DESIGN OF WALL THICKNESS AND PREVENTION OF COLLAPSE OF SERVICEABLE LARGE DIAMETER PIPELINES

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Abstract

The oil bearing Niger-delta region in Southern Nigeria has been under local and international watch because of host communities' agitation, a situation resulting from environmental pollution and degradation which has been partly due to the failure and rupture of the pipelines used in conveying both crude and refined petroleum products. This paper examined the design of wall thickness and prevention of collapse of large serviceable diameter pipelines that are subjected to related constraints posed by factors contributing to their collapse either directly or indirectly to constructions, operations and environment where these pipelines arc serviceable. Pipeline design problems were presented iteratively and as such a suggested ratio of D/t>50 was closely examined, and this criteria prevented collapse either in high stress and instability or in likelihood stable enough for horizontal drilled installation.

Introduction

Designs of pipelines are usually based on conventional formulae for internal pressure and stresses created by bending and pulling. However, when a pipeline is being installed by the horizontal drilling process, it experiences a relatively short time period when it is subjected to external pressure in addition to bending and pulling stresses, all without internal pressure. [Fredrick Slogan, 1996]

If the wall thickness is thin, relative to the pipe diameter, instability of the walls may occur and stress calculations based on conventional formulae will not be able to predict the impending collapse. The collapse will be surprisingly abrupt because immediately prior to failure the material was well within its elastic range.

The primary objective of the pipeline design process is to design a system that will reliably transport fluids produced during its lifetime and at lower cost. [Fredrick Slogan, 1996]

There is a reliable way of selecting a wall thickness sufficient to prevent collapse of a large diameter pipeline. The method offered here has been derived by superimposing specific correction coefficients into a formula by S.P. Timoshenko (1980) for collapse of empty steel pipe when subjected to uniform external pressure.

Factors Contributing to Collapse of Large Diameter Pipes

The causes of collapse of large diameter pipes can be attributed to the following according to (Gregory S.C. and Paul Becker, 1998): Out-of-roundness, Bending Strain, External pressure, etc. Bending strain, External pressure, Pulling/Pushing forces, Environmental constraint, Construction constraints, Operational constraints.

1. Out-of-Roundness: America Petroleum Institute (API) specifications allow out-of- roundness to ±1% of the normal pipe diameter primarily to eliminate problems when welding. However, any out-of-roundness will contribute to a reduction in hoop- strength (6n) and threaten collapse.

Bending Strain: Bending Strain is created as the pipeline is pulled into place and it conforms to the radius of curvature of the drilled hole. Because the hole is drilled in sequential series of sections and then reamed to a diameter somewhat greater than the pipeline, the pipeline will almost certainly attain a radius of curvature slightly shorter than the average radius measured during the drilling survey.

3. External Pressure: During installation, the pipeline is surrounded by a mixture of drilling fluid and cuttings which have a density higher than water. Even if the pipeline is filled with water to offset buoyancy, the net effect is a positive external pressure. The external pressure may seem relatively small but it may be sufficient to cause a thin walled pipe, already weakened by out of roundness and bending strain, to collapse.

Additionally, drilling fluid is being pumped down and being discharged near the leading end of the pipeline. Discharge pressure varies but it is probably in the range of 200 psi. Although this pressure "is dissipated very rapidly, it must be kept in mind that the fluid is being forced along the annulus towards the ground surface and that the pressure surrounding the pipeline will be somewhere on a hydraulic gradient between the discharge pressure at front of the pipeline and zero at the ground surface.

4. Pulling/Pushing Forces: Forces applied to pull the pipeline into the hole will theoretically offset the bending stresses. However, researchers have shown for these tensile forces to meaningfully offset the effect of out of roundness and bending strain.
   They may create stresses near the material yield strength. This situation will probably arise when pulling a small diameter pipeline into a drilled hole. Therefore, axial strain created by pulling forces need not normally be considered when examining collapse of the horizontally drilled pipeline. It is becoming more common place to apply a pushing force to the pipeline i.e. being pulled into place, while it is very unlikely that this procedure will cause a pipeline to collapse, it does contain some element of risk under the right conditions. Again, these stresses and strain need not be considered except under unique project conditions.
5. Environmental Constraints: This includes definition of waves, current mudslides, fault movement etc, which can influence pipeline during its service lifetime. Offshore pipelines are far less liable to collapse if they are securely buried in a trench, fast moving ocean and rivers may generate longer amplitude of variation in the exposed state thus leading to accelerated degradation of the pipelines. These currents are responsible for exposing the pipeline by pushing, pulling and shifting sand and mud on the sea floor. The successful design of pipelines is based on its selection of low cost, quick development and a minimum of equipment required for installation.
6. Construction Constraints: This includes the equipment used for fabrication and installation, pipeline steels welding and quality control, trench digging, backfill and a rumoring. These procedures would be to establish a pipe diameter large enough to support the present market load with a minimum of compression, in turn necessitate the use of higher strength steel, grades to avoid excessive large wall thickness. Construction methods also affects the design of a particular pipeline in that, the availability of equipments may impose or preclude certain installation procedures that have direct impact, repair and other strategies such that pipeline collapse are reduced to minimum and early detection of failure location point along the pipeline, break location points and retrieval systems.

