

Experimental study on the buckling and post-buckling behavior of thin-walled cylindrical shells with varying thickness under hydrostatic pressure

Y.G. FAKHIM^a, H. SHOWKATI^a, K. ABEDI^{b,*}

^a Postgraduate student, Department of Civil Engineering, SAHAND University of Technology, Iran

^a Associated Professor, Department of Civil Engineering, Urmia University, Iran

^{b,*} Professor, Department of Civil Engineering, SAHAND University of Technology, Iran

E-mail: k_abedi@sut.ac.ir

Abstract

The application of thin-walled cylindrical shells, as the essential structural members, has been known for engineers and functional duty of them is basic necessities of modern industries. These structures are prone to fail by buckling under external pressure which could be happened during discharging or wind load. Although the buckling capacity of the shells depends principally on two geometric ratios of "length to radius" (L/R) and "radius to thickness" (R/t), but the effect of thickness variation on the behavior of the shells is complicated to be studied. On the other hand, the buckling strength of thin cylindrical shells is sensitive to the magnitude and shape of geometric imperfections.

The effect of thickness variation and geometric imperfections on the buckling and post-buckling behavior of cylindrical shells is experimentally investigated in this paper. Top end of the specimens has conical roof and the bottom end has simply supported conditions. The measured data and obtained results are reported for the specimens under the effect of hydrostatic external pressure. Each specimen has different variation in thickness along its length. The slender parameters of tested shells are $L/R = 2, 1, 0.5$ and $R/t = 500, 600$. In addition, the considerable effect of circumferential and vertical weld line on the buckling strength and mode shapes is verified.

Keywords: Thin-walled cylindrical shells, Buckling capacity, Hydrostatic external pressure, Varying thickness, Imperfection.

1. Introduction

One of the most common types of structural and industrial elements is shells. The application of cylindrical shells is in tanks and silos, in offshore structures, aeronautical and aerospace technology, ship hulls, in pipelines and industrial chemical plant. Cylindrical shells have been interested for their special characteristic and applications. The application of cylindrical shells, as the essential structural members, has been known for engineers and their functional duty is basic necessities of modern industries.

Although the buckling capacity of the shells depends principally on two geometric ratios of "length to radius" (L/R) and "radius to thickness" (R/t), but the effect of thickness variation on the behavior of the shells is complicated to be studied. On the other hand, the buckling strength of thin cylindrical shells is sensitive to the magnitude and shape of geometric imperfections.

Malik et al. (1979) [1] studied thin walled storages with stepped varying thickness on external pressure. Ansourian and Jonaidi [2] investigated effect of harmonic settlement on cylindrical shells with varying thickness. They used two experimental and two numerical models. Aghajari et al. (1996) [3] studied the buckling and post-buckling behavior of thin-walled cylindrical steel shells with varying thickness subjected to uniform external pressure. Their experiments included four specimens with different height and thickness. Teng and Lin (2005) [4] investigated the effects of circumferential and meridian welding with TIG weld on the behaviour of cylindrical shells.

Experimental study is the most reliable method in engineering researches. In the present study, the effect of thickness variation and geometric imperfections on the buckling and post-buckling behavior of cylindrical shells is experimentally investigated under hydrostatic pressure. Three experimental specimens with varying thickness and conical roof are fabricated in high accuracy with TIG welding. The hydrostatic external pressure is produced by gauged vacuum in models using suction process. Pre-buckling, primary buckling, secondary buckling and failure have been observed and evaluated. Finally, experimental results are compared with each other.

2. Dimensions of Specimens

Specimens have been nominated with C1, C2 and C3. Their dimensions have been shown in Figures 1-3.

