Nonlinear analysis of cylindrical shells with reinforced ring under hydrostatic pressure

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Abstract: Cylindrical shells are widely used in science and Mechanical Engineering. Due to the small thickness, the stability of the shell against compressive loads is a major concern. To achieve appropriate axial and bending stiffness, and also to prevent premature buckling, generally longitudinal stiffening ring are used. In this paper, the effect of ring enhancement on enhanced nonlinear behavior of cylindrical shells under hydrostatic pressure is investigated. Several types of reinforcement, including reinforcement uniform exterior, interior, and reinforced with uniform linear height distribution have been studied. There was so much pressure on the buckling strength of the shell with a significant increase and in this regard, the strengthening of the linear distribution of height slightly greater increase in pressure created. The maximum displacements and stresses in the crust of the amplifier are reduced considerably. The positive effects would enhance by adding length to thickness ratio increases.
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1. Introduction

Cylindrical shells are widely used in Civil and Mechanical Science recipients, such as pipes, cylindrical tanks, silos, under pressure vessels, aircraft, etc. Since the thickness of the shell is often less, so the main concern is stability against compressive loads. To achieve appropriate axial and bending stiffness, and also to prevent premature buckling, generally longitudinal stiffening ring are used. In this paper, the effect of ring enhancement on enhanced nonlinear behavior of cylindrical shells under hydrostatic pressure is investigated. First, buckling of columns was solved by Euler. Cylindrical shells they are models as columns only if they were very long. Thus the theory of shell buckling analysis is commonly investigated. Several studies have investigated the elastic buckling of cylindrical shells. In this study, the load on the shell generally was under uniform and in some cases was under axial pressure. On the other hand, the shell buckling analysis of shells with no reinforcement would not easily enhance. In some previous studies, reinforced shell is equivalent to shell orthotropic are modeled. The results of this model, which is accurate only when the amplifier to be located close to each other at regular intervals [Penzes]. Many studies recently carried out after shell reinforced with longitudinal reinforcement ring. Many of these researches have been based on the theory of energy. For example, Nash & Kendrick approximate relations based on the theory of Rayleigh - Ritz for cylindrical shells with ring enhancement achieved. Later, verification obtained by the two experiments conducted was approved by Gallety et al. they found that the elastic analysis of a hard shell that have more buckling load (about 10 to 15 percent) than those outside of the shell. In addition to these researches, Wunderlich and colleagues analyzed with elastic and elasto - plastic ring stiffening effect on the behavior of cylindrical shells were investigated. Tian et al. found a relationship for elastic buckling of cylindrical shells with reinforced ring under uniform hydrostatic pressure which was linear. Xiang et al. also investigated buckling of the shells under axial loads.

However, most studies of cylindrical shell have been reinforced by elastic analysis. A few researches are done on the nonlinear behavior of cylindrical shells with ring enhancement. This paper investigates the numerical buckling of cylindrical shells with ring enhancement using ANSYS software. In this software, problem solving eigenvalues modal analysis using the elastic analysis is performed. In order to linear analysis confirmed by the validity of this model, such as the number of elements, boundary conditions, etc. was used. Then, a nonlinear model of a cylindrical steel shell will be made of the behavior of nonlinear material behavior is nonlinear due to large deformation. Nonlinear behavior of cylindrical shells reinforced with several types (external, internal, and line) are compared. Finally, a series of parametric studies to investigate the nonlinear behavior of cylindrical shells with ring enhancement was performed under hydrostatic pressure. It is noteworthy that three different reinforcement ring are modeled to be a more efficient form of reinforcing ring is specified.

2- Modeling and verification of models

One of the methods for modal and buckling analysis in ANSYS software is using the concepts of eigenvalues and eigenvectors.
General form of the eigenvalues of the equation is as follows:

(1) $\left([K]-\lambda_i[S]\right)\{\varphi_i\}=0$

Where, $[K]$ is stiffness matrix, $[S]$ is tension stiffness matrices, $\{\varphi_i\}$ is special vector and λ_i is eigenvalue of the structure. Eigenvalues of the above matrix equation occur for loads of indeterminate displacement. Linear buckling analysis and modeling process are described below. In this study, the linear regression model used only to confirm how the savings will be.

