Ultra Deep Water Subsea Pipeline Design and Assessment

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ABSTRACT

The ultra-deep water is a severe condition that leads to a challenge to the subsea pipeline during installation and operation. Subsea pipeline is subjected to extreme internal and external pressures. The difference of internal and external pressures in ultra-deep water is a critical issue in selection of wall thickness of subsea pipeline to be safe during installation and operation. In this paper, design and assessment of subsea pipeline in ultra-deep water is presented using Subsea Pro Simulation based on safety zone. In the software, the safety zone is determined based on internal and external loads acting on subsea pipeline.Results of simulation agree with current operating wall thickness.

KEY WORDS:*Safety Zone; Wall Thickness; Subsea Pipeline; Ultra-Deep Wate*.

NOMENCLATURE

t	Thickness of subsea pipeline
D	Diameter of Subsea pipeline

1.0 INTRODUCTION

In the subsea oil and gas development continue into deep water and remote region, meanwhile offshore oil and gas companies are now being planned in water depths 2000 m and greater. At these depths the technical challenges of the subsea system become increasingly severe and the need for optimizing of production operations become more important in the industry.

The ultra-deep water is a severe condition that leads to a challenge to the subsea pipeline during installation and operation. In the installation, the subsea pipeline is subjected to external pressure that may cause to collapse the pipeline structure. When the pipeline is operated at high pressure and high temperature (HP/HT), the pipeline generate stresses axially and longitudinally, which comes from internal pressure that may lead to be burst in the pipeline. The difference of internal pressure and external pressure could have influenced the stresses along with the subsea pipeline that impact on the wall thickness of the subsea pipeline. Therefore, an evaluation of the pipeline behavior should be performed in order to ensure the pipeline structural integrity are safe during installation and operation and comply with the lifetime period of operation.

On the other side, buckling is inevitable for subsea pipeline because of the pipeline will attempt to expand and contract during extreme pressure and temperature of internal pipeline, moreover the line is not free to move due to friction effect between pipe and soil consequently compressive forces are axially distributed along the pipe. Buckling is considered as instability of pipeline leading to potential hazards for severe operation of the pipeline. A number of failures have experienced in pipeline such as upheaval buckling on buried pipeline, lateral buckling on the seabed and the like. It is important to study and predict the possible buckling of subsea pipeline at designated location. Many researchers have investigated the catastrophes of pipeline and the associated literatures.

Offshore pipelines are installed and operated in the harsh environments which have to withstand to the subsea environmental load coming from hydrostatic pressure, sea current and sea water temperature and soil friction at the seabed. The level of water depth is unequal in the seabed following the seabed contour. In this circumstance, subsea pipeline is subjected to internal and external pressure in the different of water depth, such as shallow water, deep water and ultra-deep water. The differences of internal and external pressures cause the selections of wall thicknesses are to be critical during installation and operation. In addition, the internal pressure causes the pipelines to be buckled, as well as the external pressure causes to collapse the pipeline structure.

2.0 DESIGN AND CHALLENGE CONSIDERATION OF SUBSEA PIPELINE

M.BabsOyeneyin (2012) reported that the International Energy Foundation forecasts the increasing demand of oil consumption will be a shortfall of the petroleum industry, whereas the oil field of exploration will continue from deep water to ultra-deep water. The subsea production system will operate at severe internal and environmental condition have a need of advance technology to flow the crude oil. The major challenges for the companies are how to optimize production, minimize operational cost and guarantee multiphase flow in order to enhance the production and safety construction. Transportation of crude oil is one of challenge for subsea production system, there are some critical issue, especially in subsea pipelines which are need to be reviewed to guarantee flow assurance.

Maryam Maddahi et al (2011) stated that the prominent task in order to sustain the oil and gas production are the Selection of offshore facilities and flow assurance type. The offshore concepts offer the feature and advantage of offshore production facilities and introduces common component of the subsea completion system. The remoteness of production area with the harsh environment becomes a great challenge in the design of oil and gas production. The feasibility study will necessitate the development and implementation of technological solution to achieve the oil production. Different Area of oil production will cause different way to build the offshore production furthermore the right selection of facilities and subsea component are needed to avoid failure and high expenditure.

Ragnar T et al (2000) reported a pilot study for a DEEPPIPE project that the deep water has a great challenge to transport oil and gas production. This challenge imposes to high cost construction and operation. In consequence, the pipeline design must meet the tight requirement. The objective of the design was to provide more effective cost of installation and operation with regard to acceptance criteria for material selection, welded joint, service and testing for pipelines. Tension and fatigue test were carried out for the material to assure the mechanical properties. Allowable stress and strain refer to the DNV OS F101, whereas the global bending was considered as high strain and stress intensification occurred. For installation, The S-Lay method is effective cost to be applied where the pipelines are jointed at welding station.

