# Evaluation of Dent Size on the Integrity of Oil and Gas Pipeline Using Computational Methods

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**Abstract**:- **The recent increase in global energy consumption has led to the exploration and production of fossil fuels in deep-waters. The produced oil and gas from these remote locations is conveyed for further processing and consumption using pipelines. However, the integrity of pipeline system of transmission is threatened majorly by mechanical defects such as dent and gouge. In this work, the effect of dent size on the structural integrity of an oil and gas pipeline was studied using computational method. The pipe is modelled using ANSYS software and solved using the finite element capabilities of the software. The pipe is loaded laterally with a pressure load which causes the dent on the pipe and the pipe is fixed at one end and free at the other end to allow for the determination of hoop stress in the pipe. The results for one dent size is further used to solve for various sizes of dent and the corresponding stresses induced in the pipe were determined. The solution shows that after a dent size of 19mm the pipe will fail due to the ultimate tensile strength being exce**eded.

***Keywords:-*** *Mechanical Defects, Dent, Pipelines, Integrity, Failure, Ultimate Tensile Strength.*

## I. INTRODUCTION

Over the years, pipelines have been found to be the safest and the most economical way of transporting produced hydrocarbons(1). It becomes of more significance with the incidence of oil and gas exploration going into deep waters as a result of reserve depletion, increased global energy consumption and the possibility of higher prospects offshore. Because of heavy reliance by oil and gas industry on pipelines for product transportation purposes, the design approach, material selection and operation of pipelines systems consider safety. However, like every engineering product, systemic failures are occasionally found to happen in pipelines(2). Most common causes of pipeline failure include mechanical damage, weld defects, corrosion defects and bad operational practices and ageing(3). Amongst the many causes of pipeline failure, mechanical damage (external interference) contributes 49.6% to failure of oil and gas transportation pipelines, manufacturing defects 16.5%, corrosion defects make up to 15.3%, ground displacement contribute 7.3% while failures from other sources make up 11.3%. Mechanical damage as a defect is classified into dents and gouges. Dents in pipelines creates stress concentration points thereby reducing the pressure handling capacity of the pipeline thus posing a great threat to operational safety of the pipeline(4–6).

Dent in pipes defines a condition in which the a radial shift occur on the pipe walls as a result of impact with external bodies resulting in permanent plastic deformation of the pipe. The dimensions (depth, length and width) normally characterizes pipe dents. In the evaluation of the severity of dent defects, the key factor to be considered is its depth, which is defined as the maximum reduction of the shape difference in the direction of the pipe diameter relative to the original pipe diameter(7). Dent defects categorization is done to its severity and geometry as listed and defined below below(6):

- Smooth dent: this is characterized by a smooth transformation of the curvature of the pipe walls
- Kinked dent: this kind of dent displays a sudden deviation in the curvature of the pipe wall
- Plain dent: this occurs with no reduction in the thickness of the pipe walls
- Unconstrained dent: this is a type of dent that rebounds elastically when the indenting object is removed
- Constrained dent: this type of dent does not freely rebound because the indenting object is still in place.

The severity of dent defects depend on the boundary depth. The standard API 1160 (2001) stipulates that for pipe diameter of above 304.80mm, the boundary depth of 2% of the outer diameter is considered critical. For pipelines with diameter above 304.80mm, the boundary depth of 6.35mm is considered. When the dent depth is smaller than the boundary depth, the dent defect is considered negligible(8).

Several studies have been carried on mechanical defects in pipelines with early researches relying on experiments with pipe samples at the laboratory scale. The investigations evolved leading to the use of empirical methods in evaluation of the severity dents and structural integrity of pipeline systems. The effect of depth of dent on pipe burst pressure was studied based on simple approach of local strain criterion as a damage and failure prediction method for dented pipes(4). The adverse effect of mechanical defects on operational safety of gas transmission pipelines was studied, with focus on the major types of damages and the actual parameters and their influence(9). A numerical study was conducted to determine the ability of dented pipes to bear pressure and moment loading(10). The structural behavior of dented tubular members under lateral loading was studied from numerical and experimental angles and a correlation between the results of the two approaches was obtained, giving a further understanding into structural response of tubular members and risers having dent defects(11). Mechanical defects in pipelines was studied using a validated elastic-plastic finite element analysis (FEA) simulation model and the effects of the damage was quantified using broad parametric study(12). The effect of excessive displacement and localized dents due to anchor dragging was analyzed using three-dimensional (3-D) non-linear finite element model mimicking the possible events with an aim to reproduce the actual deformation in the pipeline making assessment possible(1).

