UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MONITORING AND DETERMINATION OF THE APPROPRIATE EQUIVALENT CYLINDER RADIUS FOR AXIALLY COMPRESSED STEEL CONE

This report submitted in accordance with that requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology (Bachelor's Degree in Mechanical Engineering Technology (Maintenances Technology)) (Hons.)

by

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TAJUK: **Monitoring and Determination of the Appropriate Equivalent Cylinder Radius for Axially Compressed Steel Cone**

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APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of (Bachelor's Degree of Mechanical Engineering Technology (Maintenances Technology) with Honours. The member of the supervisory is as follow:

…………………………………….

(Dr. Olawale Ifayefunmi)

ABSTRAK

Konsep silinder bersamaan diperkenalkan kerana kerumitan menerbitkan persamaan untuk cengkerang kon. Pendekatan silinder bersamaan telah dikaitkan dengan lengkokan kon bawah mampatan paksi. Falsafah ini telah diterima pakai oleh kod reka bentuk yang mempunyai berbeza bersamaan jejari silinder. Beberapa pendekatan silinder bersamaan dan reka bentuk telah dicadangkan tetapi tidak ada kata sepakat dalam memilih bersamaan jejari silinder yang paling sesuai untuk kon keluli dibawah daya mampat. Dalam projek ini, kajian menggunakan perisian komputer dan eksperimen telah dilakukan. Sempadan Keadaan Satu digunakan kerana pengunaan alur ke atas spesimen. 18 spesimen direka, dibuat, dilenturkan dan dikimpal. Spesimen telah diukur dan diuji di bawah mampatan paksi. Semakin tinggi jejari silinder bersamaan, semakin tinggi daya keruntuhan.

ABSTRACT

The concept of equivalent cylinder was introduced due to complexity of deriving the equation for conical shells. Equivalent cylinder approach has been linked to the buckling of cones under axial compression. This philosophy has been adopted by design codes which have different equivalent cylinder radius. Several equivalent cylinder approaches and design were suggested but there is no agreement in choosing the most appropriate equivalent cylinder radius for axially compressed steel cone. In this project, numerical and experimental research work has been done. Fixed boundary condition was considered with the use of grooves on the specimens. 18 specimens were designed, manufactured, rolled and welded. The specimens were measured and tested under axial compression. The higher the radius of the equivalent cylinder, the higher the collapse force.

DEDICATION

This report is dedicated to my beloved family especially my parents that have encourage me on finishing this research. Last but not least, my final year project group mates that give me support and guidelines throughout the research.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ρ	-	Radius of equivalent cylinder
r_1	-	Top radius of master cone
r_2	-	Bottom radius of master cone
β	-	Semi-vertex angle
t	-	Thickness of master cone and equivalent cylinder
H	-	Height of master cone and equivalent cylinder
L	-	Slant length of master cone
teq	-	Equivalent cylinder axial thickness
Leq	-	Equivalent cylinder axial length
P	-	Pressure
F	-	Force

CHAPTER 1

INTRODUCTION

1.0 Background

Thin shell structure was introduced as a structural form and made important contribution to the development of several branches of engineering. Examples include structural, power and chemical engineering. Conical shaped shell structures are extensively utilized in structural components in modern engineering application such as space crafts, pipelines, fluid reservoirs, pressure vessels and as transition element between two cylinders of different radii (Ghazijahani & Showkati, 2011). Practically, conical shells are subjected to various loading conditions such as internal pressure, external pressure, axial compression, torsion, bending etc., or combination of loads. Instability of this structural element is one of the cause that limit the extent to which the structures can be loaded or deform (Ifayefunmi, 2014a). Through these loads, the buckling strength of steel cones found in the offshore, oil and chemical industries becomes one of the important design considerations (Blachut, 2011).

