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Effect of Boundary Conditions on the Behavior of Stiffened and Un-Stiffened Cylindrical Shells

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Abstract

The effect of boundary conditions is very important in the analysis of cylindrical shells, and is rarely studied in the literature due to its difficult experimental simulation. For large structures such as shell roofs, the type of boundary supports is among the major factors that can minimize the stresses and deflections. In this study, experimental and numerical investigations of the effect of different boundary supports for stiffened and un-stiffened cylindrical shells were conducted. Two different models of the stiffened and un-stiffened cylindrical shells with different boundary conditions, "pinned and with rigid diaphragms", were studied. It was shown that by using rigid diaphragms for cylindrical shells, the deflections are minimized by 80%, and by (45–50) % for the stiffened cylindrical shells. From the experimental investigations and the numerical results obtained, the efficiency of the proposed boundary support types for cylindrical shells is confirmed, which can result in economic benefits.

Keywords Cylindrical shell · Shell element · Stiffeners · Rigid diaphragms · Boundary supports

1 Introduction

The boundary conditions of shell structures have an important effect on the state of stresses and the values of displacements. The rigid clamping of the edges of shell structures induces bending stresses at least over a narrow zone near the boundaries, and also prevents the structure from undergoing extensional deformations. The analysis of cylindrical shells with different boundary conditions is infrequently studied in the literature; this is mostly due to experimental difficulties. This problem also exists in many marine, aerospace and automotive engineering applications. The three main approaches involved in structural identification of behavior are the theoretical analysis, numerical simulation, and experimental investigation.

In a classical research, Flügge (1934) derived a set of cylindrical shell equations which included bending terms up to the second order. He did not solve the problem in its most general form, but suggested a solution for a simply supported cylindrical shell, in the form of trigonometric functions which satisfied the boundary conditions. This is certainly the reason this approach is not feasible after the advent of high-speed digital computers. Although the method requires numerical computation, the results are exact in the same sense that the numerical solution to the transcendental frequency equation for a beam yields an exact solution. Another study published by Sobel (1964) is on the closely related area of stability of cylindrical shells. The results of these two independent studies lead to the same conclusions regarding the importance of the various boundary conditions of cylindrical shells. Forsberg (1964) studied the influence of boundary conditions on the model characteristics of thin cylindrical shells; his research related to Flugge's and Sobel's studies, and his approach provides a powerful tool for examining a wide variety of boundary conditions and their influence on the modal behavior of

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cylindrical shells. The results of this study clearly indicate that care must be taken in any approximate analysis to use appropriate boundary conditions. An axisymmetric and an unsymmetrical analysis of conical and cylindrical shells with various boundary conditions were conducted by Wilkins et al. (1970). Chebili (1991) studied the problem of deformation of shells and found that the behavior is governed by both the geometry of the shell and its boundary supports. Skukis et al. (2013) studied the assessment of the effect of boundary conditions on cylindrical shell modal responses. In his study, a circular cylindrical shell employing arbitrary boundary conditions has been fabricated and physically tested, with several boundary conditions being used during the experimental setup. A numerical verification with the finite element code ANSYS has been performed in parallel in order to demonstrate the accuracy of the current solutions. Marchuk and Gnidash (2016) proposed two approaches for the analysis of the thick-walled cylindrical shells with different boundary conditions under local loads. It is shown that the effect of the boundary conditions on the stress–strain state is very weak for shells of high curvature and strong for shells of low curvature.

The present research is focusing on an assessment of boundary conditions and edge beam effects on the vertical and horizontal displacement of cylindrical shells. For this purpose; five semi cylindrical shell models with diameters of 32 cm are fabricated from stainless steel 304 grade, two of them with stiffeners. The deflection measurements have been performed by means of 50-C9842 ADVANTEST 9. Two different boundary conditions were used during the experimental investigation: Pinned at four points and fixed by two rigid diaphragms. The numerical analysis is performed by a flat shell finite element called "ACM-RSBE5" developed by Hamadi et al. (2015) and the "S4R, C3D8IH" developed by ABAQUS (2014). The modal characteristics and the vertical displacements are evaluated and the effect of various boundary conditions is discussed.

2 Analysis Approach

2.1 Geometry and Mechanical Properties of the Cylindrical Shell Models

The specimens have been produced by rolling of thin stainless steel sheet of 304 grade (t = 1.2 mm), to form the semi cylindrical shell structure. Five semi cylindrical models were used, two with stiffeners, one with stiffeners reposed on edge beams and two without stiffeners. Two different boundary conditions were considered; the first reposed on 4 points "pinned", and the second reposed on two rigid diaphragms "fixed". We proposed that the rigid diaphragms be welded to the semi cylinder to facilitate the experimental work. The dimensions of the semi cylinder are; the diameter is D = 320 mm and the length L = 900 mm, the thickness is the same for all specimens, the material properties are: the Young's modulus E = 190,000 N/mm^2, and the Poisson ratio $\nu = 0.265$. A concentrated load is applied at the center of the top of the shell for all models.

In this work, two types of stiffeners are used; ring stiffeners and stringers, both of them have the same material properties as the shell. Figure 1 shows the geometrical properties of the ring stiffeners and the stringers "edge beams". Figures 2a, b and 3 present the positioning of the stiffeners and edge beams on the cylindrical shell.