This study employed the use of computational method to evaluate the integrity of pipeline conveying crude, with mechanical defect in the form dent of varying sizes.

## II. LITERATURE REVIEW

### A. *Theoretical Background*

A dent in a pipeline is a permanent plastic deformation of the cross-section of the pipe. Dent when occurred in a pipeline usually causes a total distortion of the pipe cross-section. The depth of a dent or the size of the dent is the maximum reduction in the diameter of the pipe in relation to the original diameter.

To estimate and control dent, Orynyak et al. (13) proposed that dent region fails by plastic hinges mechanisms. The model is based on plastic collapse and it is applied to a pipe with longitudinally infinite indentation. Consider a pipe a shown in Figure 1, the dent has a length 2c and a depth H, failure occurs in this pipe by plastic collapse at point A, B and C. The dent depth H which is connected to radius V is given by:

$$H = 2\left(V - V\cos\frac{c}{V}\right) \qquad (1)$$

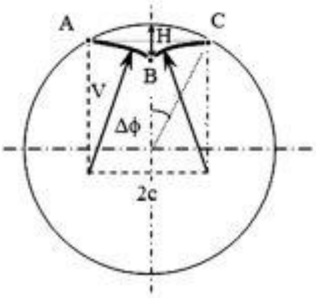

Fig 1:- Orynyak's Model of Plastic Collapse by Plastic Hingers Located In A, B and C

The angle of the pipe surface tangent at A is given as follows:

$$\Delta\emptyset = \frac{c}{V} \qquad (2)$$

The pipe strength reduction factor is given by using the expression below

$$\propto = \frac{PR}{\sigma_u\tau} = \sqrt{\frac{V^2}{\tau^2}\left(\frac{c}{V}\right)^4 + 1 - \frac{V}{\tau}\left(\frac{c}{V}\right)^2} \qquad (3)$$

Where P, V, $\sigma_u, \tau$, R and c are internal pressure, curvature radius of dent, ultimate strength, wall thickness, outer radius of pipe and half length of dent respectively.

Equation (3) can also be expressed as a function of dimensionless length of the defect (Ɣ) as shown

$$\propto = \sqrt{\gamma^4 + 1 - \gamma^2} \qquad (4)$$

$$\gamma = \frac{c}{\sqrt{Rt}} \qquad (5)$$

Hence, the burst pressure or the limit pressure given by this model is shown

$$P_{L,O} = \frac{\propto\sigma_u\tau}{R} \qquad (6)$$

## III. METHODOLOGY

### A. *Physical Model*

This work was carried out using the Structural Analysis Capability of ANSYS WORKBENCH. The pipeline was modelled with a dent at the top of the pipe where the load is acting as shown in Figure 1.

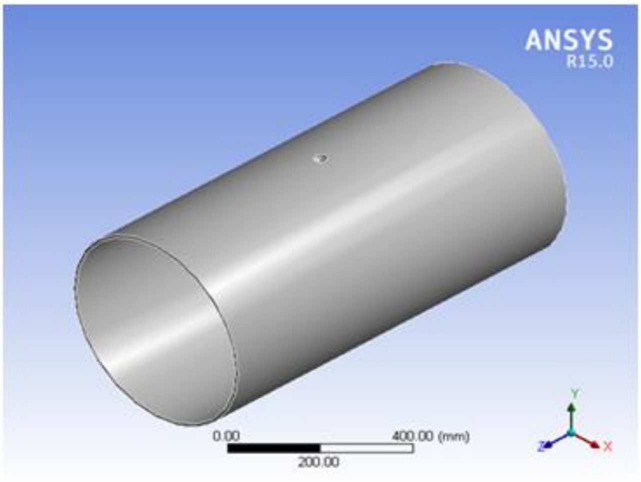

Fig 2:- Pipe geometry

The geometry of the pipe was selected according to the data used in (14), also the depth of dent was varied from 18mm up to 33mm. The pipe geometry is summarized in Table 1.

| Geometric Properties | |
|---|---|
| Outer pipe diameter | 500mm |
| Pipe thickness | 8mm |
| Initial dent size | 18mm |

Table 1:- Pipe Geometry parameters

The material data for the pipe is shown in Table 2.

