DESIGN OF SUBSEA PIPELINE

By

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Dehradun
May, 2010

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A thesis submitted in partial fulfillment of the requirements for the Degree of
Master of Technology
(Pipeline Engineering)

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Approved

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Dean

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CERTIFICATE

This is to certify that the work contained in this thesis titled "Design of Subsea Pipeline" has been carried out by Mr. Niaz Najeeb under my supervision and has not been submitted elsewhere for a degree.

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P.C. CHOUBEY

DGM (Offshore)

PLHQ, IOCL, Noida

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Date

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Mr. Adarsh Kumar Arya
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ABSTRACT

India is a country which is very much dependent on crude oil import. Mainly the crude comes in Very Large Crude Carriers (VLCC) through sea route. The main difficulty is the unloading the crude oil from these carriers with the help of small carriers to the shore, but the difficulty is that it takes lot of time for unloading.

The recent advancement in India is the wide spread implementation of Single Point Mooring(SPM) System for unloading the crude oil. The main components of this system other than the SPM are the subsea pipelines.

So immense care has to be given which designing these subsea pipelines as it has to with stand its entire life span and deliver full availability. So designing these pipelines starts with the selection of materials, wall thickness calculation, the hydrodynamic stability and also the cathodic protection system for the pipeline which helps to fulfil the entire life.

As the cost factor plays an important role in offshore projects optimizing the parameters to an apt value is very important. Thus in this project all the parameters required for this particular pipeline has been found out.

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1. INTRODUCTION

1.1Overview of Subsea Pipelines

Subsea pipelines are used to transfer oil from the production platforms to storage facilities or to the shore. Installation of subsea pipeline is a common occurrence in moderately deep water up to a few hundred meters. Subsea production is often the lowest cost alternative for marginal fields in deepwater when it is possible to tieback production from a few wells to an existing structure. Subsea systems consist of mechanical, hydraulic, electrical and structural components; usually packaged by a subsea vendor. The cost of a subsea development is partly due to the cost of this complex equipment, but in very deep waters the cost of installation and commissioning can be overriding. Large subsea systems can weigh up to several hundred tons, and they can only be lowered to the seafloor using dynamically positioned derrick vessels

1.2 Background of Problem

All submerged pipelines should be stable under the combined action of hydrostatic and hydrodynamic forces. The hydrodynamic forces which act on the pipeline is a function of the wave and underwater currents. Therefore it is very important to determine the minimum value for the wall thickness and concrete coating required to keep the pipeline submerged.

If the pipeline does not have enough submerged weight to resist the inertia and drag force the pipe becomes unstable, and may move up and down or may be laterally displaced. This can cause development of high stress on the pipe and may result in damage. In order to prevent that analysis should be done at extreme conditions.

Also another factor which has to be taken care is protection of the pipe once laid for its full design life. For this, selection of the anode material and its thickness and durability and many other operational parameters has to be taken into proper account.

1.3 Objectives

The objectives of this project are:-

i. To design a pipeline with the optimum pipe wall thickness for the subsea pipeline from SPM to the Land fall point.

ii. To determine the minimum concrete thickness for the subsea pipeline to assure proper On-bottom stability of the pipeline.

iii. To design the cathodic protection system for the line from SPM to land fall point which can effectively protect the pipeline throughout its design life.

1.4 Scope of Study

The scope of study includes the detail design of the wall thickness of the pipeline and the parameters which decide the wall thickness. Also focus will be given on the On-bottom stability analysis of the pipeline and the evaluation of the concrete coating thickness to be given for the stability. In addition to this, the amount of anode required to protect the pipeline and the current requirements are also to be found out.

Throughout this design DNV-OS-F101, DNV-RP-E305 and On-bottom stability design of submarine pipelines, October 2007 are followed and referred for various guidelines and all the basic input data has been supplied by IOCL and values relating to currents and wave heights have been taken from the reports submitted by National Institute of Oceanography (NIO).

To support the design, pipeline modules of excel sheets have been used namely 'pipe aide- engineering' and the verifications are done on the data.

2. LITERATURE REVIEW

2.1 Introduction

Subsea pipelines are pipelines which rest on the sea bed or rest on supports under the sea bed which help in the transportation of crude oil or products from an offshore platform to a storage yard or to load or unload products at the port through a Single Point Mooring system.

A subsea pipeline consists of the following lines:-

- Export (transportation) pipelines
- Flowlines to transfer product from a platform to export lines
- Flowlines to transfer product between platforms
- Pipeline bundles
- For loading and unloading of cargo to the vessel from a refinery or a port through a Single Point Mooring (SPM) system.

This gathering system contains pipelines varying in size from 2 inch to 60 inch in diameter.

Oil and Gas pipeline systems are preferred for their efficiency and low operating cost than transporting through barges. It also helps in saving a lot of time than transporting in small carriages or vessels. Although the initial cost of building up a subsea pipeline is very high compared to an onshore pipeline, in a longer run the results are seen to be truly fruitful.

In an SPM system the subsea pipeline originates from the Pipeline End Manifold (PLEM) which is located on the sea bed beneath the buoy and terminates at the storage area on shore.

Most of the subsea pipelines are protected using the Sacrificial anode Protection system.

2.2 Composition of a Subsea Pipeline

A typical Subsea pipeline consists of the following elements namely:-

- Pipe material
- Coating material
- Concrete coating

Usually the material used for the pipeline is steel but very rarely as per the requirements other materials like composite plastics and reinforced plastics are also used. Steel pipes without protection are susceptible to severe corrosion once they are exposed to the saline water. In order to prevent that pipelines are provided with corrosion coating. The efficiency of such coatings are increased by providing electrochemical measures like cathodic protection Also at times a corrosion allowance is provided to pipe while manufacturing to compensate for the loss of material.

Internal coatings are provided only when the internal roughness of the pipe is much more than the assumed value and also it depends on the nature of the product carried in the pipeline. In addition to this the external coating of the pipe is also protected by a reinforced concrete coating. This is done to increase the weight of the pipe while it is in the submerged state. Thus helps to provide bottom stability (resistance against floatation or movement of a buried pipeline on the seabed).

The cross sectional view of a pipeline is shown in fig 2.1

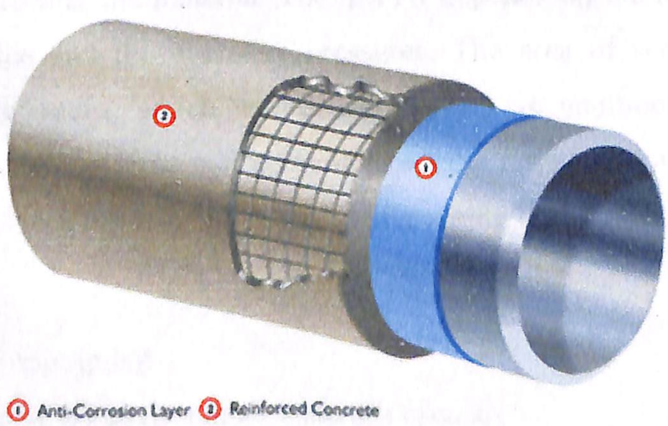


Figure 2.1

2.3 Pipe Material Specification

The selection of material of making the pipeline manufacturing is an important task.The material is decided after consideration of many parameters. Some of the important parameters which are taken into consideration while selecting material are as follows:-

- Nature of the material to be transported
- Weldability
- SMYS of the material
- Temperature and pressure of operation
- Nature of the environment
- Method of installation
- Material grade
- Fracture toughness
- Fatigue
- Elongation
- Cost
- Corrosion allowance

Out of this corrosion resistance and weldability of the material are mainly taken into consideration while selecting the material. The SMYS depends on the nature of product to be transported, the distance and the operating pressures. The area of service can determine if fatigue and impact are issues, which will further impose an additional testing requirement Method of installation, for example reel lay will affect the ratio of allowable yield strength to ultimate tensile strength as a result of the pipe yielding during the installation

2.3.1 Nature of the Environment

According to the nature of the environment materials used are:-

Materials used in Sweet environment are Carbon steel, Low alloy martensitic steels, Austenitic stainless steels, and Duplex stainless steels, Lined pipe (CRA, GRP or PE).

Materials used in sour environment are Carbon steel, duplex stainless steels, Lined pipe and clad pipe (nickel alloys).

Some of the materials used are Carbon steel, Martensitic steel, Austenitic stainless steel, Duplex stainless steel, Nickel alloys.

Some of the codes used for line pipe specification are
ISO 3183(API5L),
API 5LC,
API 5LD,
DNV OS-F101.

2.4 Loads acting on the Pipeline

2.4.1 Functional Loads:-

Loads arising from the physical existence of the pipeline system and its intended use shall be classified as functional. All functional loads which are essential for ensuring the integrity of the pipeline system, during both the construction and the operational phase, shall be considered. The weight shall include weight of pipe, buoyancy, contents, coating, anodes, marine growth and all attachments to the pipe. The soil pressure acting on buried pipelines shall be taken into account if significant End cap forces due to pressure shall be considered, as well as any transient pressure effects during normal operation

2.4.2 Environmental Loads:-

Environmental loads are defined as those loads on a pipeline system which are caused by the surrounding environment, and that are not otherwise classified as functional or accidental load.

2.4.3 Hydrodynamic Loads:-

Hydrodynamic loads are defined as flow-induced loads caused by the relative motion between the pipe and the surrounding water. When determining the hydrodynamic loads, the relative liquid particle velocities and accelerations used in the calculations shall be established, taking into account contributions from waves, current and pipe motions if significant

2.4.4 Constructional Loads:-

Loads which arise as a result of the construction of the pipeline system, comprising installation, pressure testing, commissioning, maintenance and repair, shall be classified into functional and environmental loads. All significant loads acting on pipe joints or pipe sections during transport, fabrication, installation, maintenance and repair activities shall be considered.

2.4.5 Accidental Loads:-

Loads which are imposed on a pipeline system under abnormal and unplanned conditions shall be classified as accidental loads. Typical accidental loads can be caused by:

- vessel impact or other drifting items (collision, grounding, sinking);
- dropped objects
- mud slides
- explosion
- fire and heat flux
- operational malfunction
- dragging anchors

2.5 Construction practises and equipments

Pipeline construction methods differ depending upon on the geographical are, the terrain, the environment, the type of pipeline and the standards imposed by the governments and regulatory authorities.

Pipeline construction projects have the following features:-

i. A comprehensive environmental impact studies are done in many countries to issue permit for construction.

ii. For laying the pipeline different kind of barges are used as the type of pipeline and the depth at which the pipeline is laid.

iii. There are a number of welding stations on the vessel where the required number of passes are done.

iv. Also the vessel contains facility for testing of the welded joints as it is an important part of pipeline laying.

v. Mostly the pipelines which are near to shore are buried and pipelines which are deep into sea are left open and allowed to submerge under their own weight. In order to prevent from lateral displacements they might e covered with rock dampers.

vi. Also when the construction activity approaches the shore 'shore pulling' is done to lay the pipelines. At this point of time the vessel may be at a depth of about 10m.

vii. Precautions are taken to prevent from buckling of these lines by using buckle arrestors.

viii. The construction activities are monitored in the barge and the routing are as per the right of way obtained.

ix. Timely preparation of the charts and logs are prepared and is sent for the approval from the client of the progress of the work.

x. Finally the tie-ins are done and also the hydro testing is done for the line as the standards which are at a pressure higher than the rated pressure.

Several construction methods can be used for laying the pipeline including lay barge method, reel barge method, the vertical or J lay method, tow method, S lay method. Each type of method requires large and sophisticated marine vessels.

2.6 Fundamentals of Pipeline Design

i. Ground profile

The profile of the ground has an important role in route selection of the pipeline. Normally we prefer to select a route which does not have much variations in depth and if at all if there is any undulations either we use to select a different path or use to clear of the route by dredging or cutting the obstruction.

In most of the cases the depth of the sea bed tends to increase from the shore and remain constant for certain length than change abruptly thereafter. Single point mooring systems are usually located at these shallow depths only.

2.7 Factors to be considered while designing the pipeline:-

- A review of all appropriate sources of information and the collection and evaluation of all relevant available types of data for the area of interest.
- The various factors that should be investigated :

2.7.1 Geological databases

The field of geology encompasses the study of the composition, structure, physical properties, dynamics, and history of Earth materials, and the processes by which they are formed, moved, and changed.

Figure 2.2

2.7.2 Bathymetric information

Bathymetry is the study of underwater depth of the third dimension of lake or ocean floors.

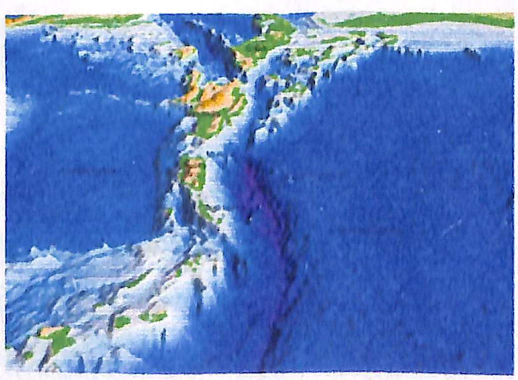


Figure 2.3

2.7.3 Geophysical data

Geophysical survey data are used to analyze potential petroleum reservoirs and mineral deposits, to locate groundwater, to locate archaeological finds, to find the thicknesses of glaciers and soils, and for environmental remediation.

2.7.4 Geotechnical data

Geotechnical data includes investigating existing subsurface conditions and materials; determining their physical/mechanical and chemical properties that are relevant to the project considered, assessing risks posed by site conditions; designing earthworks and structure foundations; and monitoring site conditions, earthwork and foundation construction.

2.7.5 Metocean data (tides, currents etc)

Metocean data are an important and highly useful category of oceanographic and marine data which comprises observed measurements of current, wave, sea level and meteorological data. (The three basic aspects of meteorology are observation, understanding and prediction of weather).

2.7.6 Seismicity

Seismicity is defined as the distribution of seismic activity in time, location, magnitude & depth during the historical & recent instrumented period. Studies of seismicity are of great importance to understand the dynamic behaviour of the earth and are useful to determine the earthquake hazard in a specific region.

2.7.7 Performance of existing pipelines

- Human activities (eg location of pipelines, cables wrecks, munitions disposal site, aggregate dredging,

The desk study is the best way of obtaining some information, including location of existing subsea infrastructure (eg pipelines and cables) which may be required for the planning of both the survey and the construction works.

The performance of a desk study alone is not normally sufficient for detailed engineering purposes.

2.8 Geophysical survey

A geophysical survey will need to be performed along the proposed route of the marine pipeline to collect information on:

- Seabed topography – by echo-sounding or swathe bathymetry. The latter is particularly important in sand wave areas or other areas of generally uneven seabed.
- Seabed features and obstructions – by methods such as side scan sonar.
- Profiling of uppermost 5m, or so, of seabed – usually by means of reflection seismic techniques (sub bottom profiling). Recent developments in towed resistivity and seismic refraction methods are providing useful complementary data. This is particularly the case in very shallow water where seismic reflection is not practical.
- Detection of existing cables, pipelines and other metallic obstructions – by means of a towed magnetometer, however, note is made that not all metallic objects may be detected, in particular small fibre optic cables.

As a general rule, the width of the survey corridor is between 500m and 1000m, centred on the proposed pipeline route.

The actual width is influenced by factors such as water depth, seabed features and the need to provide a degree of flexibility in routing.

Shore approach corridors are more likely to be around 500 metres wide, whereas areas in deeper water incorporating seabed features such as pockmarks and iceberg scars may warrant survey corridors in excess of 1000 metres to allow re-routing based on detailed engineering, to minimise the number of potential free-spans for example.

2.9 GeoBAS survey

The term 'GeoBAS' (Geophysical Burial Assessment Survey) describes survey operations using geophysical methods operated from seabed sleds, and towed by the survey ship, to provide continuous quantitative information for the first few metres of soil below seabed.

Available methods include seismic refraction and electrical resistivity systems. The use of these methods is often justified if trenching is difficult or the properties of the seabed are very variable.

2.10 Geotechnical survey

The geotechnical survey will typically encompass:

- Coring and sampling for material identification, description and subsequent laboratory testing.
- In situ testing for accurate stratification and determination of key engineering parameters.

2.11 Data coverage

The spacing of soil sampling and soil testing locations along the route of the marine pipeline will depend on the lateral variability in ground conditions revealed by the desk study and geophysical survey phases.

In selecting appropriate spacing, consideration should also be given to other project-specific factors such as:

- Trenching requirements including
    - depth of trench
    - method of trenching
    - trench side stability

- Method of backfilling
- Geotechnical input to pipeline engineering including:
    - thermal insulation provided by trench backfill
    - upheaval buckling resistance of backfill soils
    - pipeline soil interface friction properties

- Surface features or obstructions for example sand waves, pockmark, boulders or iceberg scars
- Size, purpose, location and foundation type of any seabed structures

2.12 Geophysical Equipment

The geophysical equipment used for pipeline route surveys should include as a minimum:

- Echo-sounder (single-beam or multi-beam)
- Sidescan sonar
- Sub-bottom profiler
- Magnetometer

Survey Equipment	Use of Data	Minimum Resolution Required
Single beam echosounder	Determination of water depth below survey line and an estimate of seabed gradients	1% of maximum water depth
Multi-beam echosounder	Determination of water depth and seabed gradient across full survey corridor	1% of maximum water depth
Sidescan Sonar	Identification of the nature of the seabed (sediment type, rock outcrop, coral etc.), seabed features (bed forms e.g. sand waves, megaripples), and obstructions (cables, pipelines, boulders, wrecks)	Detect a nominal $0.1m^3$ object or a 0.1m width linear object
Sub-bottom Profiler	Characterisation of shallow subseabed geology, which includes identifying vertical and lateral extent of sediments and the presence of any bedrock and other subsurface obstructions.	Vertical Resolution better than 0.5m down to a depth of 5m or depth of burial plus 3m whichever is greater
Magnetometer	Detection and location of pipelines, cables and any ferro-metallic debris, such as wrecks and munitions dumps.	1 nanoTesla or better

Table 2.1

2.13 Pipeline route

The pipeline route shall be selected with due regard to safety of the public and personnel, protection of the environment, and the probability of damage to the pipe or other facilities. Factors to take into consideration shall, at minimum, include the following:

- ship traffic;
- fishing activity
- offshore installations
- existing pipelines and cables
- unstable seabed
- subsidence
- uneven seabed
- turbidity flows
- seismic activity
- obstructions
- dumping areas for waste, ammunition etc.
- mining activities
- military exercise areas
- archaeological sites
- exposure to environmental damage; and oyster beds.

2.14 Corrosion Allowance

A corrosion allowance is primarily used to compensate for forms of corrosion attack affecting the pipeline's pressure containment resistance, i.e. uniform attack and, to a lesser extent, corrosion damage as grooves or patches. However, a corrosion allowance may also enhance the operational reliability and increase the useful life if corrosion damage occurs as isolated pits; although such damage is unlikely to affect the pipeline's resistance, it will cause a pinhole leak when the full wall thickness is penetrated. However, the extra wall thickness will only delay leakage in proportion to the increase in wall thickness.

3. DESIGN FUNDAMENTALS

3.1 Fundamentals of Pipeline design

The amount of fluid that must flow through the pipeline is one of the first items of information required for design. But a characteristic of many proposed pipelines is that future capacity requirements are difficult to forecast. Determining the capacity requirements for a pipeline gathering system to gather crude from producing fields can be difficult.

3.1.1 Pipeline Design

The most appropriate way to pipeline design is by the volume of oil or gas to be transported. With a projected volume and the origin and the destination of the pipeline known pipeline design typically follow these general steps:-

a) Determining the size and grade of the pipe as per the throughput requirement and the desired delivery pressure as per the customer requirement. Also the material of construction is decided as per the service requirements.

b) The elevation differences between both the ends are calculated and also the head requirements are taken into consideration.

c) After that we calculate the minimum wall thickness which can withstand the desire pressure rating and checked whether it passes the minimum value.

d) Then the stress analysis calculations are done for the pipeline where we consider the thermal expansion of pipe as well as the anchor lengths and determine the hoop stress, longitudinal stress and equivalent stress of the section.

e) Also the On-bottom stability of the pipeline is also taken into consideration which is usually calculated by simplified method.

f) Finally the cathodic protection system for the pipeline is also calculated by deciding the type of sacrificial anode to be provided for the pipeline. For this assume the length of the anode and also the spacing between anodes. Here another important factor to be taken into consideration is the type of material used for the anode.

This outline represents the basic steps involved in a preliminary design of a single pipeline with no branch connections, no alternative routes as well as no significant changes during its life.

3.2 Analysis and design of submarine pipelines

In order to analysis and design a subsea pipeline, the design conditions, wall thickness determination, On-bottom stability and cathodic protection system are also looked into.

3.2.1 Design conditions

All subsea pipeline are designed based on certain codes and standards that can be used to determine the standard results

3.2.1.1 Codes and Standards

Pipeline design codes and standards that are widely used include:

i. ISO 13623

ii. ASME 31.4-1999 CHAPTER VIII

iii. BS 8010 PART 3

iv. DNV OS-F101

A large number of pipelines have been successfully designed as per the above codes. In this project I have followed the DNV –OS-F101code. DNV code is considered as one of the code which has an appropriate design for the future considerations.

3.3 On-Bottom stability Analysis

3.3.1 On-Bottom stability

Subsea pipelines resting on the bed or placed in the trench are subjected to lateral instability due to environmental loads comprising of wave and current forces. The lateral instability is countered by lateral soil frictional resistance due to submerged weight of the pipeline. If the submerged weight is inadequate, the increase in submerged is normally achieved by increasing the concrete coating thickness or else by reducing the environmental loads by trenching or burial. In this design the stability is achieved by increasing the concrete coating thickness.

3.3.2 Analysis method

Pipeline Stability analysis shall be carried out in accordance with DNV RP E305. According to this three methods can be followed:-

i. Dynamic analysis method
ii. Generalized method
iii. Simplified method

Dynamic analysis involves dynamic simulation of a section of pipeline under the action of waves and current. The dynamic analysis is to be used in specialized circumstances. Generalized pipeline stability analysis is based on generalization of the results from dynamic analysis through the use of a set of non-dimensional parameters and for particular end conditions.

The simplified method is suitable for most of the design cases. The DNV RP E305 simplified static stability method on a quasi static equilibrium approach.

3.3.3 Stability Criteria

3.3.3.1 Minimum pipe submerged weight

The minimum submerged weight required to prevent any horizontal, ove, ent of the pieline under the extreme environmental loading is simply calculated by balancing the horizontal forces and the frictional forces acting on the pipe. I.e. always the submerged weight required must be less than actual submerged weight.

