# ON-BOTTOM STABILITY OF SUBMARINE PIPELINE

MOHD ASHRAF B. KHAIRUL ANUAR

CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JULY 2009

**On-Bottom Stability of Submarine Pipelines**

By

**MOHD. ASHRAF B. KHAIRUL ANUAR**

Final Report submitted in partial fulfillment of
The requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JULY 2009

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

**On-Bottom Stability of Submarine Pipelines**

by

Mohd Ashraf Bin Khairul Anuar

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(Assoc. Prof. Dr. Kurian V. John)

Approved by,

( Mr. Kalaikumar a/l Vallyutham)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2009

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD ASHRAF B. KHAIRUL ANUAR

## ABSTRACT

This report basically discusses preliminary research done and basic understanding of the chosen topic, which is **'On-Bottom Stability' of submarine pipelines.** The objective of the research is to produce the working spreadsheet that can calculate and design the on-bottom stability analysis using the MathCAD software. The working spreadsheet will give other option to the engineer for analyzing the on-bottom stability of submarine pipeline using the Generalized Stability Analysis Method rather than using the Simplified Stability Analysis Method. The scope of study in this project is to gather the detailed design of the submarine pipelines, type of waves, characteristic of the load and material specification for the submarine pipelines. The outcome expected from this project is determination of the stability requirements for designing submarine pipeline.

## ACKNOWLEDGMENT

First and foremost, I give thanks and praise to God for His guidance and blessings throughout the entire course of my training.

I wish to express my gratitude to Assoc. Prof. Dr. Kurian V. John and Mr. Kalaikumar, for their guidance and support throughout completing my Final Year Project in the Universiti Technologi Petronas Civil Engineering Department. Their knowledge is vital for the projects and activities that I have involved.

Many figures had provided immeasurable amount of guidance, ideas, assistance, support and advice. Without help from these people, this Final Year Project may not be that meaningful and successful. Greatest appreciation is expressed to the following individuals, Mr Meor, Mr Idris, Miss Nurul Husna Baharuddin, Miss Najwa Hamidi, Mr Hafiz, Miss Ainor Syafarizan and Ms Nabila and also to all staffs of Civil Engineering Department.

My acknowledgement would be incomplete without giving credit to Universiti Teknologi PETRONAS, especially Civil Engineering Department which has equipped students with essential skills for self-learning. Its well-rounded graduate philosophy has proven to be useful in the industry

Finally, I would like to thank my family. They have been a wonderful source of encouragement and joy to me and also not to forget the fellow students who's their help was a tremendous gift to me. May God bless all of us and only HE, the Almighty could repay all my debts to them.

# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 1
# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

Nowadays, with the development of offshore petroleum exploration and exploitation, more and more structures will be constructed and used in deep/shallow seas. The structure includes the topside above sea level and the subsea pipeline. The primary and efficient means to transport product from one offshore platform to other platform are by using submarine pipelines. For the past decades, the problem of submarine pipeline instability had become the major topic of interest of researchers. On-Bottom Stability Analysis is the analysis involved to determine the stability of the submarine pipeline resting on the seabed. The analysis covers the aspects such as the wave mechanics and hydrodynamic forces which are very important factors to be considered during the study.

PETRONAS Carigali Sdn Bhd (PCSB) is undertaking the development of J4 fields offshore Bintulu, Sarawak. J4 field is located approximately 53km west of the existing D35 oil and gas production facilities (D35 complex). The water depth in the J4 area is 53.6m [1].

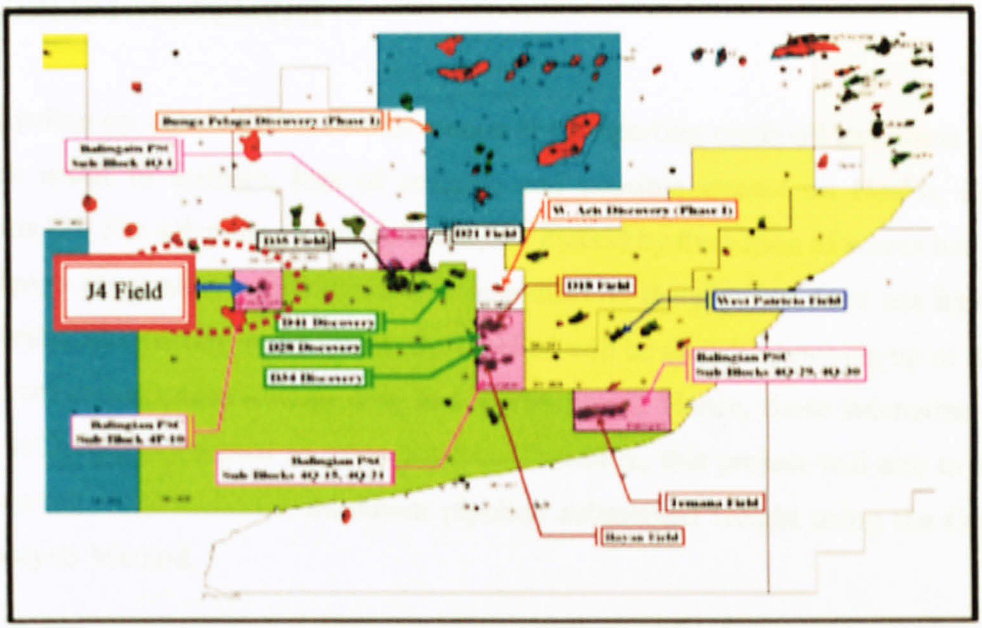



**Figure 1.1: J4 Field Location Map [1]**

The J4 wellfluid is evacuated to D35 Complex for further processing. 10" FWS pipeline has been identified as the optimum size for J4 pipeline from J4DP-A platform to the existing D35 Complex.

The specifications for the submarine pipeline materials and installation are based on the relevant PETRONAS Technical Standards (PTS) documents, revised where necessary to account for project-specific requirements and conditions.

## 1.2 PROBLEM STATEMENT

Although pipeline are considered the safest means of transporting crude oil/gas, some failures do occur which result in spillage, loss of revenue and possible impact on Health, Safety and Environments [2]. The submarine pipeline instability caused by the action of waves has become a major challenge in pipeline construction and operation. If the pipeline does not have enough stability to resist the hydrodynamic forces, the pipeline will be unstable, moving up or down (due to lifting force) and displace (due to drag and inertia force). Hence, those submarine pipelines need to be sufficiently designed in many aspects. Therefore, this project will aim to study and give other option to generate the minimum pipeline submerged weight using the Generalized Stability Analysis Method.

## 1.3 OBJECTIVE

The objectives of the study are to look into the available procedure of pipeline analysis and design hence to identify the mechanism and parameters involved in the on-bottom stability besides producing the working spreadsheet that can calculate and design the On-Bottom Stability Analysis using the MathCAD software. There are two type of method, the Simplified Stability Analysis Method and the Generalized Stability Analysis Method. The design is base on the real-life project and the result is compared with the actual pipeline behaviour. In order to achieve the objective, there are a few tasks and research need to be done by investigate and predict the behaviour of submarine pipeline using technical details related to the real-life submarine pipeline project subjected to wave and current actions.

## 1.4 SCOPE OF WORK

This project is analysis based project that required data gathering and technical details during preparation of the submarine pipelines. Data gathering included the detailed design of submarines pipelines, type of waves, characteristics of the load and material specification for submarine pipelines. However, focus will be on on-bottom stability of submarine pipeline based on code DNV RP E305 and PETRONAS Technical Standard (PTS 20.196). By using data from a case study for one of pipeline under J4 Development Project, that is for the 10-inch pipeline. The technical details is used in order to generate comparable value of submerge weight required for the concrete coating of the submarine pipelines [3].

## 1.5 RELEVANCY OF THE PROJECT

This project is relevant to the oil and gas industry all over the globe because the main concern of each analysis is for safety precaution. The significant of the project is to provide another method for on-bottom stability of submarine pipeline, which is using Generalized Stability Analysis Method using MathCAD software. Nowadays, engineers tend to use Microsoft Excel instead of MathCAD but now they are using MathCAD software as it friendly user and it is easy to trace back the error. It required a lot of effort and time to understand the flow of work using MathCAD. The one year time frame would be ample enough to garner all necessary data and collection of any relevant items or results to be kept as a record which perhaps could be enhanced in the future study. The comparison between both methods can demonstrate the different in term of cost saving as the Generalized Stability Analysis Method can reduce the usage of concrete coating if it complies with the validation of the method. It also can give the engineer another method in designing the on-bottom stability of submarine pipelines.

# CHAPTER 2
# LITERATURE REVIEW AND THEORY

## 2.1 INTRODUCTION

A pipeline has to be stable on the seabed. If it too light, it will slide away under the action of currents and waves. On the other hand, if it is very heavy, it will be difficult and expensive to construct.

Designers can increase the weight of the pipeline by adding an external concrete weight coating that also gives mechanical protection to the anti-corrosion coating. Alternatively, they can increase the submerge weight by increasing the wall thickness of the pipe, though this is a relatively costly option, particularly if the pipe is a corrosion-resistant alloy. They can also reduce hydrodynamics forces and increase stability by trenching the pipeline into the seabed or add weight by adding bolt-on weights or mattresses. To eliminate the possibility of instability, their designs can call for burying the line in the seabed or covering it with rock.
The first step in design against hydrodynamic forces induced by current and wave is to determine how large the design-steady current and the design wave ought to be. The conventional approach to design is to determine the submerge weight required so that the lateral resistance is large enough to hold the pipe in equilibrium against the combination of weight and hydrodynamic force.

There are good grounds for thinking that the conventionally accepted design method is in fact irrational and incorrect principle. That method wrongly assumes that the seabed itself is stable. In reality the seabed usually becomes unstable and mobile before the design conditions for a pipeline are reached.

### 2.1.1 Wave-Induced Pipeline Stability

The wake model reported by Lambrakos in 1987 is to calculate the soil resistance and the hydrodynamic forces upon pipeline [4], respectively base on the pipe-soil interaction model reported by Wagner in 1987 using the existing Det Norske Veritas (DnV) Recommended Practice RP E305 [5]. According to Fuping Gao; an improved analysis method for the on-bottom stability of submarine pipeline, which base on various restraint conditions obtained the hydrodynamic loading experiments [6]. There are comparisons of the submerged weights of the pipeline predicted with the DNV Practice and those with new method.

The comparison between pipe-soil and wave-pipe-soil interaction model produces by Fuping Gao consists of the comparison of the experiment setups, procedures of tests, phenomena of pipe losing indicates the critical lines for the instability of anti-rolling pipeline and freely-laid pipeline in the empirical wave-pipe-soil interaction model overall agree with the design values, base on both simplified and generalized stability methods in DnV standard respectively. With increasing in Froude number, the generalized stability methods become more conservative than the wave-pipe-soil interaction model for the on-bottom stability design for submarine pipelines. The wave-pipe-stability coupling effects should be taken into account when analyzing the on-bottom stability under wave loading [7].

According to Jeng and Seymour, there are two fundamental mechanisms for the wave-induced pore pressure in a porous seabed and the residual and oscillatory mechanisms. An analytical solution for the wave-induced residual pore pressure is deriving from a journal produces by Jeng and Seymour, with the new solution; a simple scaling analysis is performing to clarify the applicable ranges of the two mechanisms. Then, a simplified approximation for the prediction of the wave-induce liquefaction potential is proposed. The numerical results indicate that the residual mechanism is particularly important for large wave loading, while the oscillatory mechanism dominates the pore pressure under small wave loading [8].

### 2.1.2 Pipeline Stability on a Mobile and Liquefied Seabed

According to Damgaard, there are several processes that need to consider in order performing the Pipeline Stability Analysis and the processes are the hydrodynamic loads on pipeline, sediment transport and liquefaction. Significant sediment transport will take place before the pipeline start to move horizontally. The authors has found out that all realistic field condition of sandy seabed will become mobile at forcing levels significantly lower than those required to mobilize a pipeline. The marginal pipeline stability under realistic field conditions can be accompanied by seabed liquefaction, which is, in turn, is likely to result sinking of pipeline, at least for typical values of pipeline specific gravity. There is also condition for which two different types of liquefaction could theoretically coexist [9].

### 2.1.3 Reliability Analysis of On-Bottom Pipeline Stability

The instability phenomena occur due to movement where the water will push the pipeline but the movements will not necessarily cause failure to the pipeline itself. It can occur during severe hurricanes that can contribute excessive movements. The instability problem is analyzed during vector-outcrossing method. Within the reasonable thickness limits, it is impractical to reduce the expected number of crossing to be less than one. The violation of the stability criteria does not constitute a structural failure (e.g. breakout). The expected number of crossing does not provide direct information to quantify the true reliability. The more crossings a pipeline experiences the more likely it will fail because of the increase chance in encountering an extreme wave that might cause excessive pipeline movements. The assumed random variables do not have significant impact on the mean crossing rates. It is due to the drag force and lift force are proportioned to the square of the particle velocity. It was found that the inertia effect due to wave acceleration is relatively insignificant compared with the velocity effect [10].

## 2.2 THEORY

According to Chakrabati [11], it is assumed that the waves are two dimensional in the XY plane, that the ocean floor is flat of undisturbed depth, *d* from the Still Water Level (SWL), and that the waves are progressive in the positive X direction. The progressive wave is defined in Figure 2.1 in which the various symbols used to characterize the wave are given. A wave train is generally defined by its height, *H*, period, *T* and water depth, *d*.

