Structural analysis for in-service gas pipeline lowering using numerical method

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Structural analysis for in-service gas pipeline lowering using numerical method

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Abstract. Construction of new highways, buildings, airport runways and other facilities is often planned at locations where aboveground pipelines are present. Relocating such lines can be extremely expensive in terms of shutdown time and new pipeline materials. Lowering this existing pipeline can have big cost benefits. The line can be lowered while remaining in service with no lost production and the cost of such lowering an existing pipeline section is relatively cheap. In this paper, the calculation method with both analytically and numerically are discussed and explained in a 28 in pipeline lowering process while keep the pipeline is safe and still in-service.

1. Introduction

Lowering a segment of pipeline is an easy job but it can have a huge cost. Pipeline can be lowered while in-service without loss of production and the cost is not too expensive [1, 2].

New building constructions, highways, railways, airport runways etc are often planned on the location where above ground pipeline exists. Relocating such a pipeline can incur high cost with downtime and new pipeline materials (valves, fittings, flanges etc) accounted [3,4]. The alternative is to lower the pipeline with sufficient safety protection to handle the problem.

In this paper, an analytical analysis is performed to assess how to lower the pipeline to the desired depth in a gas pipeline segment suffering from lack of buoyancy control in a large swampy area. The pipeline segment also was not buried to the sufficient depth during the construction. This analysis is a real case experienced by an in-service gas pipeline. A numerical stress analysis is also carried out using non-linear Finite Element Analysis software Abaqus [5] to this 28 in pipeline by modeling several load cases to evaluate pipe structure response against pipeline profile change. A numerical analysis is also performed to lower the pipeline to the desired depth underground.

2. Analytical analysis

An optimum profile of the pipeline must be calculated first to ensure a smooth transition in the pipeline lowering process and to keep the stress in a pipe still in the allowable limit. An assessment should also be performed to determine the construction method in physically lowering the pipeline to follow this optimum profile.

Engineering and design of the new profile must be very precise to avoid sudden drop of pipe resulting in pipe rupture or buckling.

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The bending radius of lowered pipeline as shown in Fig. 1 is

$$R = \frac{x^2+y^2}{2y} \tag{1}$$

The minimum bending radius for pipeline profile is

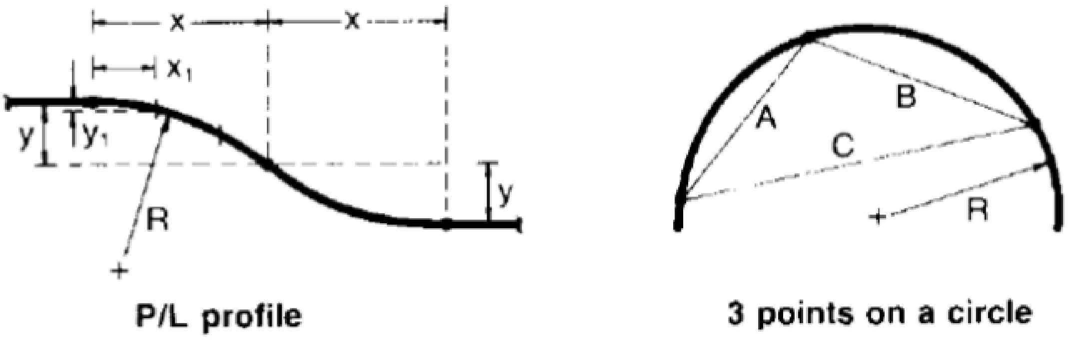
$$R = \frac{EC'}{S} \tag{2}$$

The depth and horizontal distance of pipeline to avoid undesired stress are

$$y = \frac{EC'}{S} - \sqrt{\left(\frac{EC'}{S}\right)^2 - x^2} \tag{3}$$

$$x = \sqrt{2y\frac{EC'}{S} - y^2} \tag{4}$$

$$R = \frac{A\sin\left[90 - \cos^{-1}\frac{B^2+C^2-A^2}{2BC}\right]}{\sin\left[2\cos^{-1}\frac{B^2+C^2-A^2}{2BC}\right]} \tag{5}$$



P/L profile **3 points on a circle**

Fig. 1 Optimum profile of pipeline after lowering

where: R = bending radius m; x = horizontal distance, m; y = deflection or dropped from horizontal condition, m; S = bending stress, Mpa; C' = one-half diameter of pipe, m; E = elastic modulus of pipe material, MPa; A, B and C = triangle dimension, m

From the eqs. 1 to 5, it can be seen that the bending radius R does not depend on wall thickness and cross section of the pipe.

