Relationship between Pipeline Wall Thickness (Gr. X60) and Water Depth towards Avoiding Failure during Installation

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Abstract. Oil and gas today being developed at different water depth characterized as shallow, deep and ultra-deep waters. Among the major components involved during the offshore installation is pipelines. Pipelines are a transportation method of material through a pipe. In oil and gas industry, pipeline come from a bunch of line pipe that welded together to become a long pipeline and can be divided into two which is gas pipeline and oil pipeline. In order to perform pipeline installation, we need pipe laying barge or pipe laying vessel. However, pipe laying vessel can be divided into two types: S-lay vessel and J-lay vessel. The function of pipe lay vessel is not only to perform pipeline installation. It also performed installation of umbilical or electrical cables. In the simple words, pipe lay vessel is performing the installation of subsea in all the connecting infrastructures. Besides that, the installation processes of pipelines require special focus to make the installation succeed. For instance, the heavy pipelines may exceed the lay vessel’s tension capacities in certain kind of water depth. Pipeline have their own characteristic and we can group it or differentiate it by certain parameters such as grade of material, type of material, size of diameter, size of wall thickness and the strength. For instances, wall thickness parameter studies indicate that if use the higher steel grade of the pipelines will have a significant contribution in pipeline wall thickness reduction. When running the process of pipe lay, water depth is the most critical thing that we need to monitor and concern about because of course we cannot control the water depth but we can control the characteristic of the pipe like apply line pipe that have wall thickness suitable with current water depth in order to avoid failure during the installation. This research will analyse whether the pipeline parameter meet the requirements limit and minimum yield stress. It will overlook to simulate pipe grade API 5L X60 which size from 8 to 20mm thickness with a water depth of 50 to 300m. Result shown that pipeline installation will fail from the wall thickness of 18mm onwards since it has been passed the critical yield percentage.

1. Introduction
Pipelines are major components of the oil and gas production as it transports either oil or gas from platform to the onshore for refinery and process to be the saleable product. Before the advance technologies develop, the first pipe was short and basic to get oil from drill holes and pass it or connect it to nearby tanks or refinery for continue the process. In recent years there has been an increased focus on oil and gas as a source of energy. From this thing, many technologies are invented and start to seek any field that have hydrocarbon reserves. Starting from onshore and bring to the offshore part. In order to overcome any challenges comes from both technical and economical for different level of water...
depth, considerations to pipeline and design installation must be made. For instance, design installation for deep water depth have large margin with ultra-deep water depth as the parameter of the characteristic is different from each other. To get the better result without any problem or in other word, to make pipelines installation and operations feasible in deep water depth, we need to concern on such many things. This is because significant challenges will appear regarding pipelines for oil and gas field developments in the area that have deep water depth. The large concerns that need to take action are the method of laying pipe, selection of pipeline concept and ability to do intervention. Besides that, limitation also needs to keep eye on as set the limitations to how deep pipeline can be installed or laid. Basically, pipeline installations are limited by laying vessel. But not only limitations to laying vessel tension capacity but also to technical design solution are important to consider. Usually the most common pipeline concepts are single steel pipelines. At this stage of pipeline concept, it is consider being the simplest engineering concept as has well known behaviour during the installation. Basically, this simplest engineering concept mostly suitable for more shallow fields and the cost are relatively low. Parallel to it, going to deeper waters has caused different concept and much complicated solution being considered and take action. Besides that, application in deep water we can use sandwich pipes and pipe-in-pipe as an alternation concepts to single steel pipelines. Besides that, in order to reduce the required wall thickness and pipeline weights of single steel pipelines, development of higher steel grades is explored and considered which may improve lay ability at such depths. Pipe laying vessel is one of the most important and it includes pipe conditioning apparatus located at its stern. The have several pipe conditioning apparatuses which is includes radius control apparatus, straightening apparatus and pipe guiding apparatus [1].