   Operation Constraints: This includes volume, pressure, temperature and **corrosion** of fluid to be transported; fluid escapes control measures and acceptable failure incidence. Special care should be exercised in designing pipeline containing acidic gases. Gases such as H_2S and CO_2 in the production stream are sometimes encountered, these gases are not only corrosive to pipeline but are harmful and fatal upon contact with human being. With the advent of computer programs many pipelines are monitored and controlled more effectively and efficiently. The design constraint includes the method used, routine codes guidelines, allowable stresses, factor of safety and staff shifts in operating condition. All designs must also account for regulatory requirements with a good factor of safety that will allow for future operation. [Asam, J.O., 2003)

Potential Pipeline Collapse

Studies have shown that pipes with a diameter to wall thickness ratio, D/t equal to or less than 20, will fail when the hoop stress exceeds the proportional limit before it will collapse. [Fredrick Slogan, 1996]

When'the D/t ratio is between 20 and 50, it can be mathematically shown that collapse is caused by a combination of high stress and instability because of reduced hoop strength. But, the external pressure required to cause failure in this D/t range is substantially higher than would ever be expected to occur during installation by horizontal drilling; when the only source of external pressure is a relatively low hydraulic head.

When the D/t ratio is equal to 50, the pipeline is in all likelihood stable enough for the horizontally drilled installation.

However, because prevention of collapse failure is critical. It is recommended that all designs with a D/t equal or greater than 50 be closely examined. Beginning at this level of D/t and working upward will prevent the designer from falling into the trap of overlooking a potential disaster. This was observed critically by Gregory S.C. and Paul Becker, 1995.

A Suggested Design Approach

It is now necessary to quantify the influence of each of these aspects of uncertainty; out of roundness, bending strain related to radius of curvature of the drilled hole, and external pressure. After the potential effect of each' of these factors has been quantified, the design can be completed by using the formula suggested herein. Out-of-roundness used herein is defined as

$$W \quad (Dmax \sim Dmin)/(2*Dn) \quad \ldots\ldots (1)$$

Where,

Dmax = maximum pipe diameter

Dmin - minimum pipe diameter

Dn = normal pipe diameter

The effect of pipe out of roundness on collapse depth proposed by Langner and Murphy is given by:

$$Pc^1 = \frac{Pc}{1 + 40w} \quad \ldots\ldots (2)$$

Where, PC ~ corrected collapse depth

PC = collapse depth for round pipe

And if the maximum out of rounding is permitted,

By API code, the formula now becomes

$$Pc^1 = \frac{Pc}{1.4} \quad \ldots\ldots (3)$$

As the pipeline is pulled into the drilled hole the pipe will assume the curved shape of containment to allow for the pipe bending to a slightly shorter radius of curvature.

Then, the design radius of curvature, it is suggested that a factor of 0.90 be applied. Therefore, the design specified minimum radius (R) will be altered accordingly and the radius value used in subsequent calculations will be

$$Re = R * 0.90 \quad \ldots\ldots (4)$$

Where,

Re = corrected radius of curvature.

R = specified minimum radius of curvature.

Langner and Murphy (1986) suggest the following equations to quantify the influence of bending strain on ninetine collapse.

$$(Pe/Pa) + (k/b) = 1 \quad \ldots\ldots (5)$$

Where

Pe = allowable external pressure under combined loading

Pa = allowable external pressure with bending strain

K = bending strain

b = bending strain at which collapse occurs without external pressure.

