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Numerical Analysis of Ring-Stiffener Effect on Ultimate Buckling Strength of Pipeline

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Abstract: The aim of present study is to investigate the effect of height and the shape of cross-hardening materials with the same material on the ultimate strength of reinforced pipe under external hydrostatic pressure. The possibility of reduction in thickness of pipe's wall away from the beach and submerged in deep water is evaluated. In order to make the pipes economically affordable, buckling resistance has to be provided. To achieve this goal, *in vitro* study was conducted that has limited factors for investigating on the effect of annular ring on buckling and ultra-buckling capacity of marine submerged pipeline under external hydrostatic pressure; the pressure which is generated by the weight of water above the pipes. In this study, a laboratory-scale pipeline with the same narrowness was fabricated. The nonlinear cyclic stiffeners effect, buckling and post-buckling pipeline model behaviors were investigated. The samples under uniform external pressure were designed when they receive a certain pressure, samples have been buckled. The samples were buckled gradually under low pressures and they were buckled suddenly under heavy pressures. The pressure- shift diagram has moved up to reach the buckle point. The process in all experiments was under observation and showed specific failure in these shells. The results illustrate different samples with various cross section have different buckles and movement. In order to strengthen the pipeline, this study has used cyclic stiffeners with T-shaped, rectangular and cornerstone sections. Furthermore, finite element software, ABAQUS, have used for numerical analysis. Finally, the theoretical simulated results were compared with experimental results; the obtained results were in good agreement with projected data.

Key words: Hydrostatic Pressure • Cyclic Stiffener • Peripheral Wave • Buckling Resistance

INTRODUCTION

Stability is one of the most important factors in design; if there is instability local and overall buckling appeared. In this kind of structures, the thickness ratio compare to other structure dimension is very low; therefore investigation on structural stability and instability are an important issue. In pipelines, increasing the thickness of pipes wall is a trend to increase the strength and safety of pipelines. In that case, increase in thickness of pipes wall also has its own problems like having significant difficulties in construction, installation and especially in welding. To overcome the stated problems, use of stiffeners is one of the proposed methods.

Background: Number of studies has been conducted on use of reinforced-stiffeners under steady pressure. Buckling distribution in pipes was considered by many researchers; the first article on buckling pressure and lateral buckling of axially constrained pipelines was discussed by Palmer and Baldry [1]. It was proposed a low estimation for diameter to thickness ratio to the *in vitro* results. A study on buckling distribution in pipes by Kyriakides and Netto [2] on the dynamics of propagating buckles in pipelines has investigated buckling distribution based on energy methods. Showkati and Ansourian have investigated on Influence of primary boundary conditions on the buckling of shallow cylindrical shells [3]. Aghajari, *et al.* [4], Fakhim, *et al.* [5], Golzan and Showkati [6] have conducted research on buckling and post-buckling

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behavior of thin-walled cylindrical steel shells with varying thickness subjected to uniform external pressure in view of imperfect geometry. Showkati and Shahandeh [7] have conducted *in vitro* study about distortion behavior of ring stiffeners in buckling of reinforced pipelines. Riahi, *et al.* [8] have investigated on the stiffeners effect in buckling of pipelines. Gao, *et al.* [9] have carried research on physical modeling of untrenched submarine pipeline instability. Li and Velamarthy [10] have fabricated reinforced polymeric cylindrical tubes and tested model for buckling distribution on pipes.

Kashani and Young [11] have evaluated the installation load consideration in ultra-deepwater pipeline. The uni-lateral pressure created by buckling of circular cylindrical shells has been discussed by Vodenitcharova, T. and Ansourian [12]. Karroun, *et al.* [13] have experimentally analyzed the ring-stiffened cylinders using finite element method. Also, finite element analysis is useful technique for the evaluation of tube stability in deep water [14] and fluid structure interaction in pipeline systems [15]. Modeling was performed with ABAQUS software. Buckling analysis was performed by non-linear method that is the best method for determining the buckling capacity of the structure.