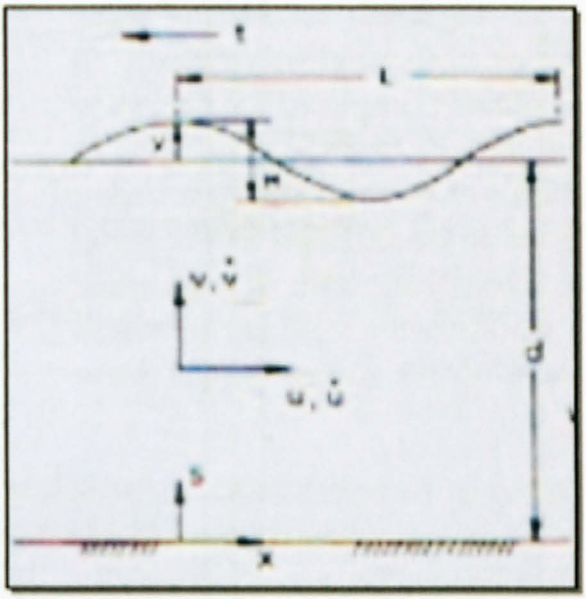


Figure 2.1: Definition sketch for a progressive wave train [11]

Wave forces on offshore structures are calculated in three ways:

- Morison equation
- Froude – Krylov theory
- Diffraction theory

The Morison equation was developed by Morison, O'Brien, Johnson, and Shaaf in describing the horizontal wave forces acting on a vertical pile which extends from the bottom through the free surface. Morison et al. propose that the force exerted by unbroken surface waves on a vertical cylindrical pile which extends from the bottom through the free surface (Figure 2.2) is composed of two components, inertia and drag.

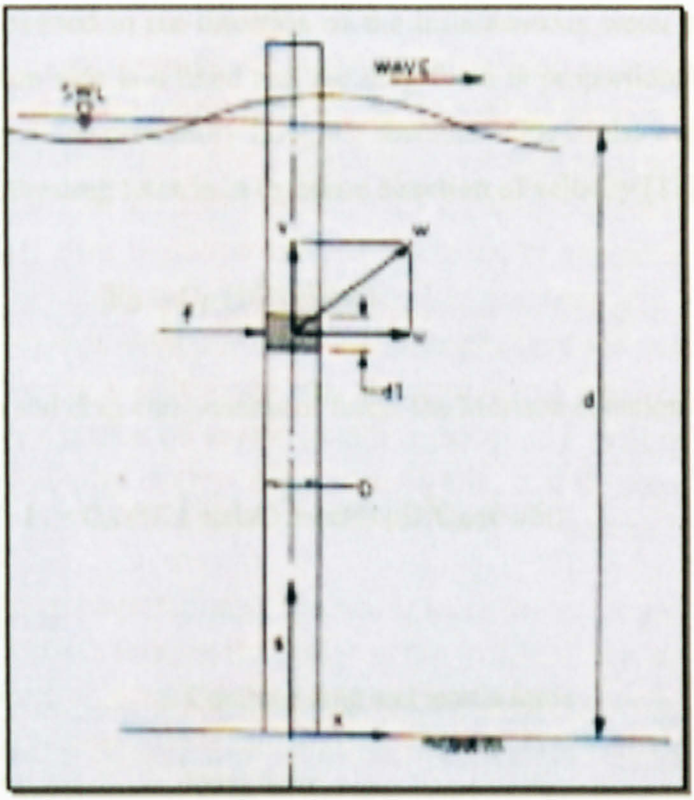


Figure 2.2: Definitions sketch for wave forces on small diameter cylinder [11]

### 2.2.1 Morison Equation

The principal cause of the drag force component is the presence of a wake region on the "downstream" side of the cylinder. The wake is a region of low pressure compared to the pressure on the "upstream" side and thus a pressure differential is created by the wake between the upstream and downstream of the cylinder at a given instant of time. The pressure differential causes a force to be exerted in the direction of the instantaneous water particle velocity. In a steady flow downstream side is a fixed and the drag force is proportional to the square of the water particle velocity. In an oscillatory flow, the absolute value of the water particle velocity is inserted to insure that the drag force is in the same direction of velocity [11].

$$F_D = C_D\,(1/2)\,\rho|u|u D \tag{2.1}$$

Combining the inertia and drag components of force, the Morison equation is written as

$$f = F_D + F_i = C_D\,(1/2)\,\rho|u|u D + (\pi/4)\,\rho D^2 C_M (\delta u/\delta t) \tag{2.2}$$

Where;

| | | |
|---|---|---|
| $F$ | = | Combine drag and inertia force |
| $F_D$ | = | Drag force |
| $F_i$ | = | Inertia force |
| $u$ | = | Instantaneous velocity |
| $C_M$ | = | Inertia coefficient |
| $D$ | = | Outside diameter of a riser |
| $\delta u/\delta t$ | = | Horizontal acceleration of water |

### 2.2.2 Pierson-Moskowitz Spectrum

As refer to book of Chakrabarti (1987), Pierson and Moskowitz in 1964 had proposed a new formula for an energy spectrum distribution of a wind generated sea state based on the similarity theory. This spectrum commonly known as P-M model has since been extensively used by ocean engineers as one of the most representative for waters all over the world. They assumed that if the wind blew steadily for a long time over a large area, the waves would come into equilibrium with the wind. This is the concept of a **fully developed sea**. Here, a long time is roughly ten-thousand wave periods, and a "large area" is roughly five-thousand wave-lengths on a side. The P-M model has been found to be useful in representing a severe storm wave in offshore structural design [11].

The P-M spectrum model is written as:

$$S(\omega) = \alpha g^2 \omega^{-5} \exp\left[-0.74\left(\frac{\omega U_w}{g}\right)^{-4}\right] \tag{2.3}$$

where a = 0.0081

### 2.2.3 Keulegan-Carpenter Number

In fluid dynamics, the Keulegan–Carpenter number, also called the period number, is a dimensionless quantity describing the relative importance of the drag forces over inertia for bluff objects in an oscillatory fluid flow. Or similarly, for objects that oscillate in a fluid at rest. For small Keulegan–Carpenter number inertia dominates, while for large numbers the (turbulence) drag forces are important [12].

The Keulegan–Carpenter number $K_C$ is defined as:

$$K_C = \frac{VT}{L} \tag{2.4}$$

Where:

$V$ is the amplitude of the flow velocity oscillation (or the amplitude of the object's velocity, in case of an oscillating object),

$T$ is the period of the oscillation, and

$L$ is a characteristic length scale of the object, for instance the diameter for a cylinder under wave loading.

A closely related parameter, also often used for sediment transport under water waves, is the displacement parameter $\delta$:

$$\delta = \frac{A}{L} \tag{2.5}$$

with $A$ the excursion amplitude of fluid particles in oscillatory flow. For sinusoidal motion of the fluid, $A$ is related to $V$ and $T$ as $A = VT/(2\pi)$, and:

$$K_C = 2\pi\delta \tag{2.6}$$

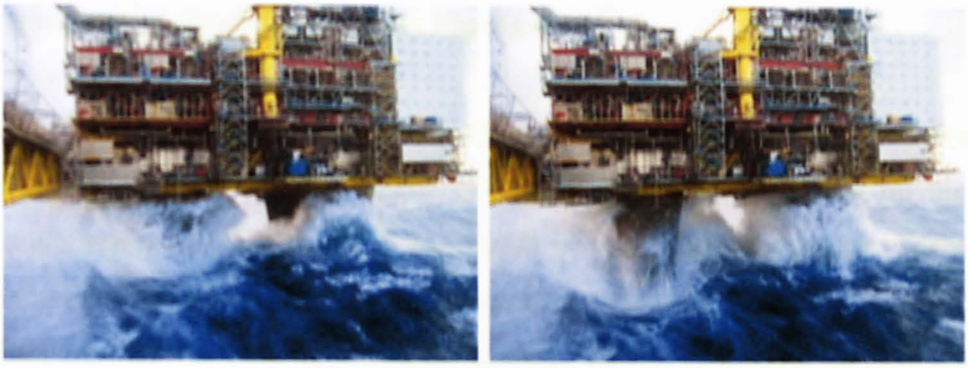


Figure 2.3: The Keulegan–Carpenter number is important for the computation of the wave forces on offshore platforms. [12]

### 2.2.4 Current

A current, in a river or stream, is the flow of water influenced by gravity as the water moves downhill to reduce its potential energy. The current varies spatially as well as temporally within the stream, dependent upon the flow volume of water, stream gradient, and channel geometrics. In tidal zones, the current in rivers and streams may reverse on the flood tide before resuming on the ebb tide.

Air currents may be caused by differences in temperature, pressure, or impurity concentration. Temperature differences can cause air currents because warmer air is less dense than cooler air, causing the warmer air to appear "lighter." Thus, if the warm air is under the cool air, air currents will form as they exchange places. Pressure differences also cause air currents as the air flows from areas of higher pressure to areas of lower pressure.

An ocean current is a continuous, directed movement of ocean water generated by the forces acting upon the water, such as the Earth's rotation, wind, temperature, salinity differences and tides caused by the gravitational pull of the Moon and the Sun. Depth contours, shoreline configurations and interaction with other currents influence a current's direction and strength.

### 2.2.5 On Bottom Stability of Submarine Pipelines

Basically, the on-bottom stability analysis of submarine pipeline is performed to determine the stability of pipeline resting on the seabed. The submarine pipeline resting on the seabed is subjected to environmental forces which can result in instability of pipeline. Therefore, these analyses need to be carried out in order to determine the stability requirement of the submarine pipeline. The On-Bottom Stability analysis covers the aspects such as wave mechanics, hydrodynamic forces and pipeline-soil interaction. The aspect of hydrodynamic forces already mentioned in the previous subsection while the pipeline-soil interaction can be defined as the interaction of the contact between the pipeline and the seabed and this interaction consists of seabed stiffness and friction definition. The contact pressure between the pipeline and the seabed governs the friction force keeping the pipeline stable on the seabed. However, the study will focus on the effect of waves and current loading and will not include the pipeline-soil interaction aspects [13].

The stability criteria may be expressed as

$$(W_{sub} - F_L) \times \mu \geq (F_D + F_I) \times S_L \tag{2.7}$$

Where;

| | | |
|---|---|---|
| $W_{sub}$ | = | Submerged weight of pipeline |
| $F_L$ | = | Lift Force |
| $\mu$ | = | Seabed friction coefficient |
| $F_D$ | = | Drag Force |
| $F_I$ | = | Inertia Force |
| $S_L$ | = | Factor of Safety on Lateral Stability |

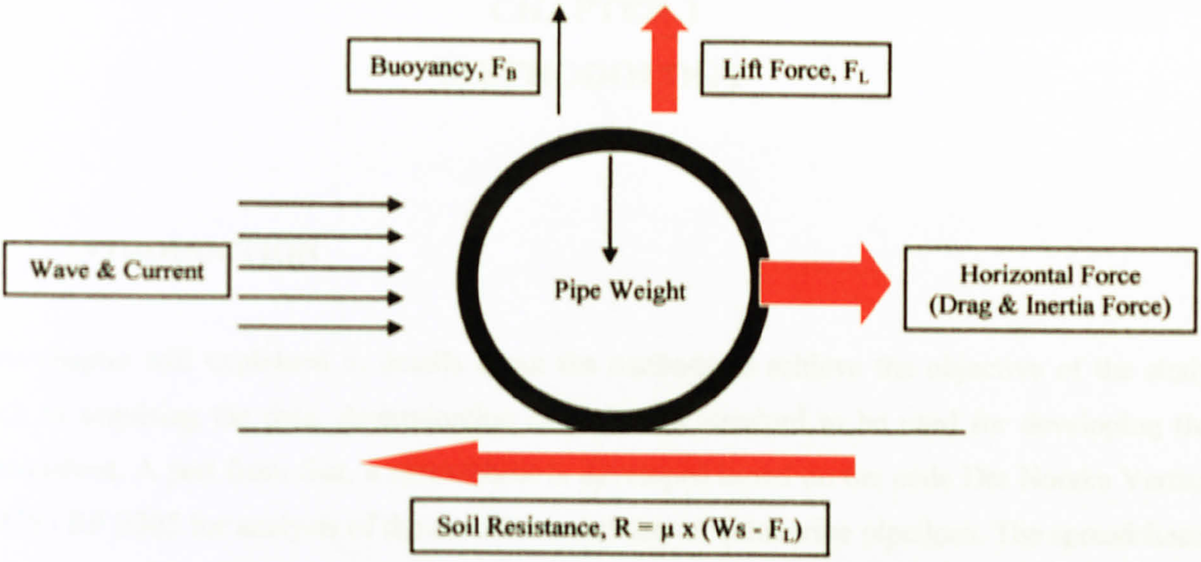



Figure 2.4: Fundamental of force acting on submarine pipelines

# CHAPTER 3
# METHODOLOGY

## 3.1 INTRODUCTION

This chapter will explained in details about the methods to achieve the objective of the study such as acquiring the data, determination of code and standard to be used for developing the spreadsheet. A part from that, a spreadsheet is developed based on the code Det Norske Veritas (DNV) RP E305 for analysis of the on-bottom stability of submarine pipelines. The spreadsheets of both Simplified Stability Analysis and the Generalized Stability Method need to be done in order to determine the concrete coating design of the submarine pipeline. In addition, the work will be done based on the real-life project in Malaysia. The collections of technical details regarding the real-life project are necessary to compare the actual behavior between the submarine pipeline in real-life project and scale model of submarine pipeline.