Several equations have been developed for determining b, two formulae which have been used are:

$$b = t/(2 * D) \quad \ldots\ldots (6)$$

$$b = 1.6 * (t/D)^2 \quad \ldots\ldots (7)$$

Equation (7) will yield a more conservative result when calculating the required wall thickness. It is well suited for use when the (D/t) ratio is greater than 30 and when the bending stresses and strains are within the normal range for a horizontally drilled pipeline installation. Bendine stress in the pipeline is calculated bv the formula

$$T_b = (E*D) / (24 * Rc) \quad \ldots\ldots\ldots\ldots (8)$$

Where,

E = modules of elasticity = 29,000,000 psi for steel

D = Diameter (inches)

R_c = Corrected radius of drill path curvature

From equation (4) above, T_b = Bending stress

However, external pressure will be exerted on the pipeline as it is drawn into the hole. Past researchers have presented formula to calculate the pipe wall thickness necessary to resist collapse when subjected to external pressure. [Dickensun, T.C., 1999]. A formula offered by S.P. Timoshenko (1970) will be used as the basis of the design calculations. This formula is specifically for use when considering pipe collapse in the elastic mode. Also, this formula is relative only to a section of pipe which is perfectly round and free of other forces. Therefore, as the effects of out-of-roundness and bendins strain are Quantified, thev will be expressed as coefficients in the S.P. Timoshenko formula.

$$t = 0.7932 * D* (P/E) \ 1/3 /(1 - Pr) \quad \ldots\ldots\ldots\ldots (9)$$

where, t = pipe wall thickness (inches)

D = Diameter of pipe (inches)

P = External pressure on the pipe (psi)

E = modulus of elasticity = 29,000,000 psi for steel

P_r - poison's ratio, = 0.30 for steel

Since external pressure is a function of feet of head and the specific gravity of the fluid surrounding the pipeline, the external pressure will be expressed in terms of head and specific gravity.

$$P = H*0.433*SG \quad \ldots\ldots\ldots\ldots (10)$$

Where, p = external pressure

H = feet of head above the pipeline (ft)

SG = specific gravity of the fluid in the annulus surrounding the pipe.

Calculation of Wall Thickness

After substituting the appropriate factors calculated above, the S.P. Timoshenko formula can be rewritten as follows:

$$t = \left[\frac{(D * H\ 0.433 * Sg * 1.4) / (1 - Pr)}{1/3\ [(2 * E) * [(1 - D) / 24 * Rc * b]}\right] \quad \ldots\ldots (11)$$

The objective is to select the wall thickness required for a pipeline to be installed by horizontal drilling. The design criteria for the pipeline is as follows: Normal Diameter of pipeline D = 36 inches Specified minimum yield strength Y = 65,000 psi Maximum depth of pipeline below grade H = lOOfeet Density of the drilling fluid and cuttings I> = 1000 per gallon Specific gravity of fluid SG = 1.20 Modulus of elasticity for steel E - 29,000,000 psi Design radius of the drilled pipe R = 3000 feet Code factor, K> 0.72

Procedure

Step 1: Select a preliminary wall thickness from the hoop stress formula from the hoop stress formula

$$t = (p * D) / (2 * y * k)$$

If the operating pressure is 1000 psi, the required wall thickness is

$$t = (1000 * 36) / (2 * 65,000 * 0.72)$$

$$t = 0.385 \text{ inches}$$

Step 2: Checking D/t $= \frac{36}{0.385} = 93.5$

Step 3: Use 0.385 to calculate b, whether it is greater than the recommended design limit of 50.

b = 16 *(t/D) 72 = 0.0856

Step 4: Calculating the required wall thickness with modified S.P. Timoshenko formula t = 0.4556 inches **Step** 5: Substituting for t = 0.4556 inches

b- 16 *(t/D) 72 = 0.002567 and

recalculate wall thickness

t = 0.4307 inches **Step 6:** Continued iteration until you would calculate the required wall thickness

$t = 0.434$ inches.

Conclusion and Discussions

The calculations and formulae here in, are not supported to be mathematically exact, they are intended to provide the pipeline designer another practical tool to use when designing large diameter pipelines.

A noteworthy observation resulting from this paper is that when the calculation is conducted on the pipelines with a (D/t) ratio greater than 50, the result is not affected by the ability of the material to resist its failure when an external force is exerted (strength of the material).

The influence of pushing and pulling forces on the pipe and its ability to withstand collapse is probably nil and they are not considered in the above. Example taken for 36 inches diameter pipeline which may collapse probably because of inadequate wall thickness during installation, hence the lighter wall thickness pipes will collapse no matter what.

Moreover, allowance must be made for any other situation which may be unique to a particular job for example. If the pipeline becomes struck while being pulled in, the pulling forces can become extremely high. [Fredrick Slogan, 1996] Therefore, the primary objective of this study is to design pipeline systems that will reliably transport fluids produced during its life time and at lower cost and will be sustainable in the Niger delta terrain.

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