Hermann Moshagen (1998) said that the design of subsea pipeline must comply with the pipeline design codes such as ANSI/ASME B31.4, API RP 1111, DNV F 101 Design Guidelines. The pipeline standard gives the strict requirements for design, materials, construction, operation and maintenance to assure that the pipelines are safe to be operated during a lifetime period without any failures or structure instabilities occurred, such as buckling, fatigue, out of roundness and excessive free spans and etc. The DNV OS F101 gives the design requirement for pressure containment which is called Load Resistance Factor Design (LRFD). The LRFD principle is the design load is not exceed the design resistance of the pipeline.

Andrew Palmer (1998) reported that the conventional pipeline design in deep water must withstand to external hydrostatic pressure. The pipeline is laid with air-filled during installation to resist collapse and buckle propagation. The wall thickness of pipe will be high and other difficulties with welding, possible repair and corresponding to high cost. The need of medium-filled to pipeline will be a question for engineering, meanwhile the inside pipeline will not be permitted to be empty to prevent a collapse. When the water is used to fill in the pipeline, it will affect to submerge weight of pipeline induce high tension on the topside. Alternative lighter liquids might have advantages to reduce submerge weight such as pentane which it has a density of 626.2 kg/m3 and boils at 36.1°C. The density of liquid will influence the top tension of pipeline with the result that the thickness of pipeline is selected to withstand the load.

Indu K. Mahendran et al (1997) studied The API and ASME restrict the selection of pipe wall thickness for the application of High Pressure and Temperature by mean of Burst Limit State Design principles to design subsea pipeline. The burst pressure limit state is a model to predict the strength of pipeline against the internal load and to acquire the reliable structure of subsea pipeline. The objective of limit state design is to estimate the strength of the pipeline structure respect to internal loads

3.0 BASIC THEORIES ON SUBSEA PIPELINE

This section provides the description of subsea pipeline theory related to the design of subsea pipeline by considering internal and external pressure. The internal pressure induces an expansion and lead to buckle during operation. The external pressure causes the pipeline to be collapse during installation and operation.

3.1 Hoop Stress

The primary requirement of the pipe wall-thickness selection is to sustain the stresses for pressure containment. The tensile hoop stress is due to the difference between internal and external pressure, and is not to exceed the permissible value as given by the following hoop stress criterion (DNV - 2000):

$$\sigma_h = (P_i - P_e)\frac{D-t}{2t} \le \acute{\eta}(SMYS - f_{y.temp}) \quad (3.1)$$

Where: the usage factor for pressure containment is expressed as

$$\acute{\eta} = \frac{2.\alpha}{\sqrt{3}.\gamma m.\gamma sc.\gamma inc} \quad (3.2)$$

where; α = Strength of material, γ_m = Resistance factor of material, γ_{sc}= safety class factor and γ_{inc}= incidental of design pressure ratio

The allowable hoop-stress F_h the criterion of ABS (2000) to be expressed by the following equation:

$F_h = \eta.SMYS.k_T$(3.3)

The hoop stress F_h in a pipe can be formulated as below:

—(3.4)

3.2 Burst Pressure Design

The pipeline is filled with pressurized liquid or gas which is called the internal pressure. The internal pressure generates stresses in the pipeline. If the stresses exceed the limit strength, then the pipeline will be burst. Burst pressure can be formulated as follows:

(3.5)

Where; , , = burst design factor of internal pressure 0.90 for pipeline and 0.75 for riser, = joint factor of weld, = Temperature derating factor, 1.0 for temp less than 121^{0}C, =Specified Minimum Burst Pressure, =Pipeline Design pressure, and = Hydrostatic test pressure

— (3.6)

Where: D= outside diameter for D/t >15
Substituting the pressure test:

(3.7)

— (3.8)

3.3. Collapse Pressure Design

API RP 1111 provides a formula to determine the collapse pressure as follows:

(3.9)

Where

– (3.10)

– (3.11)

Timoshenko and Gere (1961), propose the following design equation collapse pressure

(3.12)

3.4 External Pressure

External pressure is an important factor which should be taken into consideration in the design of subsea pipeline. The External pressure of subsea pipeline comes from hydrostatic pressure, which varies to every water depth level. The hydrostatic pressure is critical in the deep and ultra-deep water that may lead to collapse of pipeline structure. In order to determine a hydrostatic pressure for a certain water depth could be calculated as follows:

(3.13)

4.0 FIELD DESCRIPTION

This research uses Medgaz Gas Transmission Project by completion of subsea pipeline linking Algeria and Spain across the Mediterranean Sea as shown in figure.1, to overcome the challenges of 2,155 meters water depth. The pipelines are made of X70 API Grade Steel. The Medgaz subsea pipeline route traverses various contours of sea bottom as shown in figure.1. The route starts from Algerian Coastline to Spanish continental. The route has some area with sandy sediments and a clayey section between the shore approach and the outer shelf. Buckles potentially occurred from KP-22 to KP-37. The pipeline has been designed for 50 years life time period and using different thickness of concrete coating (45mm and 80 mm).

