besides that, if the column was deflected by perpendicular force, the column will bend from its straight position.

The first researcher that had begun the investigation concerning to axially loaded compressed straight column is Euler in 1744. By using Euler's theory, the column structures does not fail because of bending if the load applied is less than the critical buckling load. Euler also stated that the buckling phenomenon is highly related to the slenderness, cross-section and radius of gyration of column (Rasmussen and Hancock, 2012). Besides that, the strength of the column also affected by the end support conditions either free, pinned or fixed.

The research on stability of steel column that have non-uniform cross-section had been conducted by Theodore, Ioannis and George (2012). This paper studied on a simple and effective strategy for the investigation of non-uniform steel members with or without initial flaws or imperfections by axially loaded forces concentrically or eccentrically apply. The type of initial imperfection used is by varying the cross section of the column members. To predict the buckling deformation, a plastic criterion had been applied.

2.1 Theoretical Approach for Determination Column Strength

Most researchers used analytical and numerical solution as their theoretical approach. Analytical solution can give the exact solution while for numerical solution, it gives about the approximate value. Numerical solution is a study of algorithm that used approximate value to solve the problem that involved mathematical analysis.

2.1.1 Analytical Solution for Tapered Column

Gere and Carter (1962) had published a paper in the ASCE Journal of the Structural Division had provided the equation and design curves in order to calculate the critical buckling load of column with different cross section and four conditions of the end support which is pinned-pinned, fixed-pinned, fixed-free and fixed-fixed. The method of solution of differential equation and successive approximation of the deflection curve that had been developed by Timoshenko and Newmark had been used by Gere and Carter in order to provide a relative concise set of equations to calculate the critical buckling load. For column with a linear tapered, circular cross section and pinned-pinned, fixed-pinned end conditions, the equation is the product of the square and circular ratio of end diameters and the critical buckling load [P_{cr}] of a prismatic column. Table 2.1 shows the expression that is used to determine the critical buckling load with different end condition. In the equation used, d_a shows the dimension for the small end while d_b shows the dimension for larger end of the column. Figure 2.1 shows the notation used in tapered column geometry.

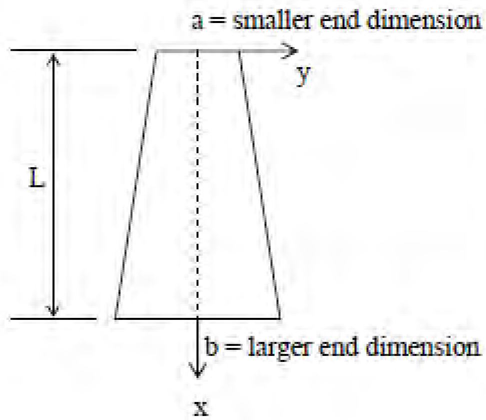
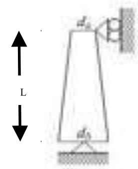
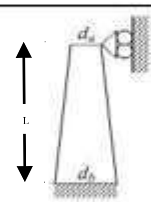
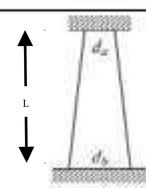


Figure 2.1: Notation used for tapered column

(Source: Gere and Carter, 1962)

Table 2.1. Buckling load for tapered column with solid cross-section of squared and circular

End Condition	Schematic	Buckling Load
Pinned-pinned		$P_{cr} = \left(\frac{\pi^2 E I_a}{L^2}\right)\left(\frac{d_b}{d_a}\right)^2$
Fixed-pinned		$P_{cr} = \left(\frac{\pi^2 E I_a}{(0.6997L)^2}\right)\left(\frac{d_b}{d_a}\right)^2$
Fixed-fixed		$P_{cr} = \left(\frac{4\pi^2 E I_a}{L^2}\right)\left(\frac{d_b}{d_a}\right)^2$

(Source: Gere and Carter, 1962)