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A Comparison of American, Norwegian, and Russian Standards in Calculating the Wall Thickness of Submarine Gas Pipeline

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Abstract

One of the key issues in the pipeline design is wall thickness calculation. This paper highlights a comparison of wall thickness calculation methods of submarine gas pipeline based on Norwegian Standard (DNV-OS-F101), Indonesian Standard SNI 3474 which refers to American Standard (ASME B31.8), and Russian Standard (VN39-1.9-005-98). A calculation of wall thickness for a submarine gas pipeline in Indonesia (pressure 12 MPa, external diameter 668 mm) gives the results of 18.2 mm (VN39-1.9-005-98), 16 mm (ASME B31.8), and 13.5 mm (DNV-OS-F101).The design formula of hoop stress due to internal pressure is interpreted in different ways for every standard. Only Norwegian Standard requires calculating hoop stresses in the inner surface, which leads to a decreased value of the wall thickness. Furthermore, the calculation of collapse factor due to external pressure is only regulated in American and Norwegian Standards while Russian Standard uses that factor as an intermediate parameter in calculating local buckling. For propagation buckling, either Russian or American Standard explains empirical formula of critical hydrostatics pressure as the input in propagation buckling calculation. This formula is almost similar to the empirical formula of Norwegian Standard. From the comparison of these standards, DNV OS-F101 gives more stringent requirements than others.

Abstrak

Perbandingan Standar Perancangan Amerika, Norwegia, dan Rusia dalam Menghitung Ketebalan Dinding Pipa Gas Bawah Laut. Salah satu parameter utama dalam perancangan jaringan pipa adalah perhitungan ketebalan dinding pipa. Studi ini membahas perbandingan metode perhitungan ketebalan dinding pipa untuk pipa gas bawah laut berdasarkan standar perancangan Norwegia (DNV-OS-F101), standar perancangan Indonesia (SNI 3474) yang mengacu pada standar Amerika (ASME B31.8), dan standar perancangan Rusia (VN39-1.9-005-98). Berdasarkan perhitungan terhadap pipa gas bawah laut di Indonesia (tekanan 12 Mpa, diameter eksternal 668 mm) didapatkan hasil ketebalan dinding pipa sebesar 18.2 mm (VN39-1.9-005-98), 16 mm (ASME B31.8), dan 13.5 mm (DNV-OS-F101). Untuk setiap standar, formula untuk *hoop stress* diintrepretasikan dengan metode yang berbeda. Hanya standar Norwegia yang menghitung *hoop stress* dari permukaan dalam pipa sehingga menghasilkan nilai ketebalan dinding pipa yang lebih kecil. Untuk perhitungan faktor *collapse* akibat tekanan luar, hanya standar Amerika dan Norwegia yang memperhitungkan faktor tersebut sedangkan standar Rusia hanya menggunakan faktor tersebut sebagai parameter antara untuk menghitung *local buckling*. Untuk *propagation buckling*, baik standar Rusia maupun Amerika menerapkan formula empiris tekanan hidrostatis kritis sebagai input dalam menghitung *propagation buckling*. Formula empiris ini hampir sama dengan formula empiris yang diterapkan pada standar Norwegia. Dari ketiga standar yang dibandingkan tersebut, standar Norwegia memberikan persyaratan desain yang lebih ketat dibandingkan yang lainnya.

Keywords: offshore gas pipeline, standards, wall thickness

1. Introduction

Compared with other forms of transport, pipelines provide more continuous, stable, and high-capacity supply of natural gas energy to the users. The capital cost of a pipeline project is largely a function of its diameter and length, although other factors such as geography and topography also should be considered. For offshore condition, there are more restrictive limitations than onshore environment. The ability to design, construct and operate safe and economic pipelines is critically affected by the requirements of the standards which are adopted.

Basically, the codes and standards are used to set the minimum requirements for the design, fabrication, installation or construction, operation, maintenance and abandonment of pipeline systems. Moreover, they are the guidelines for designers, clients, contractors and other parties not directly involved in the certification process.

In pipeline industry, standard is the basic principle that can affect the design, construction, and operation of pipeline project. The deviation from the optimal solution would bring considerable economic losses and the deviation of the quality. The risk of accidents should be controlled to a reasonable minimum, but to completely eliminate their occurrence is impossible. A careful code selection is required to ensure the safety and technical aspects for the system. Particularly for deep-water pipeline designs, the design code needs to be carefully reviewed to ensure that all critical deep water design aspects are suitably be addressed.

The development of petroleum industries has lead to diversity of pipeline standards and specifications on international and national level. There are some considerations when developing pipeline standards such as the requirements and interests of the government and other parties. Thus, it is common to find different safety and technical requirements in pipeline standards of several countries [1]. Not only on international and national level, the different requirements are also common to be found in the different national company in a same country. In Indonesia, Pertamina (national oil company of Indonesia) and PT PGN (state-owned natural gas transportation and distribution company) have own criteria in classifying gas pressure as summarized by Table 1.

