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Investigation on Buckling Behavior of Tubular Shells with Circular Cutout, Subjected to Combined Loading

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Abstract

Within this contribution, buckling of tubular steel shells with circular cutout will be analyzed. The experimental results will be compared by FEM simulation results within circular cutouts of the specimen. The experimental buckling tests have been conducted using a Servo-hydraulic machine (Instron 8802). Considering the broad application range of tubular thin-walled shells, prediction of the behavior of these elements in combined loading case (especially for buckling behavior) has gained a great level of importance. In this study, the influence of shell length, shell diameter, shell angle and diameter of circular cutouts on the predicted buckling values for the tubular shell has been explored. Numerical simulations of tubular shell subjected to combined loading were conducted. The analytical solutions show excellent agreement with the numerical results predicted by FEM.

Keywords: Tubular shell, circular cutout, combined loading, buckling, finite element method, experimental test.

Introduction

Cylindrical shells are widely used in various structures, including aerospace structures and other engineering applications. These shells, depending on the conditions, may have cutouts. In most cases, the shells are subjected to combined loads. The prediction of buckling behavior of these shells is obviously necessary and, fortunately, is possible and feasible through various experimental and numerical methods. Recently, among the latter approaches, the FEM method is considered to be a powerful tool for investigation of the final buckling load of thin-walled shells. However, to assure the authenticity of the obtained results through this method, it seems necessary that these results are validated with experimental data.

Vartdal et al.[1] studied on simply supported steel tubes with rectangular cutouts of different sizes positioned at their mid-length subjected to axial compression to assess the effect of the cutouts on the deformation behavior. Toda[2] performed an experimental investigation on the cylindrical shells with circular holes subject to axial compression. Furthermore, he placed ring-shaped stiffeners around the cutout and studied the effect of stiffeners on the buckling of cylindrical shells with circular cutouts. Shariati and Mahdizadeh[3] studied the effect of position of elliptical cutouts with identical dimensions on the buckling and post buckling behavior of cylindrical shells with different diameters and lengths and developed several parametric relationships based on the numerical and experimental results using the Lagrangian polynomial method. Also Shariati and Rokhi[4] studied numerically simulation and analysis of steel cylindrical shells with various diameter and length having an elliptical cutout, subjected to axial compression. They investigated examined the influence of the cutout size, cutout angle and the shell aspect ratios L/D and D/t on the pre-buckling, buckling, and post-buckling responses of the cylindrical shells. Jullien[5] studied the influence of circular, square, and rectangular cutouts on the buckling of cylindrical thin-walled shells under axial load and presented a parametric relationship between the shape and dimensions of the cutouts. Also, the effect of location and number of cutouts was studied. El Naschie[6] considered the buck-ling problem of a cracked shell for the first time. The buck-ling load of these shells is shown to be half of that of the perfect cylinder. Shariati and Mahdizadeh[7] performed numerical study using Abaqus software to investigate the response of steel cylindrical shells with different lengths and diameters, including elliptical cutout subjected to bending moment. They presented some relations for finding of buckling moment of these structures. Yeh et al.[8] analytically and experimentally studied the bending and buckling of moderately thick-walled cylindrical shells with cutouts. It was found that the limiting buckling moment would be higher if the cutout was on the tension side rather than on the compression side. Almorth et al.[9] performed a complex nonlinear analysis for cylindrical shells with two opposite circular cutouts subject to axial compression. They showed that the calculated numerical results are comparable to the experimental results. Poursaeidi et al.[10] considered an elastoplastic material and used Abaqus Software to analyze the plastic behavior of cylindrical shells with cutouts under pure bending. The shell had a circular cross section and both ends had been clamped. The shape of the cutouts in the shells was circular or rectangular. The influence of the size, location and number of the cutouts on the limiting bending moment of a cylindrical shell was presented. Han and Park[11] investigated numerically columns of mild steel impacted at a declined rigid wall with no friction. Different angles were tested, and the response was divided into axial collapse, bending collapse and a transition zone. An empirical expression for the critical angle was found. Rahimi and Poursaeidi[12] carried out plastic analysis of cylindrical shells with a circular hole under the effect of end pure moment. Han and Park[13] investigated numerically columns of mild steel impacted at a declined rigid wall with no friction. Different angles were tested, and the response was divided into axial collapse, bending collapse and a transition zone. An empirical expression for the critical angle was found. Studies by Reyes et al.[14] of thin-walled aluminum extrusions subjected to oblique loading showed that the energy absorption drops drastically by introducing a load angle of 5° compared to the axial crushing. This is due to the different collapse modes, as the progressive buckling of axial crushing is a much more energy-absorbing process than bending.