Total submerged weight= $W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$

Submerged weight required = $\{[(F_D+F_I)+\mu\ F_L] / \mu\}$ C

Where

F_D =hydrodynamic drag force

F_I = Inertia force

F_L = Lift force

F_W =Calibration factor from figure relating keulegan carpenter number

The static stability design is based on the following assumptions:-

i. Pipe movements are not allowed and equilibrium is achieved between loads and reactions.
ii. Soil resistance is calculated based on two-dimensional assumptions and may include simple friction as well as passive soil resistance.

3.3.3.2 Pipe submerged weight

Pipe submerged weight consist of the following parameters:-

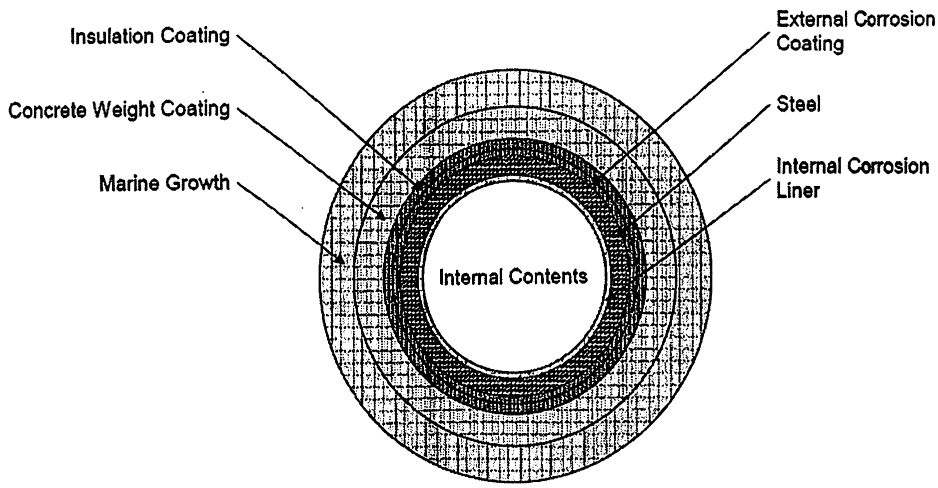


Figure 3.1

i. Steel
ii. Internal coating
iii. Corrosion coating
iv. Insulation coating
v. Marine growth
vi. Internal contents

The weights of the components are calculated as follows:-

Weight of the pipe= $\pi\ (D_S - t_S)\ t_S\ \rho_{ST}$

Marine growth= $\pi\ (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\ t_{MG}\ \rho_{MG}$

Corrosion coating= $\pi\ (D_S + t_{CC})\ t_{CC}\ \rho_{CC}$

Content$=0.25\ \pi\ (D_S - 2t_S)^2\ \rho_{PROD}$

Concrete coating$=\pi\ (D_S+2t_{CC}+t_{CON})\ t_{CON}\ \rho_{CON}$

Buoyancy$=0.25\pi\ (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2\rho_W$

Total submerged weight$=W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$

Over all outer diameter- $D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$

3.3.4 Environmental parameters

The defining sea parameters are Height of the wave and the time period of wave. From these values we can find out the significant wave velocity perpendicular to the pipe(U_D).

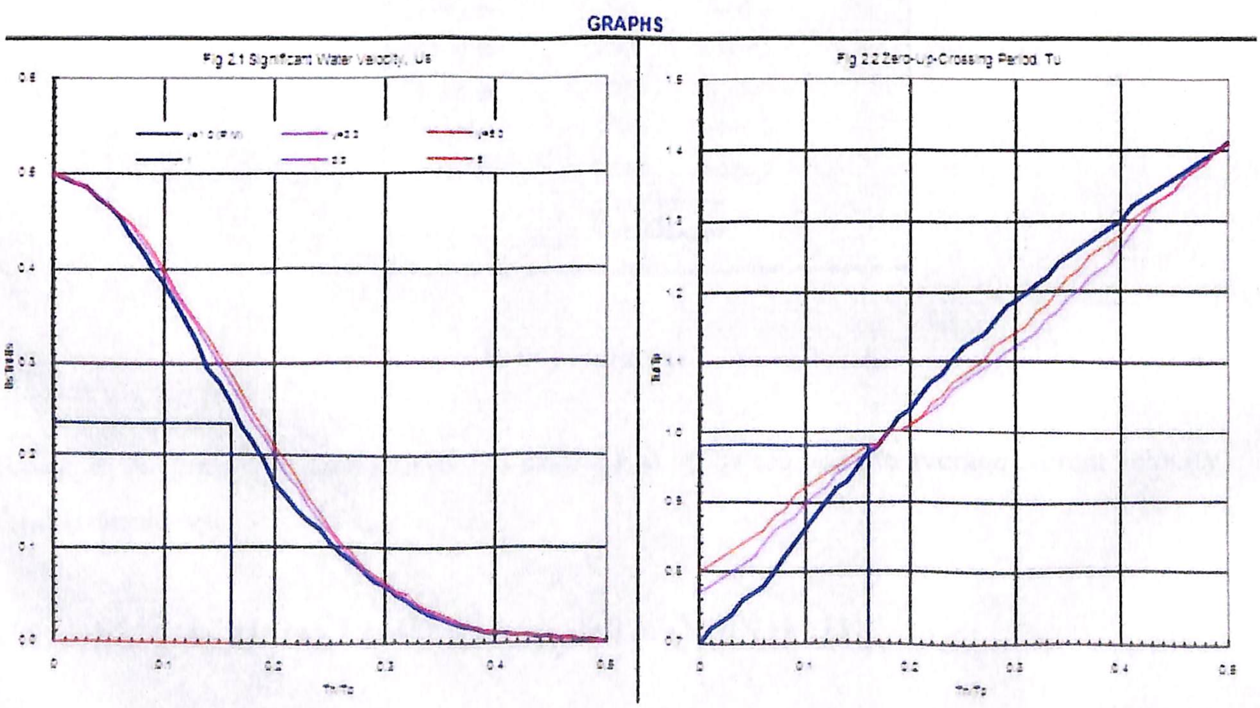


Figure 3.2

Here the significant wave velocity is determined based upon the Jonswap peakedness parameter whose values can be 1, 3.3, or 5.

3.3.5 Grain size of the sea bed materials:-

According to DNV RP E305 the size and roughness of the different types of subsea particles are shown in the table below.

Grain Size of Seabed Material

Seabed	Grain Size	Roughness
Silt	0.0625	5.21E-6
V. Fine Sand	0.125	1.04E-5
Fine Sand	0.25	2.08E-5
Medium Sand	0.5	4.17E-5
Coarse Sand	1.0	8.33E-5
V. Coarse Sand	2.0	4.67E-4
Gravel	4.0	3.33E-4
Pebble	10.0	8.33E-4
Pebble	25.0	2.08E-3
Pebble	50.0	4.17E-3
Cobble	100.0	8.33E-3
Cobble	250.0	2.08E-2
Boulder	500.0	4.17E-2

OK

Table 3.1

Based on the grain size (d_{50}) and the roughness (z_0) of the sea bed the average current velocity (U_D) is found out.

$$U_D \quad = \quad U_r \{1/\, ln(z_r / z_0 + 1)\ \{[1 + (z_0 / D)]\ ln[D / z_0 + 1] - 1\}\}$$

3.3.6 Calibration Factor:-

From the current to wave velocity ratio (M) and Load parameter (K) we can find out the calibration factor. It is used to determine the submerged weight of the pipeline.

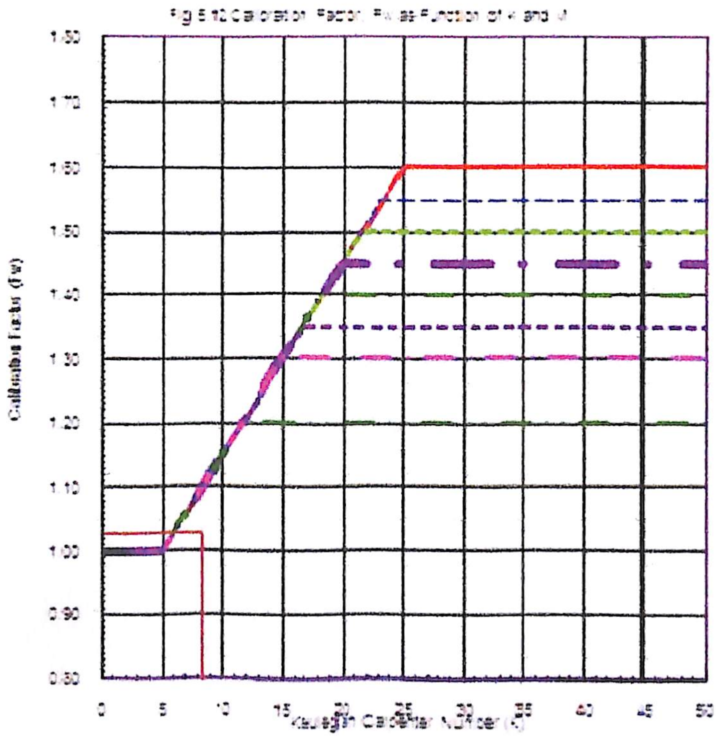


Figure 3.3

3.3.7 Hydrodynamic Forces

We further use the calibration factor (F_W) to find out the submerged weight of the pipeline using the following relationships:-

Lift force $= 0.5\rho_W D C_L [U_S \cos\theta + U_D]^2$

Inertia force $= 0.25\pi D^2 \rho_W C_M A_S \sin\theta$

Drag force $= 0.5\, \rho_W\, D\, C_D \,|\, [U_S \cos\theta + U_D] \,|\, [U_S \cos\theta + U_D]$

Where	C_D	=coefficient of drag, assumed to be 0.75
	C_L	=coefficient of Lift force, assumed to be 0.75
	C_M	=coefficient of inertia force, assumed to be 3.29

3.4 Pipeline wall thickness calculation:-

Pipeline wall thickness calculation determines the minimum wall thickness required to withstand the pressure and to avoid buckling of the pipeline.

In order to calculate the minimum wall thickness for the pipeline we require the following data:-

i. Local design pressure(P_{id}) = $d_p + \rho_c\, g\, [H_{ref} + H_{des}]$

ii. Local incidental Pressure (P_{li})= $\gamma_{inc}\, p_{ld}$

iii. Local design pressure (P_{it}) = $\gamma_t\, p_{li}$

After calculating all these forces we need to find out the usage factor and minimum wall thickness and also the factor of safety both for local design pressure and for local test system pressure.

And to establish that the value of thickness which we got is correct then factor of safety must be always greater than 1.

FOS for local design pressure = $[\, t\,(1 - \%t_{fab} / 100) - t_{corr}\,] / t_l$

FOS for local test pressure design = $t\,[1 - \%t_{fab} / 100] / t_l$

And the load cases for both installation and operating conditions are verified based on some constants as per DNV-RP-E305.

Also the elastic, plastic capacity of the pipe, as well as the characteristic wall thickness at the time of installation and operation are also found out.

Equations and formulas for the calculation of the constants and verification of the Propagating buckling pressure and initiation buckling pressure are also done. Further a comparison of the factor of safety for each initiation and propagating buckling FOS is also done

Table showing the calculation of each constant:-

Loadcase		Installation		Operating		-
Local minimum pressure	p_{min}	-	-	$d_{min} + \rho_c\, g\, [H_{ref} + H_{des}]$	0.00	Mpa
Characterictic wall thicknes	t_2	t	22.20	$t - t_{corr}$	17.40	mm
Elastic capacity	p_{el}	$2\,E\,[t_2 / D]^3 / [1 - \nu^2]$	2.75	$2\,E\,[t_2 / D]^3 / [1 - \nu^2]$	1.32	Mpa
Plastic capacity	p_p	$2\, f_y\, \alpha_u\, \alpha_A\, \alpha_{fab}\, [t_2 / D]$	18.35	$2\, [f_y - f_{y,temp}]\alpha_u \alpha_A \alpha_{fab}\, [t_2 / D]$	14.38	Mpa
Calculation constants	b	$-p_{el}$	-2.75	$-p_{el}$	-1.32	-
	c	$-[p_p^2 + p_p\, p_{el}\, f_o\, D / t_2]$	-902.59	$-[p_p^2 + p_p\, p_{el}\, f_o\, D / t_2]$	-479.33	-
	d	$p_{el}\, p_p^2$	925.59	$p_{el}\, p_p^2$	273.78	-
	u	$[-b^2 / 3 + c] / 3$	-301.70	$[-b^2 / 3 + c] / 3$	-159.97	-
	v	$[2\, b^3 / 27 - b\, c / 3 + d] / 2$	48.65	$[2\, b^3 / 27 - b\, c / 3 + d] / 2$	31.10	-
	Φ	$\cos^{-1}[-v / (-u^3)^{0.5}]$	1.58	$\cos^{-1}[-v / (-u^3)^{0.5}]$	1.59	-
	y	$-2[-u]^{0.5}\cos[\Phi/3 + 60\pi/180]$	0.11	$-2[-u]^{0.5}\cos[\Phi/3 + 60\pi/180]$	0.13	-
Collapse pressure	p_c	$y - b / 3$	1.02	$y - b / 3$	0.57	Mpa
Collapse FOS	FOS	p_c / p_{e2}	3.19	$[p_c - p_{min}] / p_{e2}$	1.78	> 1, Ok
Initiation buckling pressure	p_{inc}	$p_c / [1.1\, \gamma_m\, \gamma_{SC}]$	0.71	$p_c / [1.1\, \gamma_m\, \gamma_{SC}]$	0.40	Mpa
Initiation buckling FOS	FOS	p_{inc} / p_{e2}	2.21	$[p_{inc} - p_{min}] / p_{e2}$	1.24	> 1, Ok
Propagating buckling pressure	p_{pr}	$35\, f_y\, \alpha_u\, \alpha_{fab} / [\gamma_m\, \gamma_{SC}]\, [t_2 / D]^{2.5}$ 0.63		$35\, [f_y - f_{y,temp}]\, \alpha_u\, \alpha_{fab} / [\gamma_m\, \gamma_{SC}]\, [t_2 / D]^{2.5}$ 0.34		Mpa
Propagting buckling FOS	FOS	p_{pr} / p_{e2}	1.97	$[p_{pr} - p_{min}] / p_{e2}$	1.06	> 1, Ok

Table 3.2

3.5 Cathodic Protection Design

Pipelines and risers in the submerged zone shall be furnished with a cathodic protection system to provide adequate corrosion protection for any defects occurring during coating application (including field joints), and also for subsequent damage to the coating during installation and operation. The cathodic protection systems shall be capable of suppressing the pipe-to-seawater (or pipe-to-sediment) electrochemical potential into the range -0.80 to -1.1 V rel. Ag/AgCl/ seawater. Potentials more negative than -1.1 V rel. Ag/AgCl/ seawater can be achieved using impressed current. Such potentials may cause detrimental secondary effects, including coating disbandment and hydrogen-induced (stress) cracking or 'hydrogen embrittlement' of line pipe materials and welds.

Sacrificial anode cathodic protection systems are normally designed to provide corrosion protection throughout the design life of the protected object. Also designing the CP system includes the selection of material used for protection, the length of each anode and its thickness and also the current requirements for its entire life. For offshore purposed either bracelet anodes or slender anodes are usually preferred.

3.5.1 Bracelet anodes:-

Bracelet anodes are type of anodes used for the protection of subsea pipelines. They are half shells in shape, which together can be assembled on top of the concrete coated pipe

The design life is assumed to be 30 years and the design temperature is 45°C and the electrochemical resistivity is assumed to be 30Ωcm and coating breakdown factor is assumed to be 0.06.

The figure shows the details of the section of the bracelet anode:-

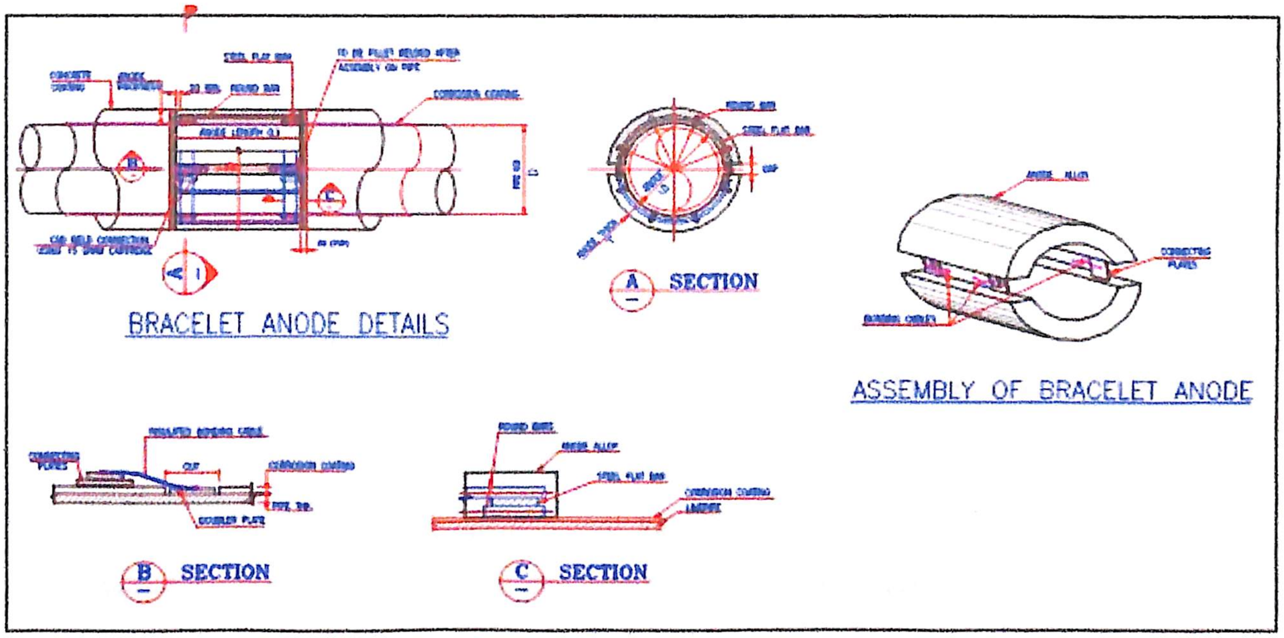


Figure 3.4

Equations used are:-

INNER DIA OF ANODE	$D + 2\ t_C$ (mm)
SPACING	$S\ L_J$ (m)
NUMBER OF ANODES	L_P / S_L
NET MASS OF EACH ANODE	$[0.25\ \pi\ [(D_I + 2\ t_A)^2 - D_I^2) - 2\ G\ t_A]\ L_A\ \rho$ (kg)
TOTAL ANODE MASS	$N\ M_A$ (kg)
MEAN CURRENT OUTPUT	$\acute{\varepsilon}\ U\ M / T$ (A)
MEAN CURRENT REQUIRED	$C_A\ b_A\ \pi\ D\ L_P$ (A)
FINAL SURFACE AREA PER ANODE	$[\pi\ [D_I + 2\ (1 - U)\ t_A] - 2\ G]\ L_A$ (m^2)
RESISTANCE OF EACH ANODE	$0.315\ \acute{\varepsilon} / [A_F]^{0.5}$ (Ω)
FINAL CURRENT OUTPUT	$N\ [V_P - V_A] / R_A$ (A)
FINAL CURRENT REQUIRED	$C_F\ b_F\ \pi\ D\ L_P$ (A)

Table 3.3

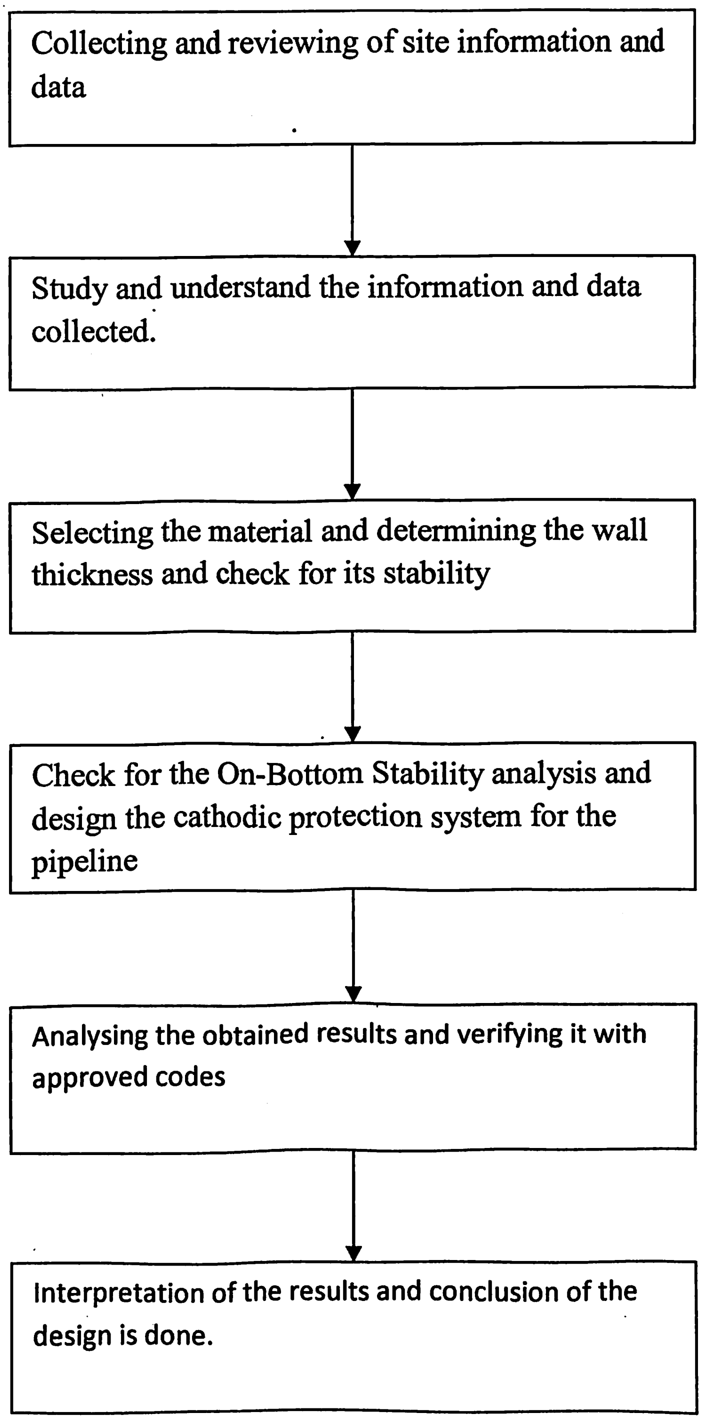
4. METHODOLOGY

4.1 Background of the Problem

To design a pipeline subsea pipeline for a length of 20.5 km from SPM to LFP and thereafter for a distance of 1 km to the tank farm. It is assumed to transfer 16 MMTPA of crude oil

The proposed pipeline has to be designed for a life period of 30 years and the parameters has to be selected with precision and accuracy after data analysis as the area is prone to extreme environmental conditions.