| Parameters | Values |
|---|---|
| Density | 7.85e-006kgmm^-3 |
| Coefficient of Thermal Expansion | 1.2e-005 C^-1 |
| Specific Heat | 4.34e+005 mJkg^-1C^-1 |
| Thermal Conductivity | 6.05e-002Wmm^-1C^-1 |
| Resistivity | 1.7e-004-ohm mm |
| Compressive Yield Strength | 250MPa |
| Tensile Yield Strength | 250MPa |
| Ultimate Tensile Strength | 460MPa |

Table 2:- Pipe material properties

### *B. Assumption and Boundary Conditions*

It was assumed that the temperature distribution throughout the pipe is uniform and the environmental temperature of 22$^{o}$C from the ANSYS software was used. It was assumed that the dent on the pipe was due to the lateral loading from various machines or earth movement on the pipe. Hence, a lateral loading of pressure on the pipe was applied and also a fixed geometry was applied to one end of the pipe and the other end was allowed to experience buckling and hoop stress. The size of the dent was increased from 18mm to 33mm and the load was increased from 5.5Mpa to 20.5Mpa respectively.

## IV. RESULTS

### *A. Result*

A steady state analysis performed and the Equivalent von mises stress, Equivalent elastic strain, Maximum shear stress, Maximum elastic strain and the Maximum principal stress was determined.

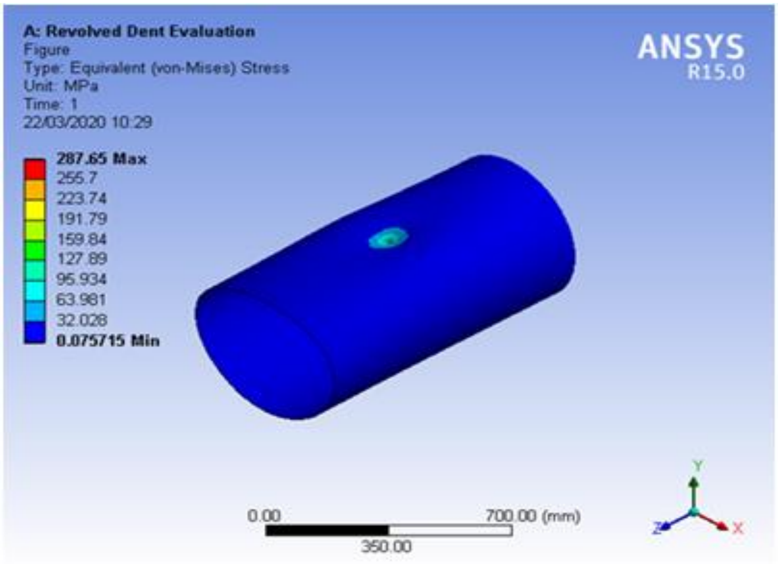

Fig 3:- Von Mises Stress

Figure 3 shows the contour plot for the Equivalent von-Mises Stress with an applied load of 5.5Mpa at a depth size of 18mm. From the plot the maximum stress induced in the pipe is 287.65Mpa.

The Equivalent Elastic Strain, Maximum Shear Stress, Maximum Shear Elastic Strain, Maximum Principal Stress are shown in Figures 3,4,5,6 respectively.