The present paper, report on using the Abaqus finite element software, were carried out in order to study the effect of the shell length (L), shell diameter (D), shell angle (α) and circular cutout diameter (d) on the buckling and post-buckling behavior of cylindrical shells. The distance between the center of the cutout and the lower edge of the shell is designated by CP. Additionally, several experimental buckling tests were performed using an INSTRON 8802 servo-hydraulic machine, and the test results were compared with the results of the finite element method. A very good correlation between experiments and numerical simulations was observed.

Material and Methods

The geometry of specimen and the circular cutouts created on it are illustrated in figure-1. As shown in this figure, parameter d shows the diameter of circular cutout. Specimens with circular cutout were nominated as follows: D42-L250-α15-CP125-d. The numbers following D and L show the diameter and length of the shell, respectively. Also, the numbers following α and CP show shell angle and the distance between the center of the cutout and the lower edge of the shell, respectively.

Experimental tests: The experiment includes different tests performed on different specimens. The circular cutouts have been created on face of specimens. The specimens were tested by servo-hydraulic machine (Instron 8802). The specimens were constrained by fixtures that design and inserted at both ends in the experimental tests, for the simulation of combined loading. It will be shown in figure-2. Furthermore this figure shows specimen D42 mm-L250 mm-α15º-CP125 mm-d18 mm, a) before loading, b) under loading and c) after loading by test setup.

Figure-3 shows how combined loading was realized in the present study. The test specimen was clamped at the upper end, and the quasi-static force was applied through a rigid body at the lower end of the specimen.

Specimens are made of stainless steel 316ti whose mechanical properties were specified through application of tensile test in accordance with ASTM E8 standard. For the tensile test, the specimens were taken from the face of the column specimen. The stress-strain curve obtained through tensile test has been shown in figure-4a. Setup test has been shown in figure-4b. Based on the linear portion of stress–strain curve, the value of elasticity module was computed as E=187 GPa. Also the value of yield stress was obtained as σ_y=334 MPa. Furthermore, the value of Poisson's ratio was assumed to be ϑ=0.33.

Geometry of samples: For this study, stainless steel 316ti tubular shells with various length L=150, 250 and 300 mm, various diameter (D=34, 42 and 50 mm), various shell angle (α=00, 05, 15 and 25 degree) and various circular cutout size (d=12, 16 and 18 mm) were analyzed. A circular geometry was selected for cutouts that were created in the specimens. Furthermore, the thickness of shells was t=1 mm.

Numerical analysis: For analyzing the buckling behavior of the stainless steel shells program Abaqus has been applied. Elastic modulus of the specimens which can be obtained from the linear part of figure was 187 GPa for all the specimens. The geometrical dimensions were chosen in accordance with the quantities measured in experimental tests. For this analysis, the nonlinear element S8R5, which is an eight-node element with six degrees of freedom per node, suitable for analysis of thin shells was used. Part of a meshed specimen with circular cutout and specimen with circular cutout are shown in figure-5.

In this study, the cylindrical shells were considered as clamped. For applying boundary conditions on the edges of the cylindrical shells, two rigid parts of fixture were used that were attached to the ends of the cylinder.

In order to analyze the buckling subject to combined load similar to what was done in the experiments. 20 mm displacement was applied centrally to the center of the lower rigid base. Figure-6 shows boundary and load condition. In this figure, parameter α shows shell angle.

Results and Discussion

In this section, the results of the buckling analyses of cylindrical shells with circular cutouts using the finite element method and experimental method are presented. Comparison of the results shows that the numerical and experimental results are well matched.

The effects of shell length (L) on the buckling behavior of cylindrical shells: To study the effect of a change in shell length on the buckling load of cylindrical shells with circular cutout, choose shell with three different lengths. Representing short (L=150 mm), intermediate-length (L=250 mm) and long cylindrical shell (L=300 mm). Then with create circular cutout on specimen at the mid-height position of shells, the effects of shell length (L) on the buckling behavior of cylindrical shells was studied. In table-1 the results of the analysis are shown. Figure-7 shows that with increasing shell length, the buckling load decreases. It is evident from figure-7 that an increase in the shell length had little effect on the buckling resistance of the shells.