Geometries and Properties of Test Specimens and Instruments

Geometries of the Models: Three pieces of pipes tested in the laboratory with diameter, length and thickness were 150, 2000 and 0.4 mm, respectively. They had four stiffeners with various sizes and shapes. The stiffeners have rectangular, T-shaped and cornerstone cross sections with a height of 30 mm; that were attached to the pipe samples. Table 1 summarized the pipeline geometric parameters such as inner and outer diameters, wall thickness and length.

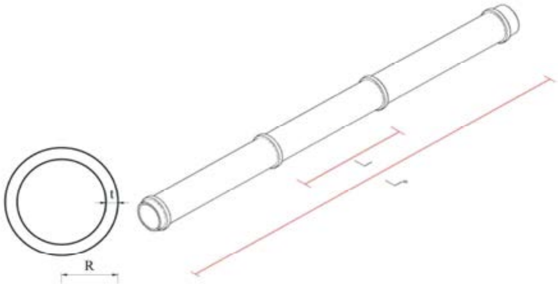

Fig. 1: Nominal geometrical pipe and Ring Stiffener's models

Figure 1 shows the picture of the testing pipeline set up and schematic diagram of the experimental set up for the specimen and testing purposes.

The propose of present study is to investigate the effect of height and cross section of stiffeners with application of the same of materials on reinforced pipelines resistance under external hydrostatic pressure. Therefore, a vast research was conducted. The desired goals and best choices of specimens and Ring Stiffener's geometric parameters achieved are shown in Table 2. Thus, the effects of changes in surface area and height of stiffeners in samples buckling were evaluated.

The Mechanical Properties of Samples: All sheets and material used to fabricate the samples was prepared from steel. To ensure the accuracy of sheets were used in the tensile test of three samples; all three sheets were separately tested. Figure 2 shows the tensions – strain graph for the type of steel used in the specimen and used in tensile test.

Finite Element Model: Modeling was carried out through software known as ABAQUS 6.8.1. Samples were analyzed by buckling eigenvalues. For modeling marine pipe, after studying library elements,

Table 1: Pipe geometric parameters

Specimen	Inner diameter (mm)	Outer diameter (mm)	L_0, length (mm)	Thickness (mm)
Pipe	149.96	150	2000	0.4

Table 2: Indicate the properties of specimens and Ring Stiffener's geometric parameters

Specimen label	Stiffener's shape	Wing length of stiffener	Wing thickness of stiffener	Stiffener's height h_w (mm)	Stiffener's thickness t_w (mm)	Rings inner radius (mm)	Rings space, L (mm)	Rings number
SR	R	0	0.4	30	0.4	75	500	4
ST	T	30	0.4	30	0.4	75	500	4
SL	L	30	0.4	30	0.4	75	500	4