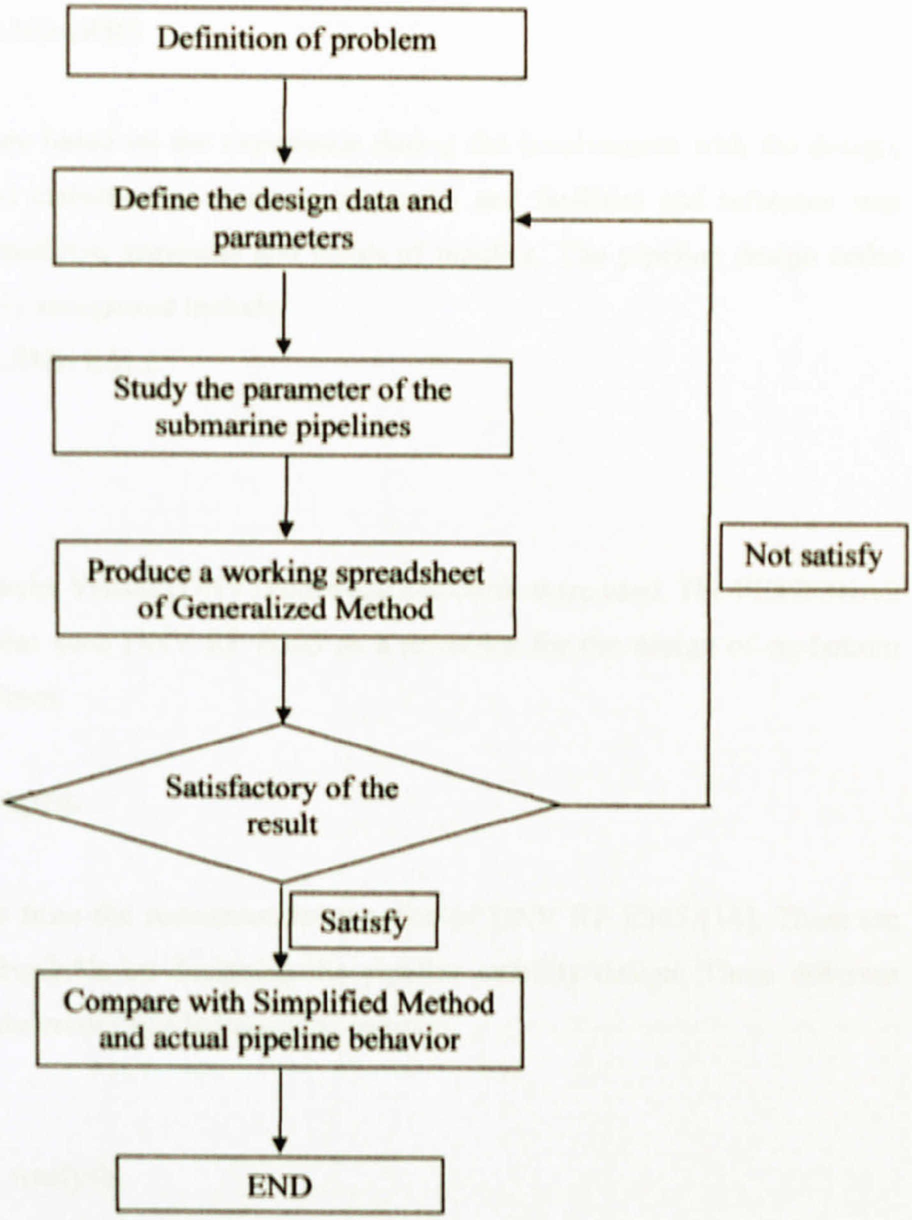



Figure 3.1: Project Flow Process

## 3.2 CODES AND STANDARDS

The codes and standards are based on the experience during the involvement with the design, construction, operation and maintenance of processing units and facilities and reference was made to national and international standards and codes of practice. The pipeline design codes and standards that are widely recognized include:

- ASME B31.4 and ASME B31.8
- DNV RP E305
- PTS 20.214

In this research, the Det Norske Veritas (DNV) codes and standards were used. The PETRONAS technical standard (PTS) also used DNV RP E305 as a reference for the design of on-bottom stability of submarine pipelines.

## 3.3 ANALYSIS METHODS

The spreadsheets are made from the recommended practice of DNV RP E305 [14]. There are several analysis methods available on designing the pipeline stability design. Three different methods are considered in the recommended practice, namely:

- Dynamic Analysis
- Simplified Stability Analysis
- Generalized Stability Analysis

The choice of the above analysis methods is dependent on the degree of detail required in results of the design analysis. For the project, the authors need to focus on the Simplified Stability Method and Generalized Stability Method.

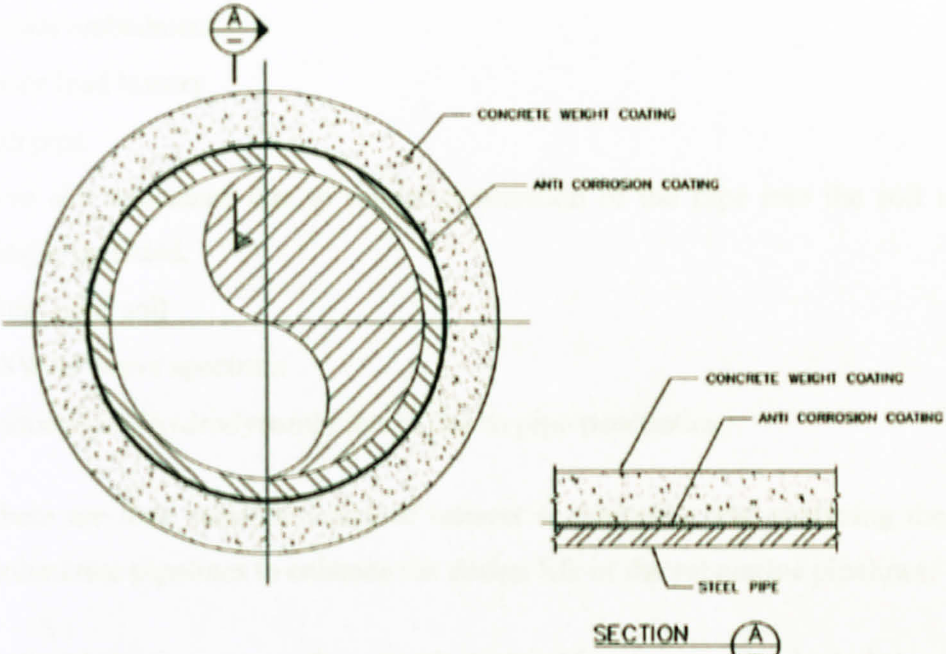



Figure 3.2: Pipeline coating details [14]

The Simplified Analysis Method is based on a quasi-static balance of forces acting on the pipe, but has been calibrated with results from the generalized stability analysis. The method generally gives the pipe weight that form a conservative envelope of those obtained from the generalized stability analysis.

The Generalized Stability Analysis is based on a set of non-dimensional stability curves which have been derived from a series of runs with a dynamic response model. This method can be used in either detailed design calculations or preliminary design calculations. The Generalized Stability Analysis method may be used on the sections of the pipeline where potential pipeline movement and strain may be important. The main assumptions of the method are given:

- Hydrodynamic forces modified for wake effects
- No initial embedment
- No prior load history
- Rough pipe
- Passive soil resistance due to partial penetration of the pipe into the soil under cycle loading is included.
- Medium sand soil
- JONSWAP wave spectrum
- No reduction of hydrodynamic forces due to pipe penetration

Generally, there are four common cases of interest in designing and analyzing the on-bottom stability of submarine pipelines to enhance the design life of the submarine pipelines:

- Operational Pristine - no marine growth or metal loss to corrosion included
- Operation End of Life – marine growth included and the corrosion allowance usage factor
- Installation – pipeline empty, no marine growth and no loss of corroded material.
- Hydrotest – as for installation but pipeline contain full of hydrotest water.

## 3.4 DESIGN DATA AND PARAMETERS

### 3.4.1 Design Data for J4 Field Development Project

Data were taken from the Detailed Design of J4 Field Development Project for pipeline on-bottom stability analysis. The 10-inch FWS pipeline is connected the J4DP-A platform to the D35R-A platform. The appendix in Details Design of J4 Development Project presents the spreadsheet produced by INTEC Engineering (SEA) Sdn. Bhd. using the Simplified Stability Analysis Method from the Det Norske Veritas (DNV) RP E305. The General Pipeline Design Parameters are shown at tables 3.1, 3.2, 3.3 and 3.4 are presented [1].

Table 3.1: Pipeline Design Parameter [1]

| | | |
|---|---|---|
| Nominal Diameter (inch) | | 10 |
| Outside Diameter (mm) | | 273.1 |
| Service | | FWS |
| Wall thickness (mm) | Zone 2 | 12.7 |
| | Zone 1 | 9.3 |
| Corrosion Allowance (mm) | | 3 |
| Approximate Pipeline Length (km) | | 51 |
| Design Pressure (MPa) | | 13.8 |
| Design Temperature ($^{o}C$) | | 90 |
| Hydrotest Temperature ($^{o}C$) | | 30 |
| Maximum Operating Pressure (MPa) | | 2.33 |
| Operating Temperature ($^{o}C$) | | 70.6 |
| Minimum Product Density ($kg/m^3$) | | 502.86 |
| Maximum Product Density ($kg/m^3$) | | 726.81 |
| Design Service Life (years) | | 16 |
| Density of Concrete Coating ($kg/m^3$) | | 3044 |
| Minimum Water Depth (m) | | 46 |
| Density of Seawater ($kg/m^3$) | | 1025 |

Table 3.2: Storm Surge [1]

| Return Period | Unit | Positive Surge |
| --- | --- | --- |
| 1-Year | m | 0.3 |
| 100-Year | m | 0.6 |

Table 3.3: Omni Wave Data [1]

| | Unit | 1-Year | 100-Year |
| --- | --- | --- | --- |
| Significant Wave Height, $H_s$ | m | 4.0 | 5.2 |
| Peak Period, $T_p$ | sec | 9.7 | 10.4 |
| Maximum Wave Height, $H_{max}$ | m | 8.0 | 10.4 |
| Associated Period, $T_{ass}$ | sec | 9.0 | 9.7 |

Table 3.4: Hydrodynamic Coefficient [1]

| | |
| --- | --- |
| Drag, $C_D$ | 0.7 |
| Lift, $C_L$ | 0.9 |
| Inertia, $C_I$ | 3.29 |

### 3.4.2 Design Data for Parametric Analysis

Data are taken from the Calculation Example - Recommended Practice Det Norske Veritas (DNV) RP E305. The appendix in the Recommended Practice of DNV RP E305 presents some calculation examples on simplified and generalized methods. The examples are for the following design cases are presented in Table 3.5, 3.6 and 3.7 [14].

Table 3.5: Pipeline Design Parameter [14]

| | | |
|---|---|---|
| Steel pipe outer diameter | $D_s$ | 0.4064m |
| Wall thickness | $t_s$ | 0.0127m |
| Internal diameter | $D_i$ | 0.3810m |
| Corrosion coating thickness | $t_{cc}$ | 0.005m |
| Density of corrosion coating thickness | $\rho_{cc}$ | 1300kg/m$^3$ |
| Density of product | $\rho_i$ | 10kg/m$^3$ |
| Density of seawater | $\rho_w$ | 1025kg/m$^3$ |
| Density of steel | $\rho_s$ | 7850kg/m$^3$ |
| Density of concrete coating | $\rho_c$ | 2400kg/m$^3$ |

Table 3.6: Environmental Data [14]

| | | |
|---|---|---|
| Significant Wave Height | $H_s$ | 14.5m |
| Peak Period | $T_p$ | 15s |
| Water Depth | d | 110m |
| Current Velocity | $U_r$ | 0.6m/s |
| Current Reference Point | $Z_r$ | 3.0m |
| Peakedness Parameter | $\gamma$ | 1.0 (P-M Spectral) |

Table 3.7: Soil Data [14]

| Soil type | Sand/clay | Sand |
|---|---|---|
| Mean Grain Size | $d_{50}$ | 0.5mm |
| Soil Shear Strength (Input "0" for sand) | $S_u$ | 0Pa |

### 3.4.3 Design criteria

Due to limitation on of a information, the following parameters had been adopted for the allowable maximum lateral displacement in the operational operation [14]:

| | |
|---|---|
| Zone 1 | 20 m |
| Zone 2 | 0 m |

Where,

Zone 1 - the part of the sea bed located more than a certain distance away from the platform or subsea template, normally taken as 500 m.

Zone 2 – the part of the seabed located close to a platform or subsea template, normally taken as 500 m.

Normally, lateral displacement would be the governing criteria. In Generalized Stability Analysis Method, the strain requirement would also be satisfied when limiting the movement to maximum 20 m. The sensitivity variations in the environmental parameters (wave height/period) should be checked. The allowable displacement criteria refer to seastate duration of 3 hours at maximum storm intensity.

The Generalized Stability Analysis is valid for the following range of parameters:

$$4 < K < 40$$
$$0 < M < 0.8$$
$$0.7 < G < 1.0 \quad \text{(for sand soil)}$$
$$0.05 < S < 8.0 \quad \text{(for clay soil)}$$
$$D \geq 0.4 \text{ m}$$

Where:

$K$ is Keulegan-Carpenter number

$M$ is current to wave velocity ratio

$G$ is relative soil weight of sand

$S$ is shear strength parameter, and

$D$ is outer diameter of the submarine pipeline

The reason for the above validity in K and M is related to the use of the wake force model in the dynamic simulation program from which the method was derived. The sand and clay models have been tested within the above specific ranges. The method presented should be limited to pipeline diameters (outer) $\geq$ 0.4 m, because the calibration has been formed for larger diameters.

For conditions outside the above range, the use of the Simplified Analysis Method is recommended.

The following assumptions have been made in the pipeline on-bottom stability analysis:

1. No pipe burial has been considered
2. No water absorption on concrete is considered
3. No marine growth on the pipeline is taken into consideration
4. Current and wave acting perpendicular to the pipeline
5. The soil friction for clay is calculated based on Figure 5.11 in Det Norske Veritas (DNV) RP E305.

## 3.5 GENERATE THE SPREADSHEET

The spreadsheet was developed using the MathCAD software in order to compute the result after the data gathering was completed. Below is the typical procedure to generate the spreadsheet using MathCAD software.

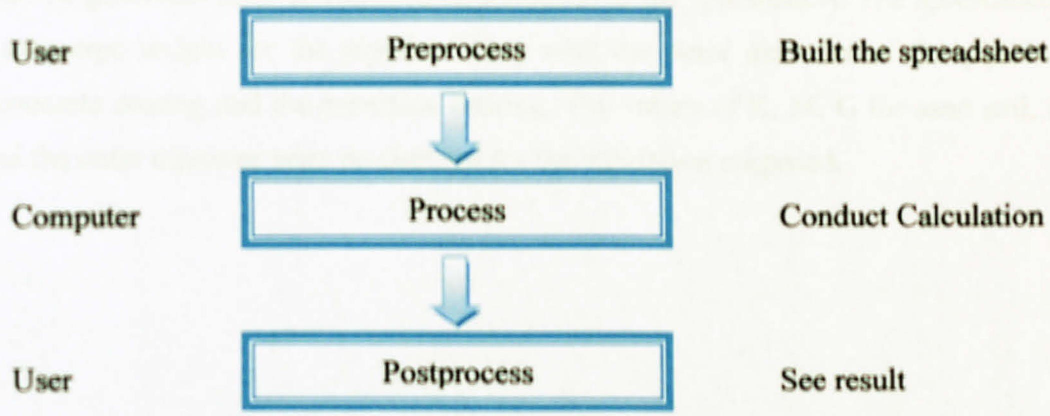



Figure 3.3: Typical Procedure for generate the spreadsheet

### 3.4.1 Preprocess

In this project, the author used the calculation example in Det Norske Veritas (DnV) Recommended Practice RP E305. From the calculation example, the software follows the formulas that were inserted in the spreadsheet according to the Simplified Stability Analysis Method and Generalized Stability Analysis Method.