3. Finite element method

Analysis was conducted using Finite Element Method to evaluate the response of the structure in linear static conditions. Finite Element model was created as a 1 dimensional beam based on geometry from the field. For models 4 to 7, soil models as rigid surface were added. The summary of model input for FEA is tabulated in Table 1.

Table 1 Model input for linear static analysis using FEA

Model	**Length (m)**	**Mid segment (m)**	**Internal pressure (psig)**	**Upward disp (m)**	**Downward disp (m)**	**Gravity**	**Concrete weight**
1	200	25	1000	0.8	2.3	No	No
2	200	50	1000	0.8	2.3	No	No
3	200	100	1000	0.8	2.3	No	No
4	200	-	1000	-	0.9	Yes	No
5	200	-	1000	-	2	Yes	No
6	200	-	1000	-	0.9	Yes	Yes
7	100	-	1000	-	0.9	Yes	Yes

Some models are illustrated in Fig.2 and Fig.3.

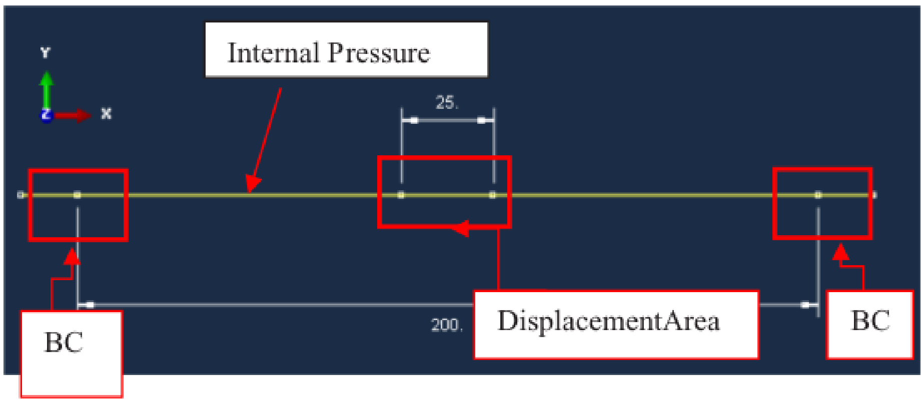


Fig. 2 Boundary conditions and loading for model 1

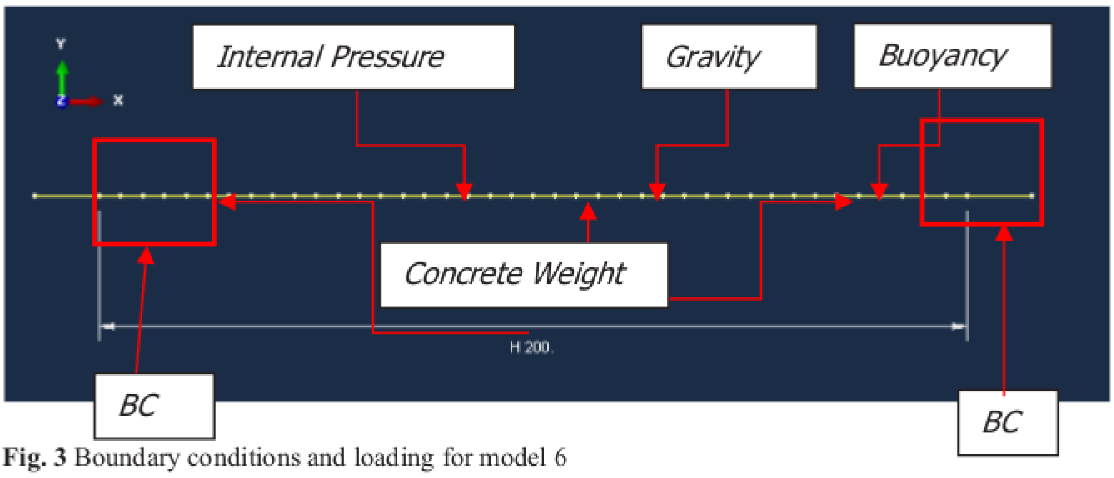


Fig. 3 Boundary conditions and loading for model 6

Boundary conditions for all models are fixed in the x, y, z direction and pipeline longitudinal axis rotation (x axis). Actual internal pressure loading is applied and in-situ conditions are assumed as mid-segment displacement as represented in model 1 to model 7.

4. General assumptions

Some general assumptions are made for the analysis. Analysis is carried out in the linear range and static condition. Pipe material has a *Specified Minimum Yield Strength* of 65,000 psi (448 MPa) and outer diameter of 28 inch (0.711 m). Soil surface is assumed