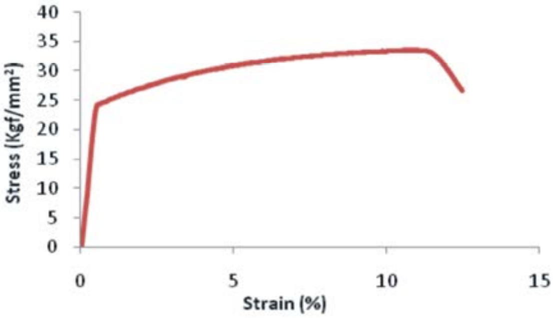

Fig. 2: Tensile stress strain relation of material

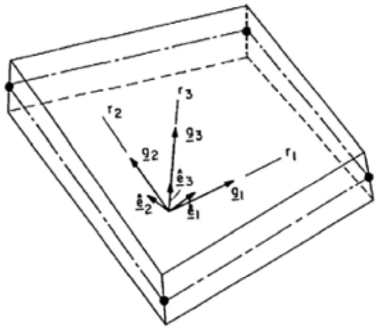

Fig. 3: Element used in the model

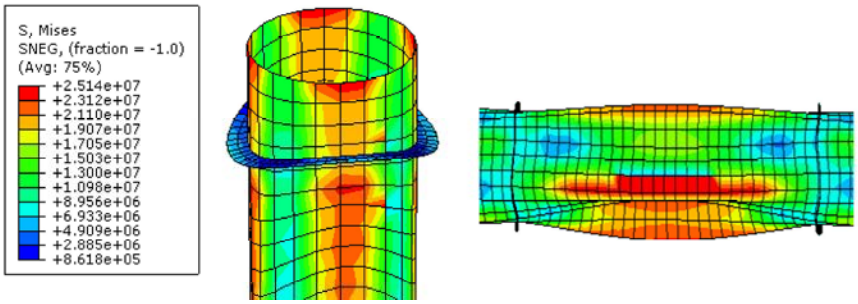

Fig. 4: Distribution of Von-Mises distortion for propagation of plasticity buckling

S4R was selected as the best choice. The shape of element was Quad from standard Sell family and we can load this kind of element in the cylindrical coordinate system. Figure 3 shows the element used in the proposed model.

This element had four nodes and so we could define orthotropic material characteristic. Considering the model of Yang (E) and Poisson's ratio (υ), shearing modulus wad determined. Stiffener screw auger was made of rolling around a shell surface that after assembling on the pipe; it became a part of the pipe. This made less error in the meshing. Choosing correct size of mesh reduced errors as well. Pressure was applied evenly. Growing load on sample (P^N) determined the buckling process which was grading by increasing load (Q_i) and then, the buckling eigenvalues were determined. The incompleteness due to geometrical defects, boundary conditions and loading conditions had a strong influence on buckling behavior of pipe. This factor has been considered in modeling. Patterns of failure were obtained from eigenvalues of buckling. To estimate the buckling load of cylindrical shell, the following equation has been used. This equation was established for ideal cylindrical shell by Showkati and Shahandeh [7].

$$q_a = \gamma E\left(R/L\right)^{\alpha}\left(t/R\right)^{\beta}, \alpha = 1.02, \beta = 2.51, \gamma = 1.033$$

Where E, R, L, t, α, β, γ are modulus of elasticity, radius of the pipe, length of pipe, pipe thickness and the coefficients of the boundary condition, respectively. All of them gain through *in vitro* results. The analysis of simulated sample (SR) is shown in Figure 4.

Evaluation of Buckling and Post-Buckling Strength: The behavior of non-elastic failure of pipe is extremely complex and associated with gradually surrender to different depth of object points. Due to the geometry of the tube, pipe failure mechanisms in the plane strain have fully plastic behavior and it is simulated with four plastic focuses joint. To analyze the pipe failure pressure from the time of deformation to the end of corruption; as illustrated in Figure 5 the tube failure mechanisms which are based on a joint plastic.

Minimum pressure required to cause local buckling of pipes (it means Failure) the pressure (Pc) can be calculated by fallowing equation:

$$P_{el} = \frac{2 \cdot E}{\left(1 - \upsilon^2\right)} \cdot \left(\frac{t}{D}\right)^3$$

$$P_{pp} = \eta_{fab} \cdot SMYS\left(T\right) \cdot \frac{2 \cdot t}{D}$$

$$f_0 = \frac{D_{\max} - D_{\min}}{D_{av}}$$

where (D_{av}) is the average diameter, SMSY (T) is minimum resistance to environmental characteristics, (E) is Modulus of elasticity, (υ) is Poisson's ratio, (η_{fab}) is derating construction factor, (f_0) is out of roundness and (D_{min} and D_{max}) are the minimum diameter of oval pipe and the maximum diameter of oval pipe, respectively. The resistance capacity for pipe failure can reasonably be calculated through the related equation.

The Calculation of the Minimum Pressure Required for Buckling Diffusion: Diffusion pressure is one of the characteristic pressure of pipe and the amount of it is less than destruction pressure.

$$P_p = 6.SMYS.\left[\frac{2.t}{D}\right]^{2.5}$$

RESULTS AND DISCUSSION

Buckling diffusion is an elasto-plastic rupture that starts by a local transverse buckling. Buckling diffusions gust have occurred among destruction pressure and diffusions pressure. Under lower pressures compare to diffusions pressure, the buckling does not occur. Buckling diffusions are suddenly under high pressure and also under low pressure. The buckling may gradually occur. Failure mechanisms of the pipes have plastic manner which is) simulated by four plastic localized joints.