4.2 Steps involved in Design



4.3 Pipeline Detail

There are total five pipelines to be installed as a part of this project in which three are mainlines and two are loop lines which interconnects the SPM and existing facilities. Each mainline has an onshore section which leads to crude oil terminal whereas loop lines are fully offshore

Table :- Length of proposed pipelines

ROUTE	PROPOSED PIPELINE	LENGTH IN km
ROUTE 1	PIPELINE FROM SPM TO LAND FALL POINT	20.5

Table 4.1

4.4 Design Data

Pipeline has been designed for lateral stability and to avoid buckling and the codes which are followed for the design are:-

a. DNV : Det Norske Veritas - Rules for submarine pipeline systems, 1981

b. DNV : Det Norske Veritas – Offshore standard OS-F-101,submarine pipeline systems,2000

c. DNV : Det Norske Veritas-On-bottom-stability design of submarine pipelines RP-F-109

4.5 Design water depth

The water depths are taken from the report submitted by Central Water and Power Research Station as per the request given by the IOCL for determining the depths at each location and the depths are as follows :-

Table- ACTUAL WATER DEPTH AND LOCATION

Sl no	Location	Minimum water depth (m)
1	SPM I,SPM II, SPMIII	32
2	KP 17	26
3	KP 1.2	14
4	From LFP to KP 1.2	Varying up to 10

Table 4.2

4.6 Environmental Data

Environmental data are taken from the report submitted by the National Institute of Oceanography which contains the various details regarding the significant wave heights and current velocity in the location for 1year (Installation) as well as 100 year (operation) at the project location.

Table:- Environmental Data at project location

DESCRIPTION	INSTALLATION (1 YEAR)	OPERATION (100 YEAR)
Astronomical tide , m	3.50	3.50
Storm Surge , m	1.30	5.45
Current velocity ,m/s	0.69	0.69
Current direction	Perpendicular to pipeline	Perpendicular to pipeline
Significant wave period (T_s) , sec	7.20	11.5
Significant wave height (H_s) , m	3.9	8.3
Wave direction	Perpendicular to pipeline	Perpendicular to pipeline

Table 4.3

4.6.1 Sea water properties:-

Sea water density , kg/m^3	1030
Sea water kinematic viscosity , m^2/s	1.51 E-6

Table 4.4

4.6.2 Hydrodynamic Coefficients:-

Drag coefficients C_D	0.75
Lift coefficient C_L	0.75
Inertia coefficient C_M	3.29

Table 4.5

4.6.3 Density of content and friction factors:-

The content to be transported is crude oil and as per the type of crude which is to be importer at Paradip it is found out that its density can be assumed as 800 kg/m^3.

Friction Factors considered between pipeline and soil:-

During Installation (1 year)	0.5 (max)
During Operations (100 year)	0.7 (max)

Table 4.6

4.7 Material Properties

The material selection for the line pipe is done based on the API Specification 5L/ISO 3183.

The material selected for the line pipe is Carbon steel and the grade of pipe is API 5L Grade X-65, PSL 2. The density of steel used for manufacturing must be at least 7850 kg/m^3 and as per standards a corrosion allowance of 3 mm has to be provided and also a corrosion coating allowance of 4 mm has to be provided.

The pipe which is delivered at site must be rolled, normalizing rolled, thermo mechanical formed, normalized formed, normalized, tempered or quenched and tempered.

The minimum and maximum yield strength of pipes which is to be delivered is 450MPa and 600MPa respectively. Also the allowable minimum and maximum values for tensile strength are 535MPa and 760MPa.

The chemical composition of the pipe with wall thickness less than 25mm is as follows as per API 5L:-

C	Si	Mn	P	S	V	Nb	Ti	CE_{Pcm}
0.12	0.45	1.65	0.020	0.010	0.10	0.08	0.06	0.22

Table 4.7

Here we have decided to use high density concrete for coating the pipes and the value is 3040 kg/m^3.

We have also decided to give a coal tar enamel coating with a thickness of 4mm to the pipe. Coal tar enamel has been selected instead of 3LPE because of its good adhesion property with the concrete and also huge cost savings.

5. ANALYSIS

The analysis is done based on the environmental data and other input parameters. A study has been done for wall thickness calculation, On-bottom stability and cathodic protection system design for the pipeline by varying the suitable parameters and an optimum value for each parameter has been decided.

5.1 Pipe wall thickness calculations

We have to supply with the input details like pipe diameter (D), density of the content, seawater, minimum and maximum outside diameters and corrosion allowance and the design pressure and the modulus of elasticity of the material.

And analysing the pressure containment and local buckling and also the checking the propagating buckling pressure is also checked. If the ratio of the difference between propagating buckling pressure and local minimum pressure to external pressure is less than 1 then the system becomes unstable and buckling initiates and the wall thickness selected becomes inadequate. In order to make it stable the next higher wall thickness is to be substituted for that particular water depth.

Also a check on the collapse pressure and collapse factor of safety is also done.

Also a check on the plastic and elastic capacity based on the selected wall thickness and to ensure it withstands the collapse pressure.

Loadcase		Installation		Operating		-
Local minimum pressure	p_{min}	-	-	$d_{min} + \rho_c\ g\ [H_{ref} + H_{des}]$	0.00	Mpa
Characterictic wall thicknes	t_1	t	22.20	$t - t_{corr}$	17.40	mm
Elastic capacity	p_{el}	$2\ E\ [t_1 / D]^2 / [1 - \nu^2]$	2.75	$2\ E\ [t_1 / D]^3 / [1 - \nu^2]$	1.32	Mpa
Plastic capacity	p_p	$2\ f_y\ \alpha_U\ \alpha_A\ \alpha_{fab}\ [t_1 / D]$	18.35	$2\ [f_y - f_{y,temp}]\alpha_U\ \alpha_A \alpha_{fab}\ [t_1 / D]$	14.39	Mpa
Calculation constants	b	$- p_{el}$	-2.75	$- p_{el}$	-1.32	-
	c	$-[\ p_p^2 + p_p\ p_{el}\ f_0\ D / t_1]$	-902.59	$-[\ p_p^2 + p_p\ p_{el}\ f_0\ D / t_1]$	-479.33	-
	d	$p_{el}\ p_p^2$	925.59	$p_{el}\ p_p^2$	273.78	-
	u	$[- b^2 / 3 + c] / 3$	-301.70	$[- b^2 / 3 + c] / 3$	-159.97	-
	v	$[\ 2\ b^3 / 27 - b\ c / 3 + d\ ] / 2$	48.65	$[\ 2\ b^3 / 27 - b\ c / 3 + d\ ] / 2$	31.10	-
	Φ	$\cos^{-1}[\ - v / (-u^3)^{0.5}]$	1.58	$\cos^{-1}[\ - v / (-u^3)^{0.5}]$	1.59	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	0.11	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	0.13	-
Collapse pressure	p_c	$y - b / 3$	1.02	$y - b / 3$	0.57	Mpa
Collapse FOS	FOS	p_c / p_{e}	3.19	$[\ p_c - p_{min}] / p_{e}$	1.78	> 1, Ok
Initiation buckling pressure	p_{init}	$p_c / [1.1\ \gamma_m\ \gamma_{SC}]$	0.71	$p_c / [1.1\ \gamma_m\ \gamma_{SC}]$	0.40	Mpa
Initiation buckling FOS	FOS	p_{init} / p_{e}	2.21	$[p_{init} - p_{min}] / p_{e}$	1.24	> 1, Ok
Propagating buckling pressure	p_{pr}	$35\ f_y\ \alpha_U\ \alpha_{fab} / [\gamma_m\ \gamma_{SC}]\ [t_2 / D]^{2.5}$		$35\ [f_y - f_{y,temp}]\ \alpha_U\ \alpha_{fab} / [\gamma_m\ \gamma_{SC}]\ [t_2 / D]^{2.5}$		Mpa
		0.63		0.34		
Propagting buckling FOS	FOS	p_{pr} / p_{e}	1.97	$[\ p_{pr} - p_{min}] / p_{e}$	1.06	> 1, Ok

Table 5.1

5.2 Pipeline Stability Analysis by DNV RP E305 – Simplified Method

For a pipeline to be stable always the submerged weight required must be less than the total submerged weight. For calculating the pipeline stability we require the pipe and coating properties, soil properties and environmental parameters.

The pipe and coating properties include pipe outer diameter, wall thickness, thickness of corrosion coating, thickness of concrete coating, thickness of marine growth, density of steel, corrosion coating, concrete, sea water, marine growth and pipe content.

The soil properties include the grain size and roughness and also the soil type whether sand or clay. Here in this case the soil type appears to be sandy throughout the depth. As the depth increased the size of the sand particles also reduced and accordingly we have to select the grain size of the particle.

Also the environmental parameters are selected from the met-ocean reports and significant wave height and time-period are selected. Velocity and acceleration perpendicular to the pipe are also calculated with the help of the graph output like significant water velocity, zero up-crossing period, reduction factor and calibration factor.

Grain Size of Seabed Material

Seabed	Grain Size	Roughness
Silt	0.0625	5.21E-6
V. Fine Sand	0.125	1.04E-5
Fine Sand	0.25	2.08E-5
Medium Sand	0.5	4.17E-5
Coarse Sand	1.0	8.33E-5
V. Coarse Sand	2.0	4.67E-4
Gravel	4.0	3.33E-4
Pebble	10.0	8.33E-4
Pebble	25.0	2.08E-3
Pebble	50.0	4.17E-3
Cobble	100.0	8.33E-3
Cobble	250.0	2.08E-2
Boulder	500.0	4.17E-2

OK

Table 5.2

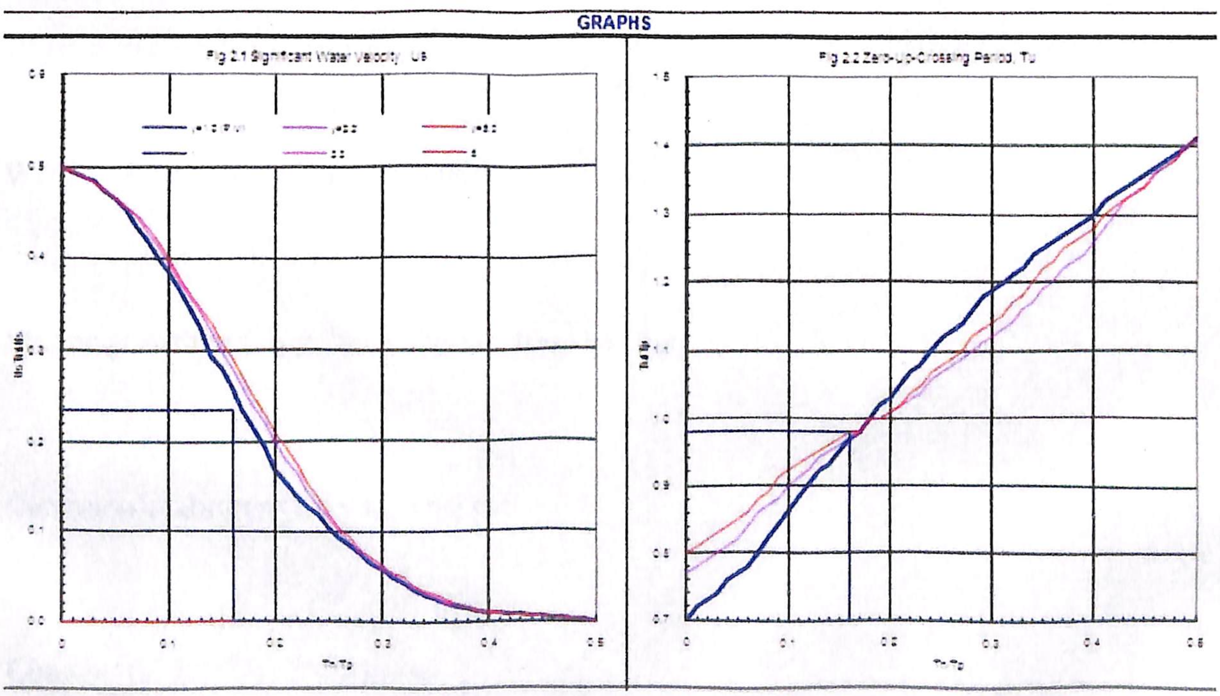


Figure 5.1

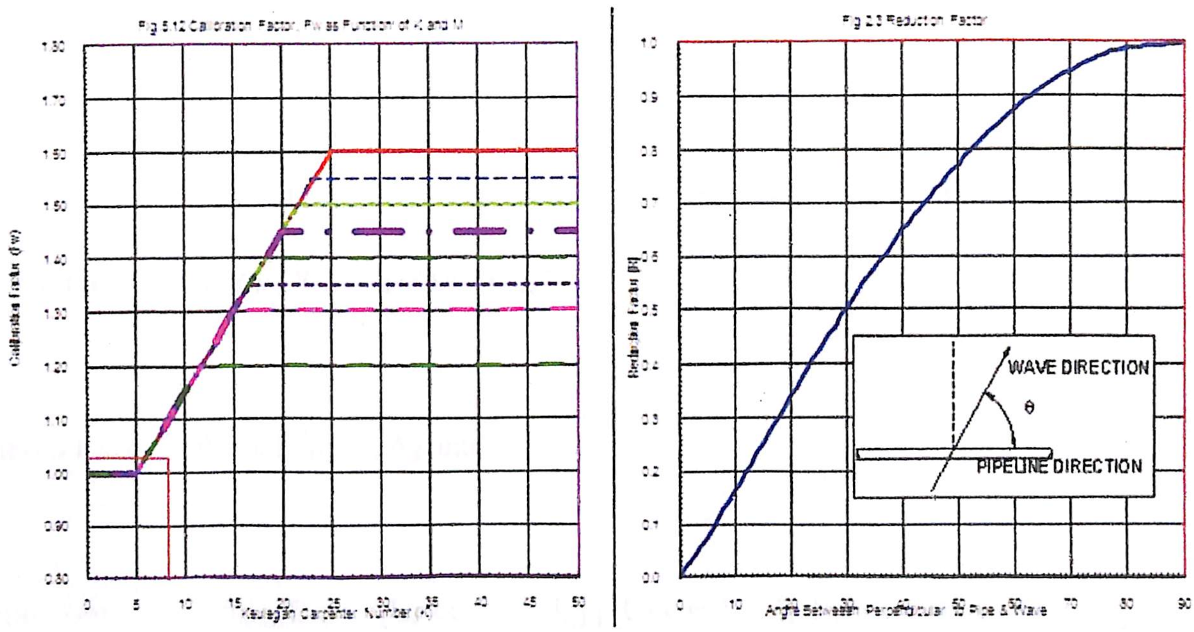


Figure 5.2

Weight of the pipe=$\pi\ (D_S - t_S)\ t_S\ \rho_{ST}$

Marine growth=$\pi\ (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\ t_{MG}\ \rho_{MG}$

Corrosion coating=$\pi\ (D_S + t_{CC})\ t_{CC}\ \rho_{CC}$

Content=$0.25\ \pi\ (D_S - 2t_S)^2\ \rho_{PROD}$

Concrete coating=$\pi\ (D_S+2t_{CC}+t_{CON})\ t_{CON}\ \rho_{CON}$

Buoyancy$=0.25\pi\,(D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2\rho_W$

Total submerged weight (W_S)= $W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$

Lift force $=0.5\rho_W\, DC_L\, [U_S \cos\theta + U_D]^2$

Inertia force $=0.25\pi\, D^2\rho_W C_M A_S \sin\theta$

Drag force $=0.5\, \rho_W\, D\, C_D\, |\, [U_S \cos\theta + U_D]\, |\, [U_S \cos\theta + U_D]$

Submerged weight required (W_{SR})= $\{[(F_D+F_I) + \mu\, F_L] / \mu\}\, F_W$

So as per this always for a pipe to be stable always W_{SR} □ W_S and also a graph is plotted showing the various forces acting at different angles.

5.3 Cathodic Protection Design-Bracelet anodes

The minimum amount of the mass of each anode and the proper spacing between the anodes and the length and thickness of each anodes are also calculated. It is finalised after calculating the minimum mass requirement and final current requirement.

INPUT

Anode type designation	A_{TYPE}	A	-	Electrochemical efficiency	ε	1650	A-hr/Kg
Pipeline OD	D	1510.00	mm	Protective potential	V_P	-800	mV
Length of pipeline	L_P	20.600	Km	Closed circuit anode potential	V_A	-1050	mV
Pipe joint length	L_J	12.192	m	Current density [Average]	C_A	125	mA/m²
Design life	T	30.0	Years	Current density [Final]	C_F	145	mA/m²
Design temperature	t	65.0	°C	Electrochemical resistivity	ρ	30	Ohm-cm
Corrosion coating thickness	t_C	4.8	mm	Anode utilization factor	U	0.85	-
Coating breakdown factor [Avg]	b_A	0.05	-	Anode length	L_A	700	mm
Coating breakdown factor [Final]	b_F	0.11	-	Anode thickness	t_A	60	mm
Anode material	A_M	Al-Zn-In	-	Gap between half shells	G	100	mm
Anode material density	ρ	2700	Kg/m³	Anode spacing	S	5	Joints

CALCULATIONS

ID of anode	D_i	$D + 2 t_C$	1519.60	mm
Spacing	S_L	$S L_J$	60.96	m
Number of anodes	N	L_P / S_L	338	-
Net mass of each anode	M_A	$[0.25 \pi [(D_i + 2 t_A)^2 - D_i^2) - 2 G t_A] L_A \rho$	540.1	Kg
Total anode mass	M	$N M_A$	182553.8	Kg
Mean current output	I_{AO}	$\varepsilon U M / T$	973.579	A
Mean current required	I_{AR}	$C_A b_A \pi D L_P$	610.765	A
Final surface area per anode	A_F	$[\pi [D_i + 2 (1 - U) t_A] - 2 G] L_A$	3.241	m²
Resistance of each anode	R_A	$0.315 \rho / (A_F)^{0.5}$	0.052	ohm
Final current output	I_{FO}	$N [V_P - V_A] / R_A$	1625.000	A
Final current required	I_{FR}	$C_F b_F \pi D L_P$	1558.672	A

RESULTS

Mass requirement	I_{AO} / I_{AR}	1.59	> 1, Ok	Final current requirement	I_{FO}/ I_{FR}	1.04	> 1, Ok

Table 5.3

The design life of the pipeline is for a period of 30 years with an operating temperature of 45 degree Celsius.

6. RESULTS

The final pipe wall thickness was decided to be 20.6mm up to a depth of 27m and thereafter with a wall thickness of 22.2mm for the pipeline to withstand the pressure and stability. The corrosion allowance to be provided is 3mm and along with a protection coating thickness to be of 4mm and the concrete coating thickness was found out to be 120mm for the pipeline to be hydro dynamically stable.

The wall thickness at all depths are verified at various depths with corresponding wave height and significant time period and the check for the submerged weight is also done and a graph is plotted with the forces acting at the various angles.

The final result shows that a total of 330204.6 kg of anode material is required for the entire length of pipeline. The material selected for the CP system is an alloy of Al-Zn-In with a material density of 2700 kg/m^3. The potential range selected for operation is in between -900 and -1050 mV with a current density of 128 mA/m^2.

A final result was obtained with a minimum requirement of 450mm length and 120mm thickness for each anode and a 100mm gap between each half shell. The weight of each anode was around 588.6 kg and the total weight of anode required to protect the entire length of 20.5 km was 330204.6 kg.

7.CONCLUSION

For the given 14 inch pipeline, a minimum wall thickness of 20.6 mm upto a depth of 27m and thereafter a wall thickness of 22.2 mm till the depth of 32 m is required for the proper operation of the pipeline for a design life of 30 years. This minimum wall thickness has been finalised based on the stability analysis and cost effectiveness. To protect this pipeline for the entire life of 30 years, a total mass of 330204.6 kg of anode is required and the anode spacing should be for three joints and the size of each anode should be 450 mm in length and 120 mm in thickness.