Every each of them have different role to play it as radius control apparatus basically for imparting a substantially uniform curve to the pipe after it is spooled from the reel. In addition, the important role for straightening apparatus is imparting a reverse bending force to the pipe opposite to the curvature imparted to the pipe by the reel. Moreover, the part of guiding pipe apparatus is to guiding the pipe into the water after it emerges from the straightening apparatus [1]. Besides that, the other apparatus is endless pipe conveyor apparatus. This apparatus doing their job to arranged around the radius control apparatus to convey the pipe over the radius control apparatus in the passage of the pipe from the reel into the pipe straightening apparatus. Basically, pipeline vessel function is laying offshore subsea pipelines for such as several uses as the gathering of oil and gas from offshore facilities or from offshore platform or from offshore subsea well. They have main method to lay the pipe. For instance, in the country like Mexico, they use “stovepiping” as their main method to lay the pipe. This method actually a pipeline is fabricated on the deck of a lay barge by welding it together individual lengths of pipe. The “stovepiping” method requires the skill from the welders and also their relatively bulking equipment accompany the pipelaying barge crew during the entire process to lay the pipe operations [1]. Generally, there have several steps that can follow in order to laying a subterranean pipeline [2]:

i. Suspending a support stinger pipe which is from vessel that having one ends removable that connected to the vessel and the second one end directed towards the subsea floor.
ii. Said stinger which including an elongated member which is having plurality of guide elements spaced longitudinally and to engage the inner walls of a pipe line segment.
iii. Adjusting the rigidity of said continuous support. This method is to regulate the curvature of the pipeline between the vessel and the subsea floor. This method settles by removable engaging additional support member.
iv. Sequentially passing pipeline segments about said stinger. This method is to regulate the pipe curvature during passage of the latter to the said floor.

In recent years the activity of the offshore drilling of oil and gas are has been increasingly. Results from this activity, the more well has created and need pipelines extending from the offshore sites to shore installations. In this case, the need for such pipeline that can stand with harsh conditions are been recognized. For instance, the pipelines that need to be laid in the underwater that is particularly exposed with saline water must be adequately protected such as coatings to against the corrosion from occur. The coating will create some problems during laying the pipeline. So, the machine for applying the coating material to the pipe and for compacting process was fully disclosed [3]. In addition, the pipe should be heavy enough to make sure the pipe sinks well to the bottom of the sea and stable
against the action of disturbing influences [4]. The pipe must need something to holding them in stable position on or below the bottom of the body of water. There is some problem that has arisen when laying the pipeline along the floor of a deep body of water, i.e. kinking, excessive bending and difficult to control movement of length [5]. There have several systems that have been devised to control such a long length which is by using extensive guide structures and buoyant elements in order to support the pipeline [5]. Unfortunately, this system is expensive and the best way is by kept continuous controlling the tension of the pipeline that need to be laid, the excessive bending and kinking of the pipeline may be avoided without the extensive support structures or buoyant support means. It is so interesting to know much about the pipeline installation. This is because in the offshore operation, pipeline installation is one of the most challenging to handle it and requires a high level of engineering design to determine the criteria of the pipe, i.e. diameter, material and method. This criterion is important later on to make cost estimation and decide the installation vessel.

Two common methods to install pipeline which is S-lay and J-lay. S-Lay methods get their name from characterised by “S” curve during the laying of the pipeline to the seabed. The pipe will be stored and assembled on the vessel before it laying the pipeline to the bottom of the water. Basically, the pipe will leave the vessel at the stern which is at the back of the vessel and through a sloping ramp [6]. Upper curved part of the pipeline is known as the overbend or upper generator convex. In addition, certain angle the pipeline will lose contact with the stinger known as chosen angle. After the pipelines lose contact with the stinger, it will continue go deeper downward straight to the bottom of the sea and then gradually bends in the opposite direction which is known as the sagbend area. Starting from the sagbend area, the rest of the pipeline will continues to reach the bottom of the sea known as seabed at the touchdown point, Figure 1 [6].

![Figure 1. Pipe Laying Configuration Using S-Lay Method](#)

Besides that, in the sagbend area or lower generator concave, the combination must safely be sustained between bending and pressure loads. Besides that, in the sagbend area also, the tension has been applied at the top which is used basically to control the curvature in the respective area. Maximum strain and maximum bending movement can be controlled during the pipeline installation via the important parameters which is the stinger length, stinger radius, tension capacity and the longitudinal trim of the vessel [7]. J-lay method (Figure 2) suitable for bigger length pipe and required tension is bigger. This method is characterized by the pipeline which is leaving the vessel and nearly forms a vertical position and has J-shape. It can reduce the required over-bend curvature so shorter stinger should be enough. When further down into the water, the pressure will be increase and the tension will decrease progressively [6].