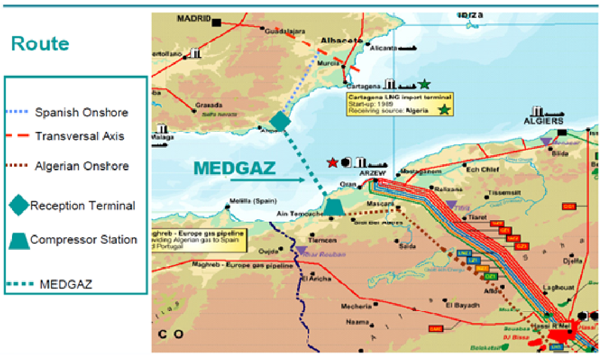


Figure 1: Route Map of Medgaz Pipeline (OTC20770)

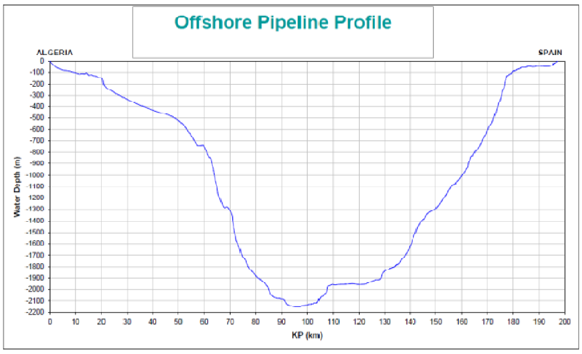


Figure2: Seabed profile along the route (OTC20770).

4.1Design Parameters

This section presents the design parameters which include the data related to pipeline geometry, mechanical properties of the material and operation and environmental loads.

Table1: Parameter Design

Parameter	Unit	Value
Outside Diameter	mm	609.6
Current Wall thickness	mm	29.9
Pipe Material Grade	-	X70
Young's Modulus (E)	GPa	207
Thermal Expansion Coef.(α)	C^{-1}	1.17x10E-05
Content density (Gas)	Kg/m^3	0.668
Design Pressure	MPa	22

Operating Temperature	^{0}C	60
Seawater Density	Kg/m^3	1027
Water Depth of Ultra-Deep Water	m	2155
External Pressure	MPa	3.5
Target Project Life	Year	50
Ambient Temperature	^{0}C	15

5.0 RESULT AND DISCUSSION

Results of simulation using the Subsea Pro Simulation are shown in Figures 3 ~ 9. Subsea pipeline wall thickness is crucial parameter when it interfaces with internal and external pressures in deep and ultra- deep waters. Figure.3 demonstrates wall thickness of subsea pipeline versus burst and collapse pressures. External pressure was calculated using hydrostatic equation (light green line for shallow, yellow line for deep and red for ultra-deep) and collapse and burst pressures were calculated using API rules.

Based on burst pressure results, the accepted minimum wall thickness of subsea pipeline is 14 mm for all water depths, which is shown by the crossing line between operating pressure and burst pressure as shown by a dash line in figure.3. In shallow water, it is indicated that burst pressure becomes dominant to be considered in the selection of wall thickness, when compared to collapse pressure. For deep water and ultra-deep water, collapse pressure becomes dominant, which is important to be considered in the selection of wall thickness. On the other hand, based on collapse pressure analysis, the minimum wall thickness differs for various water depths, as shown in the figure.3 an example: 12 mm for shallow, 18 mm for deep and 24 mm for ultra-deep. For deep water and ultra-deep water, collapse pressure is dominant to be considered to determine wall thickness of subsea pipeline.

Figures.4.a shows front page of Subsea Pro Simulation Software. This software was developed under Joint International Research Centre which can be download website as shown in Figure.4.b. Figures.5 and 6 show predicted wall thickness of subsea pipeline at shallow and ultra-deep waters using Subsea Pro Simulation Software. The predicted wall thickness showed good agreement with current operation wall thickness which is 23.4 mm and 31.8 mm.