The concept of equivalent cylinder was introduced due to the complexity in deriving the equations for designing conical shells. The buckling of cones under axial compression or external pressure has been linked to the equivalent cylinder approach. This philosophy is based on design codes. For cones under axial compression, the design code formulations differ in the definitions of the radius of curvature of equivalent cylinder (Ifayefunmi, 2014a). Some possibilities have been proposed. The past research shows there has been no agreement on the choice of the radius of curvature for the equivalent cylinder (Blachut, 2011).

This project focuses mainly on monitoring and determination of the appropiate equivalent cylinder radius for axially compressed steel cone. Therefore, proposing a new approach for determining the most appropiate radius for the equivalent cylinder.

1.1 Problem Statement

The buckling of load of conical shells is determined using the equivalent cylinder approach traditionally. However, according to literature review, there is no agreement on the choice of the radius of curvature for the equivalent cylinder between the available design codes. This has been a problem for several years. This project work is to determine the appropriate equivalent cylinder radius for axially compressed steel cone.

1.2 Objective

Based on the background and the problem statement stated above, the objectives of this project are as follows:

1. To design and manufacture master cones and five different equivalent cylinders.
2. To analyze the appropriate equivalent cylinder radius for axially compressed steel cone numerically.
3. To establish the appropriate equivalent cylinder radius for axially compressed steel cone experimentally.

1.3 Scope

Five different cases of equivalent cylinder are considered and the master cone is assumed with the top and bottom diameter of 80 mm and 140 mm respectively. The cases are as follows:

Case 1: Master Cone

Case 2: Cylinder with radius, $p = \frac{r_1}{\cos\beta}$

Case 3: Cylinder with radius, $p = r_1$

Case 4: Cylinder with radius, $p = \frac{r_1}{\cos^2 \beta}$

Case 5: Cylinder with radius, $p = r_1 \cos \beta$

Case 6: Cylinder with radius, $p = r_1 \cos^2 \beta$

The cones and cylinders are made from mild steel plate with a thickness of 2.0 mm. Each case has a set consist of three specimens. Calculations, sketches on each cases are carried out and marking on the steel plate are made to avoid any error during the manufacturing process.

CHAPTER 2

LITERTATURE REVIEW

2.0 Introduction

Conical shell structures are utilized in engineering application such as aeronautical, marine, seaward and mechanical industries. Thin conical shell structures often used in aeronautical applications where the load carrying capacity is usually limited by elastic buckling due to their high value of the radius-to-thickness ratio. Thicker shell structures that have low values of radius-to-thickness ratio are typically used in marine and offshore applications, usually buckling or collapsing in the elastic-plastic or plastic range (Ifayefunmi, 2014a).

Conical shells are mostly used as transition elements between cylindrical shells with different diameters. In that capacity, they may be subjected to a different of loading conditions, axial compression and external pressure. Due to these loads, the buckling strength of steel cones found in the offshore oil and chemical industries, becomes one of the important design considerations. A recent literature review demonstrates that there are more than 600 experimental buckling tests on truncated and non-reinforced, conical shells since 1960 (Blachut, 2011).

Cylindrical shell is the most utilized shell geometry. Because of its straightforward geometry, it can be easily produced. Another form of shell which is like the cylindrical shell is the conical shell. The contrast between conical and cylindrical shells is the cone angle. For the conical shells, their equivalent radius equation is not derivable because of their radius that is not symmetrical between top and bottom. This is why the idea of equivalent cylinder has been embraced by considering the master cone as equivalent cylinder with a given identical geometry (Ifayefunmi, 2011).

2.1 Background into Equivalent Cylinder Approach

According to (Ifayefunmi, 2014b), traditionally, the design of cones has been based on the equivalent cylinder approach. The conical shell was used as a cylindrical shell with an equivalent geometry for the purpose of obtaining the buckling strength. Several analytical and experimental research works have been carried out to correlate buckling of conical shells with buckling of the equivalent cylindrical shells.