2-1- a chosen piece

In this research, piece of shell 181 was used to modeling. The average thickness of the shell 181 is suitable for the analysis of thin shells. his part of the figure, with 4 nodes and each node has six degrees of freedom that are moving in the direction of x, y, z and rotation around the axis. This material forms part of the resort property modeling capabilities for nonlinear problems with large deformation and rotation and is suitable for nonlinear problems can vary in thickness. This component can be used to model the shell layer or sandwich structures used and the theoretical analysis of these issues Myndlyn - Rayznr used. So consistency of C^0 is sufficient for the component. Elements of shell 181 can be replaced by elements shell 91, shell 93 and the shell 99 may be used. This component of the triangular lattice is not sufficiently accurate.

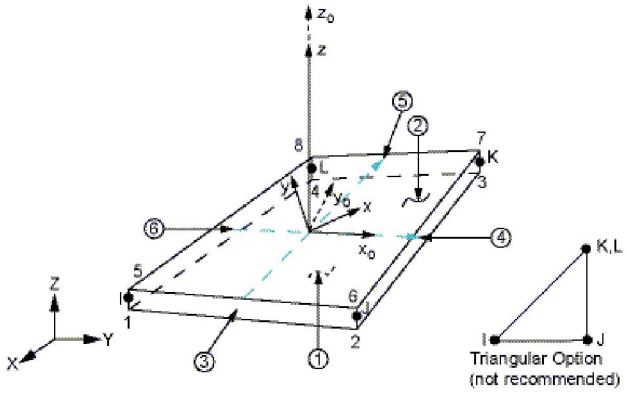

Figure 1 - The geometric shape of a crust Shell181

In Figure 2, the internal stress of the shell 181 is shown.

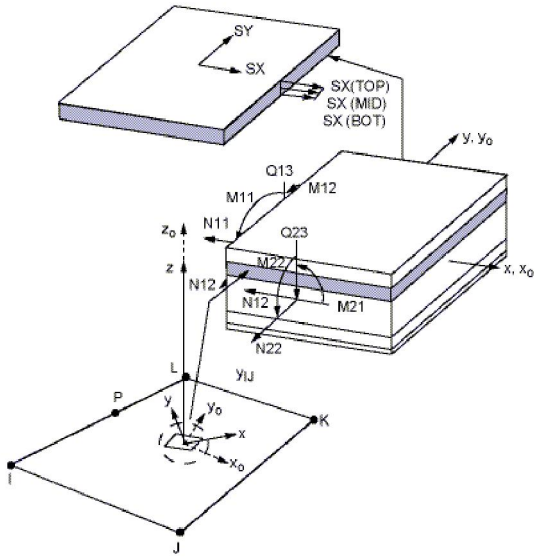

Figure 2 - Internal stresses the crust Shell 181

2-2 - Based model and model accuracy verification

In the first step, buckling analysis, modeling cylindrical shell is carried out. The shell is made of steel with mechanical properties which has shown in Figure 3. This figure is presented based on the results of experimental studies. The nonlinear analysis of the graph is preserved. The linear part of the stress - strain curve, elastic modulus $E=187.74GPa$, yield stress $\sigma_y=191.07MPa$ and Poisson's ratio $\nu=0.33$ is obtained. The strengthening of the ring model, several different samples taken from the strengthening of the name and the shape of this amplification is shown in Figure 4.