2.2 Finite Element Study

The numerical analyses have been performed by employing three finite elements, the first one is the called

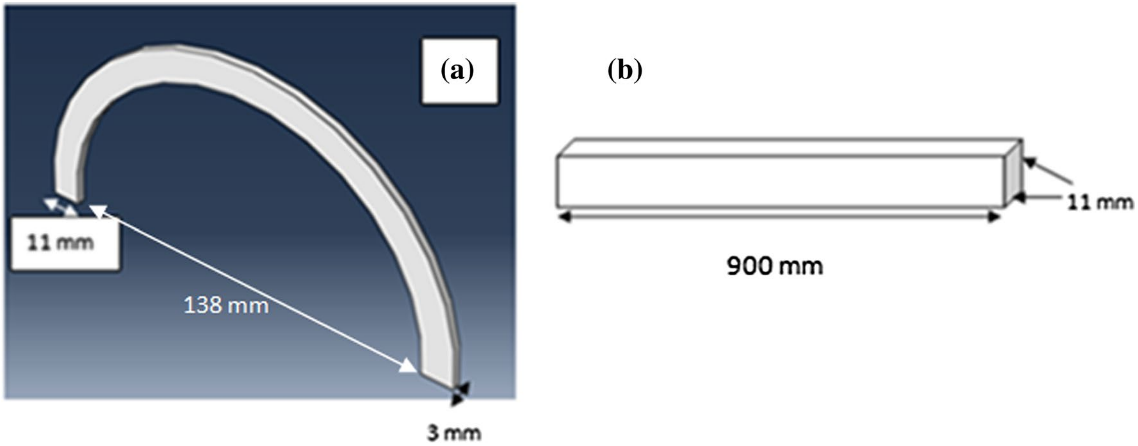


Fig. 1 Geometrical dimensions of the stiffeners. **a** Ring stiffeners. **b** Stringers "Edge beam"

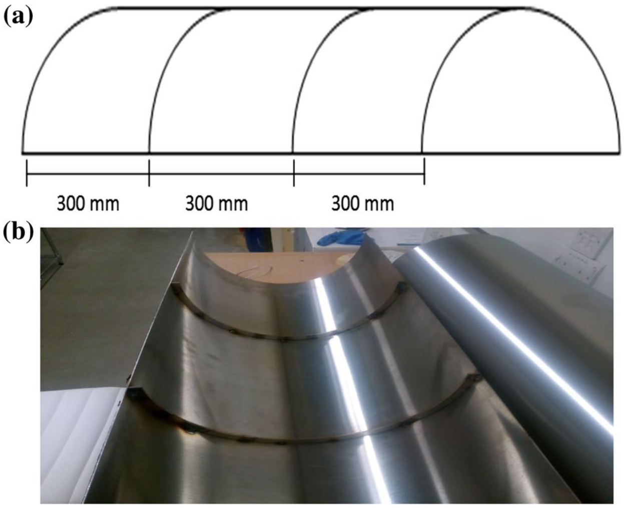


Fig. 2 Positioning of the stiffeners at the cylinder (**a**, **b**)

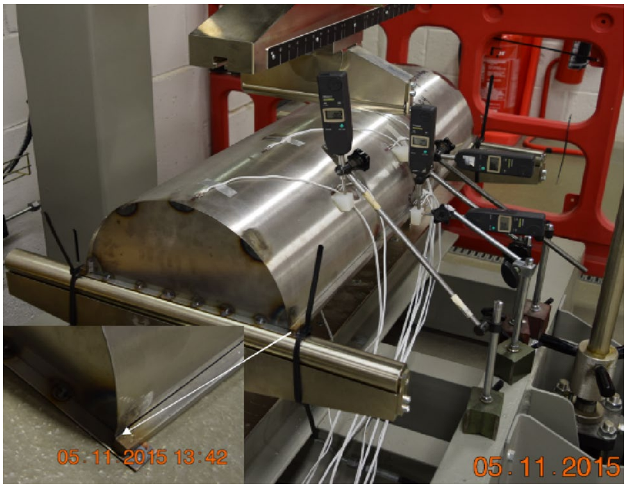


Fig. 3 Positioning of edge beams on the cylindrical shell

"ACM-RSBE5" element, and the two other elements are: the S4R and C3D8IH elements of the commercial ABAQUS code. Figure 4 presents the meshing for the finite element model used (45 × 25 elements).

2.2.1 Description of "ACM-RSBE5" Element

The ACM-RSBE5 is a rectangular flat shell element, obtained by the superposition of the RSBE5 membrane strain-based finite element with the ACM standard plate bending element originally developed by Adini and Clough (1961) and Melosh (1963). The shell element obtained ACM_RSBE5 is composed by assembling the two elements RSBE5 and ACM with an effective rotation z (see Fig. 5).

The stiffness matrix of the shell element ACM-RSBE5 is obtained by using the analytical integration of the membrane and bending stiffness matrix. The calculation of the element stiffness matrix is summarized with the following well known expressions:

$$\left[K_e\right] = \left[A^{-1}\right]^T \left[\iint_S [Q]^T [D] [Q] \, dx \, dy \right] \left[A^{-1}\right] \tag{1}$$

$$\left[K_e\right] = \left[A^{-1}\right]^T \left[K_0\right] \left[A^{-1}\right] \tag{2}$$

$$\left[K_0\right] = \iint_{\mathrm{S}} [Q]^{\mathrm{T}} [D] [Q] \, dxdy \tag{3}$$

where (D) the constitutive matrix, (A) the transformation matrix, (Q) the strain matrix, and (K_e) is the elementary stiffness matrix.

2.2.2 Description of S4R ABAQUS Element

The S4R is a 4-node doubly curved element used for thin and thick shells. It has 6 DOF at each node, and its stiffness matrix is calculated using a reduced integration and hourglass control.

2.2.3 Description of C3D8IH ABAQUS Element

The C3D8IH element is a general purpose linear brick element, with full integration points, hybrid formulation and incompatible modes. The node numbering follows the convention as shown in (Fig. 6).