There has comparison between S-lay and J-lay, for instances the top tension category, S-lay configurations have higher required top tension compared to the J-lay configuration (Figure 3). Besides that, for the critical area, S-lay configuration, the most concern critical area is located at the overbend area whereas in the J-lay configuration, the most critical area is located opposite from the overbend which is at the sagbend of the pipeline. Usually, in the strain in the overbend region should satisfy the criteria that has stated in the DNV-OS-F101 (2007) [8].
Following material characteristic need to be consider, i.e. hardness, weldability, corrosion resistance, mechanical properties, fatigue resistance and fracture toughness [8]. Besides that, in order to identify the material process, following supplementary are required:

i. Supplementary requirement S, sour services which is pipeline that needs to transport fluid with existing of hydrogen sulphide (H2S) contents need to be evaluated for the “sour service” [8].

ii. Supplementary requirement F, fracture arrest properties that valid for gas pipelines which is carrying essentially pure methane up to 80% usage factor and up to a pressure of 15MPa with the wall thickness and the diameter of 30mm and 1120 mm respectively [8].

iii. Supplementary requirement P, Plastic Deformation which is applicable to the pipeline if the total nominal strain in any direction from a single event is exceeding 1.0%. Besides that, the tensile testing should be carried out in the longitudinal direction in order to satisfy the DNV requirements. This is for the pipes that require supplementary requirement (P).

iv. Supplementary requirement D, which is Dimensional Requirements which is should be consider the influences of dimensions for the requirements for tolerance that acting on the subsequent fabrication/installation activities and the welding facilities.

v. Supplementary requirement U, Utilization which is the purchaser may in retrospect upgrade a pipe delivery. For instance, in case of more than 50 test units, it must be demonstrated that the actual average yield stress is at least two (2.0) standard deviations above the SMYS. Besides that, the actual average yield stress shall as a minimum be 2.3, if the number of test units in between the range of 10 and 20. In addition, the actual yield stress of 2.1 will be held if the number of the test units in the range between 21 and 49 [8].

2. Methodology
OFFPIPE is a sophisticated, finite element method which is based on the computer program [9]. Basically, OFFPIPE has been developed in order to perform specifically for the modelling and
structural analysis of the nonlinear problems. It also encountered in the installation and operation of the offshore pipeline. Static installation is summarized in Figure 4.

![Figure 4. Static Installation using OFFPIPE software](image-url)

### 2.1 Data Input

Samples used for these simulations were API 5L X60. Wall thicknesses (mm) used i.e. 12, 14, 16, 18 and 20. Water depth (m) use i.e. 50, 100, 150, 200, 250 and 300. Outside Diameter use i.e. 8”, 12” and 16”.

### 2.2 OFFPIPE Preparation

The most important thing in OFFPIPE software was the data input. It will affect the result of simulation as the result is so important to decide the data input is valid or not and the pipe laying is pass or not according the percent yield stress limitation of the pipe known as 85%. It also need make simplified criteria for overbend as reference as Table 1 [8].

| Criterion | X70 | X65 | X60 | X52 |
|-----------|-----|-----|-----|-----|
| I         | 0.270 % | 0.250 % | 0.230 % | 0.205 % |
| II        | 0.325 % | 0.305 % | 0.290 % | 0.260 % |

### 2.3 OFFPIPE Manual

The first steps are creating a new input data which need to create the name of the input file, i.e. “Pipe Grade X65”. After that, the Problem Heading Data, HEAD which is consist of problem title, job number, user name and problem input/ output units need to initiate. Then enter the Printed Output Control which will determine types of output that will appear in the result sheet. Next, pipe property table should be referred as to fill Property Table Index, Pipe Section Length, Elastic Modulus, Cross Section Area, Moment of Inertia, Weight in Air, Weight Submerged, Poisson’s Ratio, Steel outside Diameter, Steel Wall Thickness, Yield Stress, Drag Coefficient, added mass coefficient and Coefficient Thermal Expansion. This data we refer what type of grade we use and here also we manipulated the wall thickness.

Then enter the Pipe Coating Properties such as steel density, corrosion density, corrosion thickness pipe joint length and density of contents. Next, enter Pipe Tension at Free End which is the input is static pipe tension as this simulation if for static installation and we can manipulate the input to get several results. Then enter the Barge Data and Geometry. This data comes from what type vessel we use. Every vessel has own data and coordinate of the stinger which is we need to fill up in Stinger Data and Geometry part. Then enter the Geometry Screen that here can manipulate the water depth. Lastly, run the simulation and get the result.
2.4 Wall Thickness Design Flowchart
Wall thickness design flowchart is illustrated in Figure 5.

![Wall thickness design flowchart](image)

Figure 5. Wall thickness design flowchart [10].