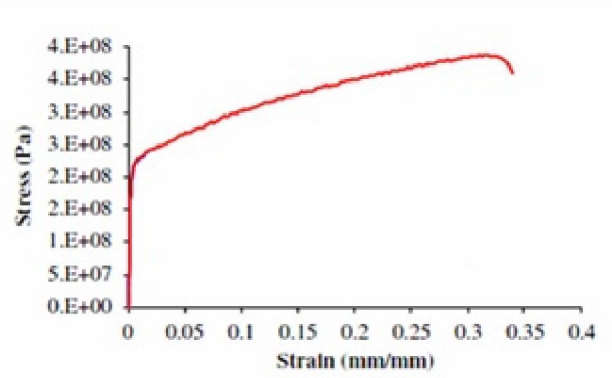

Figure 3 - stress - strain curve for steel models

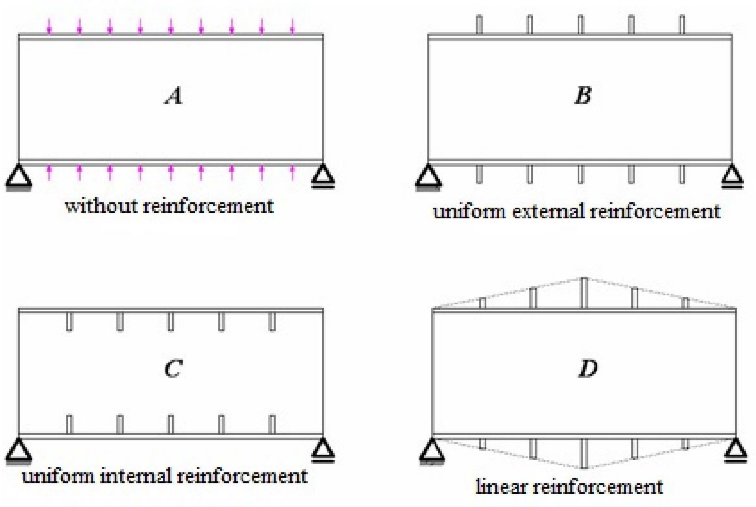

Figure 4 - Different shells analyzed

Assumed that the amount of materials used in the linear amplifier is fixed but the height is a linear amplifier instead of a uniform. Buckling behavior of the shell under uniform pressure is investigated. The body shell in order to verify the modeling results are compared with the analytical results presented in the following characteristics. The strengthening of uniformity that is primarily used in the table is presented.

Table 1 - reference cylindrical shell of geometric properties

Sample	mm (diameter)	mm (height)	mm (thickness)	R/t
Refrence-01	88	160	0.50	88
Specifications of primary strengthening				
Sample	mm (width)	mm (thickness)	mm (distance)	number
Refrence-02	3	1	20	7

The boundary conditions are simple. Which is defined as follows?

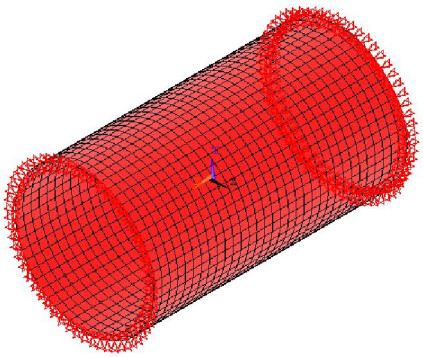

Figure 5 - Model of a cylindrical shell

End displacement along the axis of a free shell buckling is considered to be the model exists. The model is as Figure5。

The number of elements used in the analysis can be effective. Thus, by comparing the analytical results obtained for the minimum number of elements.

Preliminary results of the analysis based on linear scaling for comparison with analytical results will come. Comparison of the analytical equation using the von Mises theory is characterized by Windenborg & Trilling is used as follows: [9]

$$P_{cr} = \frac{2.42E(t/2a)^{5/2}}{(1-\nu^2)^{0.75}\left[(l/2a)-0.447(t/2a)^{1/2}\right]} \quad (2)$$

In this regard a,t,E,v,R,P_{cr} were: Critical buckling pressure, mean radius, Poisson's ratio, and modulus of elasticity, thickness and radius of the shell.

Using this relation for the number of elements that acceptable solutions are obtained. For example, Figure 6 displays difference between the theory responses to the environment instead of changing the number of elements. In order to have an appropriate response and to avoid adding unnecessary elements that will increase the computation, the number 56 elements were considered peripheral elements. The same trend has been for linear elements.

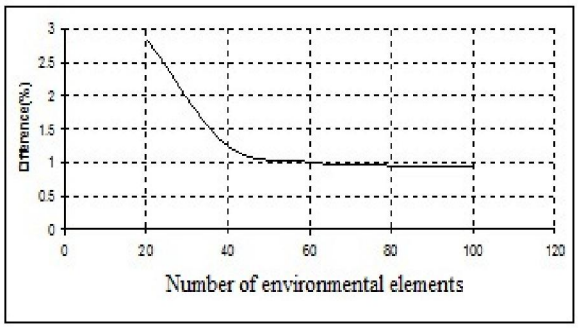

Figure 6 - Relationship between pressure and buckling model proposed changing the number of environmental elements

The linear model analysis was performed to verify the simulation results are compared with Equation 2 is confirmed. First buckling mode buckling of the shell reference comes in the form below:

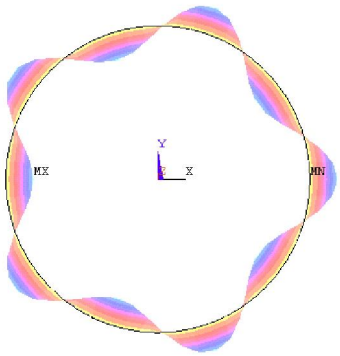

Figure 7 - Model of a cylindrical shell

Figure 8 shows the difference between the buckling pressure and related software to change these quantities L / R:

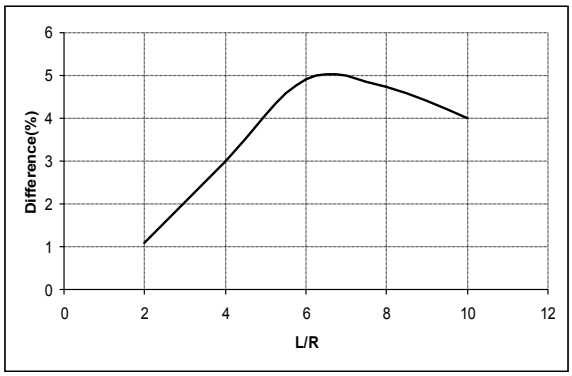

Figure 8 - Relationship between pressure and buckling model presented

It's observed that the model has good accuracy. The nonlinear analysis results will come for the shells.

3 - Non-linear buckling analysis

This kind of buckling analysis has capability of modeling the nonlinear behavior of structures including nonlinear behavior and large deformation and post-buckling behavior of the structure. This analysis is more accurate than linear analysis. This study is mainly made use of nonlinear analysis. In the nonlinear analysis, nonlinear material behavior and large deformation effects will be in order. Nonlinear buckling analysis of cylindrical shells with different stages as follows:

3-1 - modeling the nonlinear behavior

For modeling non-linear buckling of shells of the same section 2-1, the non-elastic properties also may be used. Stress - strain curve for steel used in Figure 3 is such that the material behavior is considered to be independent of time and the creep of waived. Due to the properties of the steel used in this study to model the elastic behavior of isotropic reliability advantage is hard. Iterative methods used to solve the problem. Newton - Rafsoon methods not converge in some cases in some areas. In this study, to overcome this problem and balance course in some parts of the arc length method is used. These methods are very effective for some crossing points and most recently for solving non-linear finite element programs are used. Nonlinear analysis of cylindrical shells, so increasing the amount of time given to specific structural stiffness matrix and thus there is no possibility of increasing load. At this stage, the analysis stops. Here we can draw a graph of the pressure - some buckling displacement pressure values are obtained.

3-2 - nonlinear analysis results

In this section, results of the nonlinear analysis models will represent. Therefore, nonlinear

analysis with reference to the shell without reinforcement is investigated. Again, the behavior of the nonlinear material and nonlinear behavior in this model is due to the large deformation. Other details of the model are described in the previous section. Strengthening of the shell ring that goes on nonlinear analysis results will be compared, as in Figure 4 and Table 1 is set according to their dimensions.

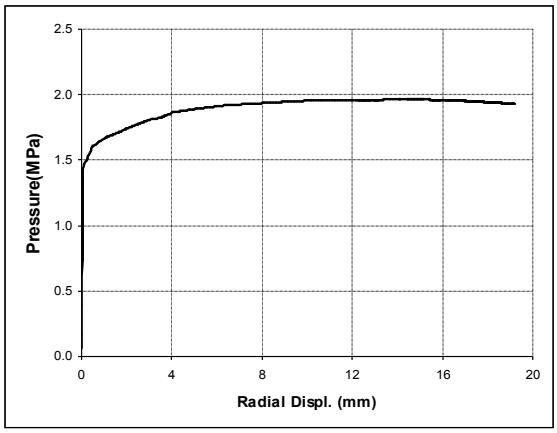

Figure 9 - Pressure - radial displacement chart of the shell without reinforcement

The figure suggests that the nonlinear analysis of buckling pressure of about 1/96 MPa is obtained. This value is significantly different from the value obtained from the linear analysis. However, after entering the shell indicates that the nonlinear behavior is respect for the shell displays inappropriate linear analysis.

Figure 10 shows contour plastic strain at the end of nonlinear analysis of shells without reinforcement. The maximum plastic strain is related to the central theme and therefore enhance type D in Figure 4 was chosen based on the largest ring in the middle of the shell should be strengthened.