to be rigid. New pipeline depth is 0.9 m at the pipe axis for maximum pipe stress of 0.5 SMYS (case 1) and 2 m for maximum pipe stress of 0.75 SMYS (case 2). Pipeline condition before lowering is buried to the one-half diameter of pipe (356 mm), fluid soil density of 1442 kg/m^3. Concrete weight is 1776 kg. Buoyancy is due to marsh (soil and water).

5. Result and analysis

5.1 Results for analytical method

Table 2 shows the summary of analytical result for pipeline lowering calculation. New pipeline profile for case 1 is illustrated in Fig.4.

Table 2 Summary of analytical result

Case	E, GPa	C_1 (m)	SMYS (MPa)	SR_{all}	σ_{all} (Pa)	Bend Radius (m)	Drop from horizontal (m)	X (m)	X_{total} (m)
1	200	0.36	448	0.5	224	317	0.45	17	34
2	200	0.36	448	0.75	224	211	1.00	21	41

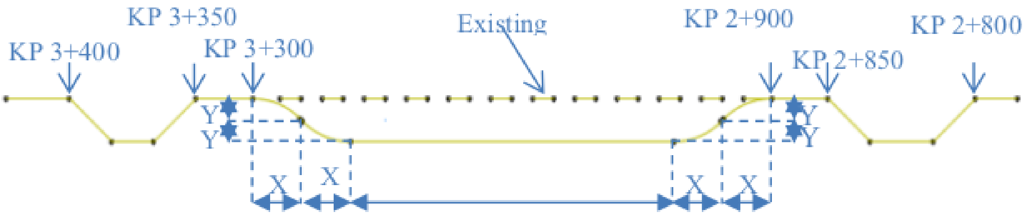


Fig. 4 Pipeline profile

For case 1, the maximum is found to be 0.91 at 2934 to KP+3267.

5.2 Linear static analysis using Finite Element Analysis

Linear static simulations are conducted for the corresponding models using Non-Liner Finite Element Analysis software Abaqus. The outputs required from the simulation are the maximum stresses for all loading conditions. Summary of linear static analysis results showing maximum stresses for every loading condition in all models are shown in Table 3.

Example of displacement and stress distribution occurs in pipeline model 1 after final loading is shown in Fig.5 while the displacement and stress distribution occurs in pipeline model 4 is illustrated in Fig.6.

