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Finite Element Assessment of Difficult Pipelines at Bends

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Abstract. This paper presents numerical assessment of difficult pipelines at bends using the finite element method (FEM). Difficult pipelines are those that are unable to be inspected using a pig inspection tool. These unpiggable pipes, especially at the bend sections, exhibit difficulties to be piggable for several reasons, thus they are exposed to hazards that can neither be inspected nor controlled. The structural response of the bends is then required to be investigated. This paper aims at simulating the structural response of bends caused by internal corrosions using the ANSYS FEM software. Circular pitting corrosion at different depths and diameters were applied to simulate the stress distribution for three pipe models, namely standard 90° pipe bend, miter bend and unbarred full-bore tees pipe bend near dead end. The results of different corrosion equivalent stress distribution were compared and the most reliable type of bend was reported.

Introduction

A typical pipeline system comprises different components and fittings, namely, the pipe itself, valve, bend, elbow, transitions (contraction, expansion) etc. The use of pipe bend, for instance, is important to cross obstacle and directional change of the flow. For a pipeline system used in the oil and gas industry, the pipe is required to be inspected and cleaned at certain interval period of time in order to ensure smooth operation of the whole system. The so called *pigging* (*pig*) is a common tool used in the maintenance of pipelines which functions to remove deposits which could obstruct or retard flow through a pipeline. The pigs are inserted into and travel throughout the length of a pipeline driven by a product flow. Their occurrence usually does not interrupt production.

Although an oil and gas pipeline is proposed to be designed with the consideration of a pig system with it, it is quite unlikely to be the case at all time, especially for old pipelines developed in the 1980s. This pipeline system is then classified as *unpiggable*.

One of the major threats for an unpiggable pipeline system is corrosion. The World Corrosion Organisation (2010) for example, highlighted an estimated \$2.2 trillion annual cost of corrosion worldwide (3 to 4 % of gross domestic product (GDP) of industrialized countries). Leakage from corrosion failures lead to oil spill in the sea water and this is something intolerable and has become one of the greatest public attentions and concerns.

For a bend placed in an unpiggable pipeline system that is prone to corrosion problem, the possibility for it to be cleaned and inspected will become a major concern. This is an example of a case of a *difficult pipeline*. The reliability and integrity of such pipe cannot be easily determined using any empirical or mathematical equations. Numerical analysis is believed to provide better solution to such problem.

This paper aims at analysing the structural response of difficult pipelines towards corrosion effect by means of numerical modeling. The effect of corrosion to three different pipe models, namely *standard 90° pipe bend*, *miter bend* and *unbarred full-bore tees pipe bend near dead end* was analysed using ANSYS finite element method (FEM). The unbarred full-bore pipe bend near dead end in particular, was chosen because of its uniqueness in design, sample of which is shown in the

Methodology section of this paper. The structural response is reported by means of stress distributions resulted from the simulation. Internal corrosions of various sizes were simulated for comparison.

Theories on Corrosions in Difficult Pipelines

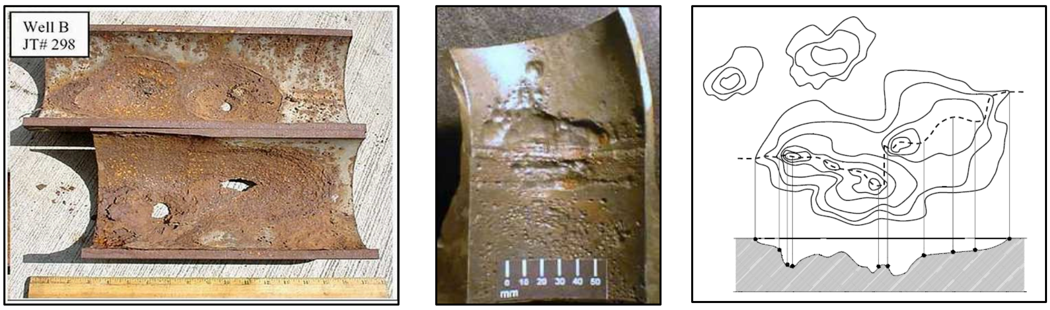
Pigging. *Pigging* in the maintenance of pipelines refers to the practice of using pipeline inspection gauges or *pigs* to perform various operations without stopping the flow of the product in the pipeline. Pipeline pigs are inserted into and travel throughout the length of a pipeline driven by a product flow. They were originally developed to remove deposits which could obstruct or retard flow through a pipeline. Their occurrence usually does not interrupt production. Physically, the pig can be spherical, elongated or composed of several parts.

