Buckling Analysis of Cylindrical Shells Subjected to Axial Compression

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Abstract – *Thin cylindrical shell structures have wide applications as one of the important structural elements in many engineering fields. Moreover, its load carrying capacity is decided by its buckling strength which depends strongly on geometrical imperfections presented in it. One of the primary design considerations for axially loaded cylindrical shells is buckling. The failure of these cylindrical shell structures is often controlled by elastic or elastic-plastic buckling failure. Buckling is charaterised by a sudden failure of a structural member subjected to high compressive stress and it is a structural instability leading to a failure mode. The buckling load decreases for shell with cutout when compared to the value of the shell without a cutout. The effect of cutout not only introduces stress concentration but also significantly reduces the buckling strength. The aim of this study is to investigate the buckling analysis of thin cylindrical shells without cutout and with cutout. Also studied the effect of increase in cutout diameter and change in cutout location. The investigation is carried out both experimentally.*

Key Words: **Cylindrical shell, Cutout, Buckling, Axial loading, Stress concentration**

1.INTRODUCTION

One of the primary design considerations for axially loaded cylindrical shell is buckling. Buckling of shells is one of the most complicated phenomenon in structural engineering. Shells are continuum structures where one dimension, the shell thickness, is very small compared to the other two dimensions. The consequence of this property is that the membrane stiffness is, in general, several orders of magnitude greater than the bending stiffness. Very small deformations takes place in the shell when it absorbs membrane strain energy. However, it deforms significantly when it absorbs bending strain energy. If the shell is loaded so that its strain energy is in the form of membrane compression and the loading reaches a stage where this stored membrane strain energy is converted into an equivalent bending energy, the shell deforms rather dramatically and fails in a process called "buckling". Cylindrical shells are widely used in civil engineering. Examples include cooling towers, pipelines, nuclear containment vessels, metal silos and tanks for storage of bulk solids and liquids, and pressure vessels. These structures may experience axial compression loads in their longevity and buckle through these loads. Furthermore, these structures usually have disruptions, such as cutouts, which may have destroyer effects on their stability. A cutout can be defined as another type of geometric imperfection. For some combination of loading case and cutout size, the presence of a cutout may reduce the buckling load of cylindrical shells significantly. The loading conditions for these shells are quite varied depending on the specific function of the shell. Axial compression, global bending, external or internal pressure and wind loading are some of the most common loading forms in practical structures. A common application of cylindrical shells is design of silos and tanks. Cylindrical shells used in engineering are generally very thin, and the mechanical behaviour is more complex than that of other structures like beams, columns and plates. The strength of a shell structure is often controlled by the buckling failure. A cylindrical shell under different loading conditions may display quite different buckling behaviour. So it is essential to understand the buckling behaviour of shell structures in different conditions comprehensively and establish suitable design methods.

Buckling may evoke an image of failure of a structure with very large deformation. However, from a scientific and engineering point of view, buckling phenomena generally occur before the deformations are very large, and the structure may appear to be not deformed or only slightly deformed. Buckling of structures is an important phenomenon in structural mechanics, because buckling often (but not always) leads to failure of structures. It is particularly important in shell structures because it often occurs without any obvious warning, and can have catastrophic effects. The buckling strength of a thin cylindrical shell under axial compression is more sensitive to imperfections than shells under other loading conditions. The buckling behaviour changes greatly with changing pattern of geometry, loading and boundary conditions, and the form and amplitude of the imperfections. For these reasons, the axially compressed cylinders are more extensively studied. Thin-walled cylindrical shells are important components of many industrial complexes. Most of these components have circular cutouts in manholes and pipe-to-shell junctions. Performance of cylindrical shells due to the extreme loading conditions shows that buckling is the major failure mode in such components. In this regard, wide investigations have been conducted by the researchers.

Anil Kumar Nagari et.al (2014) [1] conducted experimental investigation of buckling of laminated composite cylindrical shells with & without cutouts subjected to axial compression. The results which were obtained in this experiment will show how the imperfections like cutouts will affect the buckling behaviour of the shells. The load bearing capacity of the shell decrease for shells with cutout compared to the shells without cut outs.