Buckling Diffusion in Pipes: Due to buckling diffusion phenomena, pipe walls move radially towards each other; thus, the pipe is broken and become useless.

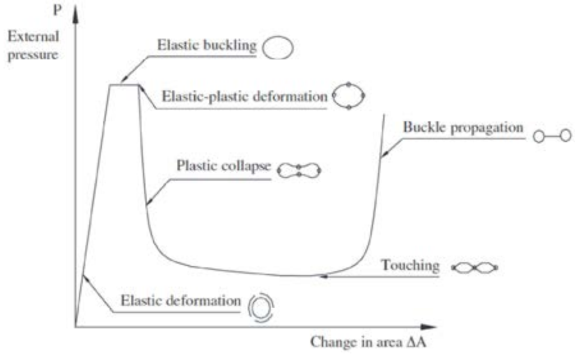

Fig. 5: Tube failure mechanisms based on a joint plastic Calculate the minimum pressure required for local buckling of the pipe

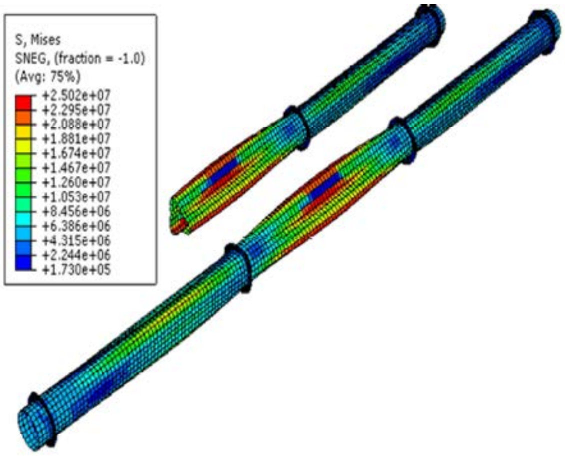

Fig. 6: Collapsed specimens (SR)

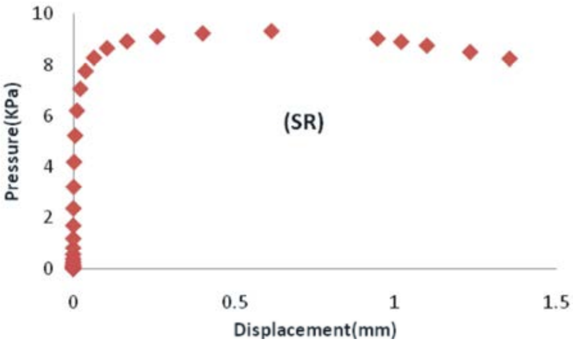

Fig. 7: Ultimate strength Curvature of the pipe model (SR)

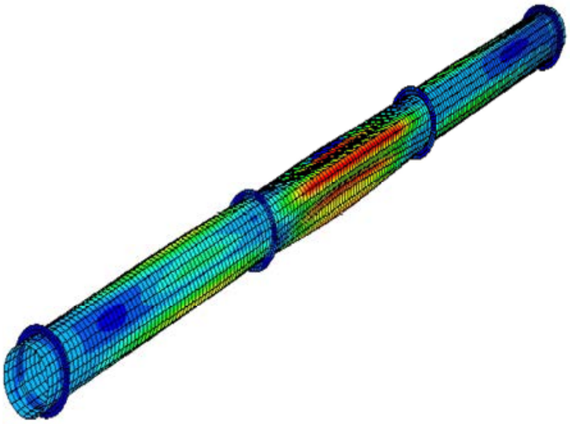

Fig. 8: Collapsed specimens (SL)

After loading the model, on specific point sample started to buckle. According to pressure-transformation graph, it showed that graph slowly accenting to get the buckling point. In other words, through any small changes in pressure, large transformations take place.