2.3 Experimental Tests

The main purpose of this experimental investigation is to study the efficiency of boundary conditions, stiffeners and edge beams, on the cylindrical shells. To carry this investigation, two experimental models are carried out. For the first one; two semi cylinder models with different boundary conditions are considered; pinned and fixed supports; and for the second one, two models; stiffened semi cylindrical shells with different boundary conditions, pinned and fixed are investigated. Figure 7 presents the UNIFLEX 300 machine and the shell model setup, and also presents the positioning of dial gauges. Figure 8a, b present the different boundary conditions used, and Fig. 9 shows the positioning of the stiffeners. Figure 10 presents the stiffened cylindrical shell reposed on rigid diaphragm and edge beams.

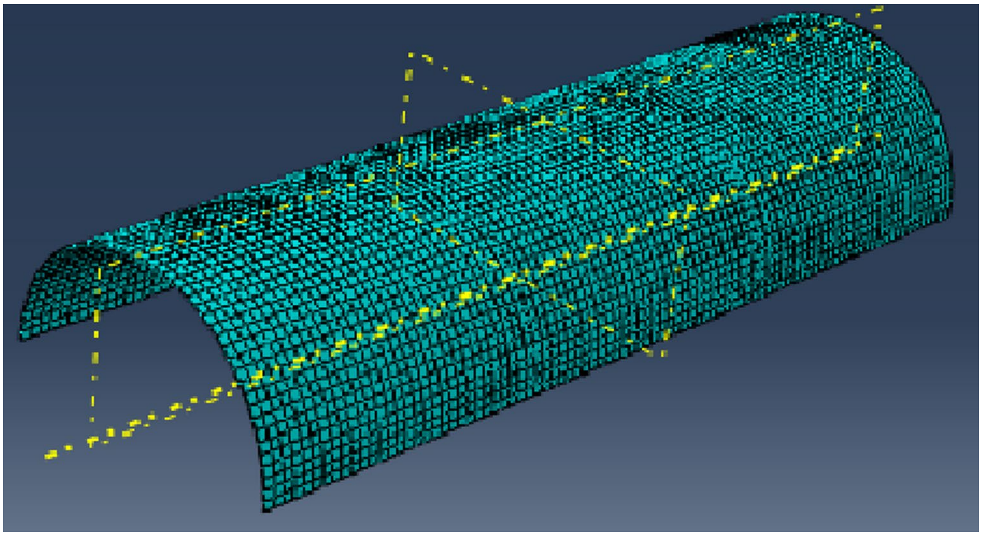


Fig. 4 Finite element mesh

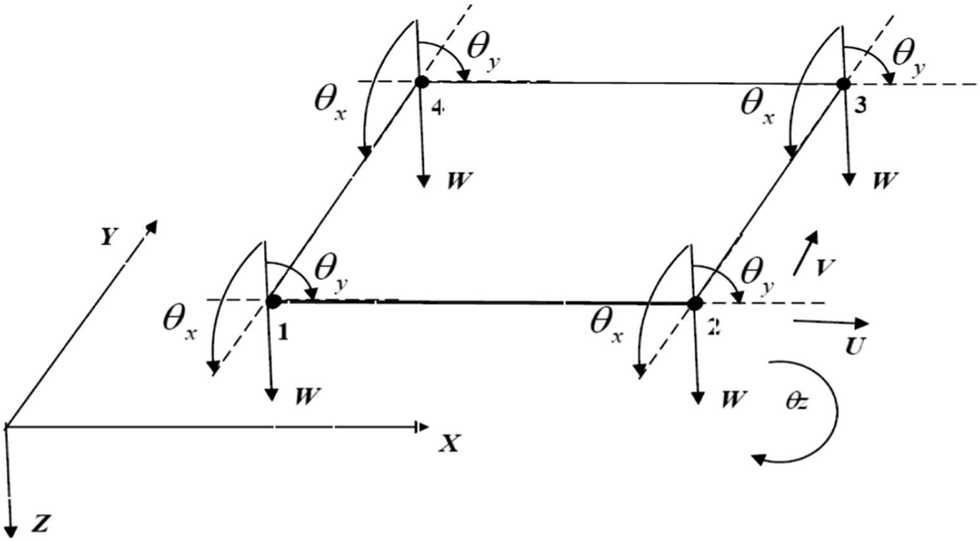


Fig. 5 The shell element ACM-RSBE5

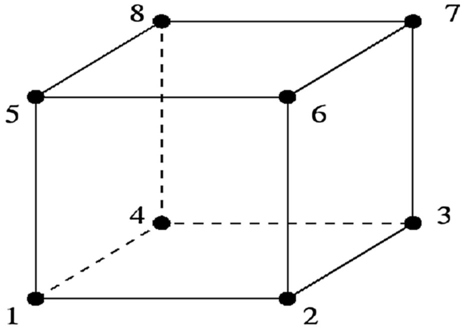


Fig. 6 8-Node brick element

We choose three points 1, 2 and 3 to record the displacement; which is given by the apparatus ADVANTEST 9 and the dial gauges (Fig. 11). The point of applied load is the top of the semi cylinder, as illustrated in Fig. 7; it is the same point where the deflection is recorded. The applied load is a concentrated static load for all tests. The structure is controlled by a vertical rod hydraulically clamped and controlled assuring high rigidity, fitted with high precision load cells for accurate and reliable test results. The tests were conducted under control of displacements performed with the ADVANTEST 9 (servo-hydraulic control console).