8. REFERENCES

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APPENDIX 1

PIPELINE WALLTHICKNESS CALCULATIONS

DESIGN AIDE PIPELINE ENGINEERING http://www.narendranath.itgo.com	DAWallThk Ver 1.0.1	**PIPELINE WALL THICKNESS CALCULATIONS - DnV-OS F101**

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA							
Outside diameter	D	*1219*	mm	Density of content	ρ_c	*850*	kg/m^3
Maximum outside diameter	D_{max}	*1467*	mm	Density of seawater	ρ_w	*1030*	kg/m^3
Minimum outside diameter	D_{min}	*1219*	mm	Fabrication tolerance	$\%t_{fab}$	*8*	%
Nominal wall thickness	t	*20.6*	mm	Minimum water depth	H_{des}	*0.00*	m
Corrosion allowance	t_{corr}	*3.0*	mm	Maximum water depth	H_{max}	*10.00*	m
SMYS	f_y	*448*	Mpa	Fluid category		*B*	
Temperature derating	$f_{y,temp}$	*0*	Mpa	Location		*1*	
Modulus of elasticity	E	*207000*	Mpa	Design safety class		*Low*	
Poisson ratio	v	*0.3*	-	Characteristic material properties		*Normal*	
Design pressure	d_p	*1.865*	Mpa	Pipe fabrication process		*UOE*	
Design minimum pressure	d_{pmin}	*0*	Mpa	Incidental pressure factor	γ_{inc}	*1.10*	-
Ref. height above datum	H_{ref}	*0*	m	Test pressure factor	γ_t	*1.15*	-
Gravity acceleration	g	*9.81*	m/s^2				

PRESSURE CONTAINMENT							
Local design pressure	$d_p+\rho_c g [H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure	$\gamma_t p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc} p_{ld}$	p_{li}	2.06	External pressure	$\rho_w g H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor		γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor		γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa			
Loadcase	Usage factor		Minimum wall thickness			Factor of safety	
Local design pressure	$2\,\alpha_U / [3^{0.5}\,\gamma_m\,\gamma_{SCP1}\,\gamma_{inc}]$		$(p_{ld} - p_{ed})\,D / [\,2\,\eta\,(f_y - f_{y,temp}) + p_{ld} - p_{ed}]$			$[\,t\,(1 - \%t_{fab} / 100) - t_{corr}\,] / t_1$	
	η	0.813	t_1	3.1	mm	FOS	**5.15** > 1, Ok
Local test system pressure	$2\,\alpha_{Ut} / [3^{0.5}\,\gamma_m\,\gamma_{SCP}]$		$(p_{lt} - p_{ed})\,D / [\,2\,\eta\,f_y + p_{lt} - p_{ed}]$			$t\,[1 - \%t_{fab} / 100] / t_1$	
	η	0.96	t_1	3.3	mm	FOS	**5.74** > 1, Ok

LOCAL BUCKLING						
Safety class resistance factor		γ_{SC}	1.04	Material strength factor	α_U	0.96
Material resistance factor		γ_m	1.15	Anisotrophy factor	α_A	0.95
Maximum fabrication factor		α_{fab}	0.85	External pressure - Mpa ($\rho_w g H_{max}$)	p_{eb}	0.10
Ovality		f_o	$[D_{max} - D_{min}] / D$		0.2034	-
Collapse and buckle initiation		$[p_c - p_{el}]\,[p_c^2 - p_p^2] = p_c\,p_{el}\,p_p\,f_o\,D / t_2$				
Loadcase		Installation		Operating		-
Local minimum pressure	p_{lmin}	-	-	$d_{pmin} + \rho_c\,g\,[H_{ref} + H_{des}]$	0.00	Mpa
Characterictic wall thickness	t_2	t	20.60	$t - t_{corr}$	17.60	mm
Elastic capacity	p_{el}	$2\,E\,[\,t_2 / D\,]^3 / [\,1 - v^2\,]$	2.20	$2\,E\,[\,t_2 / D\,]^3 / [\,1 - v^2\,]$	1.37	Mpa
Plastic capacity	p_p	$2\,f_y\,\alpha_U\,\alpha_A\,\alpha_{fab}\,[\,t_2 / D\,]$	11.74	$2\,[f_y - f_{y,temp}]\alpha_U\alpha_A\alpha_{fab}\,[t_2 / D]$	10.03	Mpa
Calculation constants	b	$-\,p_{el}$	-2.20	$-\,p_{el}$	-1.37	-
	c	$-[\,p_p^2 + p_p\,p_{el}\,f_o\,D / t_2\,]$	-447.96	$-[\,p_p^2 + p_p\,p_{el}\,f_o\,D / t_2\,]$	-294.01	-
	d	$p_{el}\,p_p^2$	302.50	$p_{el}\,p_p^2$	137.70	-
	u	$[-\,b^2 / 3 + c\,] / 3$	-149.86	$[-\,b^2 / 3 + c\,] / 3$	-98.21	-
	v	$[\,2\,b^3 / 27 - b\,c / 3 + d\,] / 2$	-13.07	$[\,2\,b^3 / 27 - b\,c / 3 + d\,] / 2$	1.66	-
	Φ	$\cos^{-1}[\,-\,v / (-u^3)^{0.5}\,]$	1.56	$\cos^{-1}[\,-\,v / (-u^3)^{0.5}\,]$	1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.06	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	0.01	-
Collapse pressure	p_c	$y - b / 3$	0.67	$y - b / 3$	0.47	Mpa
Collapse FOS	FOS	p_c / p_{eb}	**6.70**	$[\,p_c - p_{lmin}\,] / p_{eb}$	**4.70**	> 1, Ok
Initiation buckling pressure	p_{init}	$p_c / [1.1\,\gamma_m\,\gamma_{SC}\,]$	0.51	$p_c / [1.1\,\gamma_m\,\gamma_{SC}\,]$	0.36	Mpa
Initiation buckling FOS	FOS	p_{init} / p_{eb}	**5.09**	$[p_{init} - p_{lmin}] / p_{eb}$	**3.57**	> 1, Ok
Propagating buckling pressure	p_{ppr}	$35\,f_y\,\alpha_U\,\alpha_{fab} / [\gamma_m\,\gamma_{SC}\,]\,[t_2 / D]^{2.5}$		$35\,[f_y - f_{y,temp}]\,\alpha_U\,\alpha_{fab} / [\gamma_m\,\gamma_{SC}\,]\,[t_2 / D]^{2.5}$		Mpa
		0.40		0.27		
Propagting buckling FOS	FOS	p_{ppr} / p_{eb}	**4.00**	$[\,p_{ppr} - p_{lmin}\,] / p_{eb}$	**2.70**	> 1, Ok

DESIGN AIDE PIPELINE ENGINEERING	DAWallThk Ver 1.0.1	PIPELINE WALL THICKNESS CALCULATIONS - DnV-OS F101

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA

Outside diameter	D	*1219*	mm	Density of content	ρ_c	*850*	kg/m^3
Maximum outside diameter	D_{max}	*1467*	mm	Density of seawater	ρ_w	*1030*	kg/m^3
Minimum outside diameter	D_{min}	*1219*	mm	Fabrication tolerance	$\%t_{fab}$	*8*	%
Nominal wall thickness	t	*20.6*	mm	Minimum water depth	H_{des}	*0.00*	m
Corrosion allowance	t_{corr}	*3.0*	mm	Maximum water depth	H_{max}	*20.00*	m
SMYS	f_y	*448*	Mpa	Fluid category		*B*	
Temperature derating	$f_{y,temp}$	*0*	Mpa	Location		*1*	
Modulus of elasticity	E	*207000*	Mpa	Design safety class		*Low*	
Poisson ratio	v	*0.3*	-	Characteristic material properties		*Normal*	
Design pressure	d_p	*1.865*	Mpa	Pipe fabrication process		*UOE*	
Design minimum pressure	d_{pmin}	*0*	Mpa	Incidental pressure factor	γ_{inc}	*1.10*	-
Ref. height above datum	H_{ref}	*0*	m	Test pressure factor	γ_t	*1.15*	-
Gravity acceleration	g	*9.81*	m/s^2				

PRESSURE CONTAINMENT

Local design pressure	$d_p+\rho_c g [H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure	$\gamma_t p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc} p_{ld}$	p_{li}	2.06	External pressure	$\rho_w g H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor		γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor		γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa			

Loadcase	Usage factor		Minimum wall thickness			Factor of safety		
Local design pressure	$2\,\alpha_U / [3^{0.5}\,\gamma_m\,\gamma_{SCP1}\,\gamma_{inc}]$		$(p_{ld} - p_{ed})\,D / [2\,\eta\,(f_y - f_{y,temp}) + p_{ld} - p_{ed}]$			$[t\,(1 - \%t_{fab} / 100) - t_{corr}] / t_1$		
	η	0.813	t_1	3.1	mm	FOS	**5.15**	**> 1, Ok**
Local test system pressure	$2\,\alpha_{Ut} / [3^{0.5}\,\gamma_m\,\gamma_{SCP}]$		$(p_{lt} - p_{ed})\,D / [2\,\eta\,f_y + p_{lt} - p_{ed}]$			$t\,[1 - \%t_{fab} / 100] / t_1$		
	η	0.96	t_1	3.3	mm	FOS	**5.74**	**> 1, Ok**

LOCAL BUCKLING

Safety class resistance factor	γ_{SC}	1.04	Material strength factor		α_U	0.96
Material resistance factor	γ_m	1.15	Anisotrophy factor		α_A	0.95
Maximum fabrication factor	α_{fab}	0.85	External pressure - Mpa	$\rho_w g H_{max}$	p_{eb}	0.20
Ovality	f_o	$[D_{max} - D_{min}] / D$			0.2034	-
Collapse and buckle initiation		$[p_c - p_{el}]\,[p_c^2 - p_p^2] = p_c\,p_{el}\,p_p\,f_o\,D / t_2$				

Loadcase		Installation		Operating		-
Local minimum pressure	p_{lmin}	-	-	$d_{pmin} + \rho_c\,g\,[H_{ref} + H_{des}]$	0.00	Mpa
Characterictic wall thickness	t_2	t	20.60	$t - t_{corr}$	17.60	mm
Elastic capacity	p_{el}	$2\,E\,[t_2 / D]^3 / [1 - v^2]$	2.20	$2\,E\,[t_2 / D]^3 / [1 - v^2]$	1.37	Mpa
Plastic capacity	p_p	$2\,f_y\,\alpha_U\,\alpha_A\,\alpha_{fab}\,[t_2 / D]$	11.74	$2\,[f_y - f_{y,temp}]\alpha_U\alpha_A\alpha_{fab}\,[t_2 / D]$	10.03	Mpa
Calculation constants	b	$- p_{el}$	-2.20	$- p_{el}$	-1.37	-
	c	$-[p_p^2 + p_p\,p_{el}\,f_o\,D / t_2]$	-447.96	$-[p_p^2 + p_p\,p_{el}\,f_o\,D / t_2]$	-294.01	-
	d	$p_{el}\,p_p^2$	302.50	$p_{el}\,p_p^2$	137.70	-
	u	$[-b^2 / 3 + c] / 3$	-149.86	$[-b^2 / 3 + c] / 3$	-98.21	-
	v	$[2\,b^3 / 27 - b\,c / 3 + d] / 2$	-13.07	$[2\,b^3 / 27 - b\,c / 3 + d] / 2$	1.66	-
	Φ	$\cos^{-1}[-v / (-u^3)^{0.5}]$	1.56	$\cos^{-1}[-v / (-u^3)^{0.5}]$	1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.06	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	0.01	-
Collapse pressure	p_c	$y - b / 3$	0.67	$y - b / 3$	0.47	Mpa
Collapse FOS	FOS	p_c / p_{eb}	**3.35**	$[p_c - p_{lmin}] / p_{eb}$	**2.35**	**> 1, Ok**
Initiation buckling pressure	p_{init}	$p_c / [1.1\,\gamma_m\,\gamma_{SC}]$	0.51	$p_c / [1.1\,\gamma_m\,\gamma_{SC}]$	0.36	Mpa
Initiation buckling FOS	FOS	p_{init} / p_{eb}	**2.55**	$[p_{init} - p_{lmin}] / p_{eb}$	**1.79**	**> 1, Ok**
Propagating buckling pressure	p_{ppr}	$35\,f_y\,\alpha_U\,\alpha_{fab} / [\gamma_m\,\gamma_{SC}]\,[t_2 / D]^{2.5}$		$35\,[f_y - f_{y,temp}]\,\alpha_U\,\alpha_{fab} / [\gamma_m\,\gamma_{SC}]\,[t_2 / D]^{2.5}$		Mpa
		0.40		0.27		
Propagting buckling FOS	FOS	p_{ppr} / p_{eb}	**2.00**	$[p_{ppr} - p_{lmin}] / p_{eb}$	**1.35**	**> 1, Ok**

DESIGN AIDE PIPELINE ENGINEERING	DAWallThk Ver 1.0.1	PIPELINE WALL THICKNESS CALCULATIONS - DnV-OS F101

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA							
Outside diameter	D	*1219*	mm	Density of content	ρ_c	*850*	kg/m^3
Maximum outside diameter	D_{max}	*1467*	mm	Density of seawater	ρ_w	*1030*	kg/m^3
Minimum outside diameter	D_{min}	*1219*	mm	Fabrication tolerance	$\%t_{fab}$	*8*	%
Nominal wall thickness	t	*20.6*	mm	Minimum water depth	H_{des}	*0.00*	m
Corrosion allowance	t_{corr}	*3.0*	mm	Maximum water depth	H_{max}	*26.00*	m
SMYS	f_y	*448*	Mpa	Fluid category		*B*	
Temperature derating	$f_{y,temp}$	*0*	Mpa	Location		*1*	
Modulus of elasticity	E	*207000*	Mpa	Design safety class		*Low*	
Poisson ratio	v	*0.3*	-	Characteristic material properties		*Normal*	
Design pressure	d_p	*1.865*	Mpa	Pipe fabrication process		*UOE*	
Design minimum pressure	d_{pmin}	*0*	Mpa	Incidental pressure factor	γ_{inc}	*1.10*	-
Ref. height above datum	H_{ref}	*0*	m	Test pressure factor	γ_t	*1.15*	-
Gravity acceleration	g	*9.81*	m/s^2				

PRESSURE CONTAINMENT								
Local design pressure	$d_p+\rho_c g [H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure		$\gamma_t p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc} p_{ld}$	p_{li}	2.06	External pressure		$\rho_w g H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor			γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor			γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa				
Loadcase	Usage factor		Minimum wall thickness			Factor of safety		
Local design pressure	$2\alpha_U / [3^{0.5} \gamma_m \gamma_{SCP1} \gamma_{inc}]$		$(p_{ld} - p_{ed}) D / [2 \eta (f_y - f_{y,temp}) + p_{ld} - p_{ed}]$			$[t(1 - \%t_{fab}/100) - t_{corr}] / t_1$		
	η	0.813	t_1	3.1	mm	FOS	**5.15**	**> 1, Ok**
Local test system pressure	$2\alpha_{Ut} / [3^{0.5} \gamma_m \gamma_{SCP}]$		$(p_{lt} - p_{ed}) D / [2 \eta f_y + p_{lt} - p_{ed}]$			$t[1 - \%t_{fab}/100] / t_1$		
	η	0.96	t_1	3.3	mm	FOS	**5.74**	**> 1, Ok**

LOCAL BUCKLING							
Safety class resistance factor		γ_{SC}	1.04	Material strength factor		α_U	0.96
Material resistance factor		γ_m	1.15	Anisotrophy factor		α_A	0.95
Maximum fabrication factor		α_{fab}	0.85	External pressure - Mpa	$\rho_w g H_{max}$	p_{eb}	0.26
Ovality		f_o	$[D_{max} - D_{min}] / D$			0.2034	-
Collapse and buckle initiation		$[p_c - p_{el}][p_c^2 - p_p^2] = p_c p_{el} p_p f_o D / t_2$					
Loadcase		Installation		Operating			-
Local minimum pressure	p_{lmin}	-	-	$d_{pmin} + \rho_c g [H_{ref} + H_{des}]$		0.00	Mpa
Characterictic wall thickness	t_2	t	20.60	$t - t_{corr}$		17.60	mm
Elastic capacity	p_{el}	$2E[t_2/D]^3/[1-v^2]$	2.20	$2E[t_2/D]^3/[1-v^2]$		1.37	Mpa
Plastic capacity	p_p	$2 f_y \alpha_U \alpha_A \alpha_{fab} [t_2/D]$	11.74	$2[f_y - f_{y,temp}]\alpha_U\alpha_A\alpha_{fab}[t_2/D]$		10.03	Mpa
Calculation constants	b	$-p_{el}$	-2.20	$-p_{el}$		-1.37	-
	c	$-[p_p^2 + p_p p_{el} f_o D/t_2]$	-447.96	$-[p_p^2 + p_p p_{el} f_o D/t_2]$		-294.01	-
	d	$p_{el} p_p^2$	302.50	$p_{el} p_p^2$		137.70	-
	u	$[-b^2/3 + c]/3$	-149.86	$[-b^2/3 + c]/3$		-98.21	-
	v	$[2b^3/27 - bc/3 + d]/2$	-13.07	$[2b^3/27 - bc/3 + d]/2$		1.66	-
	Φ	$\cos^{-1}[-v/(-u^3)^{0.5}]$	1.56	$\cos^{-1}[-v/(-u^3)^{0.5}]$		1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.06	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$		0.01	-
Collapse pressure	p_c	$y - b/3$	0.67	$y - b/3$		0.47	Mpa
Collapse FOS	FOS	p_c / p_{eb}	**2.58**	$[p_c - p_{lmin}] / p_{eb}$		**1.81**	**> 1, Ok**
Initiation buckling pressure	p_{init}	$p_c / [1.1 \gamma_m \gamma_{SC}]$	0.51	$p_c / [1.1 \gamma_m \gamma_{SC}]$		0.36	Mpa
Initiation buckling FOS	FOS	p_{init} / p_{eb}	**1.96**	$[p_{init} - p_{lmin}] / p_{eb}$		**1.37**	**> 1, Ok**
Propagating buckling pressure	p_{ppr}	$35 f_y \alpha_U \alpha_{fab} / [\gamma_m \gamma_{SC}] [t_2/D]^{2.5}$		$35 [f_y - f_{y,temp}] \alpha_U \alpha_{fab} / [\gamma_m \gamma_{SC}] [t_2/D]^{2.5}$			Mpa
		0.40		0.27			
Propagting buckling FOS	FOS	p_{ppr} / p_{eb}	**1.54**	$[p_{ppr} - p_{lmin}] / p_{eb}$		**1.04**	**> 1, Ok**

DESIGN AIDE PIPELINE ENGINEERING	DAWallThk Ver 1.0.1	PIPELINE WALL THICKNESS CALCULATIONS - DnV-OS F101

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA							
Outside diameter	D	*1219*	mm	Density of content	ρ_c	*850*	kg/m^3
Maximum outside diameter	D_{max}	*1467*	mm	Density of seawater	ρ_w	*1030*	kg/m^3
Minimum outside diameter	D_{min}	*1219*	mm	Fabrication tolerance	$\%t_{fab}$	*8*	%
Nominal wall thickness	t	*20.6*	mm	Minimum water depth	H_{des}	*0.00*	m
Corrosion allowance	t_{corr}	*3.0*	mm	Maximum water depth	H_{max}	*27.00*	m
SMYS	f_y	*448*	Mpa	Fluid category		*B*	
Temperature derating	$f_{y,temp}$	*0*	Mpa	Location		*1*	
Modulus of elasticity	E	*207000*	Mpa	Design safety class		*Low*	
Poisson ratio	v	*0.3*	-	Characteristic material properties		*Normal*	
Design pressure	d_p	*1.865*	Mpa	Pipe fabrication process		*UOE*	
Design minimum pressure	d_{pmin}	*0*	Mpa	Incidental pressure factor	γ_{inc}	*1.10*	-
Ref. height above datum	H_{ref}	*0*	m	Test pressure factor	γ_t	*1.15*	-
Gravity acceleration	g	*9.81*	m/s^2				

PRESSURE CONTAINMENT								
Local design pressure	$d_p+\rho_c g\,[H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure		$\gamma_t p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc}\, p_{ld}$	p_{li}	2.06	External pressure		$\rho_w g H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor			γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor			γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa				
Loadcase	Usage factor		Minimum wall thickness			Factor of safety		
Local design pressure	$2\,\alpha_U / [3^{0.5}\, \gamma_m\, \gamma_{SCP1}\, \gamma_{inc}]$		$(p_{ld} - p_{ed})\, D / [\,2\,\eta\,(f_y - f_{y,temp}) + p_{ld} - p_{ed}]$			$[\,t\,(1 - \%t_{fab} / 100) - t_{corr}\,] / t_1$		
	η	0.813	t_1	3.1	mm	FOS	**5.15**	**> 1, Ok**
Local test system pressure	$2\,\alpha_{Ut} / [3^{0.5}\, \gamma_m\, \gamma_{SCP}]$		$(p_{lt} - p_{ed})\, D / [\,2\,\eta\, f_y + p_{lt} - p_{ed}]$			$t\,[1 - \%t_{fab} / 100] / t_1$		
	η	0.96	t_1	3.3	mm	FOS	**5.74**	**> 1, Ok**

LOCAL BUCKLING								
Safety class resistance factor		γ_{SC}	1.04	Material strength factor			α_U	0.96
Material resistance factor		γ_m	1.15	Anisotrophy factor			α_A	0.95
Maximum fabrication factor		α_{fab}	0.85	External pressure - Mpa		$\rho_w g H_{max}$	p_{eb}	0.27
Ovality		f_o	$[D_{max} - D_{min}] / D$				0.2034	-
Collapse and buckle initiation		$[p_c - p_{el}]\,[p_c^2 - p_p^2] = p_c\, p_{el}\, p_p\, f_o\, D / t_2$						
Loadcase		Installation			Operating			-
Local minimum pressure	p_{lmin}	-		-	$d_{pmin} + \rho_c\, g\ [H_{ref} + H_{des}]$		0.00	Mpa
Characterictic wall thickness	t_2	t		20.60	$t - t_{corr}$		17.60	mm
Elastic capacity	p_{el}	$2\,E\,[\,t_2 / D\,]^3 / [\,1 - v^2\,]$		2.20	$2\,E\,[\,t_2 / D\,]^3 / [\,1 - v^2\,]$		1.37	Mpa
Plastic capacity	p_p	$2\, f_y\, \alpha_U\, \alpha_A\, \alpha_{fab}\, [\,t_2 / D\,]$		11.74	$2\,[f_y - f_{y,temp}]\alpha_U \alpha_A \alpha_{fab}\, [t_2 / D]$		10.03	Mpa
Calculation constants	b	$-\, p_{el}$		-2.20	$-\, p_{el}$		-1.37	-
	c	$-[\,p_p^2 + p_p\, p_{el}\, f_o\, D / t_2\,]$		-447.96	$-[\,p_p^2 + p_p\, p_{el}\, f_o\, D / t_2\,]$		-294.01	-
	d	$p_{el}\, p_p^2$		302.50	$p_{el}\, p_p^2$		137.70	-
	u	$[-\,b^2 / 3 + c\,] / 3$		-149.86	$[-\,b^2 / 3 + c\,] / 3$		-98.21	-
	v	$[\,2\,b^3 / 27 - b\,c / 3 + d\,] / 2$		-13.07	$[\,2\,b^3 / 27 - b\,c / 3 + d\,] / 2$		1.66	-
	Φ	$\cos^{-1}[\,-\,v / (-u^3)^{0.5}\,]$		1.56	$\cos^{-1}[\,-\,v / (-u^3)^{0.5}\,]$		1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$		-0.06	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$		0.01	-
Collapse pressure	p_c	$y - b / 3$		0.67	$y - b / 3$		0.47	Mpa
Collapse FOS	FOS	p_c / p_{eb}		**2.48**	$[\,p_c - p_{lmin}\,] / p_{eb}$		**1.74**	**> 1, Ok**
Initiation buckling pressure	p_{init}	$p_c / [1.1\, \gamma_m\, \gamma_{SC}\,]$		0.51	$p_c / [1.1\, \gamma_m\, \gamma_{SC}\,]$		0.36	Mpa
Initiation buckling FOS	FOS	p_{init} / p_{eb}		**1.89**	$[p_{init} - p_{lmin}] / p_{eb}$		**1.32**	**> 1, Ok**
Propagating buckling pressure	p_{ppr}	$35\, f_y\, \alpha_U\, \alpha_{fab} / [\gamma_m\, \gamma_{SC}]\, [t_2 / D]^{2.5}$			$35\,[f_y - f_{y,temp}]\ \alpha_U\, \alpha_{fab} / [\gamma_m\, \gamma_{SC}]\, [t_2 / D]^{2.5}$			Mpa
		0.40			0.27			
Propagting buckling FOS	FOS	p_{ppr} / p_{eb}		**1.48**	$[\,p_{ppr} - p_{lmin}\,] / p_{eb}$		**1.00**	**<1, Not Ok**