Consider a truncated cone which is subjected to axial compression with a smaller radius on top, r_1, a bigger radius at bottom, r_2, uniform wall thickness, t height, h , slant cone length, L and semi-vertex angle, β as shown in Figure 2.1 (a). it is assumed that this master cone have an equivalent cylinder, with equivalent cylinder radius, ρ, equivalent cylinder thickness teq and equivalent axial length, Leq, as shown in Figure 2.1 (b).

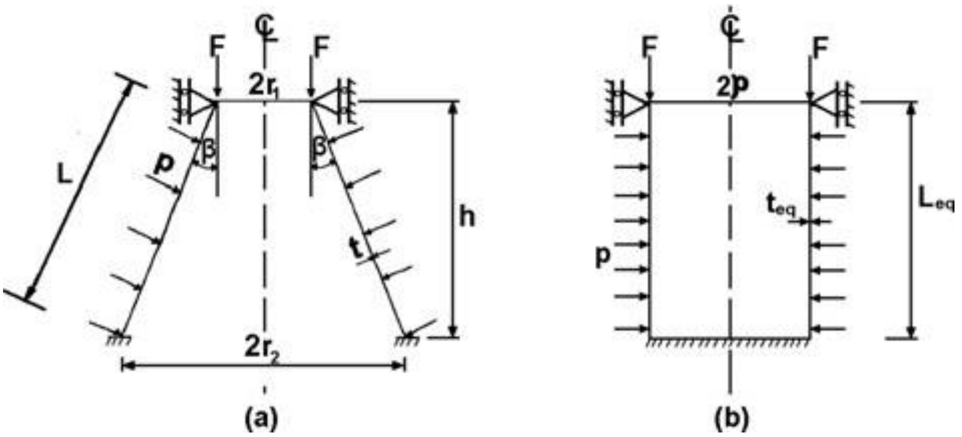

Figure 2.1: Geometry of (a) master cone and (b) equivalent cylinder with equivalent radius, ρ subjected to combined action of axial compression and external pressure acting simultaneously.

2.2 Design Codes.

The equivalent cylinder approach has been linked to buckling of conical shells under axial compression. This approach has been adopted by the major design codes, namely: (i) DIN 18800, (ii) DnV CN 30.1, (iii) API RP 2A, and (iv) ECCS TWG 8.4. However, the design codes formulations used for cones under axial compression differ in defining the radius of the equivalent cylinder. There are several possibilities and recommendation that have been suggested by DIN, DnV, API, ECCS, Samuelson & Eggwertz and Schmidt & Krysik as shown in Table 2.1.

Table 2.1: Formulation of equivalent cylinder radius for axially compressed cones by different design codes and recommendations.

Design Codes / Suggestions	Equivalent Cylinder Radius (ρ)
DIN 18800 (1990)	$\frac{r_1}{\cos\beta} \leq \rho \leq \frac{r_2}{\cos\beta}$
DnV CN 30.1 (1992)	$\frac{r_1 + r_2}{2\cos\beta}$
API RP 2A (2003)	$\frac{r_1}{2\cos\beta}$
Samuelson & Eggwertz (1992)	$\frac{r_1 + r_2}{2}$
ECCS TWG 8.4 (2013)	$\frac{r_1}{\cos\beta}$
Schmidt & Krysik (1994)	$\rho_1\left(r_1 + 2\sqrt{r_1 t \sin\beta}\right) = \frac{r_1 + 2\sqrt{r_1 t sin\beta}}{\cos\beta}$ or $\rho_2\left(r_2 - 2\sqrt{r_2 t \sin\beta}\right) = \frac{r_2 - 2\sqrt{r_2 t sin\beta}}{\cos\beta}$

From Table 2.1, it shows that the design codes and suggestions for the radius of the equivalent cylinder are all different. This has been a problem for several years and there is no agreement on choosing the most suitable radius of curvature radius, ρ, for the equivalent cylinder.