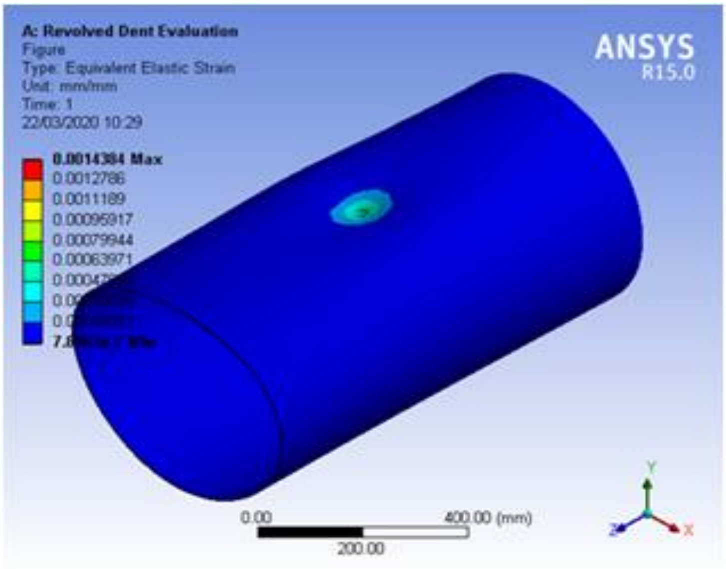

Fig 4:- Elastic Strain

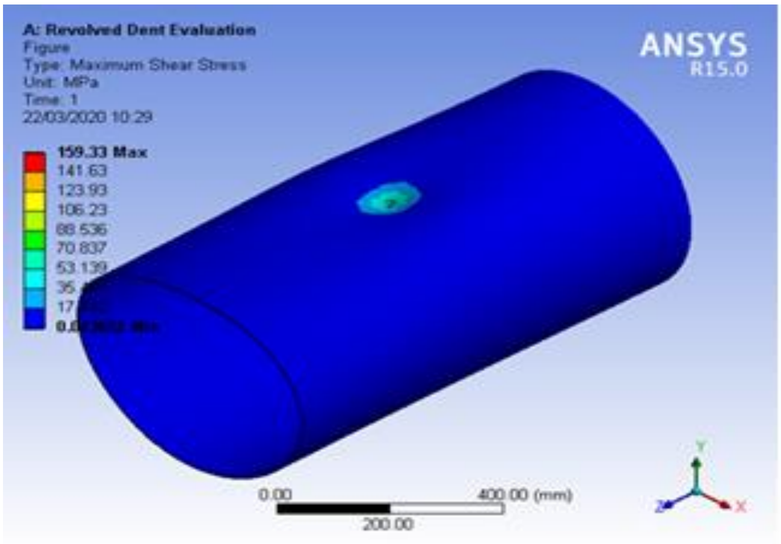

Fig 5:- Maximum Shear Stress

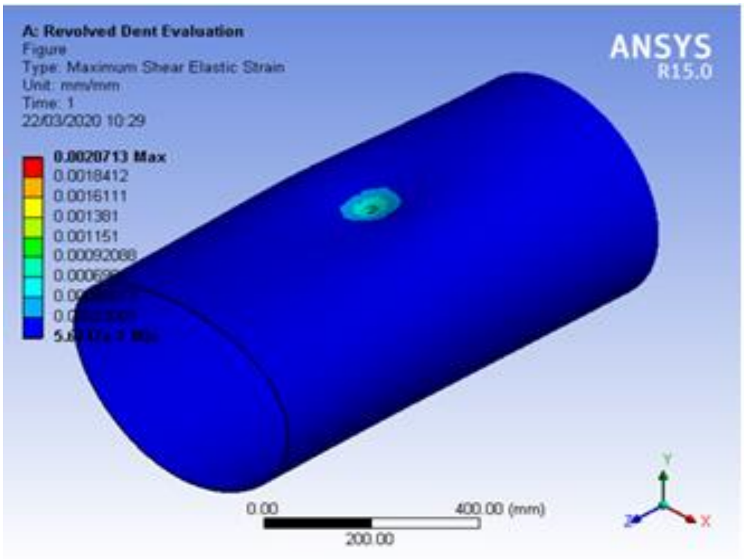

Fig 6:- Shear Elastic Strain

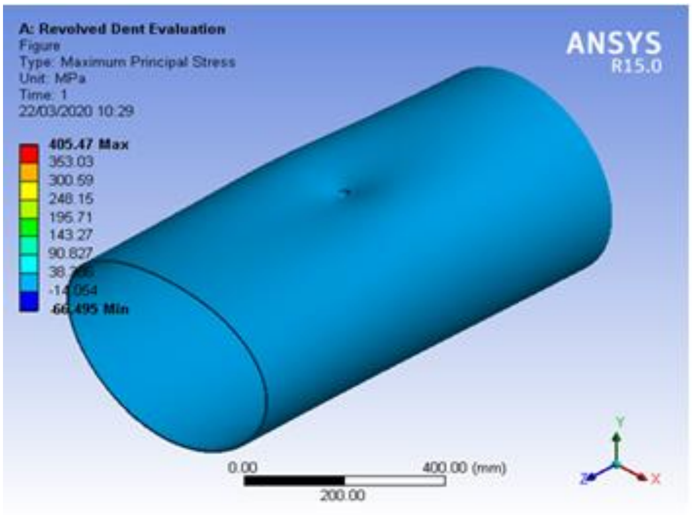

Fig 7:- Maximum principal stress

| Dent Size (mm) | Pressure (Mpa) | Von Mises (Mpa) | Elastic Strain | Shear Stress (Mpa) | Maximum Principal Stress (Mpa) |
|---|---|---|---|---|---|
| 18 | 5.5 | 287.64957 | 0.001438 | 159.328981 | 405.4701032 |
| 19 | 6.5 | 387.65064 | 0.001939 | 213.523112 | 571.5041631 |
| 20 | 7.5 | 531.38824 | 0.002657 | 291.57928 | 789.118916 |
| 21 | 8.5 | 692.91505 | 0.003465 | 377.444842 | 1070.427121 |
| 22 | 9.5 | 771.25199 | 0.003857 | 420.179879 | 1153.845484 |
| 23 | 10.5 | 854.14235 | 0.004272 | 467.96197 | 1266.362781 |
| 24 | 11.5 | 1040.5005 | 0.005204 | 566.825666 | 1561.437055 |
| 25 | 12.5 | 1164.8262 | 0.005826 | 636.142903 | 1774.835791 |
| 26 | 13.5 | 1438.6792 | 0.007195 | 788.807186 | 2145.082085 |
| 27 | 14.5 | 1439.5206 | 0.007199 | 802.210211 | 2146.518643 |
| 28 | 15.5 | 1717.8034 | 0.008592 | 935.573795 | 2598.141034 |
| 29 | 16.5 | 1871.0616 | 0.00936 | 1024.71373 | 2833.330174 |
| 30 | 17.5 | 2457.8308 | 0.01229 | 1337.54212 | 3565.103054 |
| 31 | 18.5 | 2359.5448 | 0.011799 | 1286.61682 | 3475.196506 |
| 32 | 19.5 | 2447.0285 | 0.012254 | 1378.81269 | 3364.628615 |
| 33 | 20.5 | 2796.9113 | 0.013989 | 1513.70992 | 4083.007167 |

Table 3:- Variation of Depth Size with Applied Pressure and Corresponding Stresses

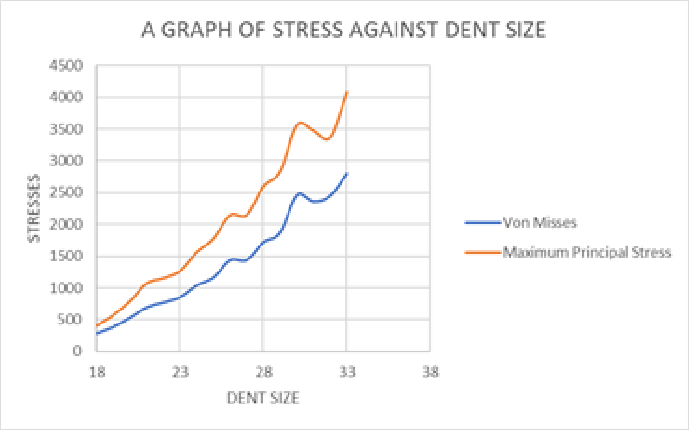

Fig 8:- Stress against dent size

*B. Discussion*

The evaluation of dent size on the structural integrity of a pipeline has been investigated, with focus on the stress distribution and the variation of dent size on the pipeline. 