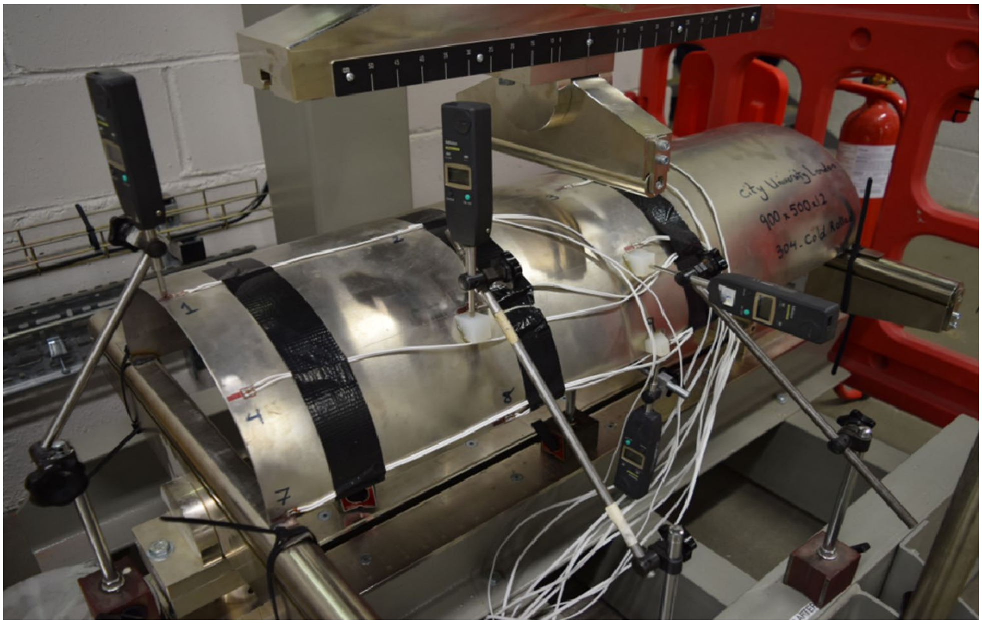


Fig. 7 The shell model setup

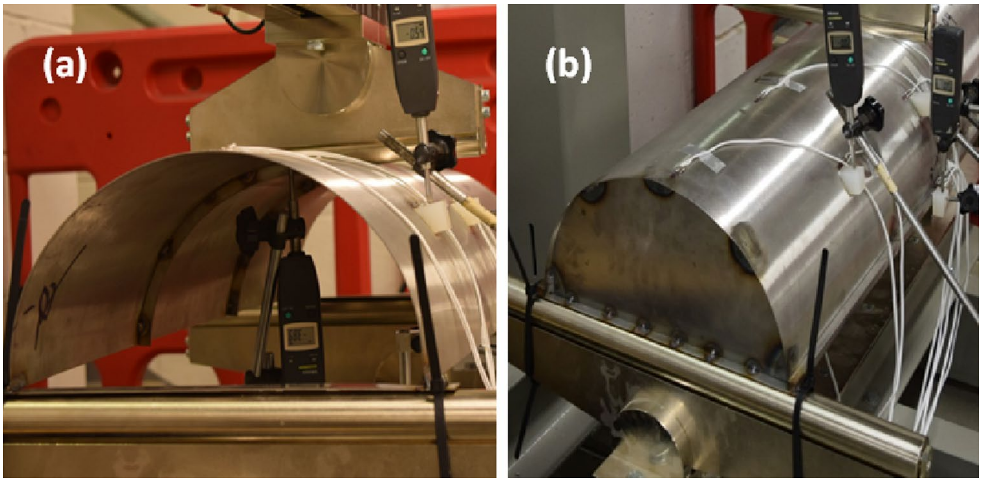


Fig. 8 **a** Cylindrical shell reposed on four points "pinned". **b** Cylindrical shell reposed on rigid diaphragm "fixed"

3 Effect of Boundary Conditions on the Behavior of Cylindrical Shells

For the study of the effectiveness of boundary conditions, two types of semi cylindrical shells with different boundary conditions are considered:

- Cylindrical shell supported on 4 points "pinned" CS4P.
- Cylindrical shell supported on two ends "Rigid Diaphragms" CSRD.

In this comparison, the following loads are applied (775 N, 800 N, 825 N, 850 N, 875 N and 900 N). Table 1 shows the results obtained from the experimental test, as well as the flat shell element ACM-RSBE5 and ABAQUS code with meshes of 10 × 10 elements. The results indicate that the finite element models slightly under-predicted the displacements at higher load levels. This can be attributed to the settlement of the test setup observed in the experiment.

The results obtained for the cylindrical shell model supported on two ends "Rigid Diaphragms" are presented in Table 1. In this case the finite element model slightly over-predicted the displacements since it assumed a fully rigid