Corrosion maintenance using the IP has received numerous attentions in the present world because of enhancement in technology. Different types of pigs have been developed and extended, a summary of which has been reported in [1]. The *in line inspection* (ILI) tool or *smart*/*intelligent pigs* (IP) are used to provide an overview (mapping) of the condition of a corroded pipe. The tool is extensively used to carry out inspection and maintenance works on corroded pipelines.

Difficult Pipelines. Difficult pipelines are pipelines that cannot be inspected by a standard pig. They exist due to some limitations in a pipeline system, such as

- No access, in case where the launcher and receiver are not equipped to the system.
- Existing piping component, such as 90° miter bends, dead ends, off-takes, reduction, dead end, one-cut bend, unbarred full bore T and valve.

Corrosions. Corrosion is the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces deterioration of the material and its properties. They deteriorate the structural strength and integrity of a pipeline. In general, corrosions can be observed either at the *internal* or *external* side of the pipeline wall. The shape of corrosion pit is governed by several *length scale* parameters, namely the *depth* (d), *longitudinal length* (l) and *circumferential width* (w). The shapes of corrosion, however, may be difficult to characterize, as shown in Figure 1.



(a) (b) (c)

Figure 1. Examples and skectch of pipeline failures due to internal corrosions

Finite Element Method Analysis at Pipe Bends

Pipe bends are critical components in a piping system. Pipe bends are curved bar with annular cross section whose reaction to external loading is complex. Several numerical studies involving pipe bends with the use of finite element methods have been carried out previously, part of which will be briefly summarized in Table 1.

Table 1. Summary of Research Works on Pipe Bends

Authors	Concern	Outcomes
Prasad and Rao, 2013 [2]	Effect of applying internal pressure to the ovality of the **bends**.	Considering the total deflection and stresses.
Bhattacharya and Long, 2010 [3]	Pipe **bend** for the stress intensification factor and flexibility factor.	Analyse assumptions made within and outside the of ASME B31 piping codes.
Swart et al., 2010 [4]	Pipe **bends**, in general.	Gurson plasticity model simulated pipe behaviour due to the longitudinal deformation, ovalization and warping. To compare with integrated Heterosis elements results.
Kim et al., 2009 [5]	Corrosion defect for hot **bend** pipe. Hot bend pipe is used for route change that is more than 16°.	Prediction of burst pressure using a pre-assumed value of bend coefficient and average thickness to the corroded.
Eckart, 1996 [6]	Pipe **bends**, in general.	To determine bend loading capacity and fatigue strength.

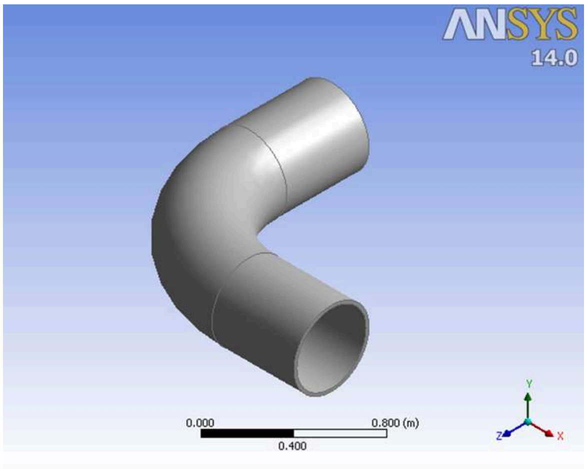
It can be seen from Table 1 that most works on pipe bends were based on understanding the impact of the structure towards different assumptions and concerns. Only the typical types of bends were selected in their studies. Not much work has been given to unique bend such as the *unbarred full-bore pipe bend near dead end*, which is considered to be unpiggable. Thus this is a gap that will be further investigated in this study. The outcomes from this will be later compared with the common *standard 90° pipe bend* and *miter bend.*

Methodology

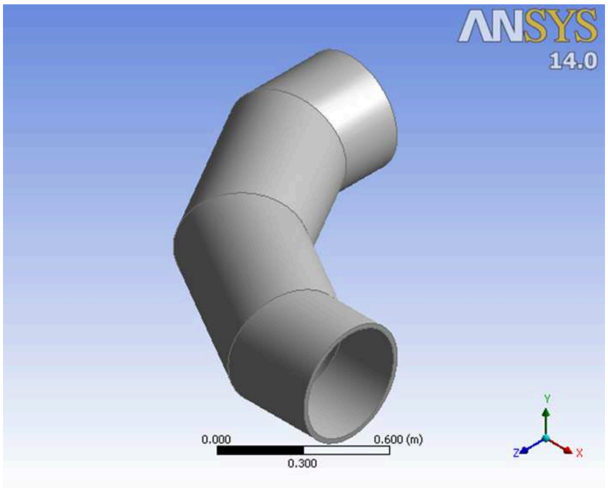
Pipe Bend Model. Three different pipe models, *i.e.* standard 90° pipe bend (Model 1), miter bend (Model 2) and unbarred full-bore tees pipe bend near dead end (Model 3) have a constant nominal diameter of 450 mm and wall thickness of 17.45 mm. The 3D models of the bends were constructed using ANSYS Workbench version 14.0, as shown in Figure 2.