DESIGN AIDE PIPELINE ENGINEERING	DAWallThk Ver 1.0.1	**PIPELINE WALL THICKNESS CALCULATIONS - DnV-OS F101**

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA

Outside diameter	D	1219	mm	Density of content	ρ_c	850	kg/m^3
Maximum outside diameter	D_{max}	1467	mm	Density of seawater	ρ_w	1030	kg/m^3
Minimum outside diameter	D_{min}	1219	mm	Fabrication tolerance	$\%t_{fab}$	8	%
Nominal wall thickness	t	22.2	mm	Minimum water depth	H_{des}	0.00	m
Corrosion allowance	t_{corr}	3.0	mm	Maximum water depth	H_{max}	27.00	m
SMYS	f_y	448	Mpa	Fluid category		B	
Temperature derating	$f_{y,temp}$	0	Mpa	Location		1	
Modulus of elasticity	E	207000	Mpa	Design safety class		Low	
Poisson ratio	v	0.3	-	Characteristic material properties		Normal	
Design pressure	d_p	1.865	Mpa	Pipe fabrication process		UOE	
Design minimum pressure	d_{pmin}	0	Mpa	Incidental pressure factor	γ_{inc}	1.10	-
Ref. height above datum	H_{ref}	0	m	Test pressure factor	γ_t	1.15	-
Gravity acceleration	g	9.81	m/s^2				

PRESSURE CONTAINMENT

Local design pressure	$d_p+\rho_c g[H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure	$\gamma_t p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc} p_{ld}$	p_{li}	2.06	External pressure	$\rho_w g H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor		γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor		γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa			

Loadcase	Usage factor		Minimum wall thickness			Factor of safety		
Local design pressure	$2\alpha_U/[3^{0.5}\gamma_m\gamma_{SCP1}\gamma_{inc}]$		$(p_{ld}-p_{ed})D/[2\eta(f_y-f_{y,temp})+p_{ld}-p_{ed}]$			$[t(1-\%t_{fab}/100)-t_{corr}]/t_1$		
	η	0.813	t_1	3.1	mm	FOS	**5.62**	**> 1, Ok**
Local test system pressure	$2\alpha_{Ut}/[3^{0.5}\gamma_m\gamma_{SCP}]$		$(p_{lt}-p_{ed})D/[2\eta f_y+p_{lt}-p_{ed}]$			$t[1-\%t_{fab}/100]/t_1$		
	η	0.96	t_1	3.3	mm	FOS	**6.19**	**> 1, Ok**

LOCAL BUCKLING

Safety class resistance factor	γ_{SC}	1.04	Material strength factor		α_U	0.96
Material resistance factor	γ_m	1.15	Anisotrophy factor		α_A	0.95
Maximum fabrication factor	α_{fab}	0.85	External pressure - Mpa	$\rho_w g H_{max}$	p_{eb}	0.27
Ovality	f_o		$[D_{max}-D_{min}]/D$		0.2034	-
Collapse and buckle initiation		$[p_c-p_{el}][p_c^2-p_p^2]=p_c p_{el} p_p f_o D/t_2$				

Loadcase		Installation		Operating		-
Local minimum pressure	p_{lmin}	-	-	$d_{pmin}+\rho_c g[H_{ref}+H_{des}]$	0.00	Mpa
Characterictic wall thickness	t_2	t	22.20	$t-t_{corr}$	19.20	mm
Elastic capacity	p_{el}	$2E[t_2/D]^3/[1-v^2]$	2.75	$2E[t_2/D]^3/[1-v^2]$	1.78	Mpa
Plastic capacity	p_p	$2f_y\alpha_U\alpha_A\alpha_{fab}[t_2/D]$	12.65	$2[f_y-f_{y,temp}]\alpha_U\alpha_A\alpha_{fab}[t_2/D]$	10.94	Mpa
Calculation constants	b	$-p_{el}$	-2.75	$-p_{el}$	-1.78	-
	c	$-[p_p^2+p_p p_{el} f_o D/t_2]$	-548.23	$-[p_p^2+p_p p_{el} f_o D/t_2]$	-370.83	-
	d	$p_{el} p_p^2$	439.69	$p_{el} p_p^2$	212.76	-
	u	$[-b^2/3+c]/3$	-183.58	$[-b^2/3+c]/3$	-123.96	-
	v	$[2b^3/27-bc/3+d]/2$	-32.01	$[2b^3/27-bc/3+d]/2$	-3.70	-
	Φ	$\cos^{-1}[-v/(-u^3)^{0.5}]$	1.56	$\cos^{-1}[-v/(-u^3)^{0.5}]$	1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.12	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.02	-
Collapse pressure	p_c	$y-b/3$	0.80	$y-b/3$	0.57	Mpa
Collapse FOS	FOS	p_c/p_{eb}	**2.96**	$[p_c-p_{lmin}]/p_{eb}$	**2.11**	**> 1, Ok**
Initiation buckling pressure	p_{init}	$p_c/[1.1\gamma_m\gamma_{SC}]$	0.61	$p_c/[1.1\gamma_m\gamma_{SC}]$	0.43	Mpa
Initiation buckling FOS	FOS	p_{init}/p_{eb}	**2.25**	$[p_{init}-p_{lmin}]/p_{eb}$	**1.60**	**> 1, Ok**
Propagating buckling pressure	p_{ppr}	$35f_y\alpha_U\alpha_{fab}/[\gamma_m\gamma_{SC}][t_2/D]^{2.5}$	0.48	$35[f_y-f_{y,temp}]\alpha_U\alpha_{fab}/[\gamma_m\gamma_{SC}][t_2/D]^{2.5}$	0.33	Mpa
Propagting buckling FOS	FOS	p_{ppr}/p_{eb}	**1.78**	$[p_{ppr}-p_{lmin}]/p_{eb}$	**1.22**	**> 1, Ok**

DESIGN AIDE PIPELINE ENGINEERING	DAWallThk Ver 1.0.1	PIPELINE WALL THICKNESS CALCULATIONS - DnV-OS F101

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA							
Outside diameter	D	1219	mm	Density of content	ρ_c	800	kg/m^3
Maximum outside diameter	D_{max}	1467	mm	Density of seawater	ρ_w	1030	kg/m^3
Minimum outside diameter	D_{min}	1219	mm	Fabrication tolerance	$\%t_{fab}$	8	%
Nominal wall thickness	t	22.2	mm	Minimum water depth	H_{des}	0.00	m
Corrosion allowance	t_{corr}	3.0	mm	Maximum water depth	H_{max}	30.00	m
SMYS	f_y	448	Mpa	Fluid category		B	
Temperature derating	$f_{y,temp}$	0	Mpa	Location		1	
Modulus of elasticity	E	207000	Mpa	Design safety class		Low	
Poisson ratio	v	0.3	-	Characteristic material properties		Normal	
Design pressure	d_p	1.865	Mpa	Pipe fabrication process		UOE	
Design minimum pressure	d_{pmin}	0	Mpa	Incidental pressure factor	γ_{inc}	1.10	-
Ref. height above datum	H_{ref}	0	m	Test pressure factor	γ_t	1.15	-
Gravity acceleration	g	9.81	m/s^2				

PRESSURE CONTAINMENT							
Local design pressure	$d_p+\rho_c g [H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure	$\gamma_t p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc} p_{ld}$	p_{li}	2.06	External pressure	$\rho_w g H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor		γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor		γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa			
Loadcase	Usage factor		Minimum wall thickness			Factor of safety	
Local design pressure	$2\alpha_U / [3^{0.5} \gamma_m \gamma_{SCP1} \gamma_{inc}]$		$(p_{ld} - p_{ed}) D / [2\eta (f_y - f_{y,temp}) + p_{ld} - p_{ed}]$			$[t(1 - \%t_{fab}/100) - t_{corr}] / t_1$	
	η	0.813	t_1	3.1	mm	FOS	5.62 > 1, Ok
Local test system pressure	$2\alpha_{Ut} / [3^{0.5} \gamma_m \gamma_{SCP}]$		$(p_{lt} - p_{ed}) D / [2\eta f_y + p_{lt} - p_{ed}]$			$t[1 - \%t_{fab}/100] / t_1$	
	η	0.96	t_1	3.3	mm	FOS	6.19 > 1, Ok

LOCAL BUCKLING						
Safety class resistance factor	γ_{SC}	1.04	Material strength factor		α_U	0.96
Material resistance factor	γ_m	1.15	Anisotrophy factor		α_A	0.95
Maximum fabrication factor	α_{fab}	0.85	External pressure - Mpa	$\rho_w g H_{max}$	p_{eb}	0.30
Ovality	f_o	$[D_{max} - D_{min}] / D$			0.2034	-
Collapse and buckle initiation		$[p_c - p_{el}][p_c^2 - p_p^2] = p_c p_{el} p_p f_o D / t_2$				
Loadcase		Installation		Operating		-
Local minimum pressure	p_{lmin}	-	-	$d_{pmin} + \rho_c g [H_{ref} + H_{des}]$	0.00	Mpa
Characterictic wall thickness	t_2	t	22.20	$t - t_{corr}$	19.20	mm
Elastic capacity	p_{el}	$2E[t_2/D]^3/[1-v^2]$	2.75	$2E[t_2/D]^3/[1-v^2]$	1.78	Mpa
Plastic capacity	p_p	$2 f_y \alpha_U \alpha_A \alpha_{fab} [t_2/D]$	12.65	$2[f_y - f_{y,temp}]\alpha_U\alpha_A\alpha_{fab}[t_2/D]$	10.94	Mpa
Calculation constants	b	$-p_{el}$	-2.75	$-p_{el}$	-1.78	-
	c	$-[p_p^2 + p_p p_{el} f_o D/t_2]$	-548.23	$-[p_p^2 + p_p p_{el} f_o D/t_2]$	-370.83	-
	d	$p_{el} p_p^2$	439.69	$p_{el} p_p^2$	212.76	-
	u	$[-b^2/3 + c]/3$	-183.58	$[-b^2/3 + c]/3$	-123.96	-
	v	$[2b^3/27 - bc/3 + d]/2$	-32.01	$[2b^3/27 - bc/3 + d]/2$	-3.70	-
	Φ	$\cos^{-1}[-v/(-u^3)^{0.5}]$	1.56	$\cos^{-1}[-v/(-u^3)^{0.5}]$	1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.12	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.02	-
Collapse pressure	p_c	$y - b/3$	0.80	$y - b/3$	0.57	Mpa
Collapse FOS	FOS	p_c / p_{eb}	**2.67**	$[p_c - p_{lmin}] / p_{eb}$	**1.90**	> 1, Ok
Initiation buckling pressure	p_{init}	$p_c / [1.1 \gamma_m \gamma_{SC}]$	0.61	$p_c / [1.1 \gamma_m \gamma_{SC}]$	0.43	Mpa
Initiation buckling FOS	FOS	p_{init} / p_{eb}	**2.03**	$[p_{init} - p_{lmin}] / p_{eb}$	**1.44**	> 1, Ok
Propagating buckling pressure	p_{ppr}	$35 f_y \alpha_U \alpha_{fab} / [\gamma_m \gamma_{SC}] [t_2/D]^{2.5}$ 0.48		$35[f_y - f_{y,temp}] \alpha_U \alpha_{fab} / [\gamma_m \gamma_{SC}][t_2/D]^{2.5}$ 0.33		Mpa
Propagting buckling FOS	FOS	p_{ppr} / p_{eb}	1.60	$[p_{ppr} - p_{lmin}] / p_{eb}$	1.10	> 1, Ok

PROJECT	*subsea pipeline design*
TITLE	*for 20.5 km pipeline from SPM to LFP*

INPUT DATA							
Outside diameter	D	1219	mm	Density of content	ρ_c	850	kg/m^3
Maximum outside diameter	D_{max}	1467	mm	Density of seawater	ρ_w	1030	kg/m^3
Minimum outside diameter	D_{min}	1219	mm	Fabrication tolerance	$\%t_{fab}$	8	%
Nominal wall thickness	t	22.2	mm	Minimum water depth	H_{des}	0.00	m
Corrosion allowance	t_{corr}	3.0	mm	Maximum water depth	H_{max}	32.00	m
SMYS	f_y	448	Mpa	Fluid category		B	
Temperature derating	$f_{y,temp}$	0	Mpa	Location		1	
Modulus of elasticity	E	207000	Mpa	Design safety class		Low	
Poisson ratio	ν	0.3	-	Characteristic material properties		Normal	
Design pressure	d_p	1.865	Mpa	Pipe fabrication process		UOE	
Design minimum pressure	d_{pmin}	0	Mpa	Incidental pressure factor	γ_{inc}	1.10	-
Ref. height above datum	H_{ref}	0	m	Test pressure factor	γ_t	1.15	-
Gravity acceleration	g	9.81	m/s^2				

PRESSURE CONTAINMENT							
Local design pressure	$d_p+\rho_c\,g\,[H_{ref}+H_{des}]$	p_{ld}	1.87	Local test pressure	$\gamma_t\,p_{li}$	p_{lt}	2.37
Local incidental pressure	$\gamma_{inc}\,p_{ld}$	p_{li}	2.06	External pressure	$\rho_w\,g\,H_{des}$	p_{ed}	0.00
Safety class resistance factor		γ_{SCP}	1.046	Effective safety class resistance factor		γ_{SCP1}	1.077
Material strength factor - operating		α_U	0.96	Material resistance factor		γ_m	1.15
Material strength factor - system test		α_{Ut}	1.00	Unit for pressure in Mpa			
Loadcase	Usage factor		Minimum wall thickness			Factor of safety	
Local design pressure	$2\,\alpha_U\,/\,[3^{0.5}\,\gamma_m\,\gamma_{SCP1}\,\gamma_{inc}]$		$(p_{ld}-p_{ed})\,D\,/\,[\,2\,\eta\,(f_y-f_{y,temp})+p_{ld}-p_{ed}]$			$[\,t\,(1-\%t_{fab}/100)-t_{corr}\,]\,/\,t_1$	
	η	0.813	t_1	3.1	mm	FOS	**5.62** **> 1, Ok**
Local test system pressure	$2\,\alpha_{Ut}\,/\,[3^{0.5}\,\gamma_m\,\gamma_{SCP}]$		$(p_{lt}-p_{ed})\,D\,/\,[\,2\,\eta\,f_y+p_{lt}-p_{ed}]$			$t\,[1-\%t_{fab}/100]\,/\,t_1$	
	η	0.96	t_1	3.3	mm	FOS	**6.19** **> 1, Ok**

LOCAL BUCKLING						
Safety class resistance factor		γ_{SC}	1.04	Material strength factor	α_U	0.96
Material resistance factor		γ_m	1.15	Anisotrophy factor	α_A	0.95
Maximum fabrication factor		α_{fab}	0.85	External pressure - Mpa $\rho_w\,g\,H_{max}$	p_{eb}	0.32
Ovality		f_o	$[D_{max}-D_{min}]\,/\,D$		0.2034	-
Collapse and buckle initiation		$[p_c-p_{el}]\,[p_c^2-p_p^2]=p_c\,p_{el}\,p_p\,f_o\,D\,/\,t_2$				
Loadcase		Installation		Operating		-
Local minimum pressure	p_{lmin}	-	-	$d_{pmin}+\rho_c\,g\,[H_{ref}+H_{des}]$	0.00	Mpa
Characterictic wall thickness	t_2	t	22.20	$t-t_{corr}$	19.20	mm
Elastic capacity	p_{el}	$2\,E\,[\,t_2/D\,]^3\,/\,[\,1-\nu^2\,]$	2.75	$2\,E\,[\,t_2/D\,]^3\,/\,[\,1-\nu^2\,]$	1.78	Mpa
Plastic capacity	p_p	$2\,f_y\,\alpha_U\,\alpha_A\,\alpha_{fab}\,[\,t_2/D\,]$	12.65	$2\,[f_y-f_{y,temp}]\alpha_U\alpha_A\alpha_{fab}\,[t_2/D]$	10.94	Mpa
Calculation constants	b	$-\,p_{el}$	-2.75	$-\,p_{el}$	-1.78	-
	c	$-[\,p_p^2+p_p\,p_{el}\,f_o\,D\,/\,t_2\,]$	-548.23	$-[\,p_p^2+p_p\,p_{el}\,f_o\,D\,/\,t_2\,]$	-370.83	-
	d	$p_{el}\,p_p^2$	439.69	$p_{el}\,p_p^2$	212.76	-
	u	$[-\,b^2/3+c\,]\,/\,3$	-183.58	$[-\,b^2/3+c\,]\,/\,3$	-123.96	-
	v	$[\,2\,b^3/27-b\,c/3+d\,]\,/\,2$	-32.01	$[\,2\,b^3/27-b\,c/3+d\,]\,/\,2$	-3.70	-
	Φ	$\cos^{-1}[\,-v\,/\,(-u^3)^{0.5}\,]$	1.56	$\cos^{-1}[\,-v\,/\,(-u^3)^{0.5}\,]$	1.57	-
	y	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.12	$-2[-u]^{0.5}\cos[\Phi/3+60\pi/180]$	-0.02	-
Collapse pressure	p_c	$y-b/3$	0.80	$y-b/3$	0.57	Mpa
Collapse FOS	FOS	$p_c\,/\,p_{eb}$	**2.50**	$[\,p_c-p_{lmin}\,]\,/\,p_{eb}$	**1.78**	**> 1, Ok**
Initiation buckling pressure	p_{init}	$p_c\,/\,[1.1\,\gamma_m\,\gamma_{SC}\,]$	0.61	$p_c\,/\,[1.1\,\gamma_m\,\gamma_{SC}\,]$	0.43	Mpa
Initiation buckling FOS	FOS	$p_{init}\,/\,p_{eb}$	**1.90**	$[p_{init}-p_{lmin}]\,/\,p_{eb}$	**1.35**	**> 1, Ok**
Propagating buckling pressure	p_{ppr}	$35\,f_y\,\alpha_U\,\alpha_{fab}\,/\,[\gamma_m\,\gamma_{SC}]\,[t_2/D]^{2.5}$		$35\,[f_y-f_{y,temp}]\,\alpha_U\,\alpha_{fab}\,/\,[\gamma_m\,\gamma_{SC}\,]\,[t_2/D]^{2.5}$		Mpa
		0.48		0.33		
Propagting buckling FOS	FOS	$p_{ppr}\,/\,p_{eb}$	**1.50**	$[\,p_{ppr}-p_{lmin}\,]\,/\,p_{eb}$	**1.03**	**> 1, Ok**

APPENDIX 2

PIPELINE STABILITY ANALYSIS BOTTH FOR 1 YEAR AND 100 YEAR DATA.

PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES							
Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*20.60*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*1.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES							
Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

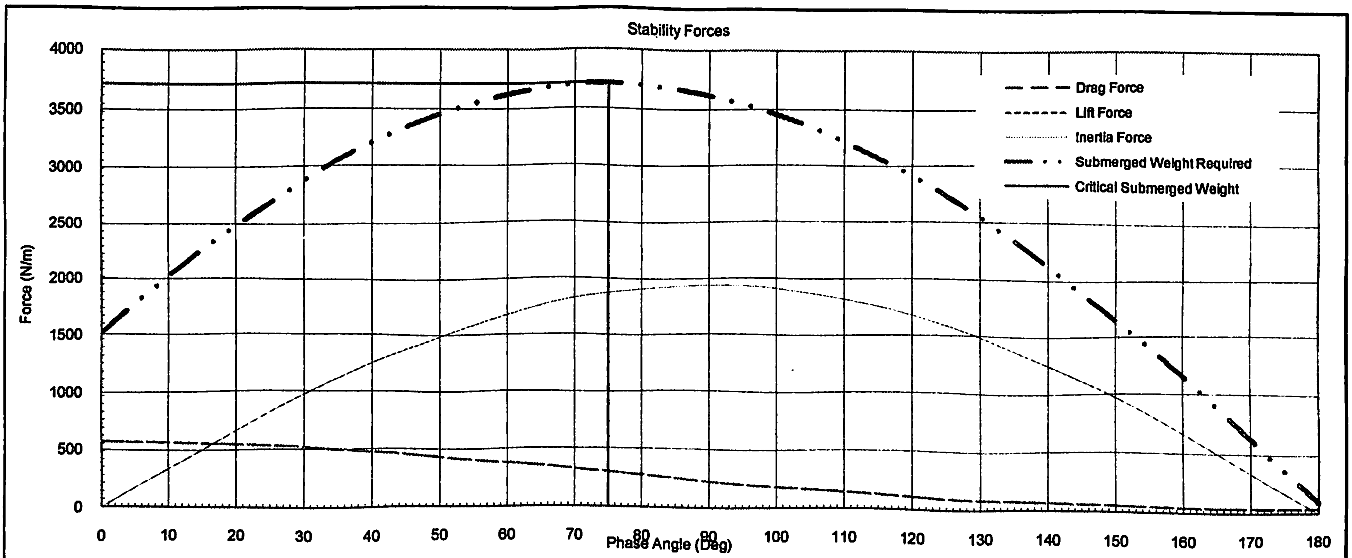
ENVIRONMENTAL PARAMETERS							
Significant wave height	H_S	*1.600*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*7.200*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*14.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]							
Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	5972.519	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi\, (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	10.688
Concrete coating	$\pi (D_S + 2t_{CC} + t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi\, (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	4282.64 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS										
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$				D	1.469	m	Reduction	R	1.000
Average current velocity	$U_r \{1/ \ln(z_r / z_O + 1)\ \{[1 + (z_O / D)]\ \ln[D/ z_O + 1] - 1\}\}$				U_D	0.63	m/s	Peakedness	γ	3.30
Parameter	$[d / g]^{0.5}$	T_n	1.195	s	Sig. wave velocity	$R\, C_1\, H_S / T_n$		U_S	0.375	m/s
Ratio	T_n / T_P	-	0.17	-	From Fig 2.2	T_U / T_P		C_2	0.97	-
From Fig 2.1	$U_S\ T_n / H_S$	C_1	0.280	-	Zero upcrossing period	$C_2\, T_P$		T_U	6.98	s
Significant acceleration	$2\pi\, U_S / T_U$	A_S	0.338	m/s^2	Load parameter (KC number)	$U_S\, T_U / D$		K		1.78
Current to wave velocity ratio	U_D / U_S	M		1.68	Calibration factor from figure 5.12			F_W		1.09

SUMMARY OF HYDRODYNAMIC LOADING							
Current velocity	U_D	0.630	m/s	Wave acceleration	A_S	0.338	m/s^2
Wave velocity	U_S	0.375	m/s	Critical phase angle	θ	75.0	Deg
Lift force $0.5\rho_W\, D C_L\, [U_S \cos\theta + U_D]^2$	F_L	299.9	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	1875.1	N/m
Drag force $0.5\, \rho_W\, D\, C_D\, \lvert U_S \cos\theta + U_D \rvert\, [U_S \cos\theta + U_D]$	F_D	299.9	N/m				