The effects of shell diameter (D) on the buckling behavior of cylindrical shells: To study the effect of a change in shell diameter on the buckling load of cylindrical shells, circular cutouts with constant size (18 mm) were created in the mid-height position of shells. Then, with changing the shell diameter from 34 mm to 50 mm, the change in buckling load was studied. The results of the analysis are shown in table-2. Buckling load vs. deformation curves produced from the FEM, are shown in figure-8. This figure shows that with increasing shell length, the buckling load increases. Furthermore, it can be seen from figure-8 that for shells with a length of 250 mm, with the increase of shell diameter from 34 mm to 50 mm, the buckling load increases 90.16%.

The effects of shell angle (α) on the buckling behavior of cylindrical shells: In order to analyze the relationship between the buckling load and changes in the angle of shell, a circular cutout with fixed diameter (d=18 mm) was created in the mid-height position of cylindrical shells with constant length and constant diameter. Then was studied the effects of shell angle (α) on the buckling behavior of cylindrical shells, with change shell length from 0º to 25º. The results of this analysis are shown in table-3. The results show that increasing the shell angle decreases the shell resistance against buckling; the reduction in the buckling load with the increase of shell length from 0º to 25º was 42.79%. Figure-9 shows summary of the buckling capacity of cylindrical shells with circular cutout versus deformation, for shells with different shell angle.

The effects of cutout size on the buckling behavior of tubular shells: In this part the effects of changing the cutout size on the buckling load of tubular shells with circular cutout were studied. For this reason, cutouts with different diameter (d=12, 16 and 18 mm) were created in the mid-height position of shells. Then FEM was used to assess the influence of cutouts diameter on the buckling behavior. The results of this analysis are presented in table-4. The buckling load versus deformations is shown in figure-10. The results show with increase in cutout diameter decreases the buckling load.

Comparison of FEM and experimental test results: Different experimental tests were conducted to confirm of the authenticity of the results obtained from the numerical method[15-19]. Later on for better comparison the load-displacement curves obtained through experimental and numerical methods have been studied. In addition for comparing the samples deformed shape and the behavior of them after occurrence of buckling, between the results obtained from the experimental tests and the results of from the finite elements method the deformed specimen's shape and the load-displacement curve for D42 mm-L250 mm-α15º-CP125 mm-d18 mm have been illustrated in figure-11. Studying these pictures proves the fact that there is good agreement in the specimens deformed shape, between the results of the FEM and the experimental method. The results of experiments are compared with numerical findings in table-5. It is evident from table-5 that there is a little difference between experimental and numerical results. For example, the biggest discrepancy between the two sets of results is 3.9%.

Conclusion

In this research, we studied the buckling load of stainless steel cylindrical shells with various shell length, various shell diameters, various shell angle and various circular cutout diameter using numerical and experimental method. Comparison of the curves shows that the numerical and experimental results are well matched. Some results were found in this study. With increasing shell length, the buckling load decreases. When the circular cutout size is constant, and shell length increases, the buckling load reduces, however the amount of reduction in the buckling load is negligible. Also results show that the buckling load increases when the diameter of cylindrical shells with a circular cutout increases. It can be seen from results that increasing the shell angle cause to decreasing the shell resistance against buckling. For cylindrical shells contain circular cutout, increasing the circular cutout diameter cause to decreasing the buckling load. For cylindrical shells with a cutout, at first the buckling occurs locally, and then the shell experiences general bending.

References

1. Vartdal B.J., Al-Hassani S. and Burley J., A tube with a rectangular cutout, Part 2: subject to axial compression, *J. Mechanical Engineering Science*, **220(5)**, 652-643 **(2005)**

2. Toda S., Buckling of cylinders with cutouts under axial compression, *Exp. Mech.*, **23(4)**, 414-417 **(1983)**

3. Shariati M. and Mahdizadeh M., Numerical and Experimental Investigations on Buckling of Steel Cylindrical Shells with Elliptical Cutout Subject to Axial Compression, *Thin-Walled Structures*, **46**, 1251- 1261 **(2008)**

4. Shariati M. and Rokhi M., Buckling of Steel Cylindrical Shells with an Elliptical Cutout, *International Journal of Steel Structures*, **10(2)**, 193-205 **(2010)**

5. Jullien J.F. and Limam A., Effect of openings on the buckling of cylindrical shells subjected to axial compression, *Thin Wall Structures*, **(31)**, 187-202 **(1998)**

6. El Naschie M.S., Branching solution for local buck-ling of a circumferentially cracked cylindrical shell, *Int. J. Mech. Sci.*, **(16)**, 689-97 **(1974)**

7. Shariati M. and Rokhi M., Investigation of buckling of Steel cylindrical shells with elliptical cutout under bending moment, *International Review of Mechanical Engineering*, **3(1**), 7-15 **(2009)**