### 3.4.2 Process

Computers would compute the equations in the spreadsheet and provide the required result.

### 3.4.3 Postprocess

The result would be generated after all required data entered to the spreadsheet. The spreadsheet will give the submerge weight for the pipeline along with the outer diameter of the pipeline including the concrete coating and the corrosion coating. The values of K, M, G for sand soil, S for clay soil and the outer diameter were re-checked for the validation purposed.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 INTRODUCTION

The focuses of the study was on the on bottom stability of a submarine pipeline which sits freely on seabed; without trenching and burial. The stability analysis of the submarine pipeline was calculated using MathCAD software. The spreadsheet was developed using formula from Det Norske Veritas (DNV) RP E305- Recommended Practice On-Bottom Stability Design of Submarine Pipelines [14]. The designed spreadsheet is attached at APPENDIX A.

## 4.2 RESULTS & DISCUSSION

### 4.2.1 10-inch J4 Field Development Project

The analysis was done by using the input parameter from J4 Field Development Project and adopted the INTEC in-house spreadsheet prepared by the analysis method given by DNV RP E305 in compliance with the requirement of PTS 20.196. The spreadsheet used the Simplified Stability Analysis Method to determine the pipe weight (submerged weight required) that satisfies absolute stability (no breakout) for the extreme wave in the design sea state. Hence, the requirement to have movement at 500m from the platform is not applicable. The Generalized Stability Analysis Method do not have the required criteria for validation as the value of K (Keulegan-Carpenter number) and M (current to wave velocity ratio) ware not in ranges. The results of the required concrete coating thickness are shown at Figure 4.1 [1].

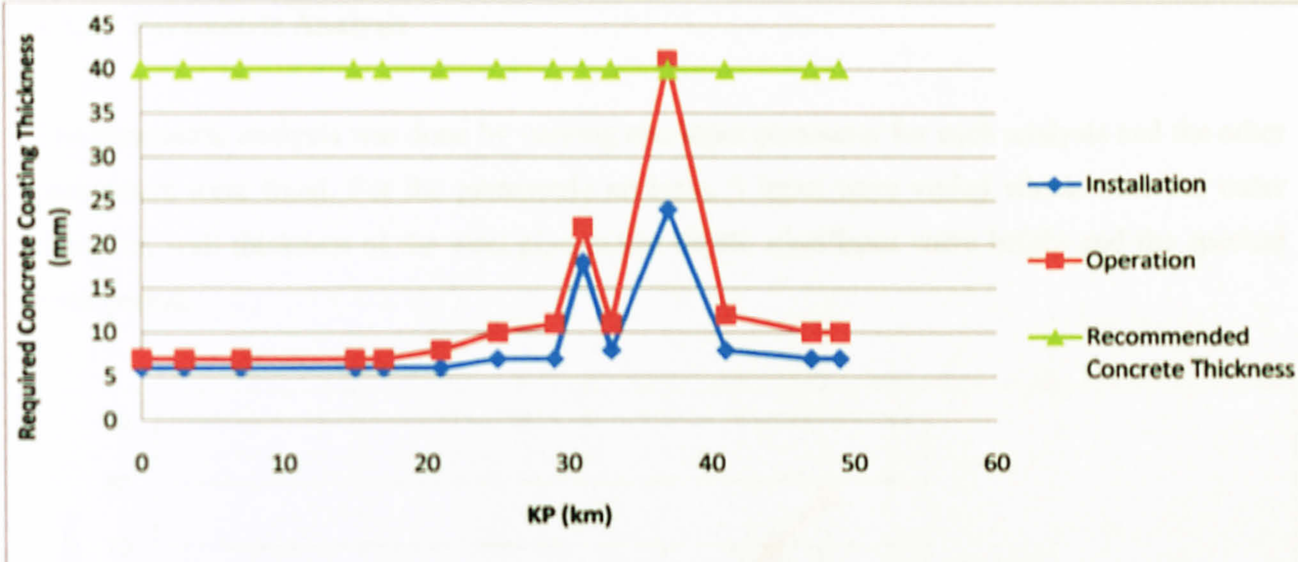



Figure 4.1: Concrete Coating Thickness of J4 Development Project

In general, the 10-inch FWS pipeline would achieve on-bottom stability during operation and installation condition with minimum concrete coating thickness ranging from 6m to 24mm for the installation but the recommended concrete coating thickness is 40mm. The stability analysis have been carried out at 15 points along the proposed pipeline route and the results show that the required concrete coating thickness along the pipeline route to be in range of 7mm to 40mm for the operating condition.

The recommended concrete coating thickness is made base on advantages associated with the constant concrete coating thickness such as to ease logistic because different concrete coating thickness will require the pipe to be tagged differently. Furthermore, proper planning would be required for supplying the line pipe to the laybarge in order to ensure the laying process would not be interrupted.

Other than that, the usage of optimum concrete coating thickness helped to minimize pipeline end expansion. This is important as it would help to optimize the expansion spool length. It can also help to provide additional impact protection for the pipeline.

### 4.2.2 Parametric Analysis

The parametric analysis was done by varying one input parameter for each analysis and the other parameters were fixed. For the parametric analysis, 5 input were varied which were the outer diameter, wall thickness of the steel pipe, water depth, significant wave height and the spectral peak period.

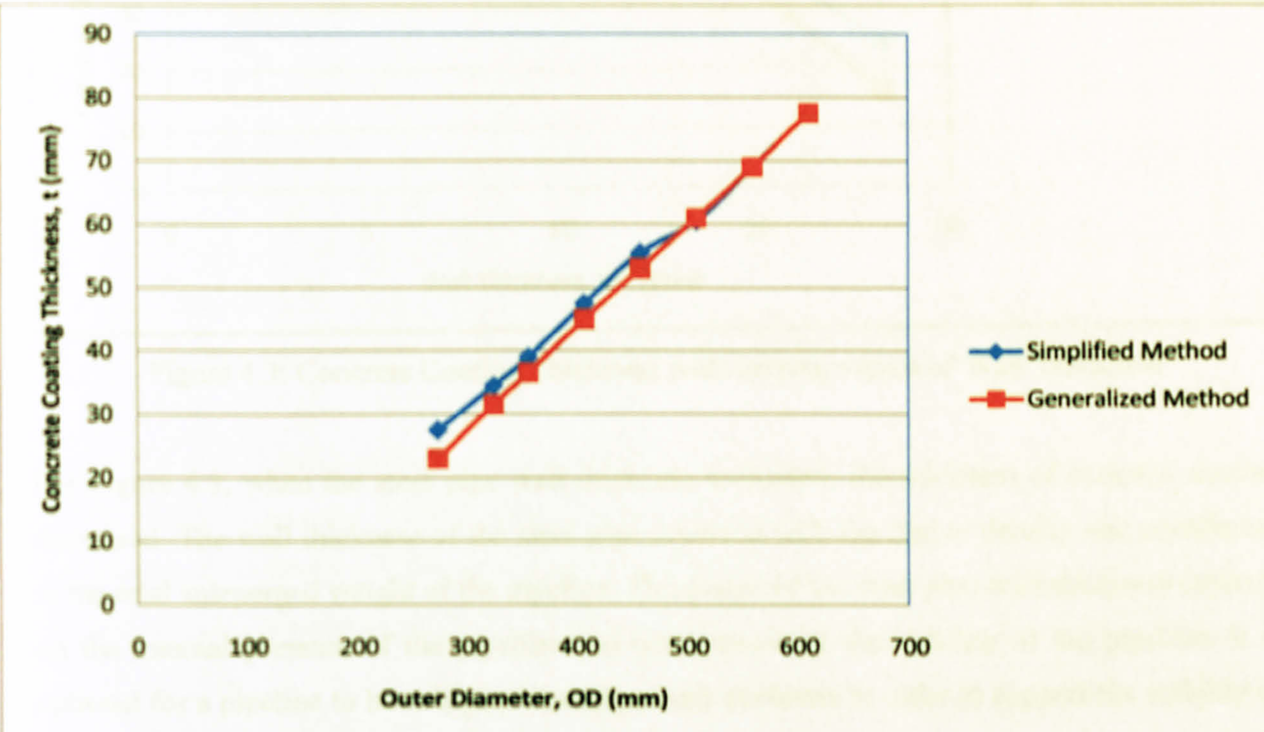



Figure 4.2: Concrete Coating Thickness with varying values of Outer Diameter

From Figure 4.2, when the pipeline outer diameter (OD) was increased, the thickness of concrete coating also increased. Pipeline outer diameter is not involved in the calculation of water particle kinematics. It affects the drag, lift and inertia forces directly. The forces increased with the increment of pipeline outer diameter. The outer diameter below 0.4m is not valid because it is not within the parameter needed to validate the generalized method.

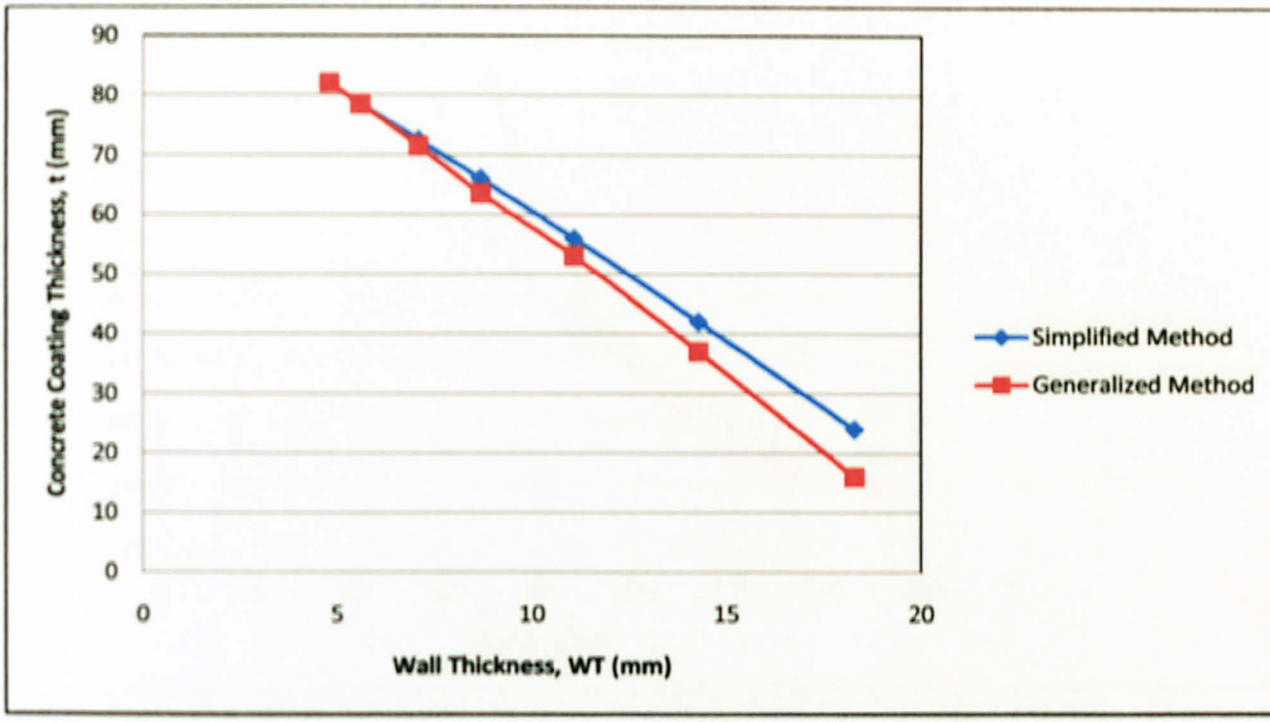



Figure 4.3: Concrete Coating Thickness with varying values of Wall Thickness

For Figure 4.3, when the steel pipe wall thickness increased, the thickness of concrete coating decreased. The wall thickness of the steel pipe involved with the higher density and contributes to the total submerged weight of the pipeline. The design of the steel pipe wall thickness depends on the internal pressure of the pipeline and not because of the stability of the pipeline. It is optional for a pipeline to have higher steel pipe wall thickness in order to support the stability of the pipeline.