Table 3 Linear static analysis results

Loading I		
Linear static analysis	**Maximum Stress**	**Stress Ratio**
Model 1, 2,3, 4, 5, 6 and 7	156 MPa	0.35
Loading II		
Linear static analysis	**Maximum Stress**	**Stress Ratio**
Model 1	162 MPa	0.36
Model 2	166 MPa	0.37
Model 3	187 MPa	0.42
Model 4	224 MPa	0.50
Model 5	336 MPa	0.75
Model 6	163 MPa	0.36
Model 7	170 MPa	0.38
Loading III		
Linear static analysis	**Maximum Stress**	**Stress Ratio**
Model 1	218 MPa	0.49
Model 2	255 MPa	0.57
Model 3	420 MPa	0.94

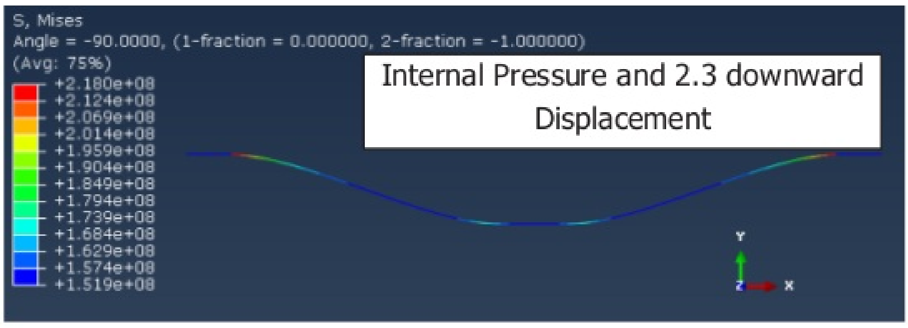


Fig. 5 Stress distribution for model 1

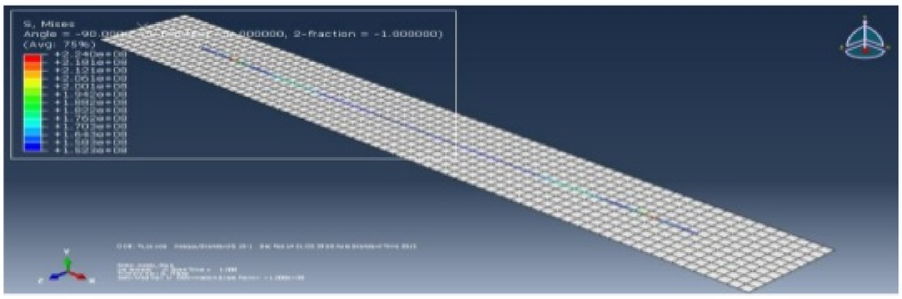


Fig. 6 Displacement and stress distribution in model 4

6. Comparison of results

The horizontal distance of pipeline that can be lowered from analytical method can be compared to the horizontal distance obtained from linear static analysis using FEM for case 1 as tabulated in Table 4.

Table 4 Comparison of horizontal distance using analytical and FEM for case 1 (0.5 SMYS)

Analysis	**Horizontal Distance, m**	
	Stress Ratio=0.5	**Stress Ratio=0.75**
Analytical	34	41
Numerical (MEH)	36.5	50

7. Conclusions and discussions

From the analysis results shown for every case, it can be concluded that:

1. Maximum stress occurs on model 3 when applying 2.3 m downward displacement with the magnitude of 420 MPa and stress ratio of 0.94.
2. FE analysis results for model 4 and model 5 show that with stress ratio limit of 0.5 and 0.75 the pipeline lowering can be executed to 0.9m and 2m respectively.
3. FE analysis for model 6 shows that by applying combination of internal pressure, gravity, buoyancy and concrete weight loads the pipeline can be lowered to 0.9m with new profile and maximum horizontal distance of 60 m with stress ratio of 0.36.
4. FE analysis result for model 7 shows that by applying combination of internal pressure, gravity, buoyancy and concrete weight loads the pipeline can only be lowered to 0.6 m depth with the stress ratio of 0.38.
5. Based on analysis results and engineering judgment considering appropriate code/standard, the 28” pipeline can be lowered to 2 m depth at pipe axis by experiencing maximum stress of 0.75 SMYS.
6. Structural analysis with FE method results are slightly difference compared to analytical results due to non-linear geometry/material considered in FE method.
7. Structural analysis with FE method can be conducted to determine maximum distance and depth of pipeline lowering to avoid overstress that can cause pipe rupture or permanent buckling.
8. Construction method executed in the field should consider the result from this analytical/numerical method.

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