8. Yeh M.K. et al., Bending buckling of an elastoplastic cylindrical shell with a cutout, *Eng. Struct*., (**21**), 996–1005 **(1999)**

9. Almorth B.O., Brogan F.A. and Marlowe M.B., Stability analysis of cylinders with circular cutouts, *AIAA J*., **11(11)**, 1582–4 **(1973)**

10. Poursaeidi E., Rahimi G.H. and Vafai A.H., Plastic buckling of cylindrical shells with cutouts, *Asian Journal of civil engineering (Building and housing),* **5(3-4)**, 191-207 **(2004)**

11. Han D.C. and Park S.H., Collapse behavior of square thin-walled columns subjected to oblique loads, Thin-Walled Structures, **(35)**, 167–184 **(1999)**

12. Rahimi G.H. and Poursaeidi E., Plastic analysis of cylindrical shells with single cutout under bending moment. In The third international conference on advanced structural engineering and mechanics, Seoul, Korea, 908–922

13. Han D.C. and Park S.H., Collapse behavior of square thin-walled columns subjected to oblique loads, *Thin-Walled Structures*, **(35),** 167–184 **(1999)**

14. Reyes A., Langseth M. and Hopperstad O.S., Square aluminum tubes subjected to oblique loading, *International Journal of Impact Engineering*, **(28),** 1077–1106 **(2003)**

15. Magarajan U., Thundil karuppa Raj R. and Elango T., Numerical Study on Heat Transfer of Internal Combustion Engine Cooling by Extended Fins Using CFD, *Res. J. Recent Sci.,* **1(6)**, 32-37 **(2012)**

16. Purkar T. Sanjay and Pathak Sunil, Aspect of Finite Element Analysis Methods for Prediction of Fatigue Crack Growth Rate, *Res. J. Recent Sci*., **1(2)**, 85-91 **(2012)**

17. Kumar Krishan and Aggarwal M.L., A Finite Element Approach for Analysis of a Multi Leaf Spring using CAE Tools, *Res. J. Recent Sci*., **1(2)**, 92-96 **(2012)**

18. Bhattacharya Sourabh, Applications of DSTATCOM Using MATLAB/Simulation in Power System, *Res. J. Recent Sci*., **1(ISC-2011)**, 430-433 **(2012)**

19. Murthy B.R.N., Lewlyn L.R. Rodrigues and Anjaiah Devineni, Process Parameters Optimization in GFRP Drilling through Integration of Taguchi and Response Surface Methodology, *Res. J. Recent Sci*., **1(6)**, 7-15 **(2012)**

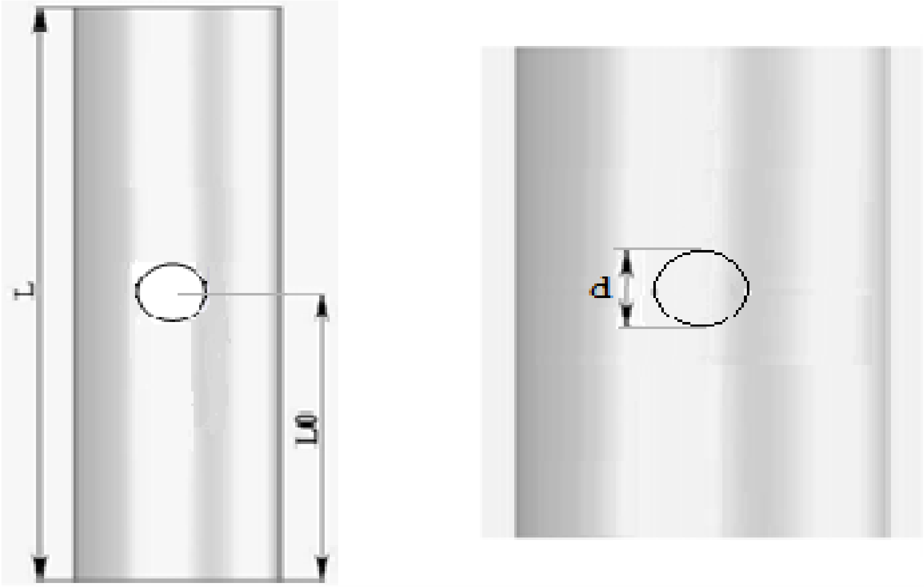
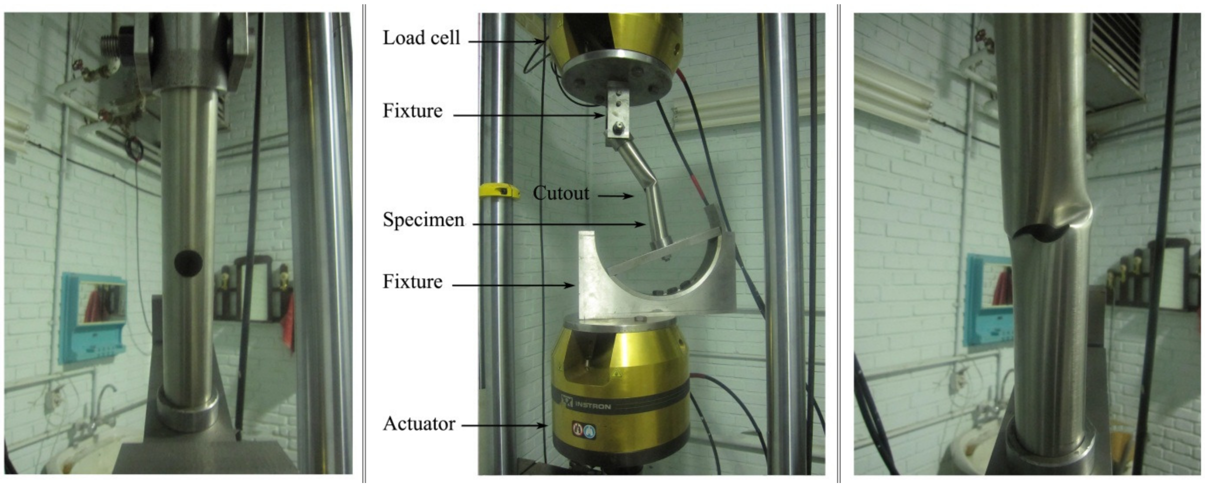