In some cases, the use of different pipeline standards has consequences when a pipeline transmission system is designed to cross different countries. The real case of this problem can be referred to Statoil (Norwegian national oil company) pipeline transmission system from the North Sea to continental Europe.

The application of different national pipeline regulations and standards within the sectors resulting the variation of wall thickness for the same pipeline from one sector to the next.

Table 1. Pressure Classification of PT PERTAMINA and PT PGN Indonesia

Pressure Classification	PT PERTAMINA (bar)	PT PGN (bar)
Very high	>16	>16
High	10-16	4-16
Medium	5-10	1-4
Low	<5	<1

Generally, every country has its own standard. But there are some standards which are widely used by many countries in designing gas transmission offshore pipeline. Two of them are American Standard, ASME B31.8 (Gas transmission and distribution piping system), and Norwegian Standard, DNV-OS-F101 (Submarine pipeline system). In Indonesia, SNI 3474 (Gas transmission and distribution piping system) is used as national standard of pipeline design. SNI 3474 basically refers to ASME B31.8. However, not all oil and gas companies in Indonesia adopt ASME B31.8 in their offshore pipeline design. Many of them prefer to apply DNV-OS-F101 to their design.

This paper will discuss the design of wall thickness using some standards. The primary objective of the linepipe design is to determine the optimal wall thickness and steel grade of the pipeline. Optimizing the wall thickness of a subsea pipeline is essential to avoid hydrostatic collapse and rupture. A pipeline may be at risk of collapse when the external water pressure exceeds the internal pressure. The interest in optimizing the pipeline wall thickness is particularly obvious for large transmission lines, typically gas pipelines. The cost of the bare steel pipe may be up to 50% of the entire pipeline project cost [2]. The three standards used in this study are ASME B31.8, DNV-OS-F101, and VN39-1.9-005-98. VN39-1.9-005-98 is Russian standard of design and construction of offshore gas pipeline. Russia has the world's largest gas transmission system and all is designed by its own standard.

The result of this study provides information for oil and gas industry especially in Indonesia to decide which standard is more applicable for their pipeline wall thickness design, both from technical and economic aspects.

2. Methods

For determining wall thickness of submarine ipeline, there are some main parameters that should be defined as the input for calculation. They are diameter of pipe, material of pipe, and environmental condition of pipeline.

This calculation will focus on the calculation of an offshore gas pipeline project in Indonesia. Location of the project is approximately 25 km from the river delta with wavy contour and 60-90 m depth. This pipeline is designed to transport natural gas by distance of 33.3 kilometers. Table 2 summarizes the input parameters for the calculation of the wall thickness. Other parameters such as water depth, sea water properties (density and kinematic viscosity), tidal elevation, as well as wave and stream are also considered in the calculation.

The initial wall thickness value is assumed or calculated using a conventional thin wall pipe formula. This value is then verified if the wall thickness satisfies all the criteria required by the standard as presented by Table 3 [3-5].

Table 2. Data Input

Parameter	Value	Unit
Outside diameter	667.74	mm
Material grade	API 5L X65	
Specified minimum yield stress	65000	psi
Specified minimum tensile stress	77000	psi
Coating thickness	2.5	mm
Density of pipe steel	7849.047	kg/m^3
Density of coating	920	kg/m^3
Density of concrete	2400	kg/m^3
Density of content	102.9	kg/m^3
Design pressure	1740	psi
Maximum temperature design	100	°C
Hydrotest pressure	2176	psi
Corrosion allowance	5	mm
Modulus elasticity (steel)	3.10^7	psi
Modulus elasticity (concrete)	4.35.10^6	psi
Coating cut back	150	mm
Concrete cut back	300	mm
Density of joint coating	730	kg/m^3
Poisson's ratio	0.3	-

Table 3. Verification Steps of Wall Thickness Value

DNV-OS-F101	ASME B31.8	VN39 -1.9-005-98
Pressure containment verification	Hoop stress and longitudinal stress checking	Hoop stress and longitudinal stress checking
System collapse verification	Combined stress checking	Combined stress checking
Combined loading verification	External pressure checking	Local buckling check
Buckling propagation verification	Bending buckling check	

3. Results and Discussion

A calculation of wall thickness for a same submarine gas pipeline in Indonesia (pressure 12 MPa, external diameter 668 mm) shows that Russian Standard gives the biggest wall thickness (18.2 mm),while Norwegian Standard gives the smallest value (13.5 mm). American Standard gives a value between these two standards (16 mm). The results of this calculation are summarized in Table 4.

An initial calculation of minimum wall thickness value by American Standard gives unsatisfying value after validation process. As the result, it needs to find the higher wall thickness value and start a simulation to verify this new value. On the other hand, Russian Standard gives the minimum value of wall thickness that can fulfill the checking parameters. Basically, these two standards using the same method in calculating the minimum wall thickness i.e. a conventional thin wall pipe formula. The difference is the Russian Standard (VN39-1.9-005-98) multiplying the result to a safety factor resulting a higher value of minimum wall thickness than American Standard (ASME B31-8).