CHECK FOR SUBMERGED WEIGHT						
Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu\, F_L] / \mu\}\, F_W$	W_{SR}	3713.79 N/m
W_{SR} < W_S			Ok			



GRAPHS

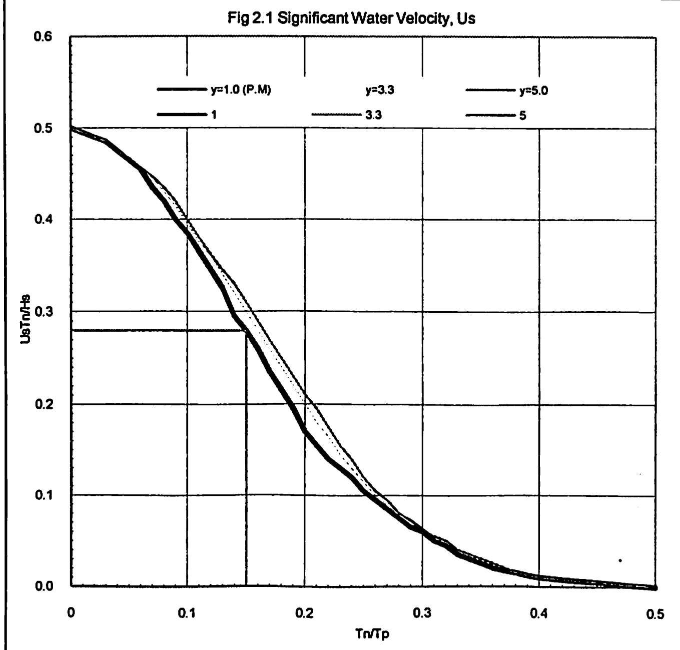


Fig 2.1 Significant Water Velocity, Us

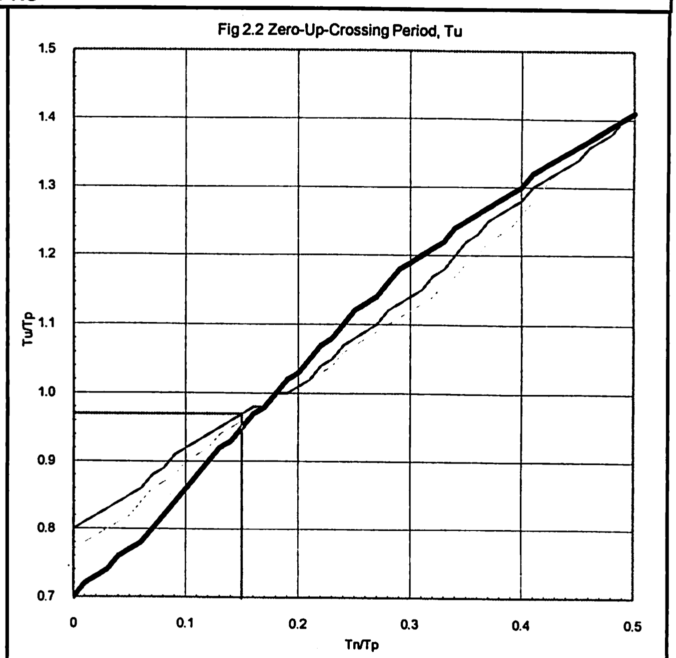


Fig 2.2 Zero-Up-Crossing Period, Tu

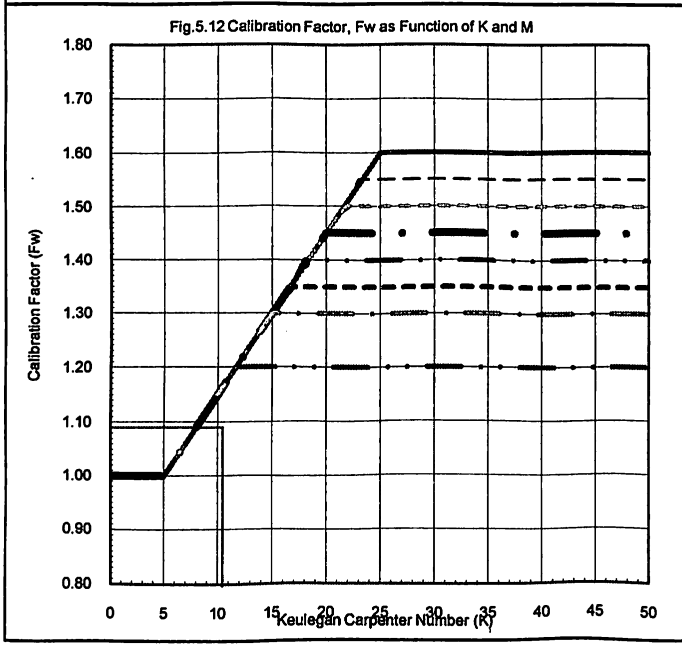


Fig.5.12 Calibration Factor, Fw as Function of K and M

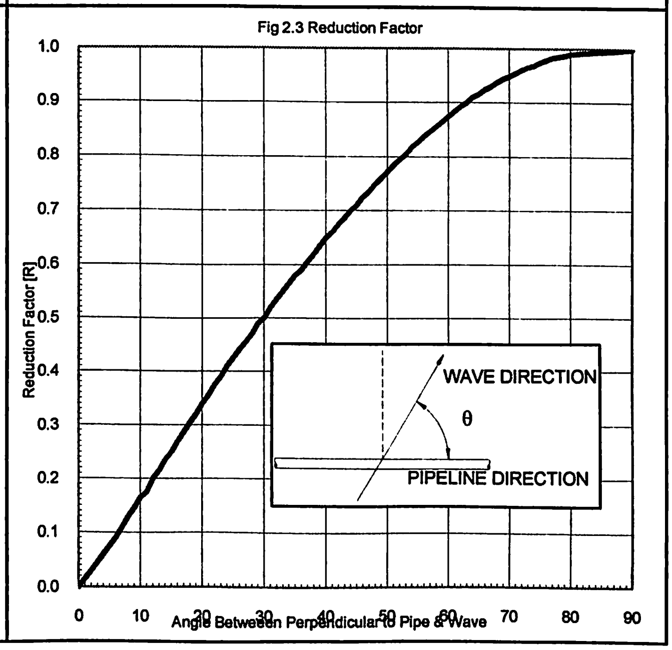


Fig 2.3 Reduction Factor

PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES

Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*20.60*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*1.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES

Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

ENVIRONMENTAL PARAMETERS

Significant wave height	H_S	*1.600*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*7.200*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*26.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]

Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	5972.519	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	10.688
Concrete coating	$\pi (D_S + 2t_{CC} + t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	4282.64 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS

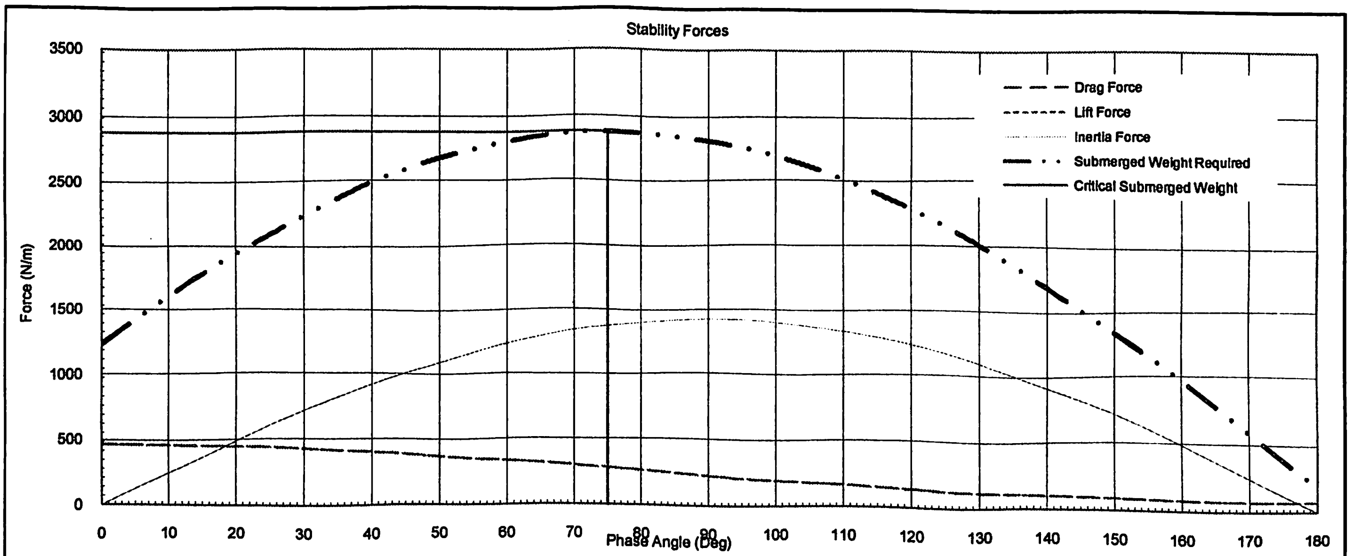
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$				D	1.469	m	Reduction	R 1.000
Average current velocity	$U_r \{1/\ln(z_r/z_O+1)\ \{[1+(z_O/D)]\ \ln[D/z_O+1] - 1\}\}$				U_D	0.63	m/s	Peakedness	γ 3.30
Parameter	$[d/g]^{0.5}$	T_n	1.628	s	Sig. wave velocity	$R\, C_1\, H_S / T_n$		U_S	0.275 m/s
Ratio	T_n / T_P	-	0.23	-	From Fig 2.2	T_U / T_P		C_2	0.97 -
From Fig 2.1	$U_S\ T_n / H_S$	C_1	0.280	-	Zero upcrossing period	$C_2\, T_P$		T_U	6.98 s
Significant acceleration	$2\pi\, U_S / T_U$	A_S	0.248	m/s^2	Load parameter (KC number)			$U_S\, T_U / D$	K 1.31
Current to wave velocity ratio		U_D / U_S	M	2.29	Calibration factor from figure 5.12				F_W 1.09

SUMMARY OF HYDRODYNAMIC LOADING

Current velocity		U_D	0.630	m/s	Wave acceleration	A_S	0.248	m/s^2
Wave velocity		U_S	0.275	m/s	Critical phase angle	θ	75.0	Deg
Lift force	$0.5\rho_W D C_L\, [U_S \cos\theta + U_D]^2$	F_L	279.0	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	1375.8	N/m
Drag force	$0.5\, \rho_W\, D\, C_D\, \lvert U_S \cos\theta + U_D \rvert\, [U_S \cos\theta + U_D]$			F_D	279.0 N/m			

CHECK FOR SUBMERGED WEIGHT

Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu\, F_L] / \mu\}\, F_W$	W_{SR}	2880.80	N/m
W_{SR}	<	W_S	Ok				



GRAPHS

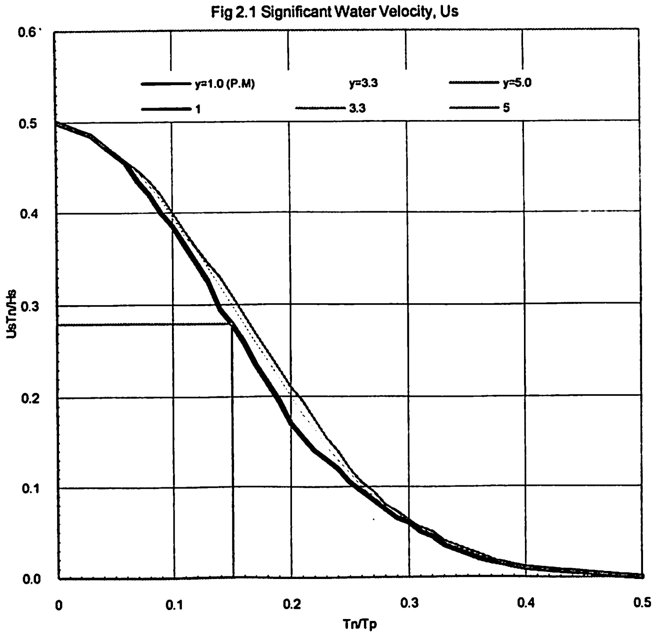


Fig 2.1 Significant Water Velocity, Us

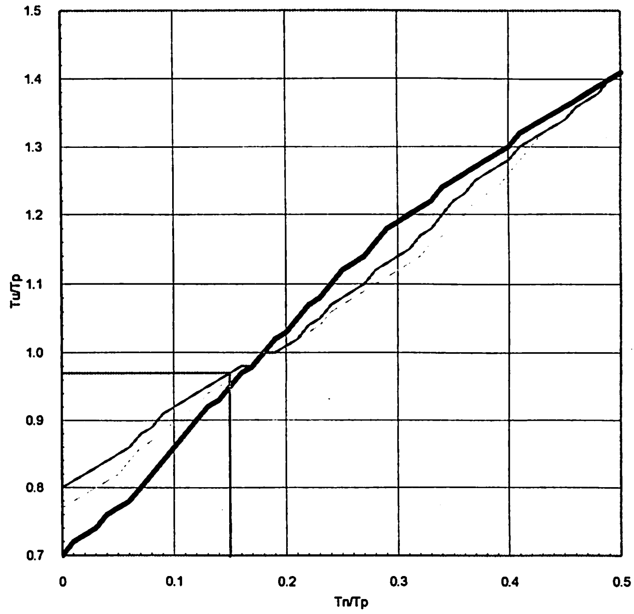


Fig 2.2 Zero-Up-Crossing Period, Tu

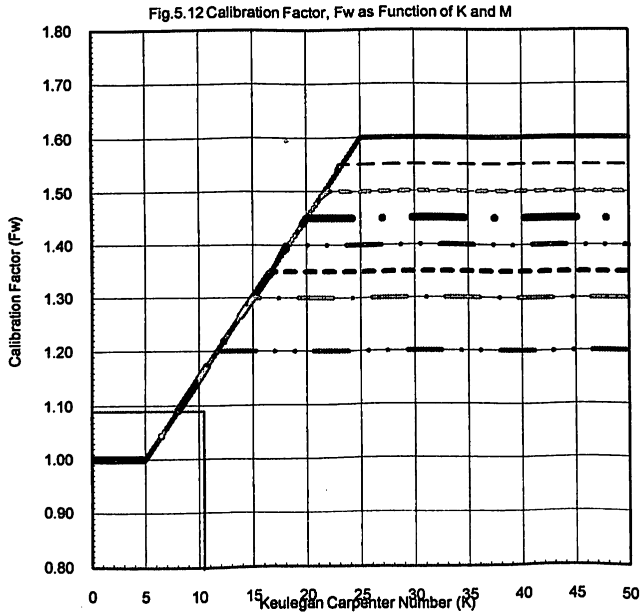


Fig.5.12 Calibration Factor, Fw as Function of K and M

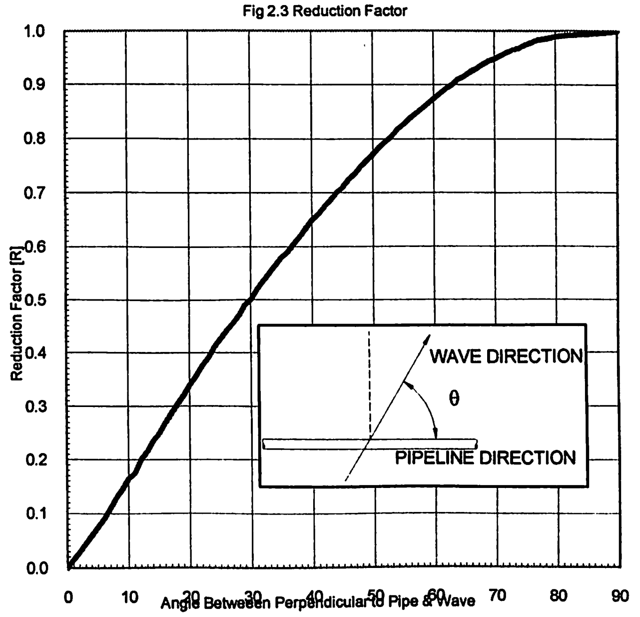


Fig 2.3 Reduction Factor

DESIGN AIDE PIPELINE ENGINEERING	DnVRPE305 Ver 1.4	**PIPELINE STABILITY ANALYSIS - DnV RP E305 : SIMPLIFIED METHOD**

PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES

Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*22.20*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*1.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES

Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

ENVIRONMENTAL PARAMETERS

Significant wave height	H_S	*1.600*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*7.200*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*32.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]

Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	6427.811	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	10.630
Concrete coating	$\pi (D_S+2t_{CC} +t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	4737.87 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS

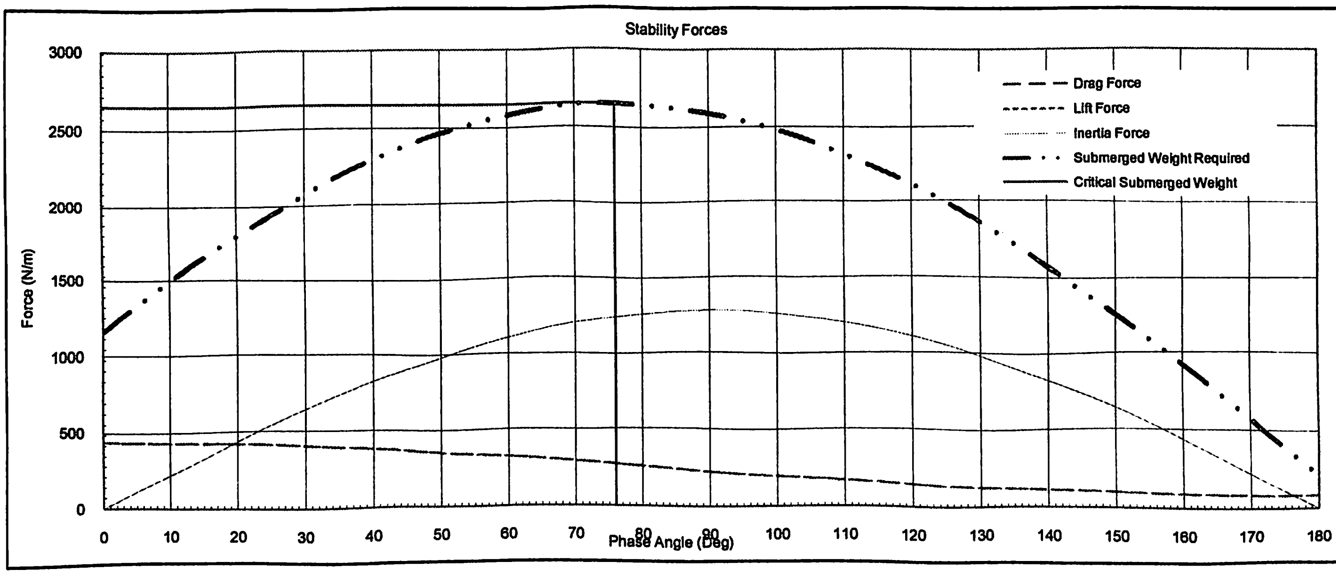
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$			D	1.469	m	Reduction	R	1.000
Average current velocity	$U_r \{1/\, ln(z_r / z_O+1)\ \{[1+ (z_O / D)]\ ln[D/ z_O +1] - 1\}\}$			U_D	0.63	m/s	Peakedness	γ	3.30
Parameter	$[d / g]^{0.5}$	T_n	1.806	s	Sig. wave velocity	$R\, C_1\, H_S / T_n$	U_S	0.248	m/s
Ratio	T_n / T_P	-	0.25	-	From Fig 2.2	T_U / T_P	C_2	0 97	-
From Fig 2.1	$U_S\ T_n / H_S$	C_1	0.280	-	Zero upcrossing period	$C_2\, T_P$	T_U	6.98	s
Significant acceleration	$2\, \pi\, U_S / T_U$	A_S	0.223	m/s^2	Load parameter (KC number)		$U_S\, T_U / D$	K	1.18
Current to wave velocity ratio		U_D / U_S	M	2.54	Calibration factor from figure 5.12			F_W	1.09

SUMMARY OF HYDRODYNAMIC LOADING

Current velocity		U_D	0.630	m/s	Wave acceleration	A_S	0.223 m/s^2
Wave velocity		U_S	0.248	m/s	Critical phase angle	θ	76.0 Deg
Lift force	$0.5\rho_W\, DC_L\, [U_S \cos\theta +U_D]^2$	F_L	270.1	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	1242.7 N/m
Drag force	$0.5\, \rho_W\, D\, C_D\, \| [U_S \cos\theta + U_D] \|\, [U_S \cos\theta + U_D]$	F_D	270.1	N/m			

CHECK FOR SUBMERGED WEIGHT

Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu\, F_L] / \mu\}\, F_W$	W_{SR}	2650.19	N/m
W_{SR}	<	W_S	Ok				