Figure-1
Geometry of circular cutout



a) Specimen before loading b) Specimen under loading c) Specimen after loading

Figure-2
Specimen D42 mm-L250 mm-α15º-CP125 mm-d18 mm

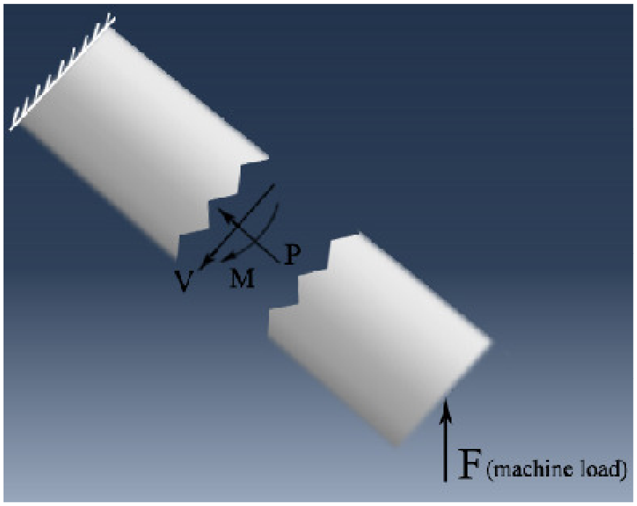
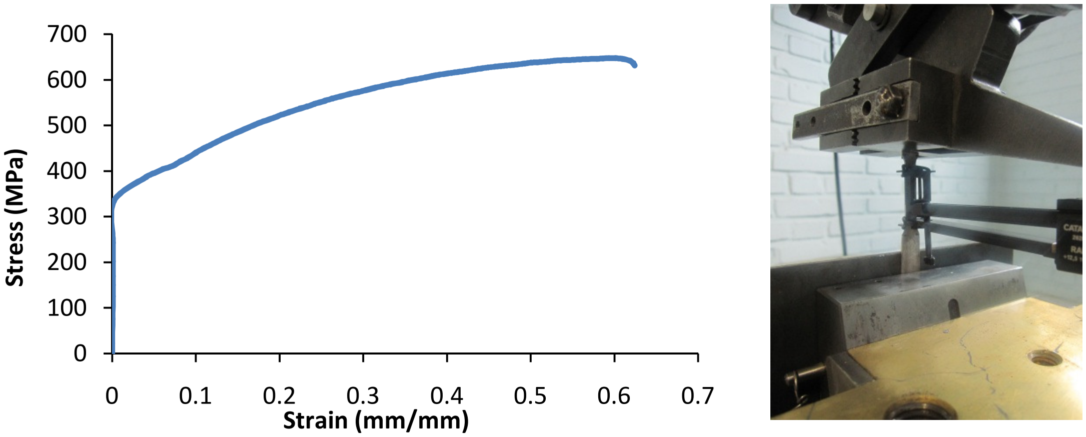