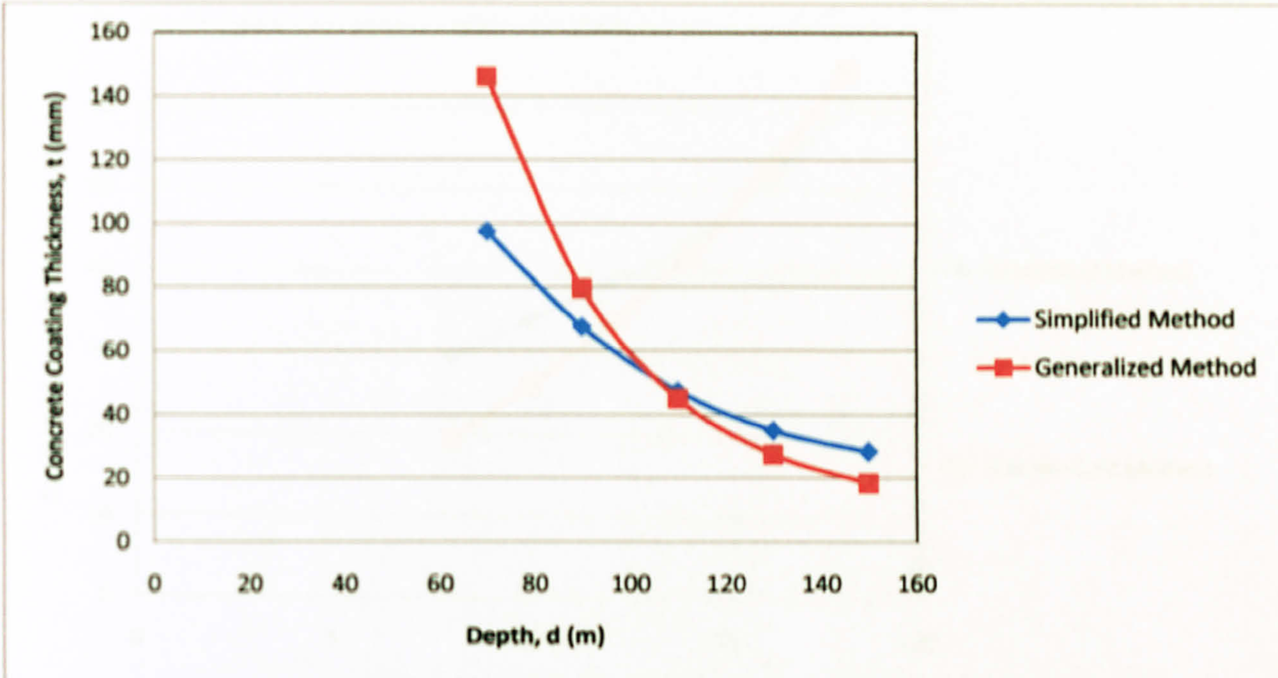


Figure 4.4: Concrete Coating Thickness with varying values of Water Depth

As for Figure 4.4, the concrete coating thickness decreases with the increment of mean water depth (d). When the mean water depth increases, the wave length (L) increases. This reduces the drag, inertia forces because the water particle kinematics decrease, which in turn contributes to the decrement of minimum pipeline submerged weight, needed to stabilize the pipeline.

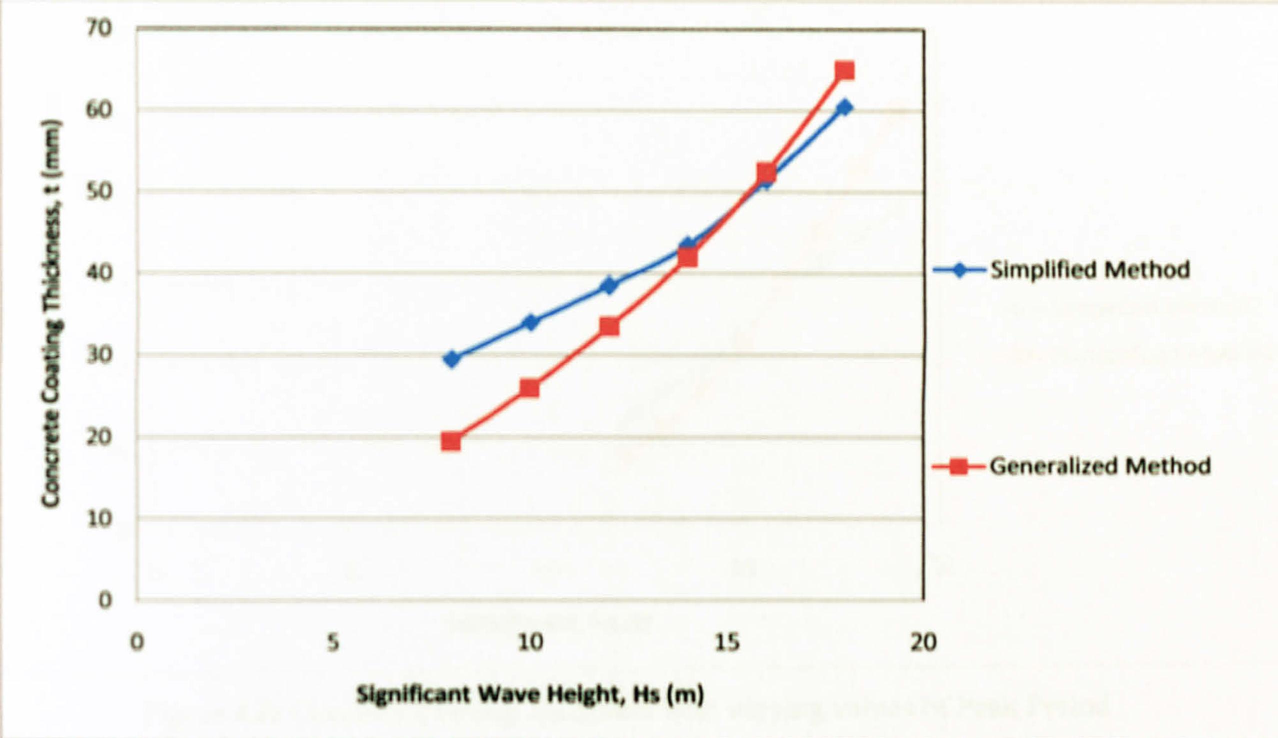



Figure 4.5: Concrete Coating Thickness with varying values of Significant Wave Height

From Figure 4.5, the concrete coating thickness increased with the increment of significant wave height (Hs). When the significant wave height increased, the water particles kinematics increased (velocity and acceleration). This would increase drag, lift and inertia forces which contributed to the minimum pipeline submerged weight. The significant wave height that is below 14m is not valid because the value for M and K parameter not in range for validation of generalized method.

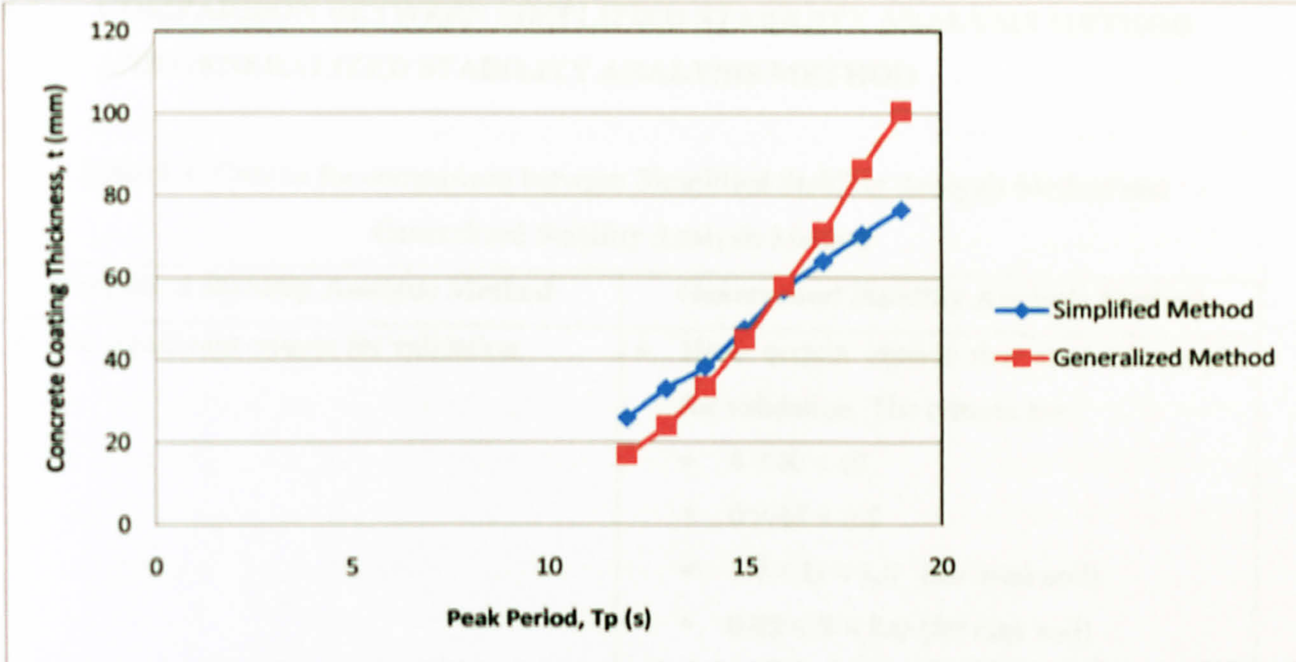



Figure 4.6: Concrete Coating Thickness with varying values of Peak Period

From Figure 4.6, if the peak period was increased, the concrete coating thickness also increased. When the peak period of the wave is increasing, it also contributed to increase the water particles kinematics that will affect the drag, lift and inertia forces. The peak period below 14s was not valid as the value for M and K parameter not in range for validation of generalized method.

## 4.3 COMPARISON BETWEEN SIMPLIFIED STABILITY ANALYSIS METHOD AND GENERALIZED STABILITY ANALYSIS METHOD

Table 4.1: Criteria for comparison between Simplified Stability Analysis Method and Generalized Stability Analysis Method

| Simplified Stability Analysis Method | Generalized Stability Analysis Method |
|---|---|
| • No significant criteria for validation | • Have certain criteria that need to comply for validation. The criteria are:<br>▪ $4 < K < 40$<br>▪ $0 < M < 0.8$<br>▪ $0.7 < G < 1.0$ (for sand soil)<br>▪ $0.05 < S < 8.0$ (for clay soil)<br>▪ $D \geq 0.4$ m |
| • The method generally gives the pipe weight that form a conservative envelope of those obtained from the generalized stability analysis. | • Based on a set of non-dimensional stability curves which have been derived from a series of runs with a dynamic response model. |
| • Can be used for the vast majority of stability calculation, where the required submerge weight is the parameter of interest. | • Can be used in either detailed design calculation or preliminary design calculation, may be used on the sections of the pipeline where potential pipeline movement and strain may be important. |
| • Can be used at any sea state. | • Not suitable for Malaysia sea state. |
| • Common usage of concrete coating | • Cost effective if comply with criteria for validation. |

For Generalized Stability Analysis Method, there were several parameters that had to be fulfilling for validation of the analysis. The parameters that the Generalized Stability Analysis needs to comply for validation were value of K (Keulegan- Carpenter number), M (current to wave velocity ratio), G (relative soil weight of sand), S (shear strength parameter) and D (outer diameter of submarine pipeline). The Simplified Stability Analysis Method does not have any significant criteria for validation of the analysis.

The Simplified Stability Analysis generally gives the pipe weight that form from a conservative envelope of those obtained from generalized stability analysis while the Generalized Stability Analysis Method were based on a set of non-dimensional stability curves which have been derived from a series of runs with a dynamic response model.

The Simplified Stability Analysis Method can be used for the vast majority of stability calculation, where the required submerge weight is the parameter of interest. The Generalized Stability Analysis Method can be used in either detailed design calculation of primary design calculation and also can be used on the sections of the pipeline where potential pipeline movement and strain may be important.

After analyzing the J4 Development Project, it was discovered that the Generalized Stability Analysis Method was not suitable for Malaysia sea state as the parameter needed for validation were not in range. Therefore, it was recommended to use the Simplified Stability Analysis Method as it can be used at any sea state without any criteria for validation.

Generally, the industry used the Simplified Stability Analysis for designing the usage of concrete coating. The Generalized Stability Analysis Method can gave cost saving to the project in term of cost and usage of concrete coating if the project comply with criteria needed for the validation of the analysis.

There are different in interpreting the data from graph for each user of the Det Norske Veritas (DNV) RP E305 as it does not have any table for data of the graph. The graph from DNV RP E305 does not have exact value for each point. For standardizing purposed, the DNV RP F109 should be adopted as it has the exact value of each graph to give users the same expected result.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

From the experiment, this research showed that designing the on-bottom stability analysis was compulsory as it was the sufficient mean for the submarine pipeline to covers the aspects such as the wave mechanics and the hydrodynamic forces which are very important factors to be considered in the study.

From the J4 Development Project showed that the Generalized Stability Analysis Method was not congruent for Malaysia sea state as the value of K (Keulegan- Carpenter number) and M (current to wave velocity ratio) were not in range for validation of Generalized Stability Analysis Method.

The Simplified Stability Analysis Method was the best way in designing the on-bottom stability analysis as it was usable for any sea state condition. The Simplified Stability Analysis Method does not have any criteria or parameters for validation.

For the parametric analysis, the result showed that the varying of one input for each analysis and the other ware remain fixed. Each parameter contributed results that were found differs from expected. Each varying parameter had the significant effects of the concrete coating thickness.

In the future, some modification can be done in order to get more accurate result. It is suggested to reduce the assumptions made in spreadsheet. Other than that, do:

- Apply soil reaction in the lab experiment.
- Use RP F109 instead of RP E305 graph data for standardizing the value of the graph.
- Develop FE modeling using ANSYS software of submarine pipeline.

## REFERENCES


1. PETRONAS, "Pipeline On-Bottom Stability Analysis Report", Detailed Design for J4 Development Project.
2. PETRONAS, (2007), "Pipeline Stress Design", Department of Pipeline Engineering.
3. Palmer, A.C and King, R.A., (2008), "Subsea Pipeline Engineering", Pennwell Books.
4. Lambrakos, K. F., Chao, J. C., Beckman, H., and Brannon, H. R., (1987), "Wake model of hydrodynamic forces on pipelines." *Ocean Eng.*, 14,117–136.
5. Wagner, D. A., Murff, J. D., Brennodden, H., and Sveggen, O., (1987), "Pipe–soil interaction model." *Proc., 19th Annual Offshore Technology Conf.*, Paper OTC 5504, 181–190.
6. Fuping Gao, Yingxiang Wu, Dong-Sheng Jeng, and Xu Jia, (2005), "Wave-Induced Pipeline On-bottom Stability: Comparison between Pipe-Soil and Wave-Pipe-Soil Interaction Models", Proc., 15th Int. Conf. on Offshore and Polar Engineering, Seoul, Korea.
7. Fuping Gao, Dong-Sheng Jeng, and Yingxiang Wu, (2006), "Improved Analysis Method for Wave-Induced Pipeline Stability on Sandy Seabed", ASCE Conf. on Transportation Engineering.
8. Jeng, D.S., and Seymour, B.R., (2005), "Wave-Induced Pore Pressure in a Porous Seabed: Clarification of two mechanisms", Asia and Pacific Coasts, Jeju Island, Korea.
9. Damgaard, J. S., and Palmer, A. C., (2001), "Pipeline Stability on a Mobile and Liquefied Seabed: A Discussion of Magnitudes and Engineering Implications", 20th Int. Conf. on Offshore Mechanics and Arctic Engineering, Rio de Janeiro, Brazil.
10. Wu, Y. T., and Riha, D. S., (2000), "Reliability Analysis of On-Bottom Stability", 8th ASCE Specialty Conf. on Probabilistic Mechanics and Structural Reliability, Notre Dame, Indiana, USA.
11. Chakrabarti, K. (1994), "Offshore Structure Modeling", JBW Printers & Binder Pte. Ltd.