Corroded Pipe Bend. Pitting corrosion defect is defined as circular shape. In ANSYS, its volume was taken out from the internal wall of the pipe [Fig. 3(a)]. In this paper, the modelling of pitting was controlled by two dimensions, namely (i) area and (ii) depth of corrosions. Model 3 in particular, was simulated with two corrosion pits (Model 4), as shown in Fig. 3(b). The value of corrosion pit depths were set to 2.0 mm, 4.0 mm, 6.0 mm, 8.0 mm, 10.0 mm and 12.0 mm. The areas of corrosion pit were varied by means of setting different diameter of pit, ranging from 0 to 80 mm. With this variations, a total of 80 cases were analysed in this study.

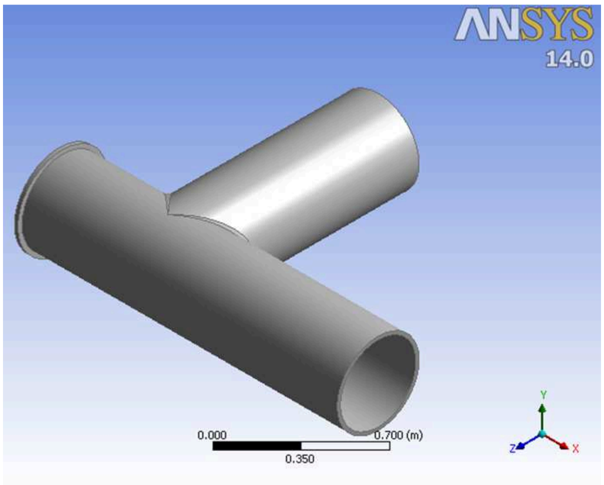
Loading. The loadings applied to the FEM pipe models were tested under the *standard earth gravity load* of 9.8066 m/s² and *internal pressure* of 250 bar.



(a) Standard 90° pipe bend (Model 1)

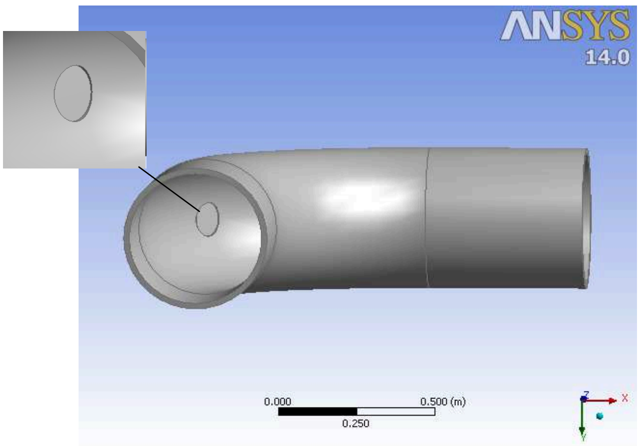


(b) Miter bend (Model 2)

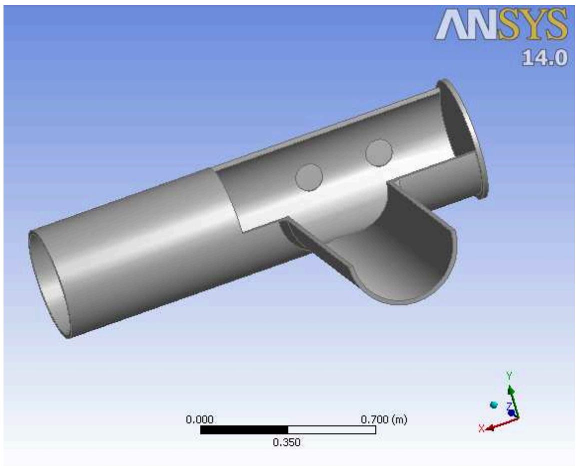


(c) Unbarred full-bored pipe bend near dead end (Model 3)