Figure-3
Decomposition of applied machine load to each section of shell (P=axial load, V=shear load and M=bending moment)



a) Stress–plastic strain curve b) test setup

Figure-4
Tensile test

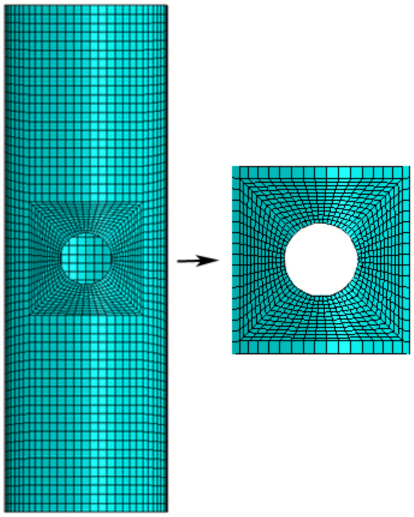


Figure-5
Samples of FEM mesh for specimen with circular cutout

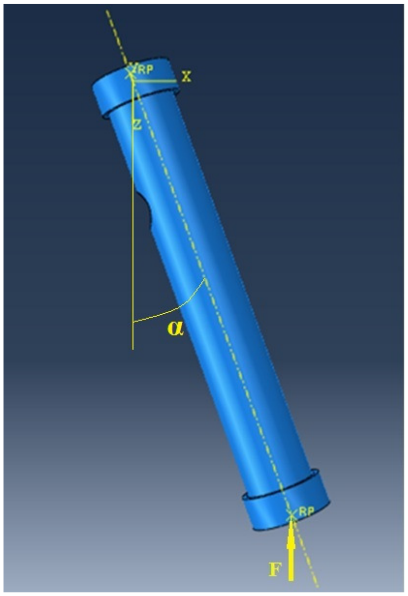


Figure-6
Boundary and loading conditions

Table-1
Summary of numerical analysis for cylindrical shells with different shell length contain circular cutout

Model designation	Shell thickness (mm)	Location of cutout (CP/L)	Buckling load (kN)
D42-L150- α15-CP75-d18	1	0.50	35.12
D42-L250- α15-CP125-d18	1	0.50	34.66
D42-L300- α15-CP150-d18	1	0.50	34.40

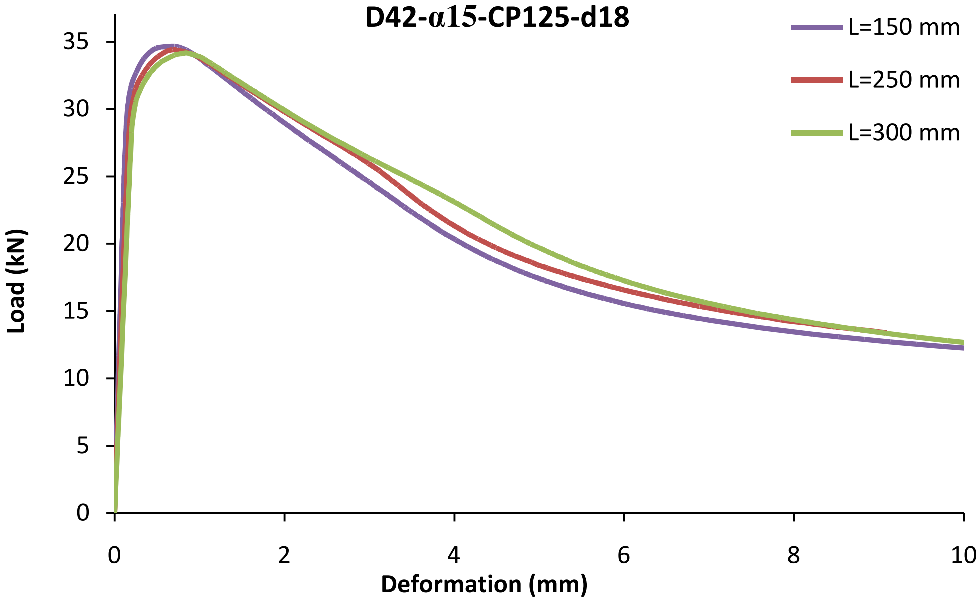


Figure-7

Buckling Load of cylindrical shells with circular cutout versus deformation curves, for shells with various length

Table-2

Summary of numerical analysis for cylindrical shells with different shell diameter (D) contain circular cutout