Figure 11 shows the contour of the radial displacements of the shell and shows the locations of the maximum radial displacement which indicating the location and number of bands are formed during buckling.

Following the same theme, in Figure 12, the diagram for the vertical displacement of the center line of the shell, is shown. The same trend is changing with the changes in other variables.

Figure 5 shows the comparison between the cylindrical shells without reinforcing the exterior of the support of B, C, and D. Vertical and horizontal axes of the graphs, the values of the maximum values of the non-reinforced shell is divided and the figures are therefore dimensionless.

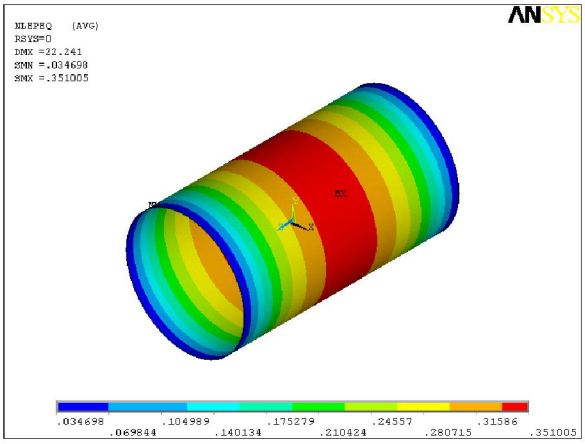

Figure 10 - Variation of plastic strain in the shell without reinforcement

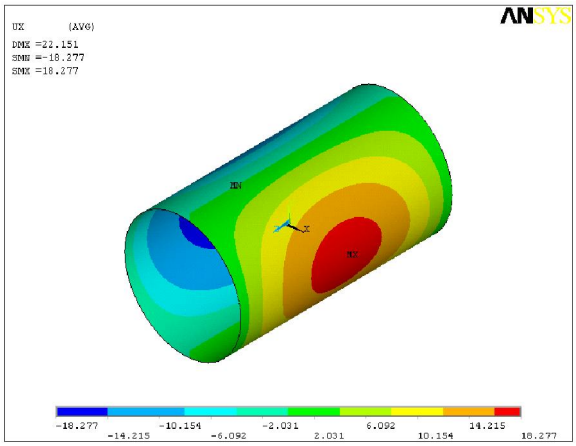

Figure 11 - The displacement of the shell without reinforcement

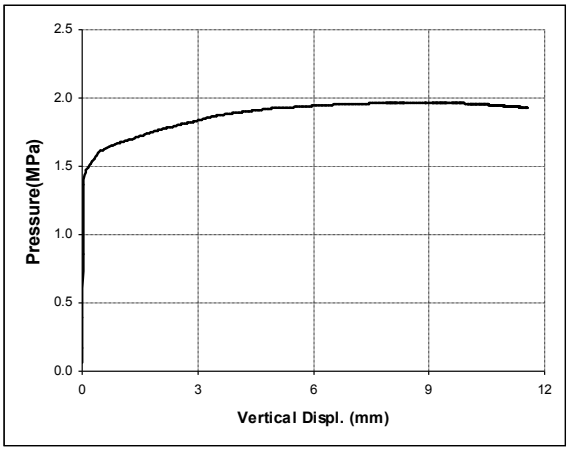

Figure 12 - Absolute vertical displacement at the center of the shell without reinforcement

Fallowing Figures show the radial displacement of the shell with reinforcing:

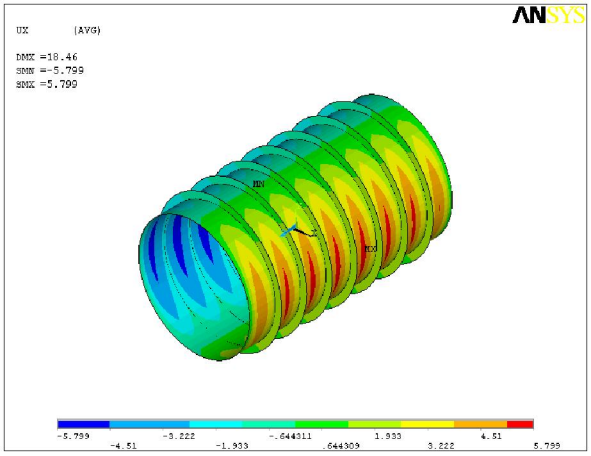

Figure 13 - The displacement of the shell with reinforcement type B

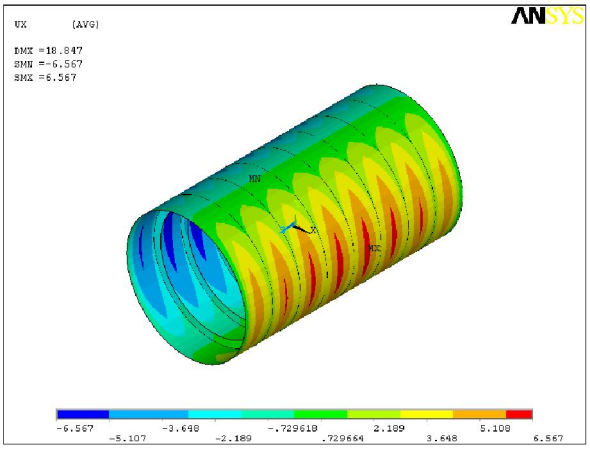

Figure 14 - Change the location of the shell with reinforcement type C

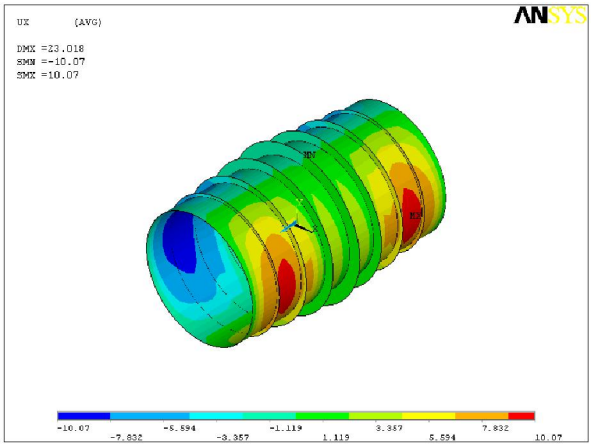

Figure 15 - Change the location of the shell with the support of D

It's obvious that the strength of type B, C which are distributed uniformly, the limit of the maximum shell reinforced areas vary in strength occurs. But the theme of strengthening primary D is weaker than the other two and is strengthened stronger middle. The difference contour displacement hull type D with B, C can be seen in the above forms can be interpreted this way. In general, it is observed that the maximum displacement of the shell with reinforcement changes compared with non-reinforced shell.

The following charts shows compare the degree of pressure, shifts and tensions between the four shells, Figure 5. The amounts in the form of a draft are shown below represent the maximum value of the corresponding shell type A (without reinforcement).

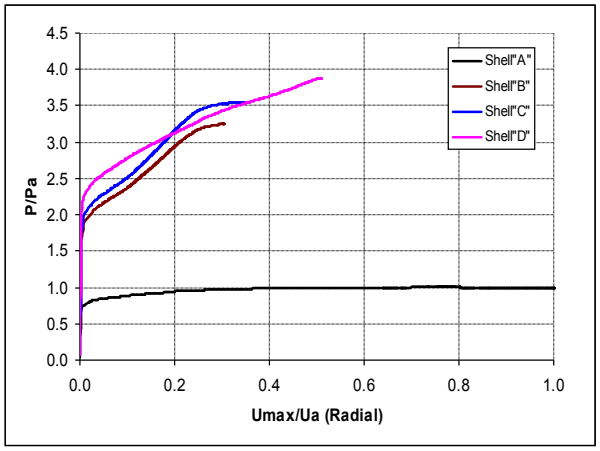

Figure 16 - Comparison of pressure - radial displacements of the 4 shells

In Figure 16, $U_{\max}, U_a$, the maximum radial displacement, radial displacement amplification and maximum shell without the shell is reinforced, respectively. Also P, P_a are buckling pressure of the shell without reinforcement, respectively (type A) to strengthen the shell buckling pressure (type B, C, D). This implies that the pressure ring shell have increased somewhat. In addition, the maximum radial displacement of the shell is reduced. For D-type shells, the result is the highest increase in time. However, the radial displacement is greater than the two other types of support. Shell with non-linear amplification range, self-hardening behavior have shown that increased the burden is so primitive after buckling. Also Figure 17 shows in the vertical displacement of the center of the shell have a radial location with the same routine. This means that a significant decrease in the reinforcing ring reducing the vertical displacement of the center of the shell.