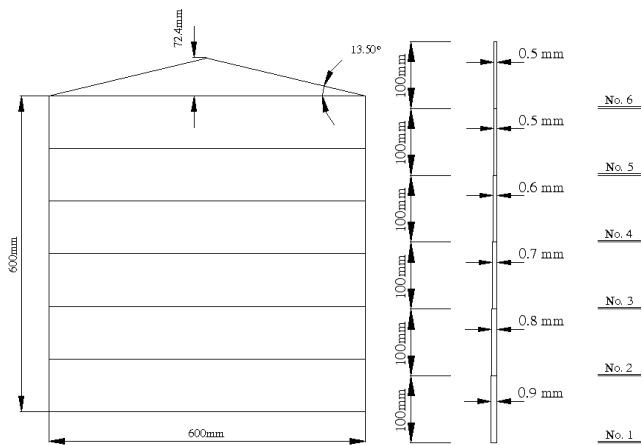


Figure 1: Dimensions of specimen C1

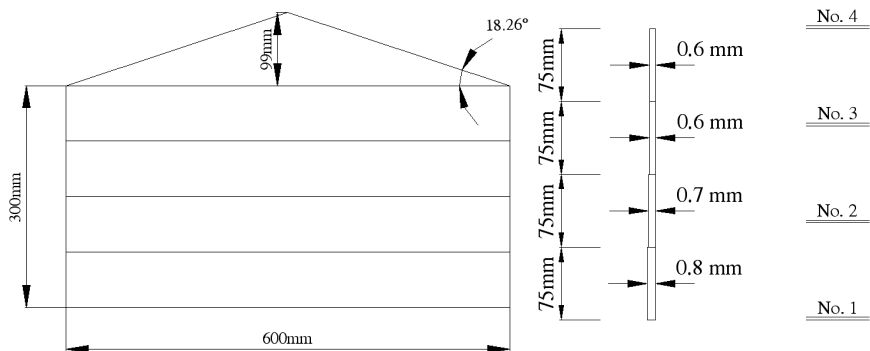


Figure 2: Dimensions of specimen C2

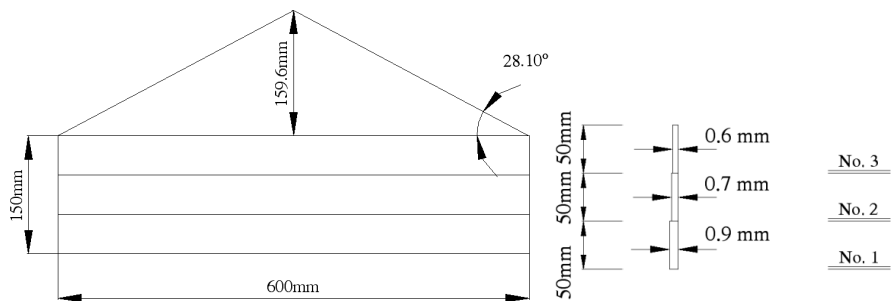


Figure 3: Dimensions of specimen C3

3. Specimens Fabrication

With respect to frangibility of sheets, some important points were considered in the welding process. The fitting of sheets were difficult. To solve this problem, the sheets were lied on the rigid steel surface. For heat reduction, copper sheets on bottom and top of sheets were used. These sheets were fixed with thick metal belts. By this method, the problem of sheet fitting could be easily and appropriately solved. TIG welding is used to connect the sheets to each other.



Figure 4: Procedure of connection of sheets

4. Experimental system and Instruments

The specimens are lied on metallic circular tracked plate. This track is embedded in specimen's side. Figure 5 shows the cross section of this track. Simple support is simulated by this method.

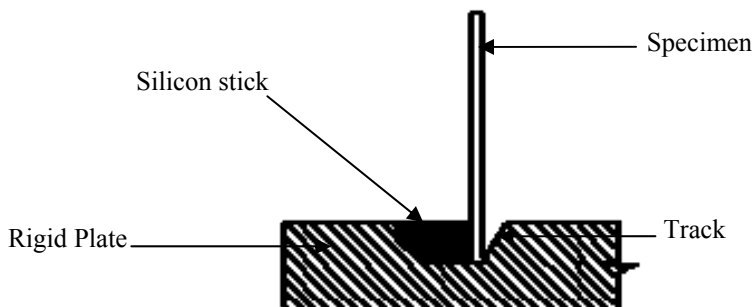


Figure 5: The cross section of tracked plate

The metallic plate includes three holes: 1- pump hole; 2- adjustment valve hole; 3- pressure transmitter hole. External pressure is produced by vacuum pump. Pressure transmitter has been used for the measurement of pressure. Strain gauges, transducers and Data logger are the main instrumental apparatus. Silicon stick is used to prevent leakage. Figure 6 shows the pressure transmitter.