L. Gangadhar et.al (2016) [2] studied buckling analysis of thin walled composite cylindrical shells with and without cutouts by applying axial load on shell. The buckling load decreases for shell with cutout when compared to the value of the shell without a cutout. The buckling load value is maximum in circular cutout and minimum in the rectangular cutout.

Mahmoud Shariati et.al (2010) [3] studied the effects of the length, sector angle and different boundary conditions on the buckling load and post buckling behaviour of CK20 cylindrical panels had been investigated using experimental and numerical methods. Increasing the length of panel will slightly decrease the buckling load. This effect is more important for shorter panels. By increasing the sector angle, the buckling load will increase.

Morteza Vakili et al. (2015) [4] conducted Experimental and Numerical Investigation of Elephant Foot Buckling and Retrofitting of Cylindrical Shells by FRP. The results of this paper showed that elephant foot buckling occurs under high internal pressure exerted simultaneously with axial compression; therefore, locating the FRP in the area of elephant foot buckling that has high circumferential stress can reduce stress and lead to best results in preventing the occurrence of buckling.

Neethi. B et.al (2015) [5] conducted an analytical study on the buckling strength of a composite cylindrical shell with cutouts. This paper studies the buckling strength of a composite cylindrical shell with cut-outs analytically. The study is also done with reinforcement around the cut-out. The results are compared with different cut-out shapes with and without discontinuities in the shell surface. Buckling load is maximum for shell without any discontinuity in its geometry. Buckling load is maximum for shell with circular cut-out and minimum for square cut-out.

S. Miladi et.al (2014) [6] conducted a parametric study on inelastic buckling in steel cylindrical shells with circular cutouts. This study aims to indicate the effect of circular cutouts on buckling capacity of cylindrical shells due to pure axial compression. The buckling capacity is reduced with increasing the cutout number in the shell width (horizontal arrangement of cutouts) and this reduction is more obvious in the cutouts with larger diameters. The increasing cutout number in the shell height (vertical arrangement of cutouts) has no significant effect on the buckling load reduction.

2. EXPERIMENTAL INVESTIGATION

An experimental investigation was carried out for cylindrical shells. Specimen with cutouts and without cutout were manufactured. In this experiment the specimen was subjected to axial compressive load in a 1000kN Universal Testing Machine. This machine is an hydraulically operated machine. It has a fixed bottom head and moving top head. The specimen to be tested was placed in between the two heads, right at the centre. Then the axial compressive load was increased in increments until buckling was observed. Specimens were tested and buckling load of each specimen is found.

Fig -1: Experimental setup for buckling test

2.1 Details of Specimen

The specimens used for tests was cylinders, 500mm long with a 150mm inside radius, made of steel sheet of 0.6mm thickness. Circular cutout of different diameter are created on face of the specimen. Specimen details are listed in Table -1.

Table -1: Specimen Details

Shape	Radius (mm)	Thickness (mm)	Length (mm)
Circle	150	0.6	500

2.2 Specimen preparation

The specimens used for tests was cylinders, 500mm long with a 150mm inside radius, made of steel sheet of 0.6mm thickness. Steel sheets were made to cut as per required dimension and cylinders were manufactured using welding process. Circular cutouts have been created on face of the specimen. Two steel rings were made and rolled to the diameter of the cylinder, one at each end. Steel plates are placed at top and bottom to ensure uniform loading.

3. EXPERIMENTAL RESULTS

3.1 Effect of cutout on cylindrical shell

In this section, buckling load of steel cylindrical shell with and without a cutout is investigated. In order to study the effect of cutouts on buckling strength, steel cylindrical shells with a circular cutout of radius 40mm is also investigated. Therefore, cutouts were created at mid-length position of the shell. The results are presented in table -2. It can be seen that the buckling load of the shell decreased considerably when a cutout was created in the shell.