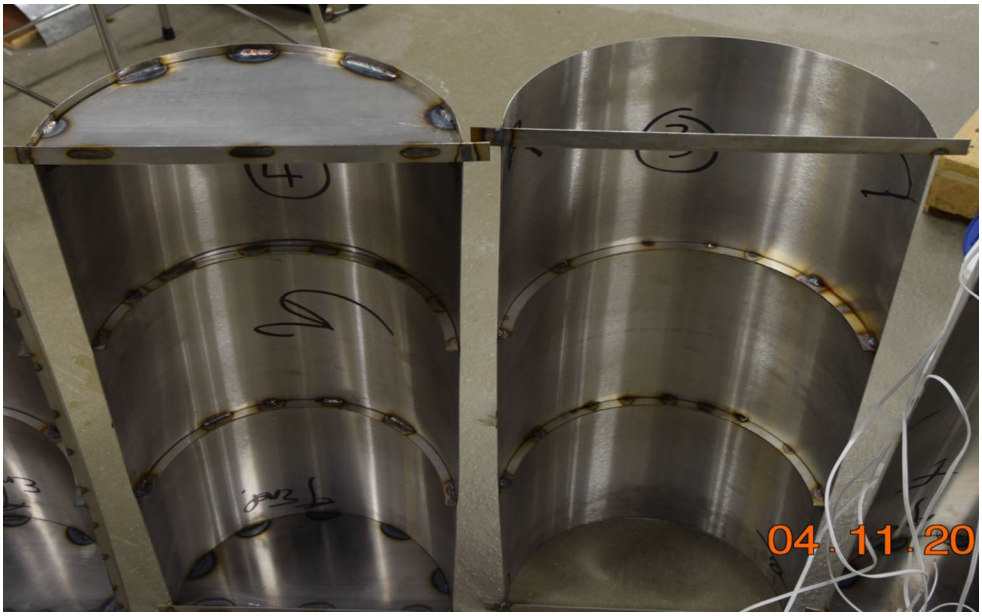


Fig. 9 Positioning of the stiffeners

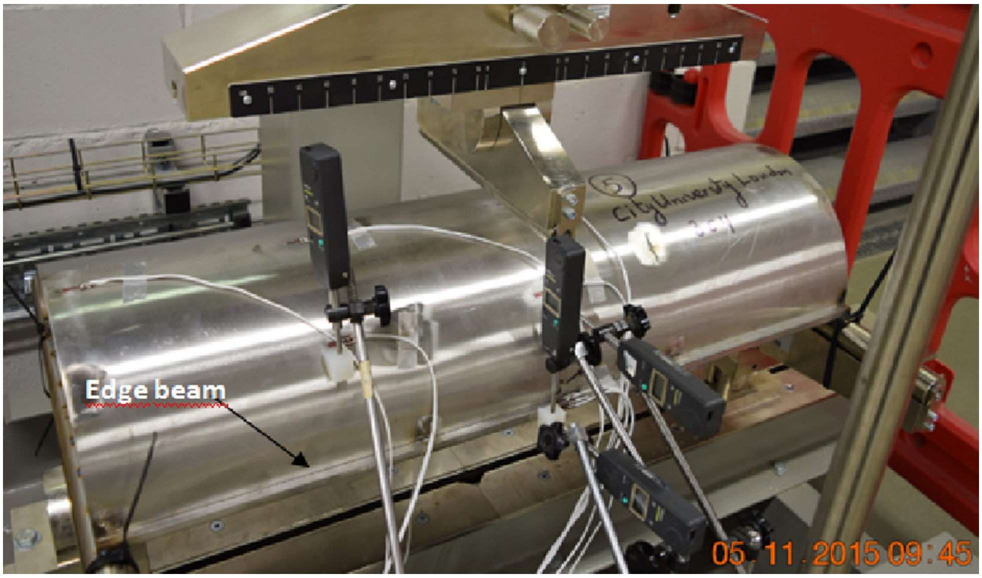


Fig. 10 Positioning of the edge beams

behavior for the end diaphragm, while a small level of deformations was observed in the tests.

3.1 Comparison of Deflection Results Between CS4P and CSRD Using ACM-RSBE5 Element, ABAQUS Code and Experimental Results

The vertical displacements at the top of the cylindrical shell models with no end diaphragms and the cylindrical shell with end Rigid Diaphragms with different loadings, and the percentage of reduction of the deflection by using ACM-RSBE5 element, ABAQUS element and the experimental results are also presented in Table 1.

Table 1 shows that the deflection diminution percentage observed from the experimental results in the presence of the rigid diaphragm and is almost 68%; that means that the rigid diaphragm minimized the vertical displacement at point 1 by 68%, which is an excellent contribution.

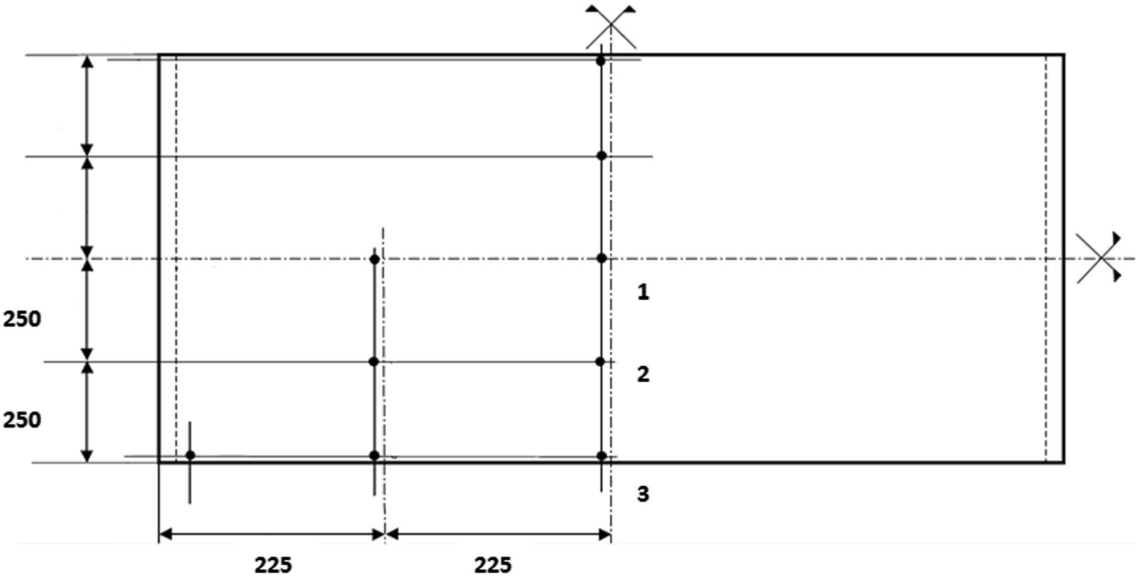
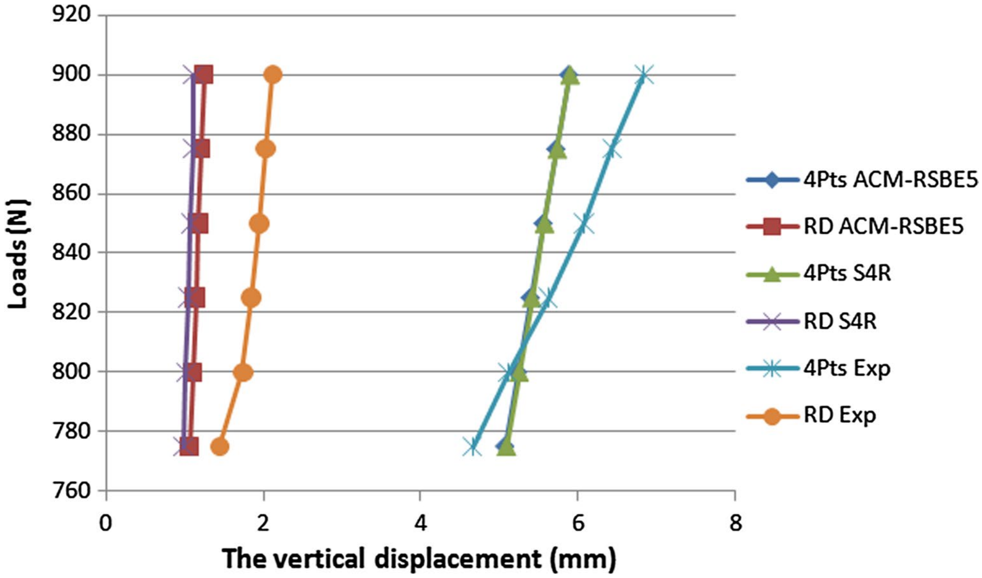