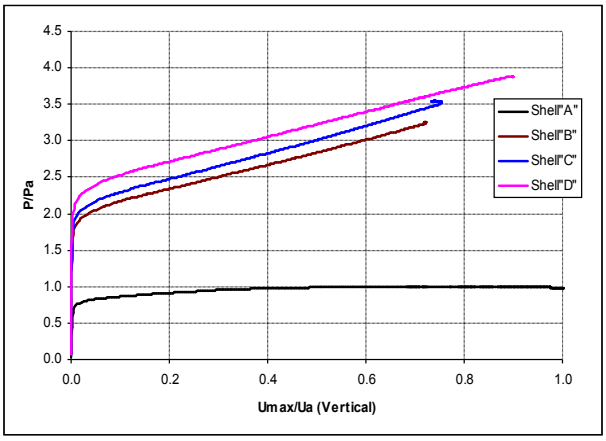

Figure 17 - Comparison of pressure - radial displacements of the 4 shells

Finally, Figure 18 illustrates a comparison between the maximum axial stresses.

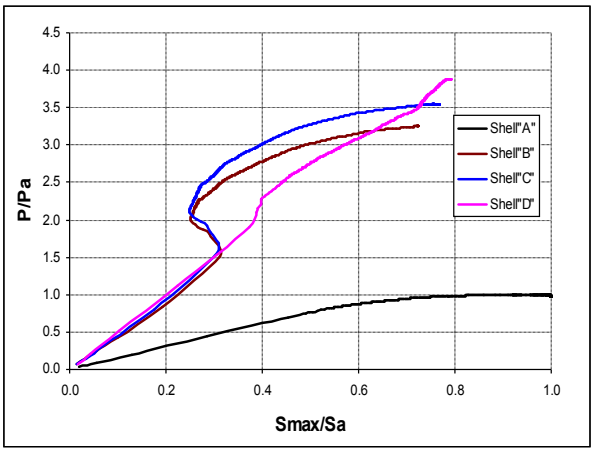

Figure 18 - Comparison of pressure - radial tensions of the 4 shells

Figure 19 displays the relationship between stress and axial displacement of the four crusts. It's observed that the behavior of reinforced shells with different shell without reinforcement. It seems very beginning of the nonlinear function, a decrease in the tension of the shell has been strengthened further by increasing pressure loading, the stresses increase. Overall, and in comparison with other shell enhancement, D-type places crust stresses and changes more than the other two types of experience will strengthen corresponding to the first amplifier, which has a lower profile the rest is strengthening, respectively. The reason was mentioned earlier. However, the displacement and stress-shell type D, a significant amount of non-reinforced shell is less.

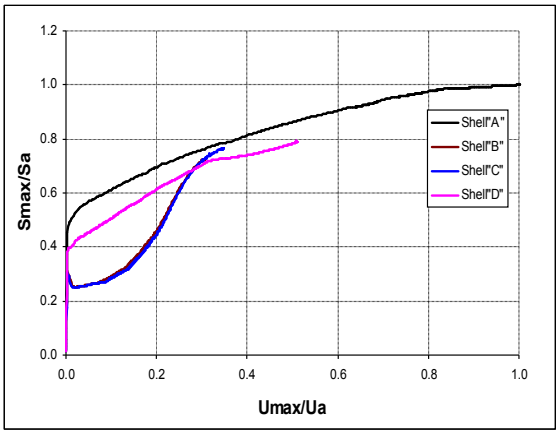

Figure 19 - Comparison of pressure - radial displacements of the 4 shells

4- Reinforcement specifications:

In this section, some of the enhanced features of the ring modes A, B, C will be changed to enough pressure determine the effect on shell buckling. Hence, strengthening, N , and also ratio of width/ thickness, k , assumed variable. Then extent pressures than non-reinforced shell buckling to the pressure point, *Ratio* is calculated. The result for uniform shell with reinforcement ring is indicated in Figure 20.