Figure 6: Pressure transmitter

5. Imperfection measurement

The Geometric imperfection in structures leads to difference between theoretical and experimental results. This problem is overcome by modeling the geometric imperfection. A probe system designed for imperfection measurement. Initial imperfection for each specimen is shown in Figure 7-9.

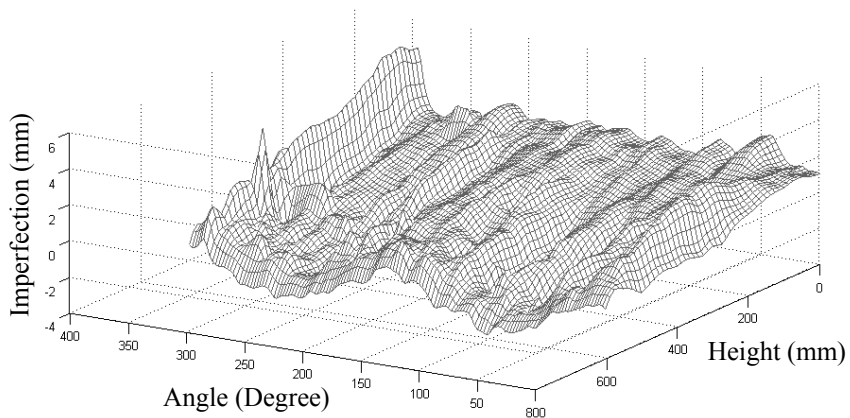


Figure 7: Initial imperfection of specimen C1

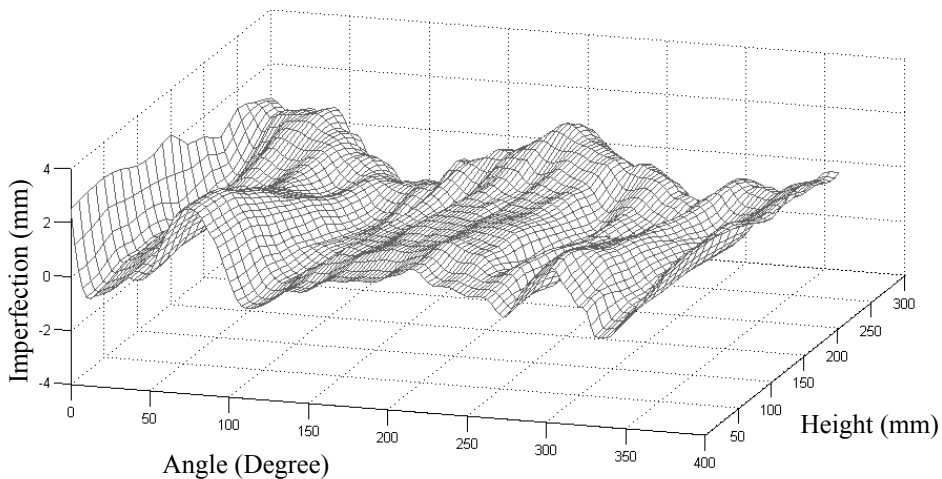


Figure 8: Initial imperfection of specimen C2