12. Keulegan, G. H.; Carpenter, L. H. (1958), "Forces on cylinders and plates in an oscillating fluid", Journal of Research of the National Bureau of Standards **60** (5): 423–440.

13. Nurul Husna Bt. Baharudin, (2009), "Experimental Investigation on On-Bottom Stability of Submarine Pipelines under Wave", UTP.

14. Det Norske Veritas, (1988), "On-bottom stability of submarine pipelines", Recommended Practice RP E305.

15. Palmer, A.C and King, R.A., (2nd edition, 2008), "Subsea Pipeline Engineering", Pennwell Books.

16. Trevor Jee Associates, (2005), "Subsea Pipeline Engineering", Tunbridge Wells, Kent.

# APPENDIX A

# Calculation Example of Recomended Practice – DNV RP E305

## On-Bottom Stability Analysis

## APPENDIX B

## CALCULATION EXAMPLES

### B.1 INTRODUCTION

This Appendix presents some calculation examples of the simplified and generalized methods. The examples are for the following design case:

Pipeline design parameters:

- Steel pipe outer diameter, $D_s = 0.4064$ m
- Wall thickness, $t_s = 0.0127$ m
- Internal diameter, $D_i = 0.3810$ m
- Corrosion coating thickness, $t_{cc} = 0.005$ m
- Density of corrosion coating, $\rho_{cc} = 1300$ kg/m³
- Density of concrete coating, $\rho_c = 2400$ kg/m³
- Density of internal content, $\rho_i = 10$ kg/m³ (gas)
- Density of seawater, $\rho_w = 1025$ kg/m³
- Density of steel, $\rho_{st} = 7850$ kg/m³

Soil type: Medium sand of density, $\rho_s = 1860$ kg/m³

Environmental data:

- significant wave height, $H_s = 14.5$ m
- spectral peak period, $T_p = 15$ s
- water depth, $d = 110$ m
- current 3 m above bottom, $U_r = 0.6$ m/s

### B.2 SIMPLIFIED METHOD

1. Find water particle velocities:

For wave, using Fig. 2.1 - 2.3.

$$T_n = \sqrt{(d/g)} = \sqrt{(110/9.81)} = 3.348$$

$$T_n/T_p = 3.348/15 = 0.223$$

From graph, Fig. 2.1 (Pierson Moskovitz, PM): $(U_s{}^*T_n)/H_s = 0.14$

$$U_s{}^* = (H_s/T_n)\cdot 0.14 = (14.5/3.348)\cdot 0.14 = \underline{0.606 \text{ m/s}}$$

Zero-up-crossing period, $T_u$ - using Fig. 2.2

$$T_u/T_p = 1.07 \rightarrow T_u = 1.06\cdot T_p = 16.05 \text{ sec.}$$

Directional and spreading factor assumed to be

$$R = 1.0 \text{ - no reduction.}$$

$$\underline{U_s = U_s{}^*\cdot R = 0.606 \text{ m/s}}$$

$$\underline{T_u = 16.05 \text{ sec.}}$$

Current velocity:

The current velocity 3 m above seabed ($Z_r = 3$).

$$U_r = 0.6 \text{ m/s}$$

To calculate average velocity across the pipe assuming an approximate pipe diameter of 0.5 m (i.e. including corrosion coating plus 40 mm of concrete coating).

Medium sand assumed, from Table A1,

$$d_{50} = 0.5 \text{ mm}$$
$$Z_0 = 4.17 \cdot 10^{-5} \text{ m}$$

which gives:

$$D / Z_0 = 11990$$

$$Z_r / Z_0 = 3.0 / 4.17 \cdot 10^{-5} = 71942$$

Substituting in equation A.3:

$$\frac{U_D}{U_r} = \frac{1}{\ln(71942+1)} \cdot \left\{ \left[ 1 + \frac{1}{11990} \right] \ln(11990+1) - 1 \right\}$$

$$U_D / U_r = 0.7504$$

$$U_D = 0.7504 \cdot U_r = 0.6 \cdot 0.7504 = 0.45 \text{ m/s}$$

2. Using simplified static stability method:

Medium sand has been assumed, $\mu = 0.7$.

$$C_L = 0.9, C_D = 0.7, C_M = 3.29$$

An approximate diameter, $D \approx 0.5$ m

$$A_s = 2\pi \cdot \frac{U_s}{T_u} = 2\pi \cdot \frac{0.606}{16.05} = 0.2372 \text{ m/s}^2$$

$$M = \frac{U_D}{U_s} = \frac{0.45}{0.606} = 0.75$$

$$K = \frac{U_s \cdot T_p}{D} = \frac{0.606 \cdot 16.05}{0.5} = 19.45$$

From Fig. 5.12, $F_w = 1.25$

Computing hydrodynamic forces and iterating to find the phase angle ($\theta$) giving maximum submerged weight requirement ($W_s$).

For $\theta$ = 21 degrees, max $W_s$ is found:

$$\left.\begin{array}{l} F_L = 237.9 \text{ N/m} \\ F_D = 185.1 \text{ N/m} \\ F_I = 56.4 \text{ N/m} \end{array}\right\} W_s = \left[\frac{(185.1+56.4)+0.7\cdot 237.9}{0.7}\right]\cdot 1.25 \text{ [N/m]}$$

$$W_s = 728.75 \text{ N/m}$$

<u>A minimum submerged weight of 728.75 N/m is required.</u>

(Calculate concrete density required to achieve the above submerged weight with the estimated concrete thickness. Revise concrete thickness and density as necessary and repeat until a satisfactory combination of density and thickness is achieved).

## B.3 GENERALIZED METHOD

From simplified static analysis, we have determined the following start values:

$W_s$ = 728.75 N/m
D = 0.5 m (initial approximate outer pipe diameter)

Using the flowchart, section 5.2.3.4, assume thicknesses in first trial to be as for Simplified Method above.

Check diameter against formula:

$$D = \left\{\frac{1}{2400-1025}\left[\frac{728.75}{0.25\cdot\pi\cdot 9.81}+0.3810^2(7850-10)+ 0.4064^2(1300-7850)+0.4184^2(2400-1300)\right]\right\}^{\frac{1}{2}} \text{ [m]}$$

D = 0.5 m → required outer diameter.

Calculate parameters: (environmental data from simplified static stability method).

$$K = \frac{U_s \cdot T_u}{D} = \frac{0.606\cdot 16.05}{0.5} = 19.45$$

$$M = \frac{U_D}{U_s} = \frac{0.45}{0.606} = 0.75$$

$$T = \frac{T_1}{T_u} = \frac{3\cdot 60\cdot 60}{16.05} = 672.90 \text{ (3 hours storm duration)}$$

$$\text{Target displacement} = 10\ \text{m};\ \delta = \frac{\text{displacement}}{D} = \frac{10}{0.5} = 20$$

Using Fig. 5.1 to 5.6 to determine L by interpolating with respect to values for δ and T as necessary:

$$\left.\begin{array}{l} \delta = 20,\ T = 500\ \text{give}\ \sqrt{L} = 2.65 \\ \delta = 20,\ T = 1000\ \text{give}\ \sqrt{L} = 2.85 \end{array}\right\}\ \text{interpolating,}\ \sqrt{L} = 2.72$$

$$\rightarrow L = 7.40$$

Computing new

$$\begin{aligned} W_s &= L \cdot 0.5 \cdot \rho_w \cdot D \cdot U_s^2 \\ &= 7.40 \cdot 0.5 \cdot 1025 \cdot 0.500 \cdot 0.606^2\ \text{N/m} \\ W_s &= 696.4\ \text{N/m} \end{aligned}$$

Compute new D:

$$D = \left\{ \frac{1}{2400 - 1025} \left[ \frac{696.4}{0.25 \cdot \pi \cdot 9.81} + 0.3810^2 (7850 - 10) + 0.4064^2 (1300 - 7850) + 0.4184^2 (2400 - 1300) \right] \right\}^{\frac{1}{2}} [\text{m}]$$

D = 0.497 m (i.e. 0.6% difference from trial figure of 0.500 m, therefore acceptable).

Check strain level:

From Fig. 5.1 - 5.4, by interpolation $\varepsilon' = 2.6\%$

Engineering strain, section 5.2.3.3:

$$\varepsilon = \left( \frac{8 \cdot 666.3 \cdot 0.500}{\pi \cdot 2.1 \cdot 10^{11} \cdot 0.0127 \cdot 0.4064} \right)^{\frac{1}{2}} \cdot 2.6 = 0.0023\ \%:\ \text{OK (i.e.} < 0.2\ \%\text{)}$$

# Simplified Stability Analysis Method Spreadsheet

# PIPELINE ON-BOTTOM STABILITY ANALYSIS

PETRONAS CARIGALI

**Project** SKO Pipeline Replacement Project

**User** DFE/5

**Date** 4-Dec-09

CASE: 100-year storm condition - Hydrotest

INPUT DATA:

PIPE DATA

| | | | | |
|---|---|---|---|---|
| Pipe Outside Diameter | | 273.100 | mm | *Zone 1 |
| Pipe Wall Thickness | | 9.500 | mm | |
| Content Specific Gravity relative to Water | | 1.000 | | |
| Concrete Coating Density | | 3044.000 | $kg/m^3$ | |
| Concrete Coating Cutback | | 350.000 | mm | |
| Anti-Corrosion Coating Thk | | 5.500 | mm | |
| Anti-Corrosion Coating Density | | 1280.000 | $kg/m^3$ | |
| Anti-Corrosion Coating Cutback | | 1280.000 | mm | |
| Field Joint Density | | 2000.000 | $kg/m^3$ | |

ENVIRONMENTAL DATA

| | | | | |
|---|---|---|---|---|
| Significant Wave Height | (Hs) | 3.300 | m | |
| Peak Period | (Tp) | 8.600 | sec | |
| Water Depth | (d) | 28.600 | m | |
| Current Velocity | (Ur) | 0.410 | m/s | (90 deg. to pipe at Zr) |
| Spreading Exponent (INPUT "N" = 999999, 8, 4 or 2) | (N) | 999999 | | |
| Wave Angle wrt pipeline | | 90.000 | deg | |
| Current Reference Point | (Zr) | 2.86000 | m | (Above seabed) |

SOIL DATA

| | | | | |
|---|---|---|---|---|
| Mean Grain Size | (d50) | 0.110 | mm | |
| Soil Shear Strength | (Su) | 10.000 | kpa | (For clays) (INPUT "0" For sand) |

TRIAL CONCRETE COATING THICKNESS:

| | | | |
|---|---|---|---|
| Concrete Coating Thk | 0.000 | mm | (INPUT) |

CHECK VALIDITY OF METHOD FOR BOUNDARY LAYER REDUCTION OF COMBINED WAVE AND CURRENT FLOW

| | | | | | |
|---|---|---|---|---|---|
| Soil Roughness | (Zo) | 9.17E-06 | m | | |
| 0.2Ao(Ao/Kb)^-0.25 | | 0.007 | m | Valid, Zr > 0.2Ao | 0.000 |
| Ao / Kb | | 680 | | Valid, Ao/Kb >=30 | |
| Us/Ur | | 0.33 | | Not Valid, Us/Ur<1 | |
| Zr/Kb | | 10,400 | | | |
| Zoa/Zo | | 1.00 | (Input Zoa/Zo=1, if reduction due to combined wave and current is not considered Otherwise input Zoa/Zo from Figures A.1 to A.7) | | |

CALCULATED BOTTOM HYDRODYNAMICS:

| | | | | |
|---|---|---|---|---|
| Reduction Factor due to Wave Spreading & Direction | (R) | 1.000 | | (From Figure 2.3) |
| Significant Wave Velocity | (Us) | 0.137 | m/s | PIERSON MOSKOVITZ (PM) spectrum is used |
| Zero-Up-Crossing Period | (Tu) | 8.914 | sec | |
| Ave. Current Velocity | (Uc) | 0.303 | m/s | |

OUTPUT RESULTS:

| | | | | | |
|---|---|---|---|---|---|
| Total Pipe Outside Diameter | (D) | 284.100 | mm | | |
| K = Us x Tu / D | | 4.289 | | | |
| M = Uc / Us | | 2.215 | | | |
| Shear Strength Parameter | (1/S) | 5.327 | | | |
| Soil Friction Factor | | 0.198 | | (From Figure 5.11) | |
| Actual Pipe Submerged Weight | | 533.310 | N/m | (No water absorption is considered) | |
| Pipe Specific Gravity | | 1.837 | | | |
| Significant Wave Acceleration | (As) | 0.096 | m/s^2 | | |
| Reynold's Number | | 1.04E+05 | (Default for kinematic viscosity of seawater is 1.2E-6m^2/s) | | |
| Lift, Drag, Inertia Coeffs | | 0.900 | 1.200 | 3.290 | |
| Lift, Drag, Inertia Forces | (N/m) | 21.255 | 28.340 | 14.048 | |
| CRITICAL PHASE ANGLE OF HYDRODYNAMIC FORCES | (THETA) | 43.00 | deg | | |
| CALIBRATION FACTOR | (Fw) | 1.000 | | (From Figure 5.12) | |
| LIMITING PIPE SUBMERGED WEIGHT | (Ws) | 234.936 | N/m | (ok Less than actual pipe submerged weight) | |

CONCLUSION:

| ACTUAL PIPE SUB. WEIGHT, N/m | REQUIRED PIPE SUB. WEIGHT, N/m | ACTUAL SAFETY FACTOR | REQUIRED SAFETY FACTOR | CONCRETE COATING THICKNESS ACCEPTABLE |
|---|---|---|---|---|
| 533.31 | 234.94 | 2.27 | 1.00 | YES |

# Generalized Stability Analysis Method Spreadsheet

# PIPELINE ON-BOTTOM STABILITY DESIGN

This MathCAD sheet calculates the required concrete coating thickness for lateral stability of submarine pipelinesin accordance with the guidelines stipulated by DNV RP E305. The method considered in this spreadsheet is the Simplified Stability Analysis which is based on the quasi-static balance of forces acting on the pipe and calibrated with results from the generalized stability analysis.