2.3 Past Work on Equivalent Cylinder Approach

2.3.1 Numerical Analysis

The development of computers and highly efficient numerical techniques has come to a state where any shape of shell structure can be calculated and design no matter how complicated the geometry, how dominant the imperfection influence and how nonlinear the load applied. This useful numerical tool is no longer in the hands of researching academics, but the tools are also available in the form of commercial FEM packages for conventional structural design engineers such as ABAQUS FE software (Schmidt, 2000).

Numerical analysis on buckling of equivalent cylinder and cones can be found in (Barkey et al., 2007; Blachut, 2011; Ifayefunmi, 2014b). (Barkey et al., 2007) carried out an analysis on the taper ratio on conical shells with different cone angle and equivalent cylinder. Adjustments was applied depending on the taper ratio of the cone, $\Psi - \left(1 - \frac{R_1}{R_2}\right)$. The buckling pressure of a cone can be expressed as the equivalent cylindrical pressure multiplied by a relationship function that is a function of the taper ratio is shown as follow:

$$p_{cone} = \overline{p_{cyl}} \times f(\Psi) \qquad \text{(Equation 2.1)}$$

This expression was first found by (Seide, 1959) and then examined by (Singer and Weller, 2000). Figure 2.2 shows the correlation between cone with different cone angle and equivalent cylinder subjected to external pressure.

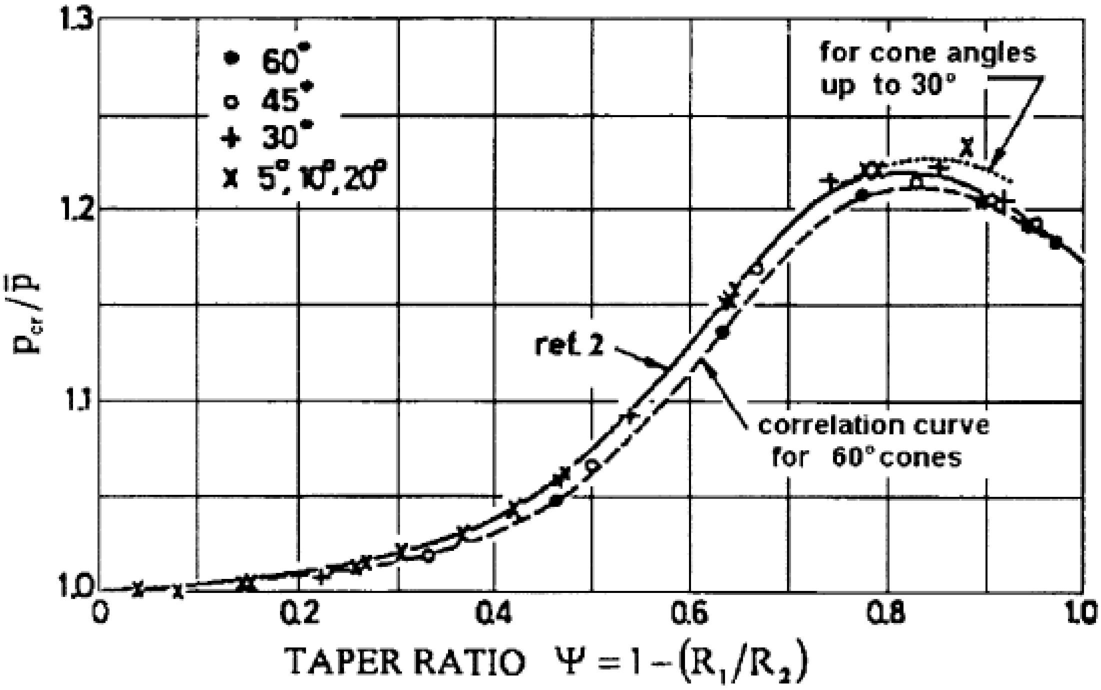

Figure 2.2: Correlation between cone with different cone angle and equivalent cylinder subjected to external pressure.