Model designation	Shell thickness (mm)	Location of cutout (CP/L)	Buckling load (kN)
D34-L250- α15-CP125-d18	1	0.50	28.35
D42-L250- α15-CP125-d18	1	0.50	34.66
D50-L250- α15-CP125-d18	1	0.50	53.91

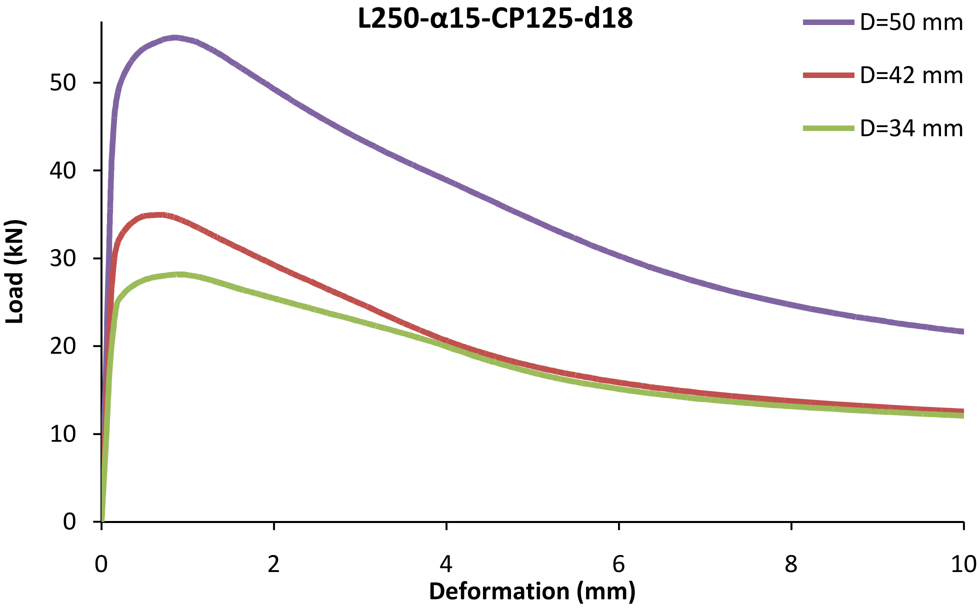


Figure-8

Buckling load of cylindrical shells with circular cutout versus deformation curves, for shells with various diameters

Table-3
Summary of numerical analysis for cylindrical shells with different shell angle contain circular cutout

Model designation	Shell thickness (mm)	Location of cutout (CP/L)	Buckling load (kN)
D42-L250- α00-CP125-d18	1	0.50	40.68
D42-L250- α05-CP125-d18	1	0.50	39.22
D42-L250- α15-CP125-d18	1	0.50	34.66
D42-L250- α25-CP125-d18	1	0.50	28.49

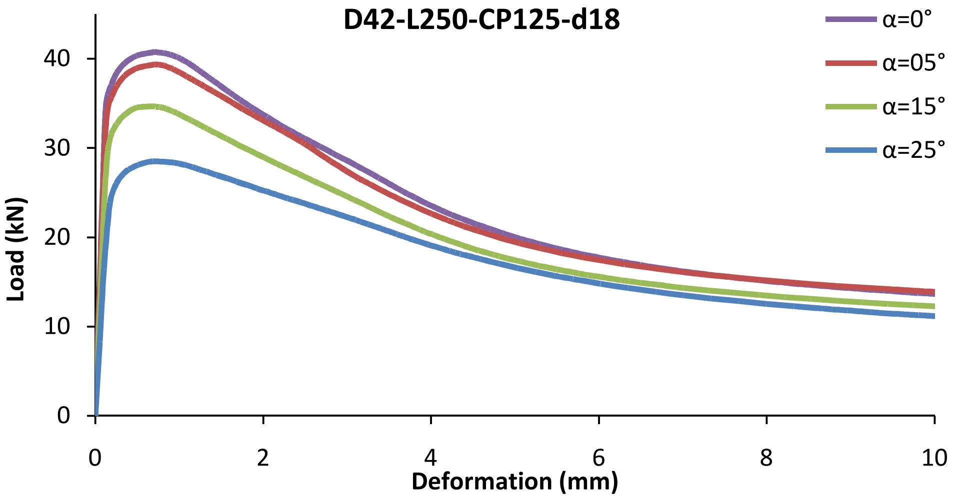


Figure-9
Buckling load of cylindrical shells with circular cutout versus deformation curves, for shells with various shell angle

Table-4
Summary of numerical analysis for cylindrical shells with different cutout size