INPUT PIPE DATA

| | |
|---|---|
| Pipeline Outside Diameter | $OD := 406.4mm$ |
| Pipeline Wall Thickness | $t_{wall} := 12.7mm$ |
| Steel Density | $\rho_{steel} := 7850kg \cdot m^{-3}$ |
| Product Density | $\rho_{prod} := 10kg \cdot m^{-3}$ |
| Concrete Coating Density | $\rho_{conc} := 2400kg \cdot m^{-3}$ |
| Concrete Coating Cutback | $x_{conc} := 0mm$ |
| Corrosion Coating Thickness | $t_{corr} := 5mm$ |
| Corrosion Coating Density | $\rho_{corr} := 1300 \cdot kg \cdot m^{-3}$ |
| Corrosion Coating Cutback | $x_{corr} := 0mm$ |
| Field Joint Material Density | $\rho_{field} := 0kg \cdot m^{-3}$ |
| Pipe Joint Length | $L_{joint} := 12m$ |

ENVIRONMENTAL DATA

| | |
|---|---|
| Density of Sea Water | $\rho_{sea} := 1025kg \cdot m^{-3}$ |
| Kinematic Viscosity of Seawater | $\nu_{sea} := 1.2 \cdot 10^{-6} \frac{m^2}{s}$ |
| Significant Wave Height | $Hs := 14.5m$ |
| Peak Period | $T_p := 15s$ |
| Water Depth | $d := 110m$ |
| Current Velocity | $Ur := 0.6m \cdot s^{-1}$ |
| Wave Angle wrt Pipeline, $\theta - \theta_p$ (deg) | $\theta := 90$ |
| Current Reference Point | $Zr := 3.0m$ |
| Peakedness Parameter (1.0, 3.3 or 5.0) | $\gamma := 1.0$ |
| Spreading Exponent (NN = 9999, 8, 4 or 2) | $NN := 9999$ |

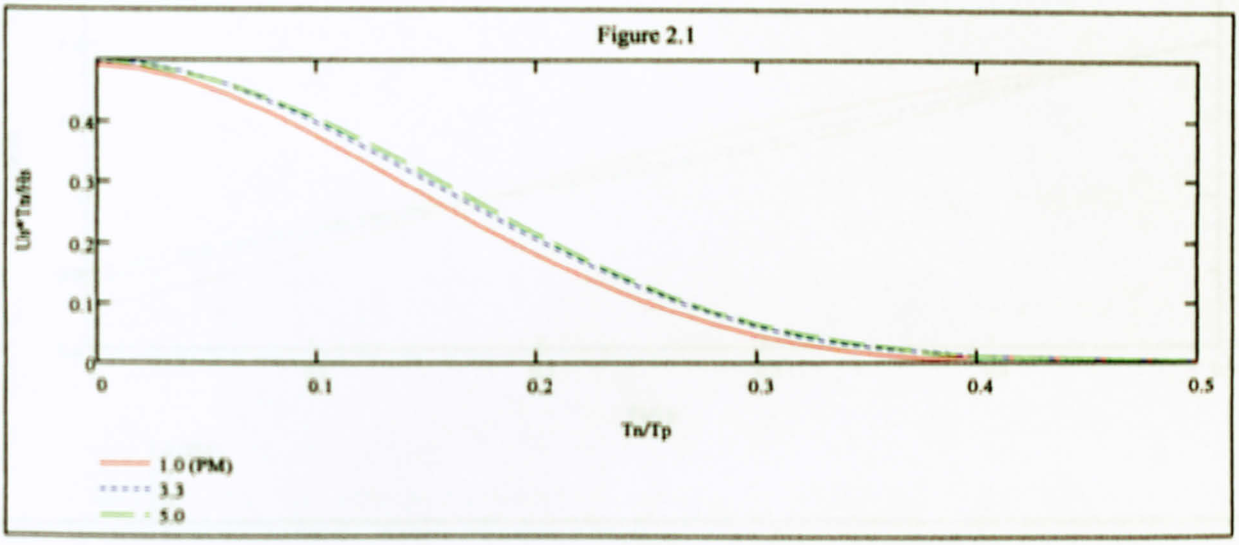
SOIL DATA

| | |
|---|---|
| Soil Type (sand/clay) | Soil := "sand" |
| Mean Grain Size | $d50 := 0.5mm$ |
| Soil Shear Strength (Input "0" for sand) | $Su := 0Pa$ |
| Trial Concrete Thickness | $t := 40 \cdot mm$ Update from the value calculated at $t_{conc2}$ |

## CALCULATIONS

$T_n := \sqrt{\frac{d}{g}}$ $\quad T_n = 3.349\,s \quad \frac{T_n}{T_p} = 0.223$

Based on Figure 2.1, Tn/Tp calculated above and g.
(g = Peakedness Parameter and 1.0 is for Pierson Moskovitz
(PM)

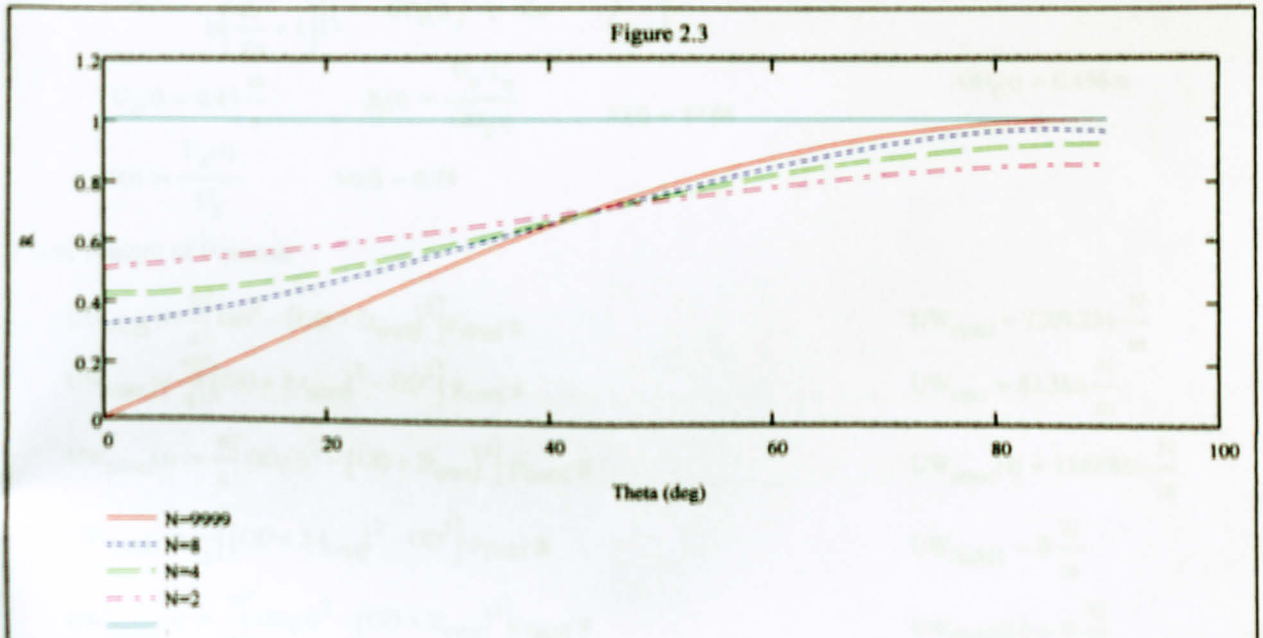



$Fig21 := if(\gamma = 1.0, \gamma_{1.0}, if(\gamma = 3.3, \gamma_{3.3}, if(\gamma = 5.0, \gamma_{5.0}, "\#")))$ $\quad Fig21 = 0.14$

Given $\quad \frac{U_s \cdot T_n}{Hs} = Fig21 \quad U_s := Find(U_s) \quad U_s = 0.608\frac{m}{s}$

Based Figure 2.3 , for Spreading Exponent, NN,

$\theta = 90 \qquad q - q_p$




$R := if(NN = 9999, R_{9999}, if(NN = 8, R_8, if(NN = 4, R_4, if(NN = 2, R_2, "Error"))))$

$R = 1$

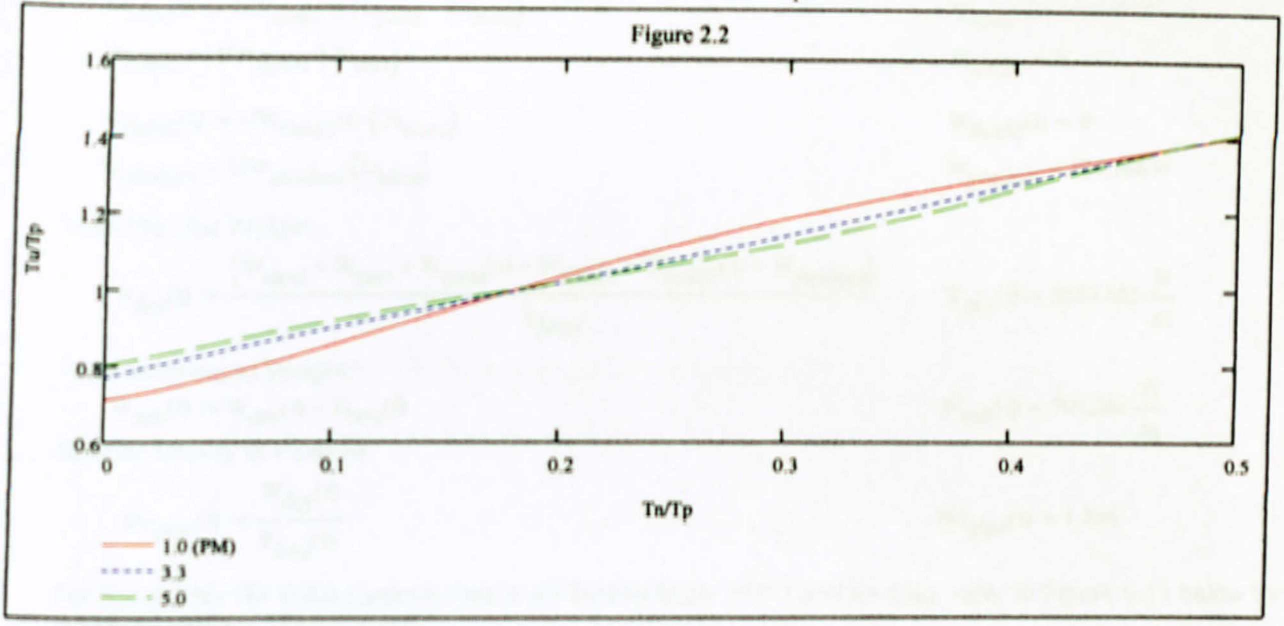
$U_s := U_s \cdot (R) \qquad U_s = 0.608\frac{m}{s}$

*Soil Roughness, Zo*

$$Zo := \frac{2.5d50}{30} \qquad Zo = 0.042\cdot mm$$

Based on Figure 2.2, Tn/Tp and g (Peakedness Parameter).

$$\frac{T_n}{T_p} = 0.223$$




$$P := \mathrm{if}\left(\gamma = 1.0, \gamma'_{1.0}, \mathrm{if}\left(\gamma = 3.3, \gamma'_{3.3}, \mathrm{if}\left(\gamma = 5.0, \gamma'_{5.0}, \text{"Error"}\right)\right)\right)$$

Given $P = 1.07 \qquad \frac{T_u}{T_p} = P \qquad T_u := \mathrm{Find}(T_u) \qquad T_u = 16.05\,s$

Average Current Velocity, Uc

$$OD_f(t) := OD + 2\left(t_{corr} + t\right)$$

$$U_c(t) := \frac{1}{\ln\left(\frac{Zr}{Zo} + 1\right)}\left[\left(1 + \frac{Zo}{OD_f(t)}\right)\ln\left(\frac{OD_f(t)}{Zo} + 1\right) - 1\right]\cdot Ur$$

$$U_c(t) = 0.45\frac{m}{s} \qquad K(t) := \frac{U_s \cdot T_u}{OD_f(t)} \qquad K(t) = 19.66 \qquad OD_f(t) = 0.496\,m$$

$$M(t) := \frac{U_c(t)}{U_s} \qquad M(t) = 0.74$$

Unit Weight of Pipeline

$$UW_{steel} := \frac{\pi}{4}\left[OD^2 - \left(OD - 2t_{wall}\right)^2\right]\rho_{steel}\cdot g \qquad UW_{steel} = 1209.231\cdot\frac{N}{m}$$

$$UW_{corr} := \frac{\pi}{4}\left[\left(OD + 2\cdot t_{corr}\right)^2 - OD^2\right]\cdot\rho_{corr}\cdot g \qquad UW_{corr} = 82.385\cdot\frac{N}{m}$$

$$UW_{conc}(t) := \frac{\pi}{4}\left[OD_f(t)^2 - \left(OD + 2t_{corr}\right)^2\right]\cdot\rho_{conc}\cdot g \qquad UW_{conc}(t) = 1349.856\cdot\frac{N}{m}$$

$$UW_{field1} := \frac{\pi}{4}\left[\left(OD + 2\cdot t_{corr}\right)^2 - OD^2\right]\cdot\rho_{field}\cdot g \qquad UW_{field1} = 0\cdot\frac{N}{m}$$

$$UW_{field2}(t) := \frac{\pi}{4}\left[OD_f(t)^2 - \left(OD + 2t_{corr}\right)^2\right]\rho_{field}\cdot g \qquad UW_{field2}(t) = 0\cdot\frac{N}{m}$$

$$UW_{product} := \frac{\pi}{4}\left(OD - 2t_{wall}\right)^2\left(\rho_{prod}\right)g \qquad UW_{product} = 11.18\cdot\frac{N}{m}$$

$$F_{bou}\left(t_{conc}\right) := \frac{\pi}{4}OD_f(t)^2\cdot\rho_{sea}\cdot g \qquad F_{bou}(t) = 1945.351\cdot\frac{N}{m}$$