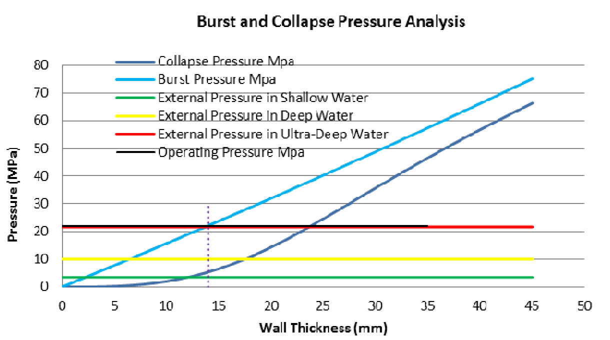
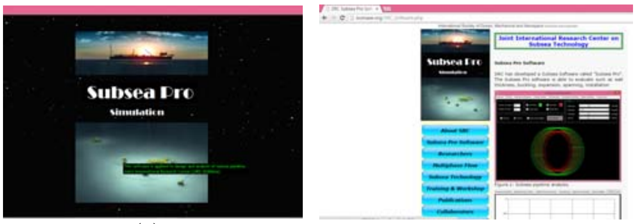


Figure 3:Safety Zone based on burst and collapse pressures analysis.



(a) (b)

Figure 4: Subsea Pro Simulation Software.

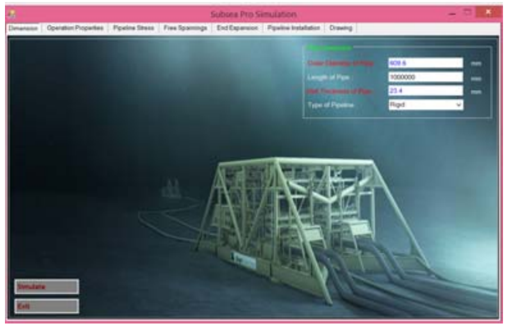


Figure 5:Dimension of subsea pipeline.

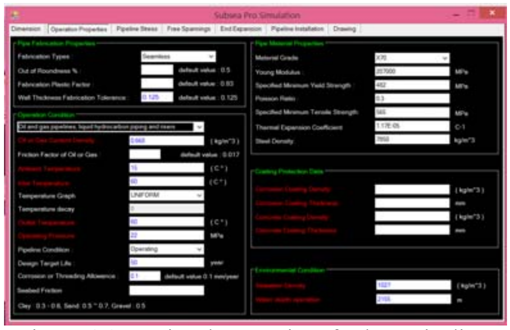


Figure 6:Operational properties of subsea pipeline.

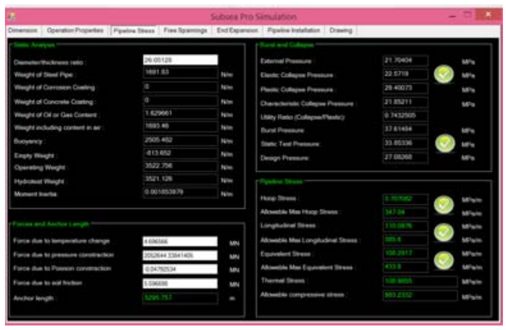


Figure 7:Static, stress and collapse analysis of subsea pipeline

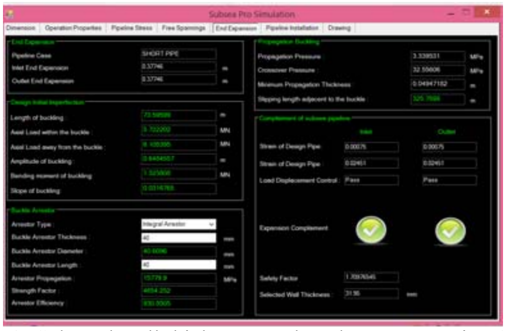


Figure 8: Selected wall thickness at ultra-deep water using Subsea Pro Simulation software.

Figure 9:Design of selected wall thickness at ultra-deep water using Subsea Pro Simulation software

6.0 CONCLUSION

In conclusion, this research determines and evaluates safety zone of wall thickness in design of subsea pipeline using Subsea Pro Simulation. As a case study, Medgaz project was applied. In the method, internal and external pressures are two parameters which are needed to be considered in selection of wall thickness. In shallow, burst pressure becomes dominant instead of collapse pressure. Safety zone of wall thickness is determined based on burst pressure. For deep and ultra-deep water, collapse pressure becomes dominant instead of burst pressure, hence safety zone of wall thickness based on burst pressure. This configuration provides a safety zone of wall thickness for every water depth. Predicted wall thickness using Results of simulation shows

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