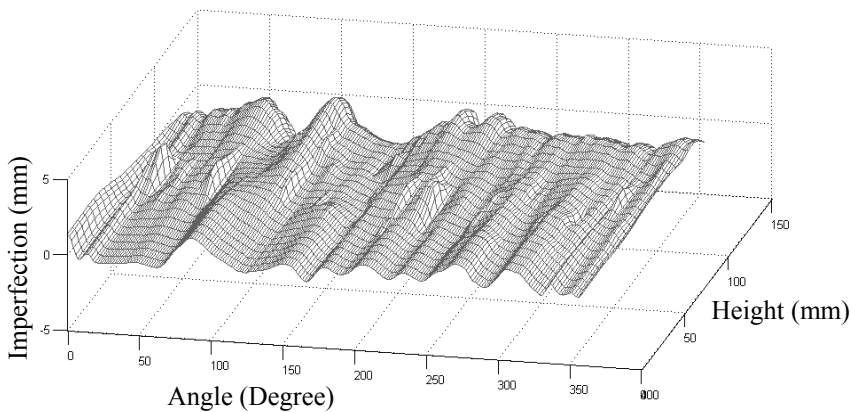


Figure 9: Initial imperfection of specimen C3

6. Steps of experiments

Measurement objects were installed on the specimens after initial imperfection measurement. The locations of strain gauges and displacement transducers are shown in Figures 10-12.

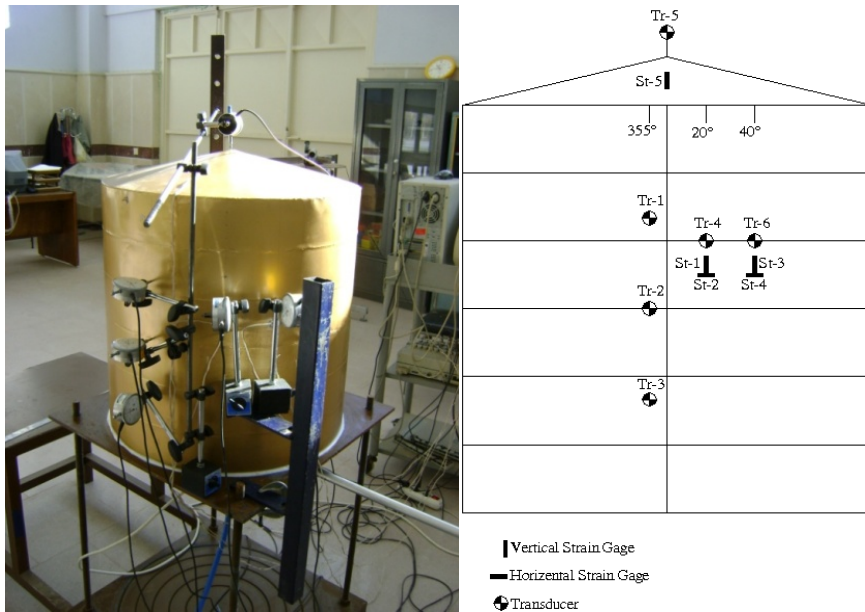


Figure 10: The locations of strain gauges and displacement transducers in specimen C1

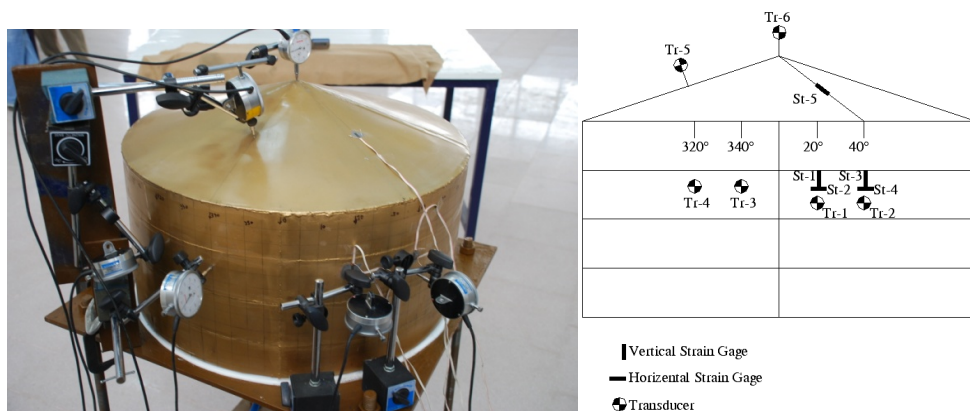


Figure 11: The locations of strain gauges and displacement transducers in specimen C2