Total Dry Weight per Joint

$W_{steel} := UW_{steel} \cdot L_{joint}$ $\qquad W_{steel} = 14510.774\,N$

$W_{corr} := UW_{corr} \cdot (L_{joint} - 2x_{corr})$ $\qquad W_{corr} = 988.62\,N$

$W_{conc}(t) := UW_{conc}(t) \cdot (L_{joint} - 2x_{conc})$ $\qquad W_{conc}(t) = 16198.271\,N$

$W_{field1} := UW_{field1} \cdot (2x_{corr})$ $\qquad W_{field1} = 0$

$W_{field2}(t) := UW_{field2}(t) \cdot (2x_{conc})$ $\qquad W_{field2}(t) = 0$

$W_{product} := UW_{product} \cdot (L_{joint})$ $\qquad W_{product} = 134.166\,N$

Total Dry Unit Weight

$$W_{dry}(t) := \frac{(W_{steel} + W_{corr} + W_{conc}(t) + W_{field1} + W_{field2}(t) + W_{product})}{L_{joint}} \qquad W_{dry}(t) = 2652.653 \cdot \frac{N}{m}$$

Total Submerged Weight

$$W_{sub}(t) := W_{dry}(t) - F_{bou}(t) \qquad W_{sub}(t) = 707.302 \cdot \frac{N}{m}$$

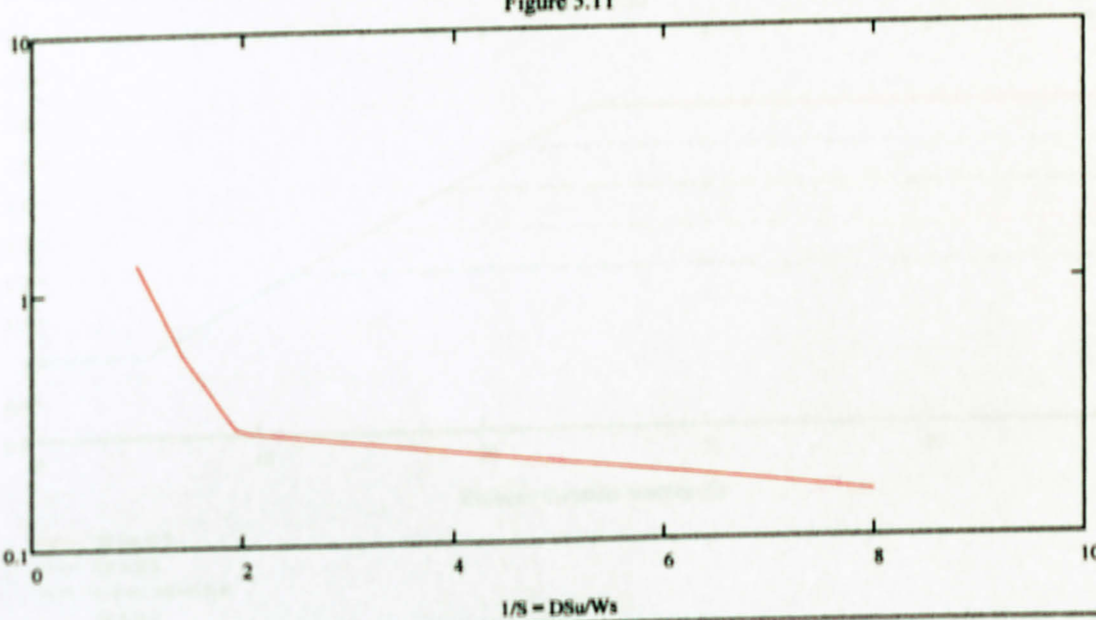
Specific Gravity of Pipeline

$$SG_{pipe}(t) := \frac{W_{dry}(t)}{F_{bou}(t)} \qquad SG_{pipe}(t) = 1.364$$

For Sand, DNV RP E305 recommends a soil friction factor of 0.7 and for Clay, refer to Figure 5.11 below for recommended soil friction factor.

$$invS(t) := \frac{OD_t(t) \cdot Su}{W_{sub}(t)}$$

Figure 5.11




$\mu_{clay}(t) := \mu_{clay5}(t)$

$\mu_{clay}(t) = \text{"Error"}$

$\mu_{sand} := 0.7$

From Figure 5.11 above, soil friction factor,

m
Refer to Figure 5.11 for Clay and set to 0.7 for Sand

$\mu(t) := if(Soil = \text{"sand"}, \mu_{sand}, if(Soil = \text{"clay"}, \mu_{clay}(t), \text{"Error"}))$

$\mu(t) = 0.7$

Significant Wave Acceleration, As (Refer to DNV RP E305, Pg 28)

$$A_s := 2\pi \cdot \frac{U_s}{T_u}$$ $$A_s = 0.238 \frac{m}{s^2}$$

Reynold's Number

$$Re(t) := \frac{\left(U_s + U_c(t)\right) OD_t(t)}{\nu_{sea}}$$ $$Re(t) = 4.376 \times 10^5$$

From DNV RP E305, Pg 28

$C_L := 0.90$ Lift Force Coefficient

$C_D(t) := \text{if}\left(Re(t) < 3 \cdot 10^5 \wedge M(t) \geq 0.8, 1.2, 0.7\right)$ Drag Force Coefficient

$C_D(t) = 0.7$

$C_M := 3.29$ Inertia Force Coefficient

To compute the angle b that will result in maximum submerged weight.

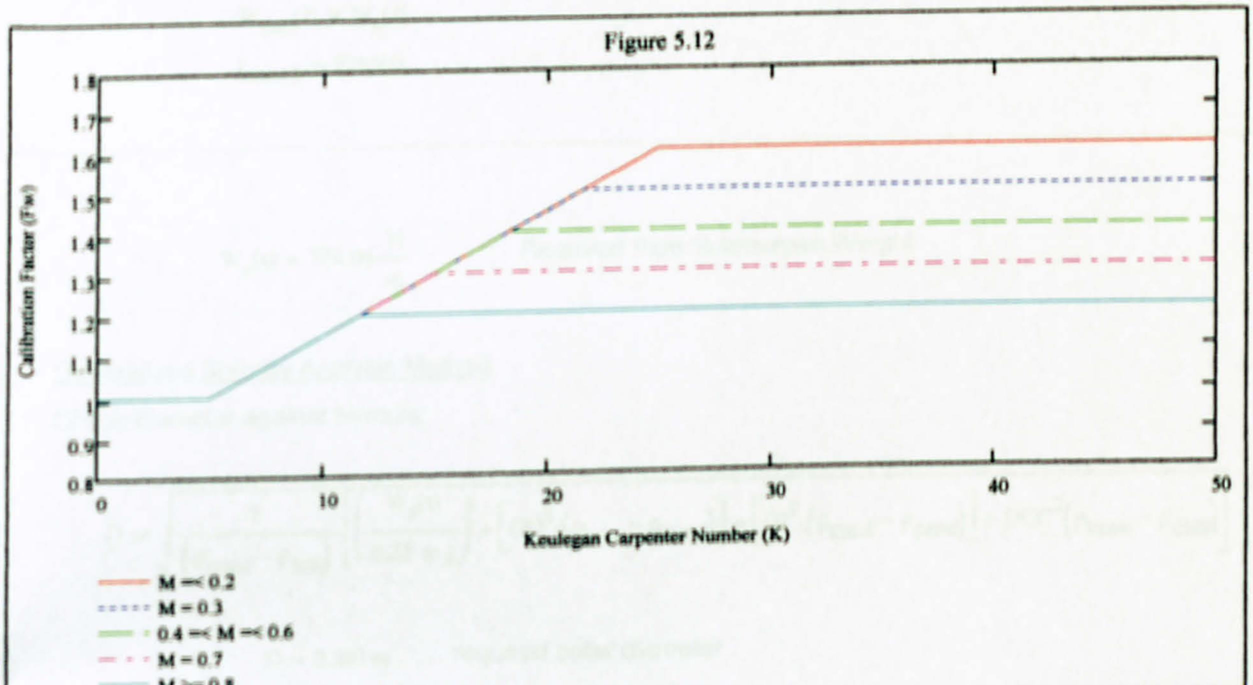
$$F_L(\beta) := \frac{1}{2} \cdot \rho_{sea} \cdot OD_t(t) \cdot \left[C_L \cdot \left(U_s \cdot \cos(\beta) + U_c(t)\right)^2\right]$$

$$F_D(\beta) := \frac{1}{2} \cdot \rho_{sea} \cdot OD_t(t) \cdot C_D(t) \cdot \left|U_s \cdot \cos(\beta) + U_c(t)\right| \cdot \left(U_s \cdot \cos(\beta) + U_c(t)\right)$$

$$F_I(\beta) := \frac{\pi}{4} \cdot OD_t(t)^2 \cdot \rho_{sea} \cdot C_M \cdot A_s \cdot \sin(\beta)$$

From Figure 5.12 below, based on K and M,

$K(t) = 19.66$ $M(t) := \text{round}(M(t), 1)$ $M(t) = 0.7$




$$F'_w(t) := \text{if}\left(M(t) \leq 0.2, Fw_{0.2}(t), \text{if}\left(M(t) = 0.3, Fw_{0.3}(t), \text{if}\left(0.4 \leq M(t) \leq 0.6, Fw_{0.4}(t), \text{if}\left(M(t) = 0.7, Fw_{0.7}(t), Fw_{0.8}(t)\right)\right)\right)\right)$$

$F'_w(t) = 1.3$

The Calibration Factor, Fw, obtained from Figure 5.12 above.
If K > 50 and M >=0.8, a constant Fw = 1.2 may be applied.

$F_w(t) := \text{if}\left(K(t) > 50 \wedge M(t) \geq 0.8, 1.2, F'_w(t)\right)$ $F_w(t) = 1.3$

The limiting value of submerged weight, Ws, from varying b

$$W_s(\beta) := \left[\frac{\left(F_D(\beta) + F_I(\beta)\right) + \mu(t)\cdot F_L(\beta)}{\mu(t)}\right]\cdot F_w(t)$$

$$\beta := \text{Maximize}\left(W_s, \beta\right)$$

$$\beta = 20\cdot \text{deg}$$

$$W_s(\beta) = 754.064\cdot\frac{N}{m}$$

To compute the required concrete thickness from the maximum b angle calculated above

$$F_L(t) := \frac{1}{2}\cdot\rho_{sea}\cdot OD_t(t)\cdot\left[C_L\cdot\left(U_s\cdot\cos(\beta) + U_c(t)\right)^2\right] \qquad F_L(t) = 238.275\cdot\frac{N}{m}$$

$$F_D(t) := \frac{1}{2}\cdot\rho_{sea}\cdot OD_t(t)\cdot C_D(t)\cdot\left|U_s\cdot\cos(\beta) + U_c(t)\right|\cdot\left(U_s\cdot\cos(\beta) + U_c(t)\right) \qquad F_D(t) = 185.325\cdot\frac{N}{m}$$

$$F_I(t) := \frac{\pi}{4}\cdot OD_t(t)^2\cdot\rho_{sea}\cdot C_M\cdot A_s\cdot\sin(\beta) \qquad F_I(t) = 53.917\cdot\frac{N}{m}$$

The limiting value of submerged weight, Ws, for the calculated b above

$$W_s(t) := \left[\frac{\left(F_D(t) + F_I(t)\right) + \mu(t)\cdot F_L(t)}{\mu(t)}\right]\cdot F_w(t)$$

Given

$$W_{sub}(t) = W_s(t)$$

$$t_{conc2} := \text{Find}(t)$$

$$W_s(t) = 754.06\cdot\frac{N}{m}$$ Required Pipe Submerged Weight

Generalized Stability Analysis Method

Check diameter against formula:

$$D := \sqrt{\frac{1}{\left(\rho_{conc} - \rho_{sea}\right)}\cdot\left[\left(\frac{W_s(t)}{0.25\cdot\pi\cdot g}\right) + \left[OD^2\cdot\left(\rho_{corr} - \rho_{steel}\right)\right] + \left[DI^2\cdot\left(\rho_{steel} - \rho_{prod}\right)\right] + DCC^2\left(\rho_{conc} - \rho_{corr}\right)\right]}$$

$$D = 0.501\,m$$ required outer diameter

Calculated parameters:

$$K := \frac{U_s\cdot T_u}{D} \qquad K = 19.486$$

$$M(t) := \frac{U_c(t)}{U_s} \qquad M(t) = 0.74$$

$T := \frac{T_l}{T_u}$ $\quad T = 672.881$ $\quad$ 3 hours storm duration

Target Displacement =10m ; $\delta := \frac{displacement}{D}$

$\delta = 19.967$ $\quad$ take $\delta := 20$

Using Figure 5.1 to 5.6 to determine L by interpolating with respect to values for δ and T as necessary:

$\delta 1 := 20 \quad T1 := 500 \quad$ give $\quad L_1 := 2.65$

$\delta 2 := 20 \quad T2 := 1000 \quad$ give $\quad L_2 := 2.85$

interpolating

$$L := \left[\left[\frac{L_2 - L_1}{T2 - T1}\cdot(T - T1)\right] + L_1\right]^2$$

$L = 7.394$

Computing new $\quad W_s(t) := L \cdot 0.5 \cdot \rho_{sea} \cdot D \cdot U_s^{\ 2}$

$$W_s(t) = 701.628\,\frac{kg}{s^2}$$

$$\frac{W_{sub}(t)}{W_s(t)} = 1.008$$

Compute new D

$$D := \sqrt{\frac{1}{\left(\rho_{conc} - \rho_{sea}\right)}\cdot\left[\left(\frac{W_s(t)}{0.25\cdot\pi\cdot g}\right) + \left[OD^2\cdot\left(\rho_{corr} - \rho_{steel}\right)\right] + \left[DI^2\cdot\left(\rho_{steel} - \rho_{prod}\right)\right] + DCC^2\left(\rho_{conc} - \rho_{corr}\right)\right]}$$

$D = 0.496\,m$