Finite Element Analysis of Pipes Considering The Effects of Stress Concentration Factors Due to Dents

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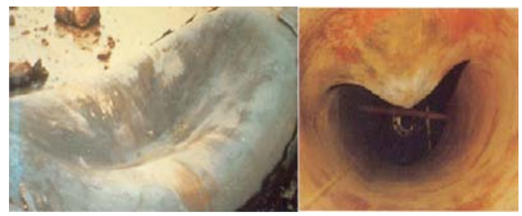
Abstract: Mechanical damage in the form of dents on pipes has deserved thorough investigation so far. Not only do the offshore industry have concerned about the subject, but it has also attracted a lot of attention in the providing water companies. They can be damaged by the impact of anchors, rocks or any kind of heavy objects, thereby producing a localized stress concentration. A numerical analysis of indented pipes based on the Finite Element within the framework of the software Comsol is analyzed. Two-dimensional solid plane strain elements are evaluated. Geometric nonlinear analysis, plasticity and contact were also incorporated into the models. The dents are applied by means of cylindrical indenters. Different geometries are used for the pipe and indenter. The stress concentration factor is obtained by using the deformed geometry as initial configuration of the model, applying an internal pressure of 0.1 MPa so as to generate an enough elastic response.

Keywords: Stress Concentration, Dents, Finite Elements.

1. Introduction

Through the years, pipes have been constantly aimed by either researchers of the scientific community or professionals of the industries. More importantly, they have been used for transporting fluids such as water, gas, oil or sewage. However, they can be subjected to mechanical damage such as corrosion, cracking, dents or other defects. These defects can be associated with impacts due to falling objects such as anchors, trawling, rocks or landslides. Dents are the most common type of defect, thereby causing an inward displacement of the surface of the pipe, Figure 1. Moreover, the dent depth can also cause a detrimental effect on the structural strength of the pipes subjected to internal[1] or external pressure[2] and cyclic loads[3]. Mainly, the dents can cause a localized stress concentration. As result of it, some experimental and numerical studies have been developed so far in order to evaluate the structural integrity of dented pipes.



(a) External View (b) Internal View
Figure 1 – Dented pipes[4]

The main objective of this work is to investigate the effect of stress concentration on dented pipes[5] due to variation of some parameters such as cylindrical indenter diameter, thickness of the pipe and angle of support. Herein, it will only be considered the so-called plain dents, which no contain wall thickness reductions such as gouges, cracks, other defects or imperfections[6].

2. Geometry and Materials

The pipes were laid on a rigid surface whose length is the same size of the external diameter of the pipe and thickness of 10mm. Different angles of support (θ) are considered, respectively, 0º, 45º e 90º, Figure 2. The dent depth was taken as 2%, 4%, 6%, 8% and 10% of the external diameter of the pipe whereas the indenter diameter was 10%, 25%, 50%, 75% and 100% of the previous parameter. The main geometric parameters of the models are presented in Table 1, where D is the external diameter of the pipe, Di is the external diameter of the indenter, t is the thickness of the pipe and d is the dent depth.

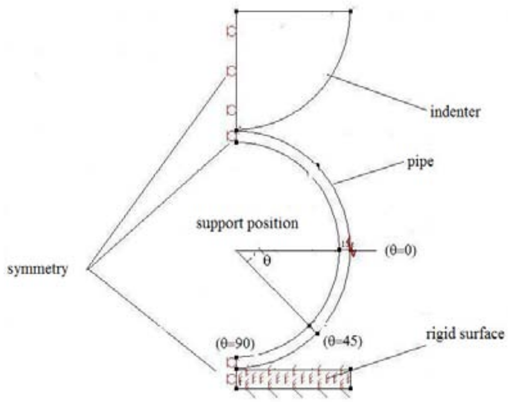


Figure 2 - Indenter and pipe set on a rigid base.