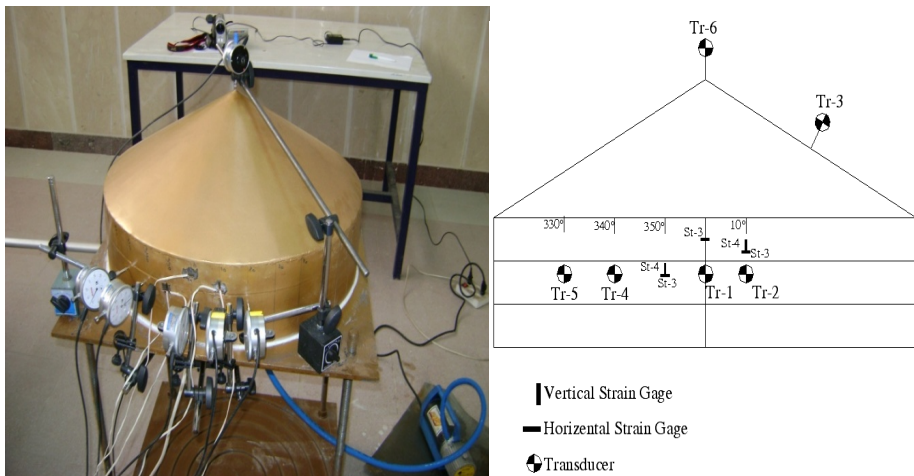


Figure 12: The location of strain gauges and displacement transducers in specimen C3

After controlling of instruments, the loading was begun. A data logger has been used for recording the measurements. Figures 13, 14 and 15 show the specimens at the end of tests.



Figure 13: The specimen C1 at the end of test



Figure 14: The specimen C2 at the end of test



Figure 15: The specimen C3 at the end of test

Table 1 gives the initial buckling load and number of buckling modes for each specimen. Figures 16 and 17 show pressure-strain and pressure-displacement response for specimen C1.

Table1: The initial buckling load and number of buckling modes for each specimen

Cylinders Number	Initial buckling load (KPa)	Number of buckling modes
C1	7.9	8
C2	18.3	9
C3	82.74	14

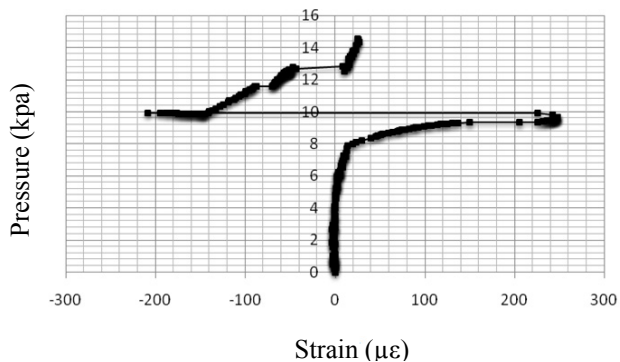


Figure 16: Pressure-strain response for specimen C1

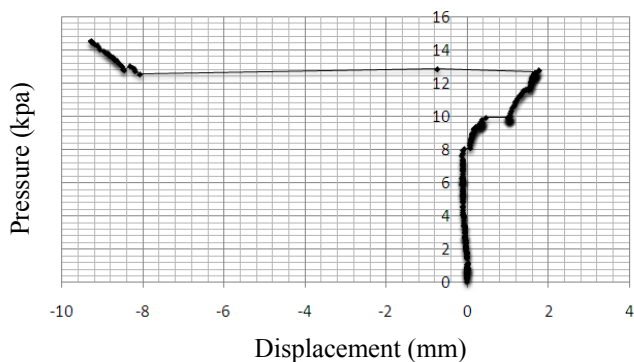


Figure 17: Pressure-Displacement response for specimen C1

Figures 18 and 19 show pressure-strain and pressure-displacement response for specimen C2. Pressure-strain and pressure-displacement responses for specimen C3 are illustrated in Figures 20 and 21.