Figure 2. Three pipe bend models constructed using the ANSYS FEM



(a) Pit corrosion in Models 1 and 2



(b) Two corrosion pits in Model 4

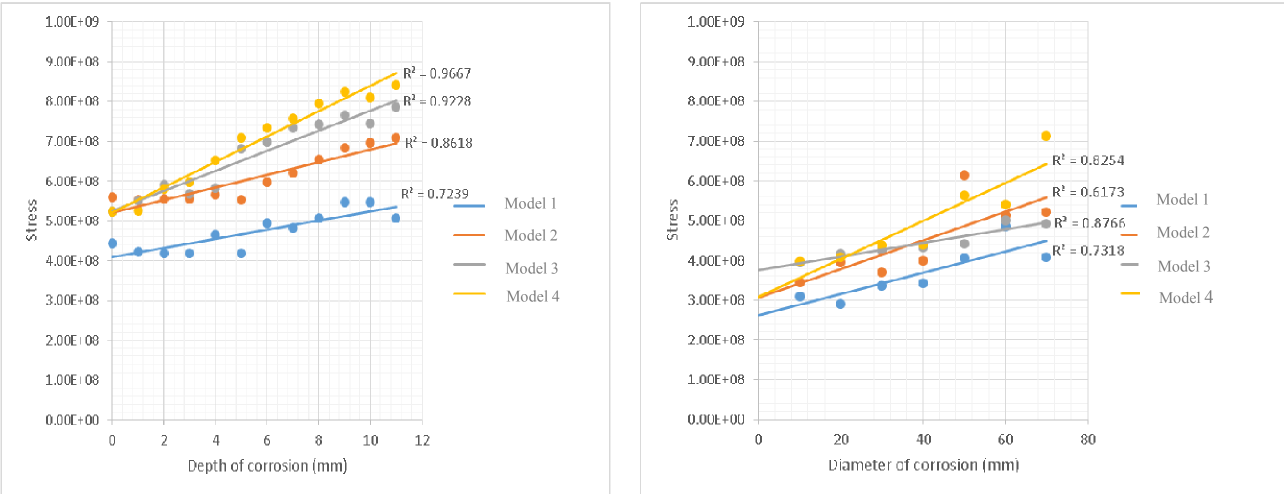
Figure 3. Sample of pitting corrosions at pipe bend models constructed using the ANSYS FEM

Results and Discussion

Stress Definition. Equivalent stress or sometimes referred to as the *Von Mises Stress* (σ_e) is related to principle stress by the equation,

$$\sigma_e = \left\{ \frac{1}{2} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right] \right\}^{1/2} \quad (1)$$

with σ_1, σ_2, and σ_3 represent stresses exerted on different surfaces of a 3D body. The structural performance of the corroded pipe bends was described using Equation (1) and the results are presented in Figure 4 (a) and (b).



(a) Corrosion pit with varying depths (b) Corrosion pit with varying areas (by varying diameter)

Figure 4. Stress distributions obtained for different corrosion scenarios

In general, results from all pipe bends showed an increment in stresses when the corrosion pit was made deeper (through its depth) or larger (through its diameter). Higher stress responds to greater danger to a structure.

A miter bend (Model 2) exhibited higher stresses than a normal standard bend. This is true because such bend comprises several joints made by beveling each of two surfaces, usually at a 45° angle, to form a corner, usually a 90° angle. Thus such design creates more frictions to the structure. Frictions can be considered as obstacles to a structure. Therefore a mitered bend design tends to produce more stresses compared to a frictionless bend (Model 1).

Results for the difficult pipe bend (Model 3) were compared with those from Models 1 and 2. It can be seen that the unique design of Model 3 produced higher stresses as compared to the common bend shapes of the two models. Such bend design coupled with its limitation to be inspected and cleaned (piggable) will then raise a concern to pipeline operators on the potential hazards that it is exposed to.

The impact of corrosion density at difficult pipe bend could be illustrated by comparing results from Models 3 and 4. As expected, the stresses of Model 4 which has more corrosion pits were higher to the one with less corrosion pits (Model 3). This supports the fact that corrosion at a difficult area will influence the integrity of a pipeline.

Summary

Extensive finite element method (FEM) ANSYS simulations were presented in this paper for different pipe bend models by means of varying the size (depth or area) of the corrosion pits. Difficult pipe bend of type unbarred full bore pipe bend near dead end produced highest stress due to its unique design, followed by the mitered bend and the standard 90^o bend. As expected, difficult pipe bend with more corrosion pits will provide more hazards to the structure. Therefore, an unpiggable pipe bend of such type should be properly monitored and inspection to avoid corrosion damage to the pipeline system. It has been shown that the FEM is well suited for the prediction of pipe bends failure with respect to maximum stress distribution of a pipe bend.

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