Wall thickness is designed for several conditions such as installation, hydrotest , and operation. For installation condition, pipe has no content and is not affected by corrosion factor. Environment force for this condition is environment force with 1 year cycle period. For hydro-static testing, pipe is filled with water and the water density is taking account to the calculation. Wall thickness design for this testing applies environment force with 1 year cycle period and does not consider corrosion effect. For operation condition, pipe is filled with gas and the density of gas is taking account to the calculation. Wall thickness for operation condition is designed by considering corrosion effect and take 100 years cycle period of environment force [3].

There are some reasons for the different wall thickness value of the standards. The different results primarily due to the choice of safety factors. These ratios reflect the need to provide the required level of reliability, depending on the category of the site, the quality of the manufacture of pipes , construction, and welding. The stress factor also contributes in giving different results. As illustrated by Figure 1, the stress in the pipe material consists of hoop or circumferential stress and longitudinal or axial stress. For all standards, the calculation of hoop stress due to internal pressure is calculated by applying a thin walled cylinder model [6]. However, the design formula is interpreted in different ways, resulting different results. Only Norwegian Standard requires calculating hoop stresses in the inner surface, which leads to a decreased value of the wall thickness. Furthermore, the calculation of collapse factor due to external pressure is

Table 4. Pipeline Wall Thickness Value for Different Standards

Standard	Wall Thickness (mm)
DNV FS OS-101	13.5
ASME B31-8	16
VN39-1.9-005-98	18.2

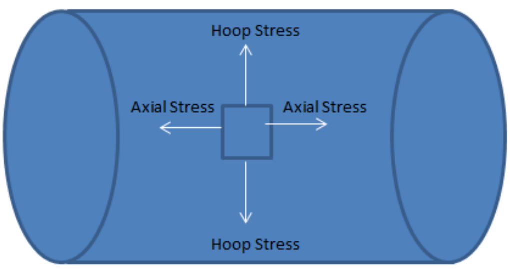

Figure 1. Hoop Stress and Axial Stress in a Pipe

only regulated in American and Norwegian Standards, while Russian Standard uses collapse factor as an intermediate parameter in calculating local buckling.

Regarding to local buckling, ASME B31.8 states this factor but does not briefly define the calculation method and refers to API 1111 for further description. On the other side, Norwegian Standard defines the local buckling calculation method for load controlled and displacement controlled condition. Norwegian standard requires comparing the capacity to collapse to the hydrostatic pressure of the water, which under certain conditions can be the criterion for selecting the thickness of the wall. For propagation buckling, either Russian or American Standard explains empirical formula of critical hydrostatics pressure as the input in calculating propagation buckling.

In ASME B31.8, the wall thickness is calculated based on traditional Allowable Stress Design (ASD), in which design stresses are compared to a factorized yielding stress level [6]. While this method is relatively easy to use not all the capabilities of the pipeline are fully explored, generally resulting in a more conservative design. Related to the other design aspects, this code does not give clear explanation on how to assess and mostly suggests the users to refer to API RP 1111.

API RP1111 is an American Standard based on Limit State Design. This means that the design codes are based on the probability of failure and the structural reliability of the pipeline for different limit states. As a consequence of this method, safety design factors are applied for the loads and the characteristic of resistance. In API RP1111, the bending safety factors are not defined in wall thickness calculation. The designers have to use their experience and there is possibility of a subjective approach. In some design aspects, API RP1111 refers to other design codes, including DNV recommended practices.

DNV FS OS-101 is based on the more stringent quality requirements for the manufacture of pipes. DNV FS OS-101 applies Load Factor and Resistance Design (LFRD system) in analyzing any loads that influence structure of pipe. The principle of the LRFD design format is to ensure that the level of structural safety is such that the design load on the pipeline does not exceed the design resistance of the pipeline except for a stated level of failure probability. It means this standard includes not only the requirements of the minimum value of the yield strength, but also to the parameters of its probability distribution as an incidental variable. In other word, LFRD system provides higher factor safety on the loads. The safety factors for different design conditions are well presented. Thus, this standard allow the application of lowest value of the wall thickness. Related to the other design aspects, DNV OS-F101 refers to relevant DNV recommended practices, resulting in a cohesive code structure for the complete design. Although both of Norwegian and Russian Standard define the result as minimum wall thickness, but Russian standard regulates more stringent requirement that does not allow the project to lay the smallest wall thickness [7]. From the comparison of these Standards, DNV-OS-F101 gives more stringent requirements than others.

4. Conclusions

Wall thickness of pipe should be calculated by considering all the combination stresses which may lead buckling and collapse not only in construction phase but also when the pipeline is located on the seabed. In designing wall thickness of subsea gas pipeline, DNV FS OS-101 gives more stringent requirements and the smallest value of wall thickness than ASME B31.8 and VN39-1.9-005-98. As the cost of bare steel pipe is a function of pipe dimension, the cost of pipe material of DNV FS OS-101 will be lower than ASME B31.8 and VN39-1.9-005-98.

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