Fig. 11 Location of the points 1, 2 and 3

Table 1 The deflection diminution percentage using ACM-RSBE5 element, ABAQUS element and the experimental results for the CS4P and CSRD at Point 1

Load (N)	ACM-RSBE5			S4R ABAQUS			Experimental solution		
	Deflection (mm)		Percentage (%)	Deflection (mm)		Percentage (%)	Deflection (mm)		Percentage (%)
	CS4P	CSRD		CS4P	CSRD		CS4P	CSRD	
775	5.061	1.064	78.97649	5.08	1.087	80.7165358	4.649	1.438	69.06862
800	5.224	1.098	78.981623	5.241	1.122	80.70979	5.098	1.727	66.12397
825	5.387	1.133	78.96789	5.403	1.157	80.69591	5.606	1.831	67.338566
850	5.551	1.167	78.976761	5.564	1.192	80.69734	6.060	1.936	68.052805
875	5.714	1.201	78.981449	5.726	1.227	80.684597	6.422	2.013	68.654625
900	5.877	1.236	78.96886	5.888	1.262	0.216033	6.822	2.103	69.173263

Fig. 12 The comparison of deflections for the cylindrical shell models with different boundary conditions (experimental and numerical results)



The deflection diminution percentage is almost 80% according to both the ACM-RSBE5 and ABAQUS results, indicating both models resulted in reasonable simulation of the behavior.

Figure 12 presents the analytical and experimental load–displacement curves for the cylindrical shell model reposed on 4 points and the cylindrical shell model reposed on two rigid diaphragms. For the deflection of the cylinder reposed on 4 points, the finite element results obtained with ACM-RSBE5 and S4R elements are very close. These results present a good agreement between the ACM_RSBE5 element, S4R element and those from the experimental tests. Also, for the cylinder model with end rigid diaphragm, the results obtained with both finite element models mentioned above are close to the experimental one. In Fig. 12, it can be observed that the diminutions of deflections using the rigid diaphragm are as follow: 68% for the experimental results, 79% for the ACM-RSBE5 finite element model and 80% for the ABAQUS model.

For the cylindrical shell model supported on four points, the load applied at the top of the cylinder spreads out on the skin and goes towards the supports “4 points”; but for the cylindrical shell supported by the rigid diaphragms, the load goes from the skin to the curved boundaries of the cylinder then to the rigid diaphragms reducing the vertical displacements.

4 Effectiveness of Boundary Conditions Supports on the “Cylindrical Shell with Stiffeners”

For the study of the effectiveness of rigid diaphragms on cylindrical shell structures with stiffeners, especially for deflections, experimental tests were performed on two models and the percentage of the vertical displacements between the stiffened cylindrical shell models reposed on four points “pinned” SCS4P and the stiffened cylindrical shell supported on two ends by Rigid Diaphragms SCSRD are compared.

4.1 Comparison of Deflection Results Between SCS4P and SCSRD Using Experimental and ABAQUS Analysis Results

The following values of the loads (900 N, 950 N, 1000 N, 1050 N and 1100 N) are applied separately to the stiffened cylindrical shell reposed on four points and the stiffened cylindrical shell with end Rigid Diaphragms, the displacements results are computed and recorded in Table 2. Table 2 presents the vertical displacement at point 3 (Experimental and numerical results) for the stiffened cylindrical shell reposed on 4 points “pinned” SCS4P and the stiffened cylindrical shell supported on Rigid Diaphragms SCSRD with different loadings.

4.2 Comparison of Deflection Diminution Between “SCS4P” and “SCSRD” Models with ABAQUS Analysis

The percentage of deflection reduction for cylindrical shell models “SCS4P” and “SCSRD”, from both the experimental and ABAQUS results are presented in Table 2.

From Table 2, the percentage of deflection diminution according to the experimental results ranges between 40 and 50%. So, the use of a rigid diaphragm on the stiffened cylindrical shell minimized the vertical displacement at the top by around 45%, representing an excellent contribution.

From Table 2, the percentage of deflection diminution according to the ABAQUS results is almost 45% indicating that the finite element model produced satisfactory results.

Figure 13 presents the difference of deflection between the stiffened cylindrical shell model reposed on 4 points and the stiffened cylindrical shell reposed on two end rigid diaphragms, for both the numerical and experimental results. For the deflection of the stiffened cylinder reposed on 4 points, the finite element model C3D8IH presents a good correlation to the experimental results.