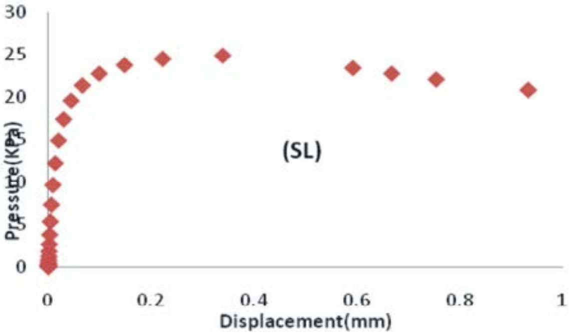

Fig. 9: Ultimate strength Curvature of the Pipe Model (SL)

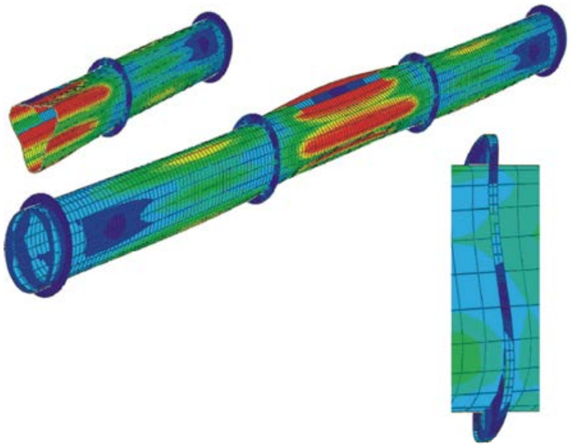

Fig. 10: Collapsed specimens (ST)

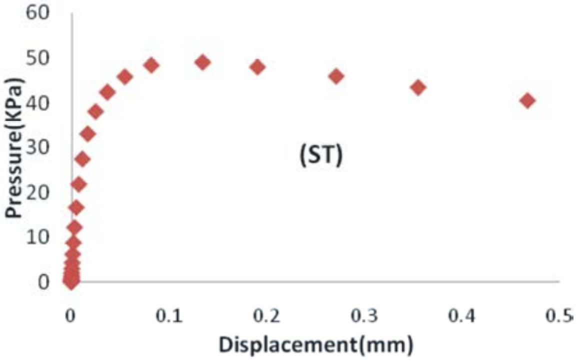

Fig. 11: Ultimate strength Curvature of the pipe Model (ST)

The same process in all analysis was observed; so it shows special type of shell damage in these structures. Significant result is the shell element damages under the pressure. Figures 6, 8 and 10 show the images of collapsed specimens for SR, SL and ST, respectively. The ultimate strength curvature of the pipe models for SR, SL and ST are shown in Figures 7, 9 and 11, respectively.

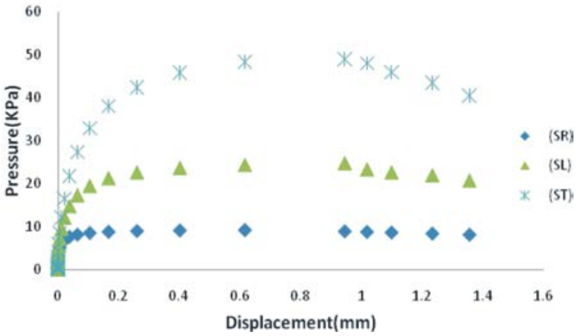

Fig. 12: Diagram Ultimate strength of the models (SR, SL and ST)

Figure 12 shows the ultimate strength of the pipe models for SR, SL and ST.

CONCLUSION

It was concluded that submerged pipe in marine environment under external hydrostatic pressure is affected by bucking of the pipelines. There are possibilities of reduction in thickness of pipe's wall submerged in deep water. The pipeline external hydrostatic pressure is built up by the weight of water above the pipes. The work was conducted by actual experiment on four pieces of pipe and the data were analyzed by the nonlinear cyclic stiffeners effect, buckling and post-buckling pipeline model behaviors. Finite element analysis of buckling and post buckling stiffened pipeline with spiral stiffener was conducted. Experimental and theoretical investigations of distortional buckling in ring-stiffened pipeline considering stiffeners buckling were evaluated. In addition, finite element software, ABAQUS, was used for numerical analysis. Besides actual data, the theoretical simulated results were compared. The obtained results were in good agreement with the projected model.

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