3. Results and Discussion

3.1 Limitation Test
Limitation test were conducted by using OFFPIPE Software where we make reference for the sag bend area that Percent Yield Stress should be take place. Set up the limitation of the percent yield stress at 85%. From this limitation we can make assumption which pipeline that exceeds this kind of limitations, the pipeline will be consider fail because the pipeline will have damaged due to overstress. Opposite form this, which pipeline below this limitation consider pass for laying the pipeline.

3.2 OFFPIPE’s Software Output.
Based on the software output, it can be seen clearly which criteria of the pipeline that does not meet the required and exceed the limitations of the yield stress. What Figure 6 shows that, the pipeline grade X60 and outside diameter of 8 inch was pass for the wall thickness of 12mm, 14mm and 16mm. The data is summarized in Table 2.

![Graph showing effect of wall thickness and water depth](image)

Figure 6. Effect of Wall Thickness and Water Depth by 8” OD
Unfortunately, the pipeline was failed at the wall thickness of 18mm and 20mm. From the graph it can see the critical yield percentage line was setup at 85%. Usually, the pipeline tends to fail because so many factor, in these experiments maybe wall thickness cannot stand enough to the such water depth and lead overpressure in the result of the stress

| Water Depth (m) | Wall Thickness (mm) | 12 | 14 | 16 | 18 | 20 |
|----------------|---------------------|----|----|----|----|----|
| 50             |                     | 21.6 | 24.3 | 27.1 | 30.2 | 33.3 |
| 100            |                     | 26.3 | 32.7 | 38.8 | 44.7 | 50.4 |
| 150            |                     | 48.3 | 58.1 | 67.5 | 77.0 | 86.5 |
| 200            |                     | 67.1 | 80.1 | 93.1 | 105.8 | 119.8 |
| 250            |                     | 84.3 | 100.4 | 117.6 | 135.2 | 140.0 |
| 300            |                     | 100.4 | 121.0 | 147.17 | 150.00 | 155.00 |

From the Figure 7, it is clearly seen that we run input for outside diameter of 12 inch. But, the main point here is to check either the listed wall thickness can stand such pressure or not. We can see that for wall thickness of 12 mm start to fail at 250 m of water depth and above 14 mm wall thickness starts to fail at 200 m and above (Table 3). The rest start to fail in range of 150 m to 200 m of water depth.

Figure 7. Effect of Wall Thickness and Water Depth by 12” OD

Figure 8, the graph shows that the 12mm wall thickness start to fail at water depth of 200m. The wall thickness of 14mm, 16mm, 18mm and 20mm was started to fail at water depth in range of 100m to 150m (Table 4). So, basically from this graph shoes that, for outside diameter of 16 inch is suitable for water depth of 200m and below for the respectively wall thickness. Above this range, the pipeline will tend to start fail.
### Table 4. Output for 16” Outside Diameter

| Water Depth (m) | Wall Thickness (mm) |
|----------------|---------------------|
|                | 12  | 14  | 16  | 18  | 20  |
| 50             | 22.6| 27.8| 33.2| 38.2| 43.1|
| 100            | 30.6| 42.7| 52.7| 62.1| 70.9|
| 150            | 59.3| 75.9| 91.0| 105.1| 119.4|
| 200            | 83.0| 103.8| 124.3| 144.9| 165.9|
| 250            | 103.8| 130.2| 156.5| 184.1| 190.0|
| 300            | 123.75| 155.64| 188.67| 200.00| 250.00|

**Figure 8.** Effect of Wall Thickness and Water Depth by 16” OD

### 4. Conclusion

Generally, the research work was wholly based on the wall thickness stability in such water depth of 50m, 100m, 150m, 200m, 250m and 300m. From the graph, it was proving that the wall thickness is depends on the water depth. Besides that, every wall thickness has their own maximum water depth that they can stand with. That is why the pipeline will tend to fail when wall thickness exceeds its own maximum limitation and this failure can be detect by such various way such as yield stress percentage. In this experiment, the yield stress percentage was setup as 85%. All samples that exceed the limitation will consider fail. This percentages were followed the standard and setup as reference to decide the yield stress is past or not. Besides that, the deeper the water depth the more pressure will act on the pipeline and the bigger wall thickness the heavier the pipeline. For future work and reference, this experiment need to be considered and run the OFFPIPE software properly with the correct input to get the best layable result and automatically it will reflect the economic part which is perfect layable will reduce the cost impact and can give better budget suggestion for the project.

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