D(mm)	Di(mm)	t(mm)	d(mm)
120	12	2	2.4
	30	2.4	4.8
	60	3	7.2
	90	4	9.6
	120	6	12

Table 1 – Geometric Parameters of the Models

Two different materials were also used so as to verify their influence on the stress concentration factor. 6082-T6 Aluminum used in experimental work[7] and X60 Steel for pipes of the oil industry. Their main mechanical properties is shown in Table 2, where E is the Young Modulus, σ_y is the yield stress and σ_u is the ultimate tensile stress. Figure 3 also shows the true stress-strain curves of both materials.

Properties	6082-T6 Aluminum	X60 Steel
E (MPa)	70000	206820
σ_y (MPa)	300	485
σ_u (MPa)	351	574

Table 2 – Mechanical Properties of the Materials

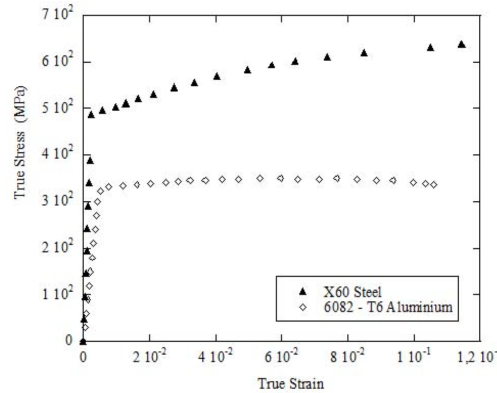


Figure 3 - True stress-strain curves of 6082-T6 aluminum and X60 Steel.

3. Numerical Models

The numerical models were developed within the framework of Comsol[8]. Eight-nodes, quadratic and two-dimensional elements were used in the analyses. A sensibility study of the mesh was carried out so as to evaluate the accuracy of the results and computational effort. It was adopted a mesh with 734 elements, however, the region near the indentation was more refined with 560 elements. The model has been previously calibrated[9].

Plane strain, frictionless contact, nonlinear geometric analysis were also considered in the model. However, these analyses were only involved the following steps: the dent is generated by means of a prescribed displacement using a cylindrical indenter and after that, the indenter is removed. The indenter is modeled as a rigid surface. Contacts among the indenter, pipe and rigid surface are also considered. Due to symmetry, half of the model is analyzed. The effect of residual stresses induced in the model, when the dent is generated was not considered.

The deformed configuration is stored after the indenter is removed and used to calculate the stress concentration factor by means of applying an internal pressure of 0.1MPa enough to generate an elastic response[10], Figure 4.

The stress concentration factor is calculated by the ratio between the maximum Von Mises stress and the nominal stress at the centre of the dent[11], Equation 1. The numerical results are compared to an analytical equation[12], Equation 2, where d is the dent depth, D is the external diameter of the pipe and t is the thickness of the pipe.

Particularly, this equation was derived from a solution of a pipe internally pressurized. The authors propose calculating the stress concentration on the external surface at the dent centre.

$$K_t = \sigma_{max} / \sigma_{nom} \quad (1)$$

$$K_{anal} = 1 - 1.74 * d/D + 5.22 * d/t \quad (2)$$

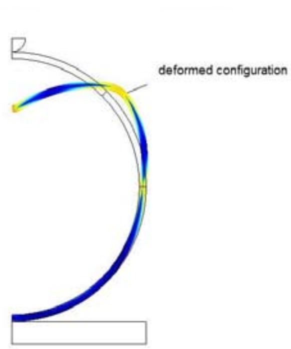


Figure 4 – Deformed Configuration of the Model

4. Results and Discussion

The influence of the variation of different D/t ratios are compared to different type of materials and dent depth (d). The stiffness of the pipe herein is measured by the external diameter (D)/ thickness (t) ratios, Figure 5. So, it is noteworthy that an increase of the D/t ratio also causes an increase of the stress concentration induced into the defect (dent).