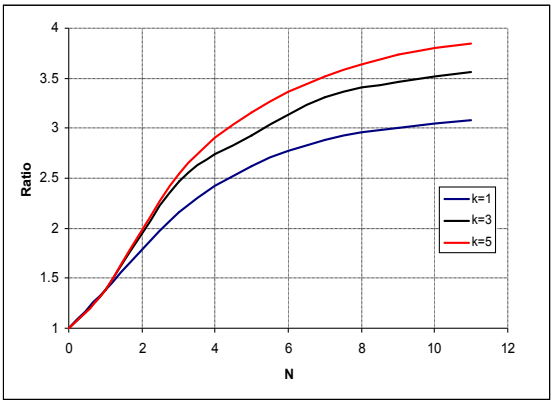

Figure 20- ratio of limit pressure of buckling of the shell with strengthening to the shell and without strengthening/ based on changing in number of strengthening in shell type B

It's obvious that steep gradient at the increasing number of reinforced slope is more gentle. Adding too much of the amplifier, so the crust will not have a significant effect on hypertension. Therefore, such a graph is for the optimal number of amplification. Increasing the ratio of width to thickness reinforcement buckling of shells increases so the pressure ring, this is kind of predictable. The three types of reinforcement used in the shell are depicted in Figure 22.

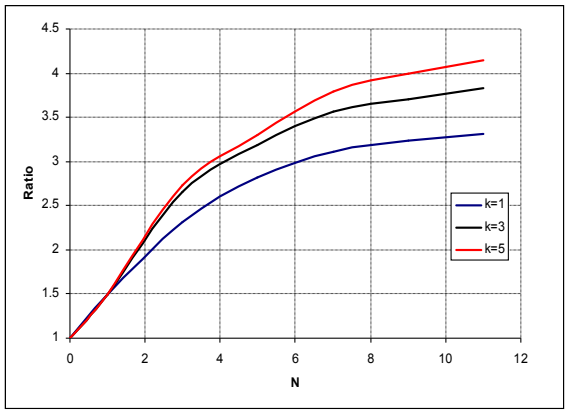

Figure 20- ratio of limit pressure of buckling of the shell with strengthening to the shell and without strengthening/ based on changing in number of strengthening in shell type C

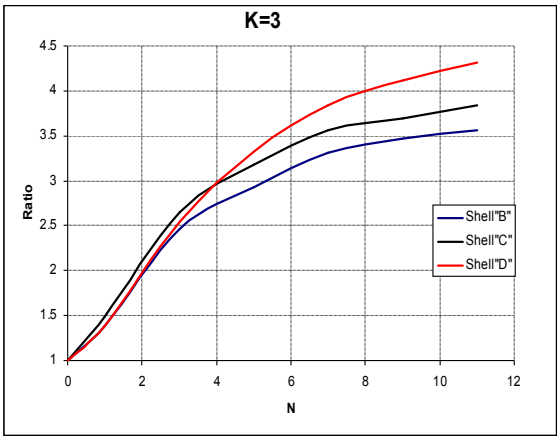

Figure 22 - Comparison of pressure ratio with the change of buckling slightly enhanced for K = 3

Finally, it was observed that the higher the ratio of width to thickness of reinforced and strengthened, the extreme pressure shell type D amplification makes more difference with the other two. The lower the ratio, the k amount of D-type shell is even weaker than the other two, due to the low primary reinforcement in the form of a shell. It seems to strengthen the position of D is more effective in terms of adding some pressure.

5- Conclusion:

In this paper, we investigate the effect of different types of nonlinear behavior of reinforced ring on cylindrical shells under hydrostatic pressure were investigated. In this regards, the outer cylindrical shell with uniform ring enhancement (type B), uniform internal reinforcement ring (type C) and with ring enhancement with linear and nonlinear analysis of the height distribution (type D), including material nonlinearity and large deformation, were involved. Responses obtained were compared with the results of nonlinear analysis of shells without reinforcement. The thickness of reinforcing ring and height were considered as variable parameters. The effect of these parameters on the extent of pressure obtained from nonlinear analysis of reinforced shells with different shapes was studied. The following results were obtained:

1 - Strengthening of the ring causes a significant increase and slightly buckling pressures than non-reinforced shell. Meanwhile, the reinforced shell and then type C type D developed the most extreme pressure.

2 - Strengthening the radial and vertical displacements of the ring decreased compared to non-reinforced shell. The strengthening of the shell type C and type D followed by reduction of the dislocation created.

3- With the added enhancement of the ring, so buckling pressure increases. However, the increased intensity at higher and increasing the number of ring enhancement of certain significant effect on the buckling pressure does not limit.

4 - The ratio of length to thickness of reinforcing ring, the pressure increases slightly. Enhancement of the ratio of length to thickness D is more effective than the other two, so the pressure difference is greater.

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