Table -2: Experimental results of specimen without cutout and with cutout

Experimental Results	Without Cutout	With Circular Cutout
Buckling Load (kN)	52.6	42.8

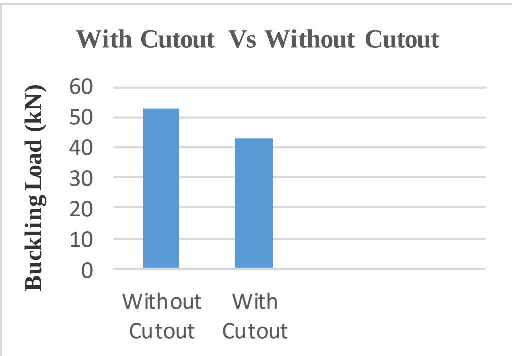
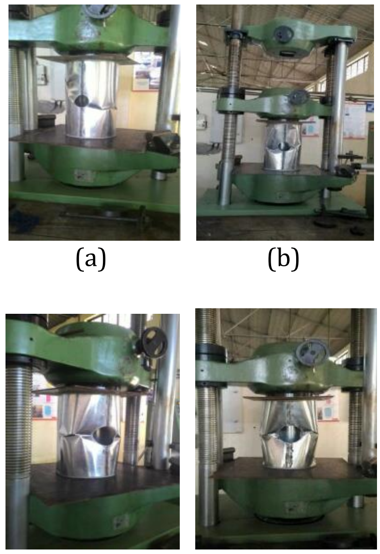


Chart -1: Effect of cutout on buckling load

3.2 Effect of change in cutout radius on shell

In this section, effect of changing cutout radius on the buckling load of cylindrical shells is studied. For this reason, cutouts with fixed height (250 mm) were created in the mid-height position of shells. Then, by changing radius of the cutouts from 40 to 70 mm, the change in buckling load was studied. The results of this investigation are presented in Table -3.

The results show that by increasing the cutout size, the buckling load of the steel cylindrical shell decreases continuously. It is evident from table -3 that an increase in the cutout radius when the cutout height is constant causes a considerable reduction in the buckling load of composite cylindrical shells.



(a) (b) (c) (d)

Fig -2: Buckling modes of cylindrical shell with cutouts of (a) r = 40mm, (b) r = 50mm, (c) r = 60mm, (d) r = 70mm

Table -3: Experimental results of cylindrical shell with cutouts of different radius

Experimental Results	Radius (mm)			
	40	50	60	70
Buckling Load (kN)	42.8	40.6	33.4	28.6

3.3 Effect of change in cutout positon on shell

To study the effect of change in cutout height on the buckling load of cylindrical shells, cutouts with constant diameter (d= 50 mm) were created in the mid-height position of shells. Then, with changing height of the cutouts from L/8 to L/2 distance from the shell's top and bottom, the change in buckling load was studied. The results of the analysis are shown in Table -4.

From chart -2, it is evident that, with changing position of the cutout from shell top and bottom towards the mid height of the shell, the buckling load gets reduced. Buckling load is maximum at L/4 distance from bottom of the shell. So it can be choosen as the best position for providing cutout.

Table -4: Experimental results of cylindrical shells with cutout at different position

Specimen with cutouts at different position	Buckling Load (kN)		
	L/2	L/4	L/8
From bottom	40.6	49.8	48
From top	40.6	40	29.6

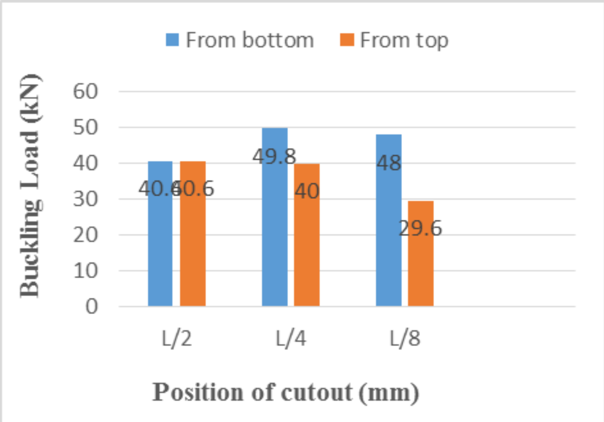


Chart -2: Effect of change in cutout position on buckling load

6. CONCLUSIONS

In this study, experimental investigation of cylindrical shells were carried out and the results obtained are summarized as follows:

- The buckling load of the cylindrical shell is decreased considerably when a cutout is created in the shell.
- An increase in the cutout diameter when the cutout height is constant causes a considerable reduction in the buckling load of steel cylindrical shells.
- It is observed that by changing the position of the cutout from shell bottom and top towards the mid height of the shell, the buckling load gets reduced.

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