Model designation	Shell thickness (mm)	Location of cutout (CP/L)	Buckling load (kN)
D42-L250- α15-CP125-d12	1	0.50	40.81
D42-L250- α15-CP125-d16	1	0.50	36.94
D42-L250- α15-CP125-d18	1	0.50	34.66

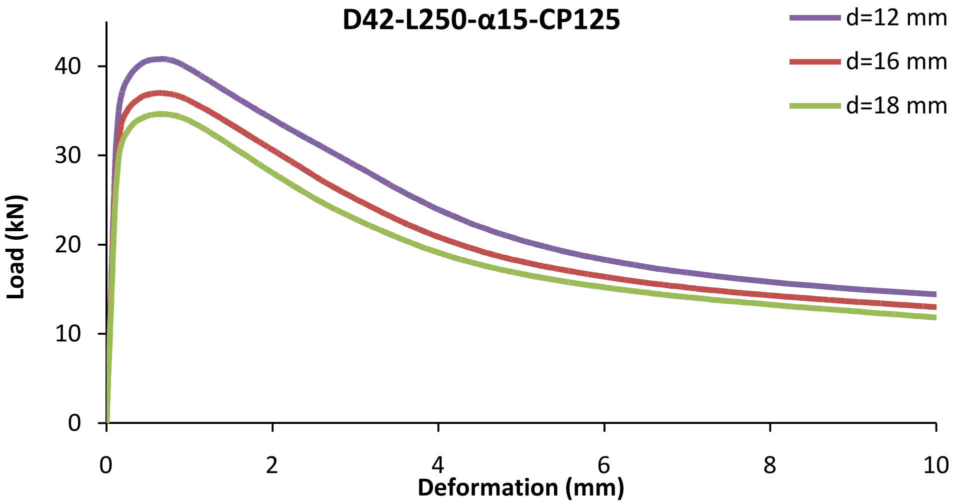
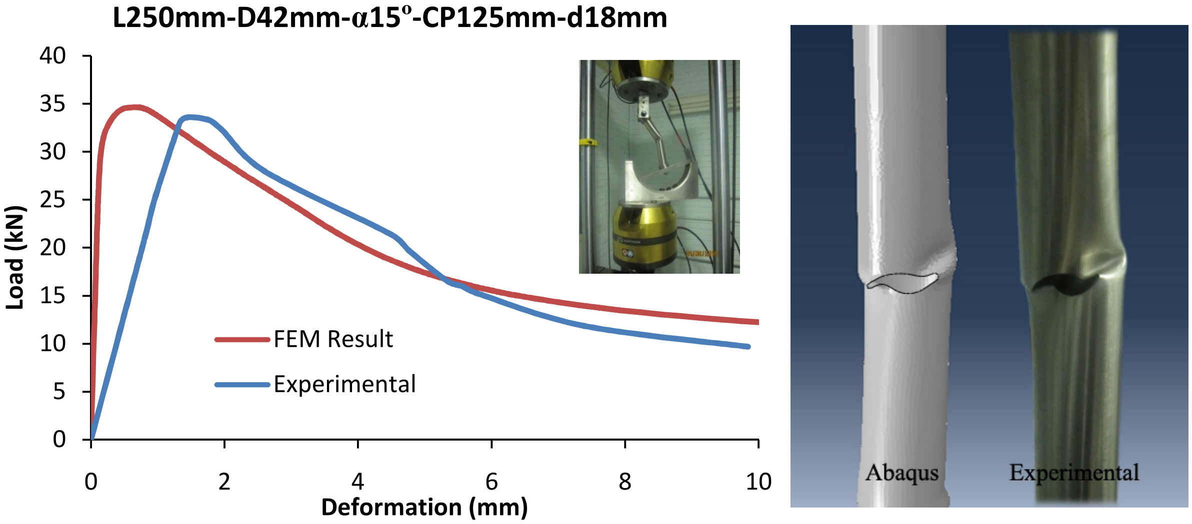


Figure-10
Buckling load versus deformation curves for cylindrical shells with various circular cutout sizes

Table-5
Comparisons of the experimental and numerical results

Model designation	Shell angle, α	Buckling load (Experimental) (kN)	Buckling load (FEM Result) (kN)	Error (%)
D42-L250-CP125-d18	15	33.44	34.66	3.6
D42-L250-CP125-d16	15	36.01	36.94	2.6
D42-L250-CP62.5-d18	15	34.11	34.97	2.5
D42-L250-CP125-d18	25	27.42	28.49	3.9



a) loading-deformation curves b) deformed shapes

Figure-11
Comparison of the experimental and numerical results for the specimen D42 mm-L250 mm-α15°-CP125 mm-d18 mm