Also, from Fig. 12, it can be seen that the diminution of deflection using the rigid diaphragm is between 40 and 50% for the experimental results and 44% for the ABAQUS model. The changing of boundary supports from the pinned

Table 2 The deflection diminution percentage using ABAQUS element and the experimental results for the SCS4P and SCSRD at point 3

Load (N)	S4R ABAQUS			Experimental solution		
	Vertical displacement (mm)		Percentage (%)	Vertical displacement (mm)		Percentage (%)
	SCS4P	SCSRD		SCS4P	SCSRD	
900	2.595	1.447	44.238921	3.453	1.591	53.924124
950	2.737	1.527	44.208988	3.529	1.755	50.269198
1000	2.991	1.607	46.27215	3.806	1.607	57.777194
1050	3.023	1.688	44.161429	3.829	2.138	44.162967
1100	3.165	1.768	44.139021	3.966	2.355	40.620272

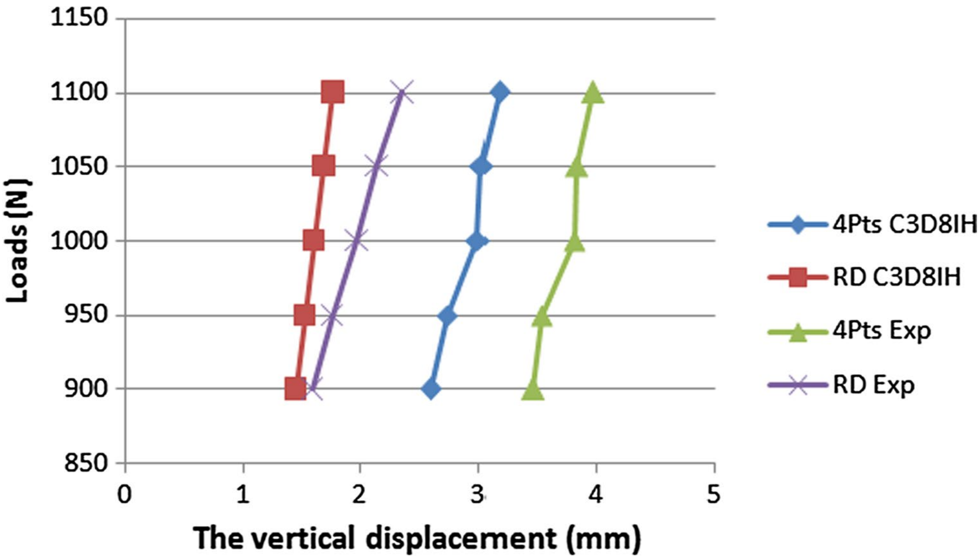


Fig. 13 The comparison of deflections for the stiffened cylindrical shell models with different boundary conditions (experimental and numerical results)

Table 3 The vertical displacement W_1 at point 1 (experimental and ABAQUS results with meshes of 45×25) for the *Cylindrical shell with two end diaphragms and two stiffeners "SCD"*

Loads (N)	Displacement W_1 at point 1 (mm)	
	Experimental solution	C3D8IH ABAQUS
800	1.229	1.286
850	1.398	1.366
900	1.591	1.447
950	1.795	1.527
1000	1.966	1.607
1050	2.138	1.688

conditions to the rigid diaphragm reduces the vertical displacement of the stiffened cylindrical shell by about 40%. In this case, by using ring stiffeners, the load is distributed from the skin to the stiffeners resulting in smaller deformations. The load is then transferred equally to the four supports. As a comparison, the stiffeners reduce the vertical displacement by about 70%, and the addition of the rigid diaphragm reduces the vertical displacement by about 40%. This is considered an excellent diminution to the deflection, and represents a great solution to improve the performance of the structure.

5 Effectiveness of Edge Beams on the Stiffened Cylindrical Shells

For the study of the effectiveness of the edge beams on the stiffened cylindrical shells; two semi cylindrical shells with rigid diaphragm are considered:

Table 4 The vertical displacement W_1 at point 1 (experimental and ABAQUS results with meshes of 45×25) for the *Cylindrical shell with two end diaphragms and two stiffeners resting on longitudinal beams "stringers" SCDS*

Loads (N)	Displacement W_1 at point 1 (mm)	
	Experimental solution	C3D8IH ABAQUS
800	0.883	1.280
850	0.958	1.360
900	1.043	1.440
950	1.143	1.520
1000	1.229	1.600
1050	1.482	1.681
1100	1.686	1.761
1150	1.913	1.841
1200	2.162	1.921
1250	2.469	2.001
1300	2.722	2.081

- Stiffened cylindrical shell supported on two ends "Rigid Diaphragms" "SCD".
- Stiffened cylindrical shell supported on two ends "Rigid Diaphragms" with two edge beams (Stringers) "SCDS".

In this comparison the same procedure as the previous one is followed. The vertical displacements are recorded at point 1 and the horizontal displacement at points 2 and 3. Tables 3 and 4 present the vertical displacements at the top of the model obtained by ABAQUS and experimental results for (SCD) and (SCDS). Table 5 presents the

Table 5 Percentage of vertical displacements diminution with experimental results for the SCD and SCDS, at point 1

Load (N)	Displacement for the SCD (mm)	Displacement for the SCDS (mm)	Diminution percentage (%)
800	1.229	0.883	28.15
850	1.398	0.958	31.47
900	1.591	1.043	34.44
950	1.795	1.143	36.32
1000	1.966	1.229	37.49
1050	2.138	1.482	30.68
1100	2.355	1.686	28.41
1150	2.575	1.913	25.71
1200	2.851	2.162	24.17
1250	3.146	2.469	21.52
1300	3.378	2.722	19.42

percentage of diminution of the vertical displacements at point 1 using the experimental and ABAQUS results for the SCD and SCDS.

5.1 Cylindrical Shell with Two end Diaphragms and Two Stiffeners (t = 1.2 mm)

Table 3 presents the vertical displacement W_1 at point 1 (Experimental and ABAQUS results with meshes of 45×25).