GRAPHS

Fig 2.1 Significant Water Velocity, Us

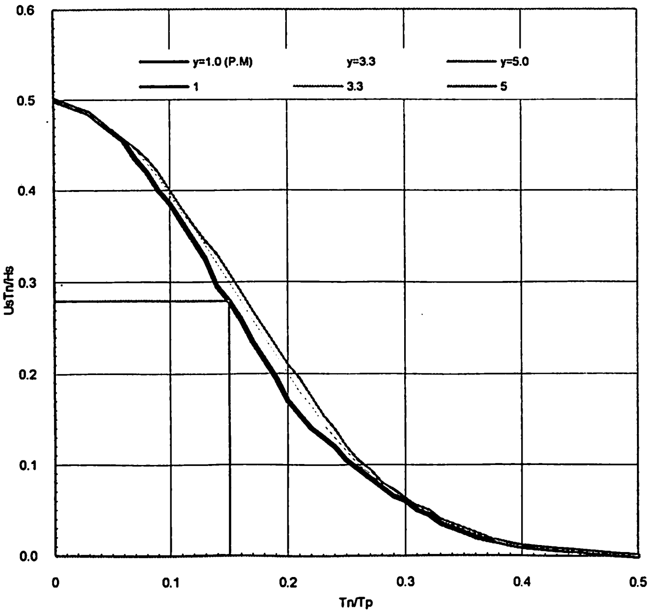


Fig 2.2 Zero-Up-Crossing Period, Tu

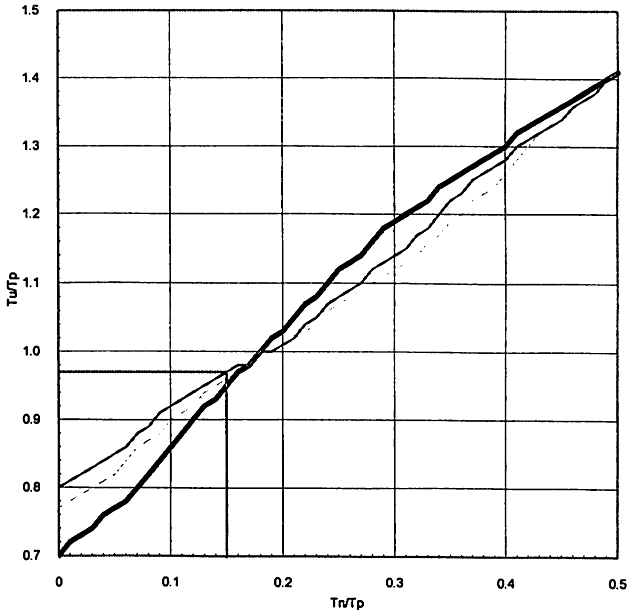


Fig.5.12 Calibration Factor, Fw as Function of K and M

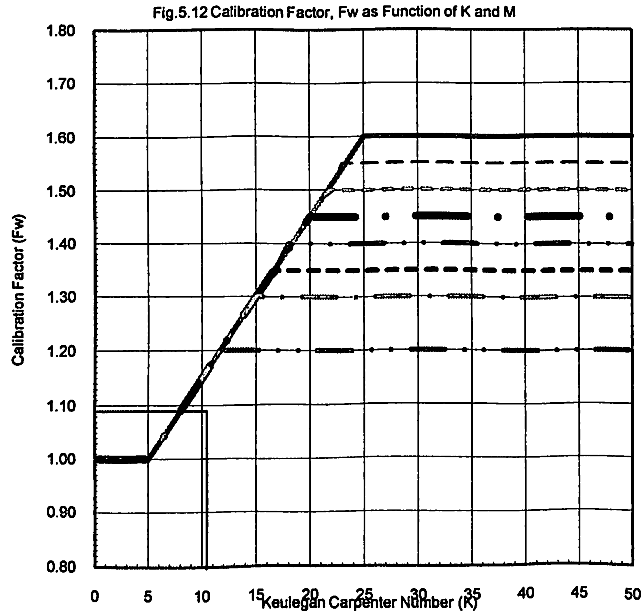
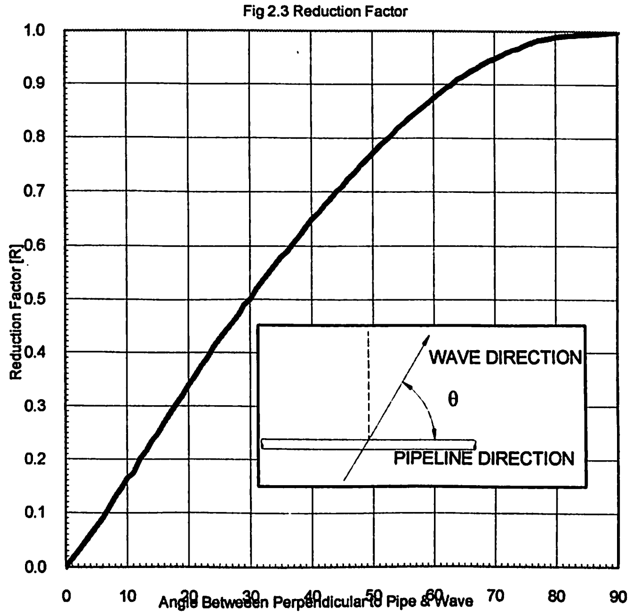


Fig 2.3 Reduction Factor



DESIGN AIDE PIPELINE ENGINEERING	DnVRPE305 Ver 1.4	PIPELINE STABILITY ANALYSIS - DnV RP E305 : SIMPLIFIED METHOD

PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES

Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*20.60*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*850.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES

Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

ENVIRONMENTAL PARAMETERS

Significant wave height	H_S	*8.300*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*11.500*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*13.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]

Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	5972.519	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi\, (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	9084.916
Concrete coating	$\pi (D_S + 2t_{CC} + t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi\, (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$				W_S	13356.87	N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS

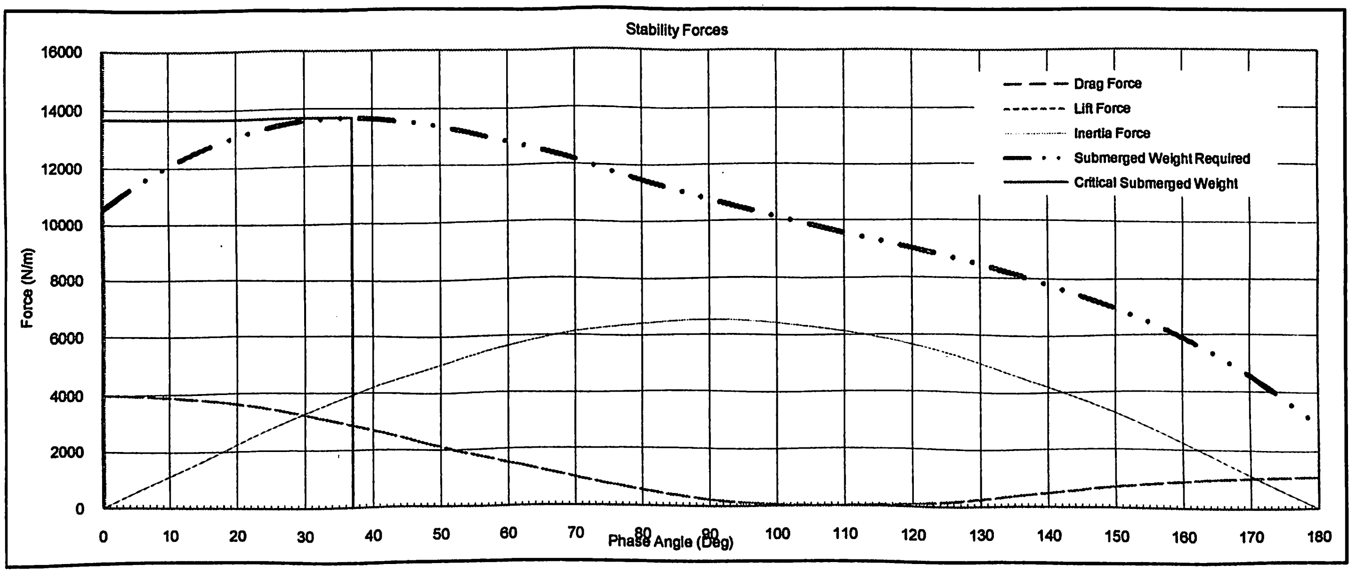
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$			D	1.469	m	Reduction	R	1.000
Average current velocity	$U_r \{1/ \ln(z_r / z_O + 1)\, \{[1 + (z_O / D)] \ln[D/ z_O + 1] - 1\}\}$			U_D	0.63	m/s	Peakedness	γ	3.30
Parameter	$[d / g]^{0.5}$	T_n	1.151	s	Sig. wave velocity	$R\, C_1\, H_S / T_n$	U_S	2.019	m/s
Ratio	T_n / T_P	-	0.10	-	From Fig 2.2	T_U / T_P	C_2	0.97	-
From Fig 2.1	$U_S\ T_n / H_S$	C_1	0.280	-	Zero upcrossing period	$C_2\, T_P$	T_U	11.16	s
Significant acceleration	$2\, \pi\, U_S / T_U$	A_S	1.137	m/s^2	Load parameter (KC number)	$U_S\, T_U / D$		K	15.34
Current to wave velocity ratio		U_D / U_S	M	0.31	Calibration factor from figure 5.12			F_W	1.09

SUMMARY OF HYDRODYNAMIC LOADING

Current velocity	U_D	0.630	m/s	Wave acceleration	A_S	1.137	m/s^2
Wave velocity	U_S	2.019	m/s	Critical phase angle	θ	37.0	Deg
Lift force $0.5 \rho_W D C_L [U_S \cos\theta + U_D]^2$	F_L	2853.2	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	3930.0	N/m
Drag force $0.5\, \rho_W\, D\, C_D\, \vert [U_S \cos\theta + U_D] \vert\, [U_S \cos\theta + U_D]$	F_D	2853.2	N/m				

CHECK FOR SUBMERGED WEIGHT

Friction factor	μ	0.700	Submerged weight required	$\{[(F_D + F_I) + \mu\, F_L] / \mu\}\, F_W$	W_{SR}	13672.39 N/m
W_{SR} > W_S		Not Ok				



GRAPHS

Fig 2.1 Significant Water Velocity, Us

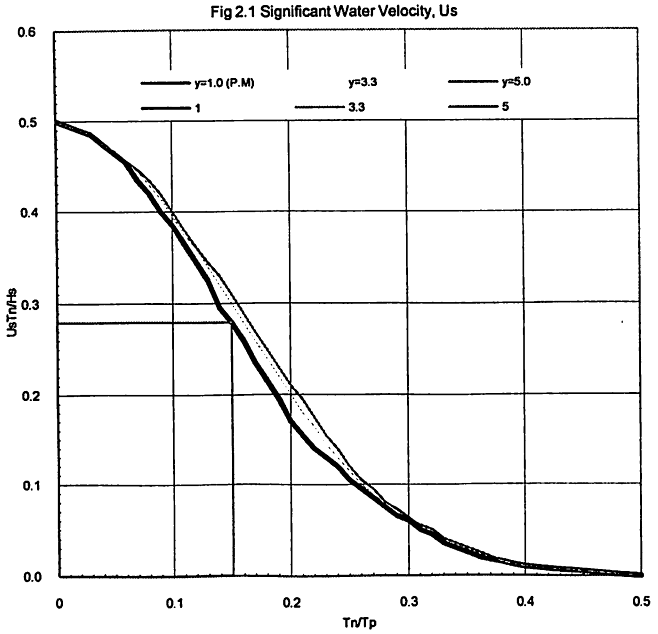


Fig 2.2 Zero-Up-Crossing Period, Tu

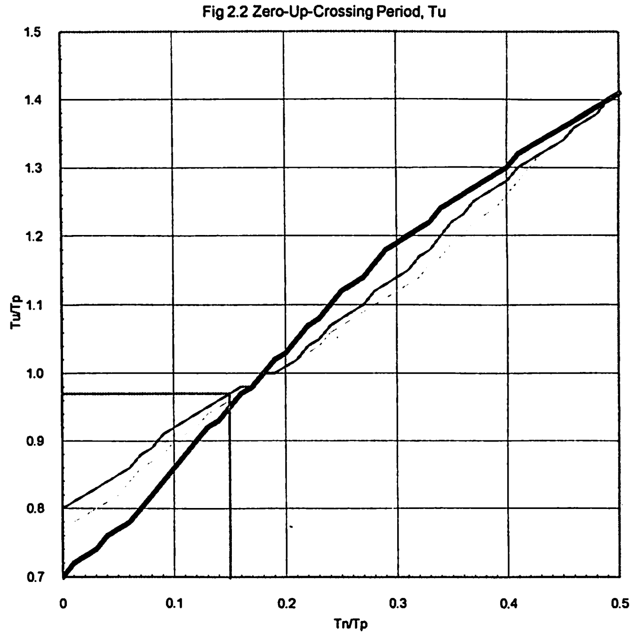


Fig.5.12 Calibration Factor, Fw as Function of K and M

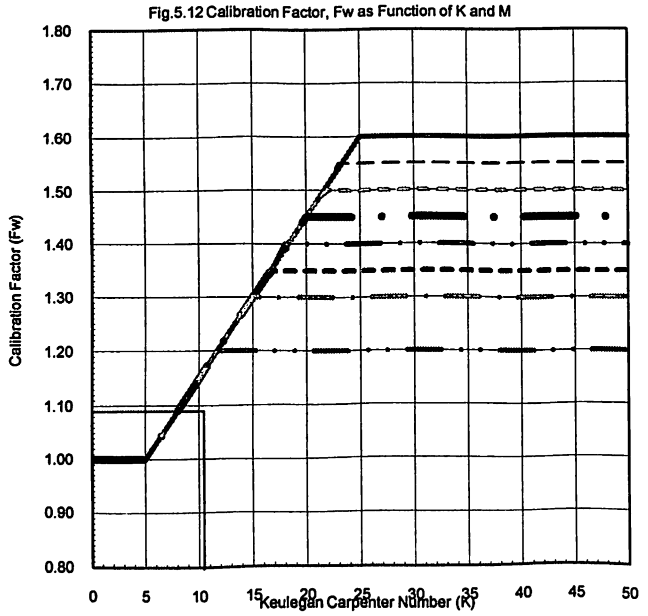
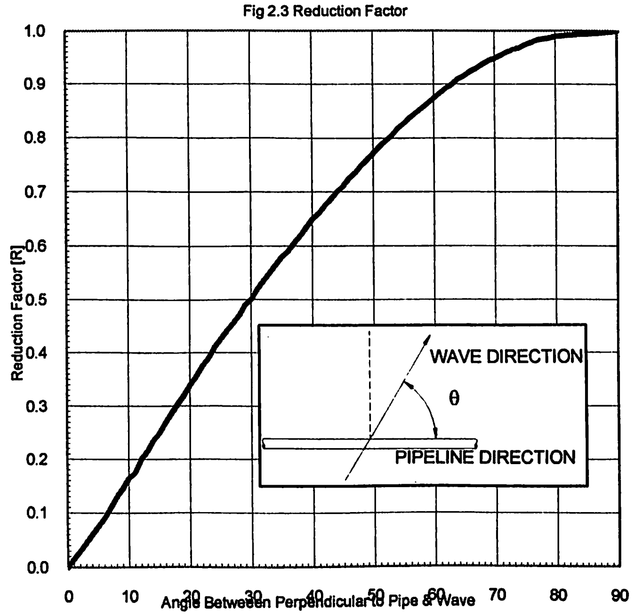


Fig 2.3 Reduction Factor



PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES

Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*20.60*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*850.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES

Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

ENVIRONMENTAL PARAMETERS

Significant wave height	H_S	*8.300*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*11.500*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*14.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]

Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	5972.519	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi\, (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	9084.916
Concrete coating	$\pi (D_S + 2t_{CC} + t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi\, (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	13356.87 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS

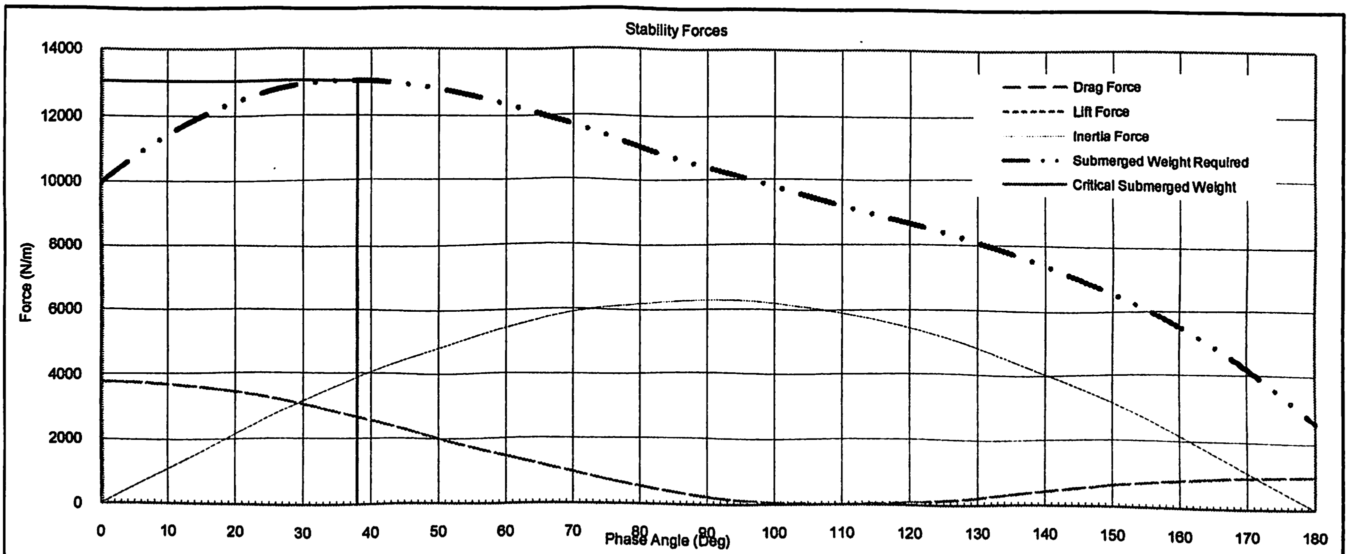
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$			D	1.469	m	Reduction R	1.000
Average current velocity	$U_r \{1/ ln (z_r / z_O+1) \{[1+ (z_O / D)]\, ln[D/ z_O +1] - 1\}\}$			U_D	0.63	m/s	Peakedness γ	3.30
Parameter	$[d / g]^{0.5}$	T_n	1.195 s	Sig. wave velocity	$R\, C_1\, H_S / T_n$	U_S	1.945	m/s
Ratio	T_n / T_P	-	0.10 -	From Fig 2.2	T_U / T_P	C_2	0.97	-
From Fig 2.1	$U_S\, T_n / H_S$	C_1	0.280 -	Zero upcrossing period	$C_2\, T_P$	T_U	11.16	s
Significant acceleration	$2\, \pi\, U_S / T_U$	A_S	1.095 m/s^2	Load parameter (KC number)	$U_S\, T_U / D$	K	14.78	
Current to wave velocity ratio	U_D / U_S	M	0.32	Calibration factor from figure 5.12		F_W	1.09	

SUMMARY OF HYDRODYNAMIC LOADING

Current velocity		U_D	0.630	m/s	Wave acceleration	A_S	1.095	m/s^2
Wave velocity		U_S	1.945	m/s	Critical phase angle	θ	38.0	Deg
Lift force	$0.5\rho_W\, D C_L\, [U_S \cos\theta + U_D]^2$	F_L	2653.8	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	3871.9	N/m
Drag force	$0.5\, \rho_W\, D\, C_D\, \lvert U_S \cos\theta + U_D \rvert\, [U_S \cos\theta + U_D]$	F_D	2653.8	N/m				

CHECK FOR SUBMERGED WEIGHT

Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu\, F_L] / \mu\}\, F_W$	W_{SR}	13054.18	N/m
W_{SR}	<	W_S	Ok				



GRAPHS

Fig 2.1 Significant Water Velocity, Us

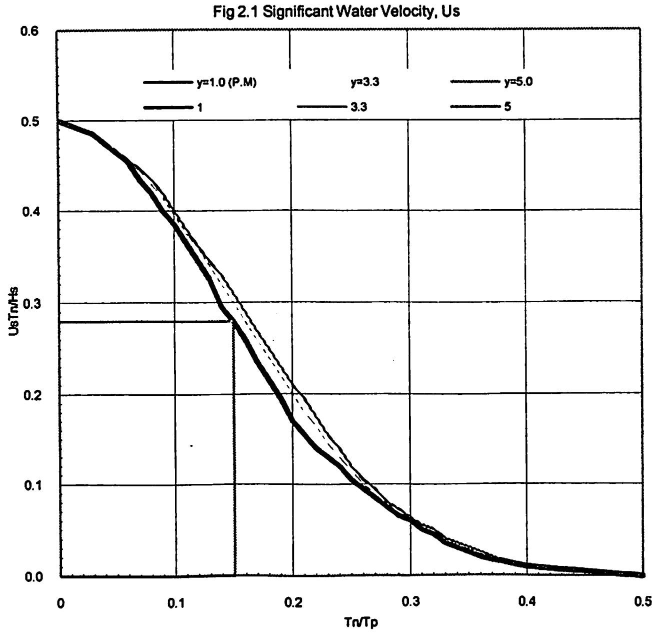


Fig 2.2 Zero-Up-Crossing Period, Tu

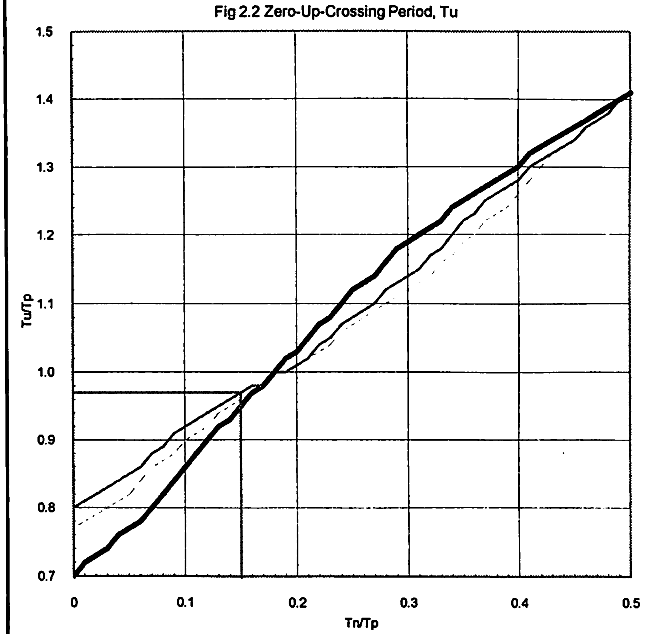


Fig.5.12 Calibration Factor, Fw as Function of K and M

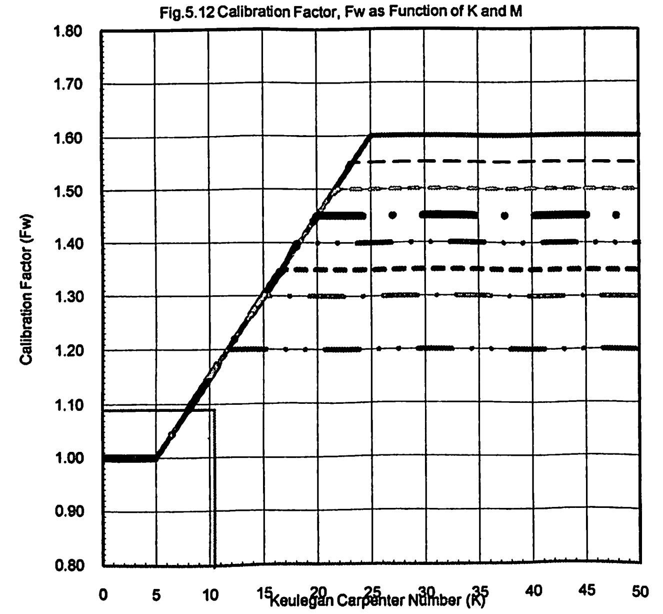
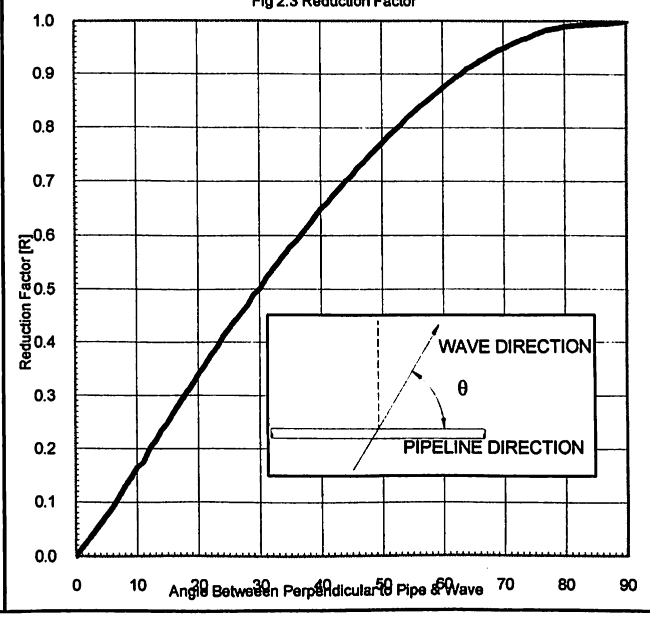