In this case, the analytical results are more conservative in relation to numerical ones, mainly with deeper dents. The type of the material has low effect for low stiffness pipes. Furthermore, there was a good correlation among numerical-analytical results of the models based on the stress concentration factor.

Figure 6 shows the influence of the variation of the indenter diameter on the stress concentration factor for different d/D ratios. It worths mentioning that the stress concentration factor increases as lower as the indenter diameter. It is also observed that the analytical equation has a favorable response to using low indenter diameter. The numerical results are more conservative in relation to analytical ones for higher indenter diameter.

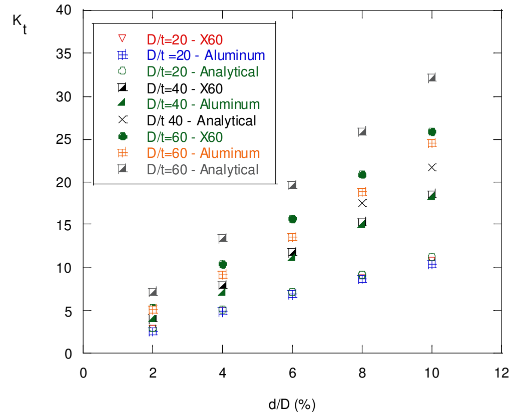


Figure 5 - K_t x d/D (numerical x analytical, θ=45° ,Aluminum, X60 steel)

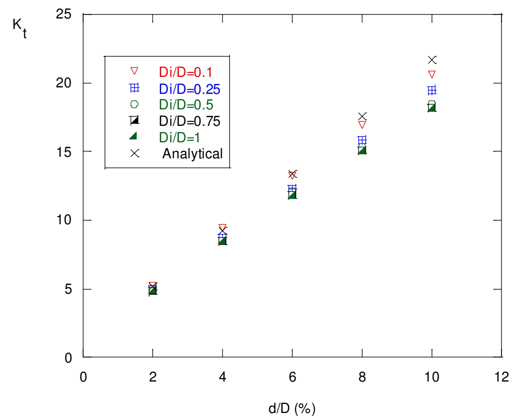


Figure 6 - K_t x d/D (numerical x analytical, θ=0° X60 steel, D/t=40)

Figure 7 shows the variation of the angle support of the pipe. It seems that lower angles increase the stress concentration factor due to the proximity of the support in relation to the indentation region. Conversely, higher angles substantially decrease the stress concentration factor induced on the model.

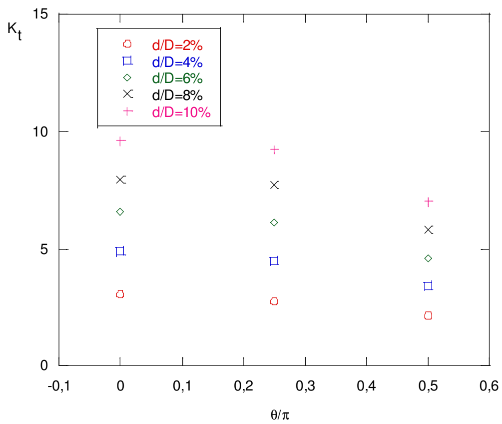


Figure 7 - K_t x θ/π (X60 steel, D/t =20).

5. Conclusions

The study of stress concentration factor was evaluated through a Finite Element Analysis. Analytical equation from scientific community was used to compare to the numerical results. The variation of some parameters such as external diameter, thickness of the pipe, indenter diameter and angle of the support were also observed. An increase of the D/t ratio also triggers an increase of the stress concentration induced into the defect (dent). The analytical results are more conservative in relation to numerical ones, mainly for deeper dents. It was also observed that lower indenter diameters have a more detrimental effect on the stress concentration induced on the model than higher indenter diameters .

6. Acknowledgements

The authors would like to acknowledge the financial support from National Counsel of Technological and Scientific Development (CNPq) and Fundação Cearense de Apoio ao Desenvolvimento Científico (Funcap).

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