5.2 Cylindrical Shell with Two end Diaphragms and Two Stiffeners Resting on Longitudinal Beams "Stringers" (t = 1.2 mm)

Table 4 presents the vertical displacement W_1 at point 1 (Experimental and ABAQUS results with meshes of 45×25).

5.3 Percentage of Vertical Deflection Diminution Between "SCD" and "SCDS" Models with Experimental Results and Numerical Analysis

Table 5 presents the percentage of vertical displacements diminution from the experimental results for the SCD and SCDS, at point 1.

For the experimental results shown in Table 5, the effect of longitudinal beams "Stringers" added to the cylindrical shell with two end diaphragms and two stiffeners is very high; the vertical displacement reduction is about 20–38%.

Table 6 Percentage of horizontal displacements diminution with experimental results for the SCD and SCDS, at point 2

Load (N)	Displacement for the SCD (mm)	Displacement for the SCDS (mm)	Diminution percentage (%)
1000	0.24	0.09	91.67
1100	0.28	0.109	85.71
1200	0.33	0.119	75.76
1300	0.39	0.129	66.67
1400	0.47	0.139	59.57

Table 7 Percentage of horizontal displacements diminution with ABAQUS results for the SCD and SCDS, at point 2

Load (N)	Displacement for the SCD (mm)	Displacement for the SCDS (mm)	Diminution percentage (%)
1000	0.147	0.09	38.77
1100	0.162	0.109	32.72
1200	0.177	0.119	32.77
1300	0.192	0.129	32.81
1400	0.207	0.139	32.85

Table 8 Percentage of horizontal displacements diminution with experimental results for the SCD and SCDS, at point 3

Load (N)	Displacement for the SCD (mm)	Displacement for the SCDS (mm)	Diminution percentage (%)
1000	0.47	0.21	55.32
1100	0.57	0.29	49.12
1200	0.70	0.39	44.29
1300	0.85	0.52	38.82
1400	1.03	0.67	34.95
1500	1.25	0.87	30.40

5.4 Percentage of Horizontal Displacements Diminution at Point 2 Using the Experimental and Numerical Results

Tables 6 and 7 present the percentage of horizontal displacements diminution at point 2 using the experimental and ABAQUS results for the SCD and SCDS.

From the results obtained in Table 6, the percentage of horizontal displacements diminution at point 2 varied between 59 and 91%; so the longitudinal beams presented a good contribution to the behavior in this case. Meanwhile; the percentage obtained by ABAQUS element is almost stable at 32% for all applied loads.

Table 9 Percentage of horizontal displacements diminution with ABAQUS results for the SCD and SCDS, at point 3

Load (N)	Displacement for the SCD (mm)	Displacement for the SCDS (mm)	Diminution percentage (%)
1000	0.651	0.394	39.48
1100	0.717	0.434	39.47
1200	0.783	0.475	39.34
1300	0.848	0.515	39.27
1400	0.914	0.555	39.28
1500	0.980	0.596	39.18

5.5 Percentage of Horizontal Displacements Diminution at Point 3 Using the Experimental and Numerical Results

Tables 8 and 9 present the percentage of horizontal displacements diminution at point 3 using the experimental and numerical results, for the SCD model and SCDS model.

The same previous comments for point 2 can be given for the diminution of horizontal displacement for point 3 (Tables 8, 9), and the average is around 40% for both numerical and experimental results in the presence of longitudinal beams "Stringers".

These results confirm that a very good diminution of the horizontal displacements, especially at points 2 and 3, is observed. In this case, when the load is applied at the top of the cylinder, the stringers obstruct the tendency of the straight borders to deform reducing the horizontal displacements.

6 Conclusions

From the results obtained by the experimental investigation and numerical analysis presented above, the following points can be drawn:

For all tests done and presented above, acceptable results are obtained for the numerical analysis in comparison the experimental work.

1. A significant effect on deflections can be obtained by the Rigid Diaphragms; the percentage of displacement reduction is close to 68% from the experimental observations, and 80% from the ACM-RSBE5 element and the ABAQUS code. That means the vertical displacement at the top of cylinder "the point of applied the load" is minimized by 68% when using the Rigid Diaphragms. So a high percentage of deflection reduction can be achieved with Rigid Diaphragms. This is due to the fact that when using rigid diaphragms, the effect goes from the skin to the curved boundaries of the cylinder then to the rigid diaphragms. So, the cylinder with rigid diaphragms can support much higher loads with smaller deformations.
2. The same previous comment can be concluded for the stiffened cylindrical shell supported on 4 points and the stiffened cylindrical shell model with two end Rigid Diaphragms; good results can be obtained when using Rigid Diaphragms, the percentage of deflection reduction is close to 50% from the experimental results and 45% from the ABAQUS analysis. That means that the rigid diaphragms minimized the deflection to the half. In this case, by using ring stiffeners, the load pressure is distributed from the skin to the stiffeners resulting in smaller deformations. The load is then transferred equally to the four supports.
3. The stiffeners have an important effect on the deflection of cylindrical shell structures; but the efficiency of boundary conditions is more significant than the stiffeners, especially for the locations of stiffeners adopted in the experimental tests presented in this work.
4. Both rigid diaphragms and stiffeners play an important role in minimizing the deflections of shell structures; that means their presence can result in good design and reduce the economic cost of the structure.
5. The effectiveness of edge beams is very important as concluded from the experiment. The reduction is about 20–38% for the vertical displacement of point 1, varied between 59 and 91% for the horizontal displacements of point 2, and is 40% for the horizontal displacement at point 3. When using stringers, they obstruct the tendency of the straight borders to deform reducing the horizontal displacements.
6. The numerical modeling approach used in this work proves its efficiency compared to the experimental results for the case of cylindrical shells with and without stiffeners.

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