16 data point were used in this analysis to get the stresses (Von Mises and Maximum Principal Stress) in the data points. The geometry of the pipe is shown in Figure 2 and the pipe material properties are also shown in Table 2, a dent size of 18mm was used to perform the Numerical analysis and a pressure of 5.5MPa was applied laterally to cause the dent on the pipe. The resulting effect on the pipe is shown on the contour plot of the stress and strain diagram as shown in Figure 3-7. Also, the deformation shape of the pipe due to the loading is shown on these figures. At a dent size of 18mm and an applied pressure of 5.5MPa the maximum stress induced in the pipe is 287.64957MPa, it should be noted that at this point the von mises stress is higher than the tensile strength of the pipe but below the ultimate tensile strength, hence the pipe could still function at this stress level.

Different dent sizes were then imputed using ANSYS parameters to get the values of stresses for those size of dent. Table 3 shows the various dent sizes and their corresponding stresses and strain. A graph of the Von Mises stress and the Maximum Principal Stress was plotted against the dent size as shown in Figure 8. From the graph it is obvious that at every dent size the maximum principal stress is higher than the Von Mises stress. Also, the graph shows that generally an increase in dent size corresponds to an increase in the stress in the material, however, this relationship is not linear as shown in this study.

## V. CONCLUSION

The evaluation of dent size on the structural integrity of oil and gas pipeline is carried out in this study. The extent to which a dent will affect the strength of the pipeline was determined and the relationship between size of dent and the stress induced in the pipe was observed. It can be concluded that the relationship between dent size and the stress induced in the pipe is directly proportional but not a linear relationship. Also, at dent size greater than 19mm the pipe will buckle and fail due to the ultimate tensile strength being exceeded.

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