(Blachut, 2011) conducted an analysis on buckling of equivalent cylinders subjected to axial compression or external pressure using BOSOR5 code. It is assumed that wall thickness of 3.0mm and equivalent axial length of 111.8 mm for equivalent cylinder. Five cases were considered, namely:

1. $p = \frac{r_1+r_2}{2}$
2. $\frac{r_1}{\cos\beta} \leq \rho \leq \frac{r_2}{\cos\beta}$
3. $p = \frac{r_1+r_2}{2\cos\beta}$
4. $\rho_1\left(r_1 + 2\sqrt{r_1 t \sin\beta}\right) = \frac{r_1+2\sqrt{r_1 tsin\beta}}{\cos\beta}$
5. $\rho_2\left(r_2 - 2\sqrt{r_2 t \sin\beta}\right) = \frac{r_2-2\sqrt{r_2 tsin\beta}}{\cos\beta}$

For the buckling strength of equivalent cylinder subjected to external pressure only, case (2) and (5), the predictions of failure remains on the safe side, which means that the magnitude of collapse force are lower than the collapse force of the cone. The remaining radii of equivalent cylinder can lead to unsafe estimates of buckling loads. Nevertheless, for axially compressed equivalent cylinders, the collapse force of cone is lower than the magnitude collapse force for all equivalent cylinders. Therefore, all the equivalent cylinders are on unsafe side, i.e., they are much stronger than the cone. Further analysis of buckling loads for case (2) equivalent cylinder radius subjected to combined loading, i.e. axial compression and external pressure acting simultaneously, were conducted. The combined stability plots for cone and two equivalent cylinders are plotted as shown in Figure 2.3. The cylinders can support higher axial loads than cone referring to the Figure 2.3.

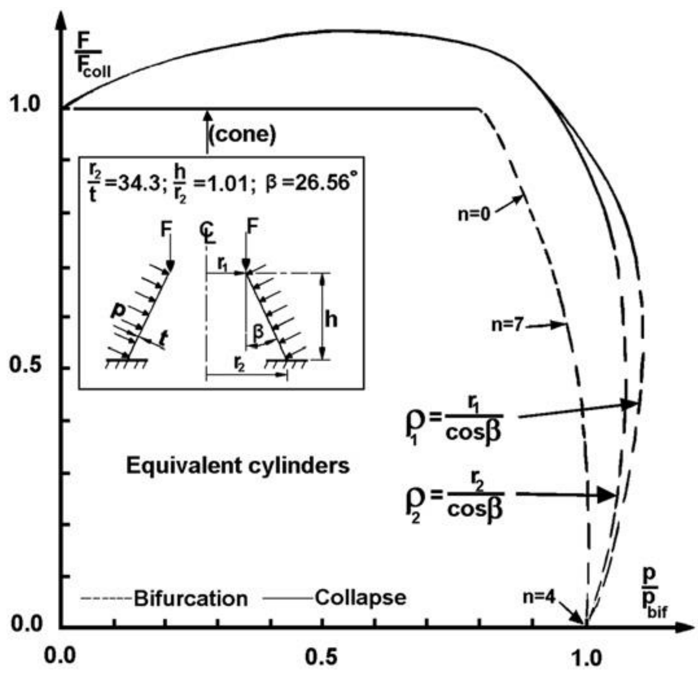

Figure 2.3: Combined stability plots for cone and two equivalent cylinders with different radii under combined loadings [Blachut, 2011].

(Ifayefunmi, 2014b) conduct a similar analysis on combined stability plot for equivalent cylinder and master cone. Equivalent cylinder and cone were subjected to combined action of axial compression and external pressure acting simultaneously. Three cases of equivalent cylinder radius were considered, they are:

Case 1: $p = \frac{r_1+r_2}{2}$

Case 2: $p = \frac{r_1+r_2}{2\cos\beta}$