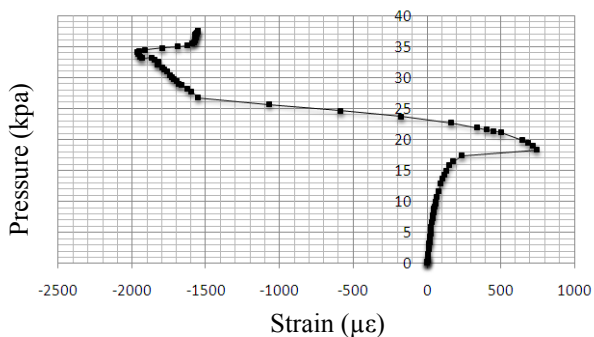


Figure 18: Pressure-strain response for specimen C2

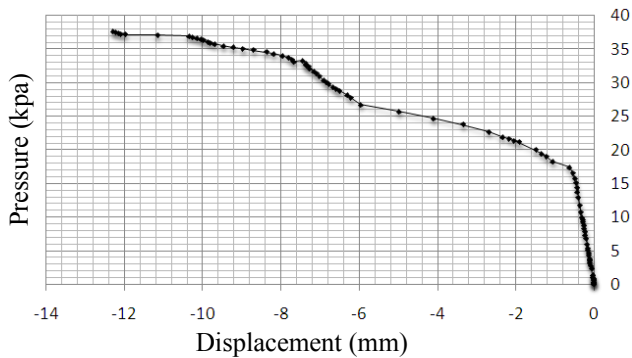


Figure 19: Pressure- Displacement response for specimen C2

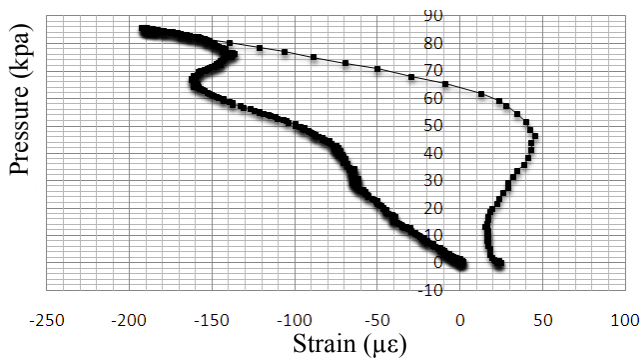


Figure 20: Pressure-strain response for specimen C3

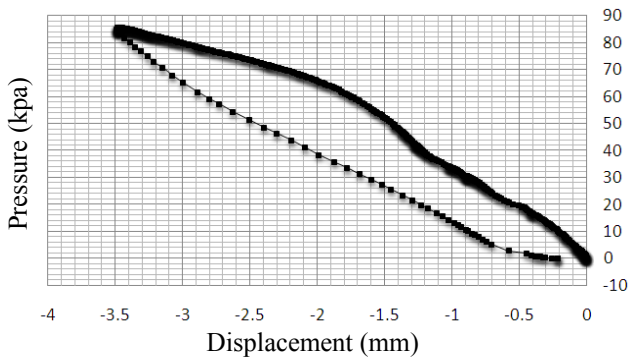


Figure 21: Pressure- Displacement response for specimen C3

7. Observation and Conclusion

In the present paper, the effect of thickness variation and geometric imperfections on the buckling and post-buckling behavior of cylindrical shells is experimentally investigated. The results of the experimental study are used to obtain certain conclusions. Strictly speaking, the scope of the conclusions is limited to the cases considered for the experimental study. However, it is likely that the conclusions are of more applicability.

- Difference between initial buckling and overall buckling load in specimens is considerable, that is, post-buckling strength exists obviously in all specimens.
- The initial buckling is occurred when one or more buckling modes are observed. The loading is continued to the general buckling in which all of buckling modes are formed.
- The thickness variation affects the location of final waves to be formed in thinner part of shells.
- The buckling waves have been affected by meridian welding. First and second buckling waves are usually formed around welding zone especially in longer shells. Maybe, it will not happen in shorter shells.
- The buckling waves are formed in short shells all over the height of shell. With increasing height, the wave grows less in lower parts. Also in longer shells, the buckling waves in top parts are wider than in lower parts. With decreasing height, these waves are symmetric.
- Torsion pattern is severe in longer shells and is disappeared in shorter shells.

Acknowledgement

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