Fig 2.3 Reduction Factor



PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES

Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*20.60*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*850.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES

Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

ENVIRONMENTAL PARAMETERS

Significant wave height	H_S	*8.300*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*11.500*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*15.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]

Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	5972.519	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	9084.916
Concrete coating	$\pi (D_S+2t_{CC}+t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	13356.87 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS

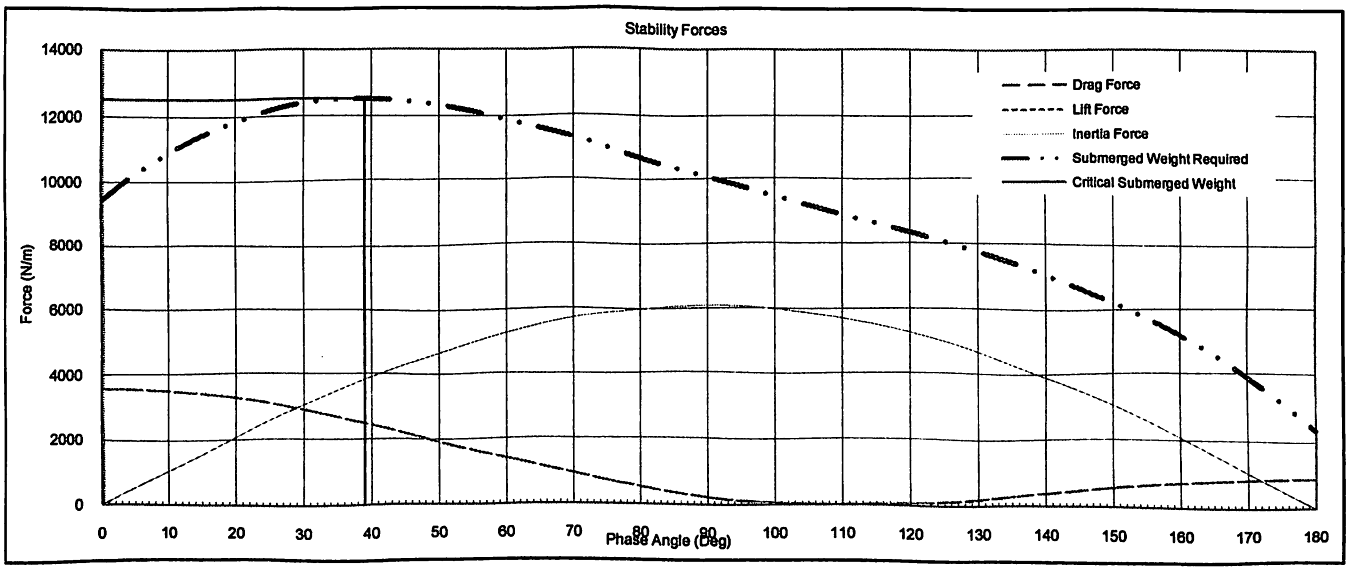
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$		D	1.469	m	Reduction	R	1.000
Average current velocity	$U_r \{1/\ln(z_r / z_O+1)\, \{[1+ (z_O / D)]\, \ln[D/ z_O +1] - 1\}\}$		U_D	0.63	m/s	Peakedness	γ	3.30
Parameter	$[d / g]^{0.5}$	T_n	1.237	s	Sig. wave velocity $R\, C_1\, H_S / T_n$	U_S	1.879	m/s
Ratio	T_n / T_P	-	0.11	-	From Fig 2.2 T_U / T_P	C_2	0.97	-
From Fig 2.1	$U_S\ T_n / H_S$	C_1	0.280	-	Zero upcrossing period $C_2\, T_P$	T_U	11.16	s
Significant acceleration	$2\, \pi\, U_S / T_U$	A_S	1.058	m/s^2	Load parameter (KC number) $U_S\, T_U / D$	K	14.27	
Current to wave velocity ratio	U_D / U_S	M	0.34		Calibration factor from figure 5.12	F_W	1.09	

SUMMARY OF HYDRODYNAMIC LOADING

Current velocity		U_D	0.630	m/s	Wave acceleration	A_S	1.058 m/s^2
Wave velocity		U_S	1.879	m/s	Critical phase angle	θ	39.0 Deg
Lift force	$0.5\rho_W D C_L\, [U_S \cos\theta + U_D]^2$	F_L	2479.1	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	3824.1 N/m
Drag force	$0.5\, \rho_W\, D\, C_D\, \vert U_S \cos\theta + U_D\vert\, [U_S \cos\theta + U_D]$		F_D	2479.1	N/m		

CHECK FOR SUBMERGED WEIGHT

Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu\, F_L] / \mu\}\, F_W$	W_{SR}	12517.07 N/m
W_{SR}	<	W_S	Ok			



GRAPHS

Fig 2.1 Significant Water Velocity, Us

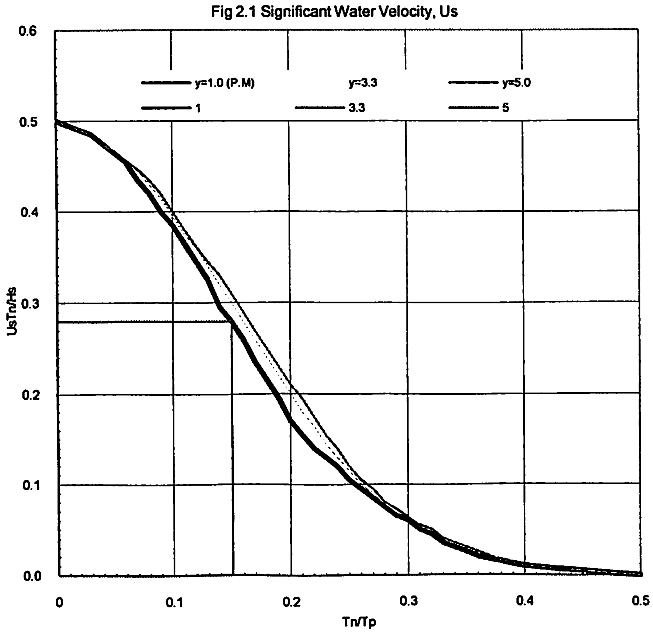


Fig 2.2 Zero-Up-Crossing Period, Tu

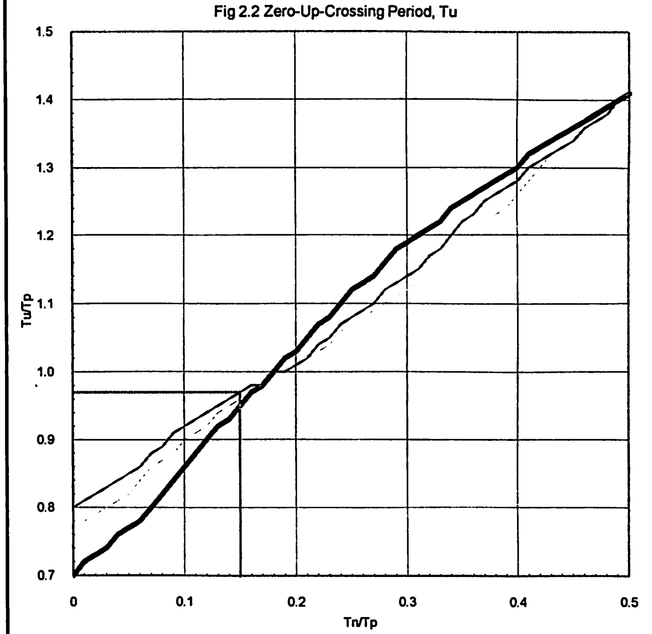


Fig.5.12 Calibration Factor, Fw as Function of K and M

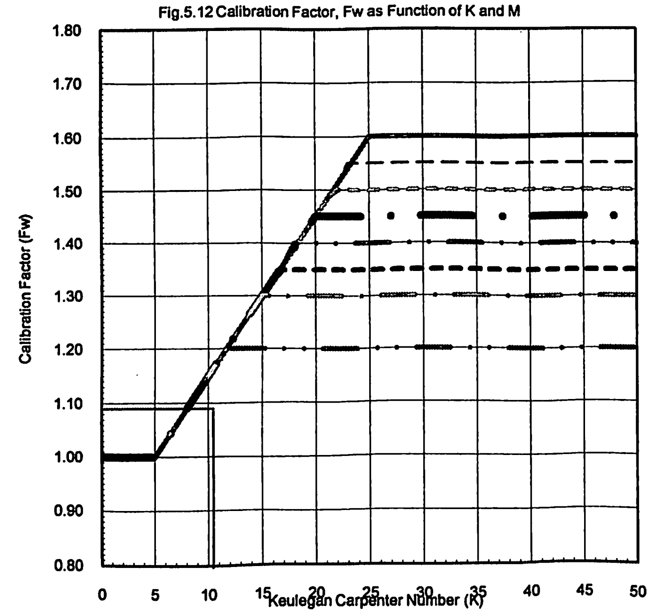
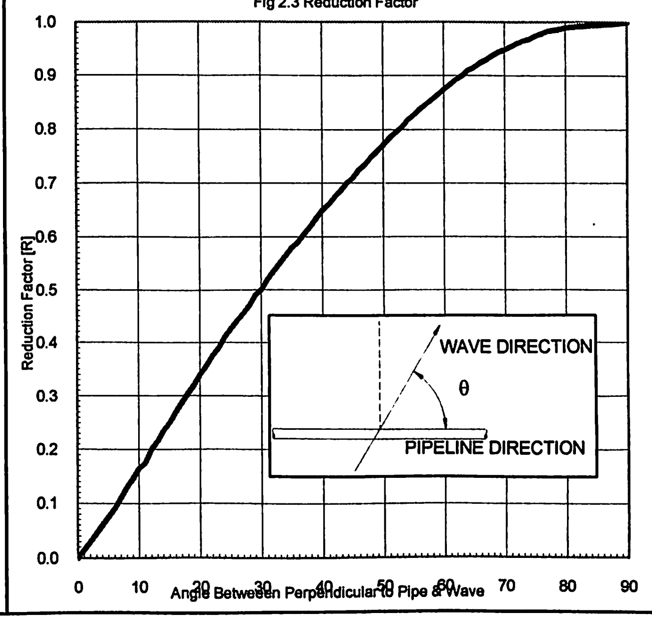


Fig 2.3 Reduction Factor



PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES							
Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*20.60*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*850.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES							
Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

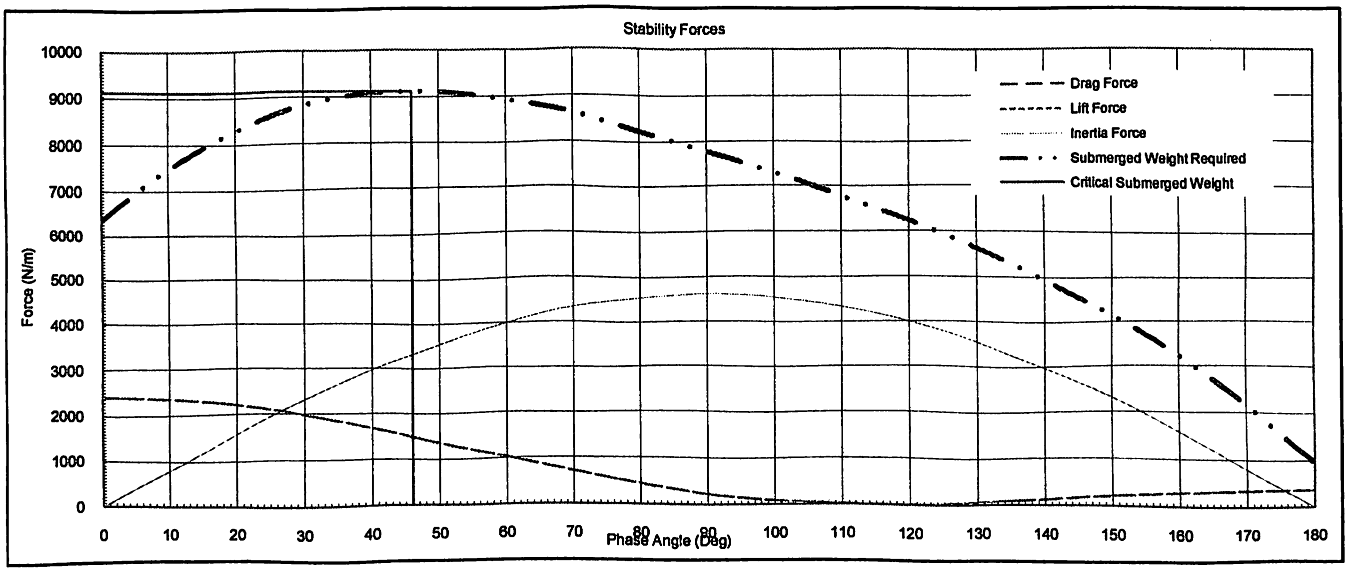
ENVIRONMENTAL PARAMETERS							
Significant wave height	H_S	*8.300*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*11.500*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*26.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]							
Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	5972.519	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	9084.916
Concrete coating	$\pi (D_S+2t_{CC}+t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	13356.87 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS									
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$			D	1.469	m	Reduction	R	1.000
Average current velocity	$U_r \{1/ \ln(z_r / z_O+1)\ \{[1+ (z_O / D)] \ln[D/ z_O +1] - 1\}\}$			U_D	0.63	m/s	Peakedness	γ	3.30
Parameter	$[d / g]^{0.5}$	T_n	1.628	s	Sig. wave velocity	$R\, C_1\, H_S / T_n$	U_S	1.428	m/s
Ratio	T_n / T_P	-	0.14	-	From Fig 2.2	T_U / T_P	C_2	0.97	-
From Fig 2.1	$U_S\ T_n / H_S$	C_1	0.280	-	Zero upcrossing period	$C_2\, T_P$	T_U	11.16	s
Significant acceleration	$2\pi\, U_S / T_U$	A_S	0.804	m/s^2	Load parameter (KC number)		$U_S\, T_U / D$	K	10.85
Current to wave velocity ratio	U_D / U_S	M	0.44		Calibration factor from figure 5.12			F_W	1.09

SUMMARY OF HYDRODYNAMIC LOADING							
Current velocity		U_D	0.630	m/s	Wave acceleration	A_S	0.804 m/s^2
Wave velocity		U_S	1.428	m/s	Critical phase angle	θ	46.0 Deg
Lift force	$0.5\rho_W D C_L [U_S \cos\theta + U_D]^2$	F_L	1492.7	N/m	Inertia force $0.25\pi D^2 \rho_W C_M A_S \sin\theta$	F_I	3321.7 N/m
Drag force	$0.5\, \rho_W\, D\, C_D\, \lvert U_S \cos\theta + U_D\rvert\, [U_S \cos\theta + U_D]$	F_D	1492.7	N/m			

CHECK FOR SUBMERGED WEIGHT							
Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu F_L] / \mu\} F_W$	W_{SR}	9123.75	N/m
W_{SR}	<	W_S	Ok				



GRAPHS

Fig 2.1 Significant Water Velocity, Us

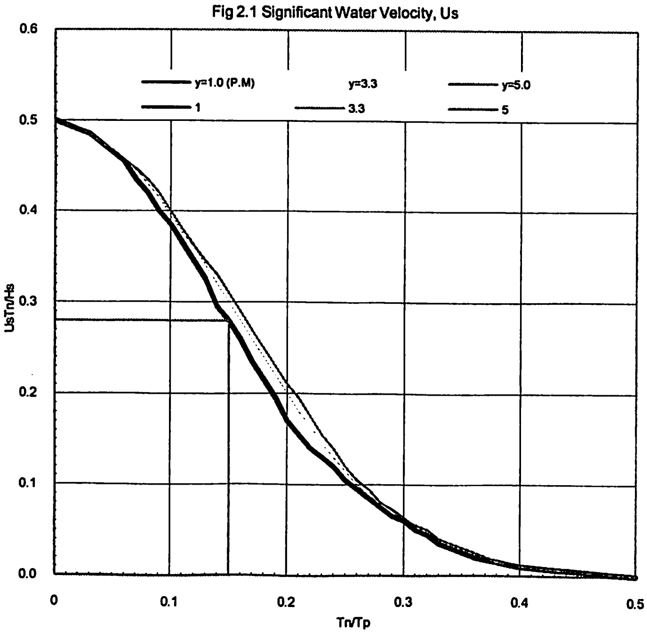


Fig 2.2 Zero-Up-Crossing Period, Tu

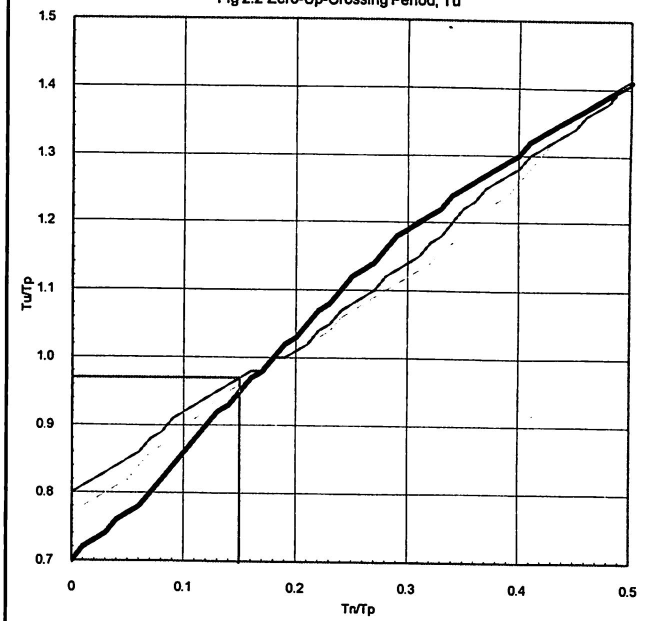


Fig.5.12 Calibration Factor, Fw as Function of K and M

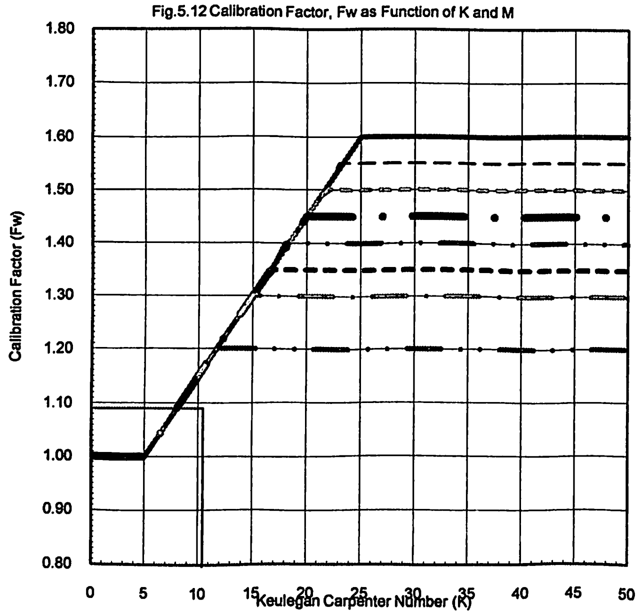
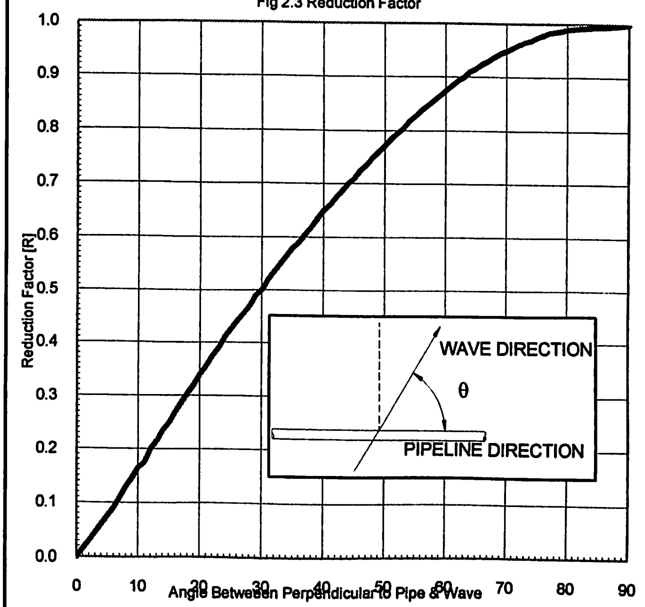


Fig 2.3 Reduction Factor



DESIGN AIDE PIPELINE ENGINEERING	DnVRPE305 Ver 1.4	PIPELINE STABILITY ANALYSIS - DnV RP E305 : SIMPLIFIED METHOD

PROJECT	*Preparation of DnV RPE305 Stability Analysis Software*
TITLE	*for 20.5 km pipline from SPM to LFP*

PIPE AND COATING PROPERTIES

Pipe outer diameter	D_S	*1219.00*	mm	Density of corrosion coating	ρ_{CC}	*1400.00*	Kg/m^3
Pipe wall thickness	t_S	*22.20*	mm	Density of concrete	ρ_{CON}	*3040.00*	Kg/m^3
Thickness of corrosion coating	t_{CC}	*4.80*	mm	Density of sea water	ρ_W	*1030.00*	Kg/m^3
Thickness of concrete coating	t_{CON}	*120.00*	mm	Density of marine growth	ρ_{MG}	*0.00*	Kg/m^3
Thickness of marine growth	t_{MG}	*0.00*	mm	Density of pipeline content	ρ_{PROD}	*850.00*	Kg/m^3
Density of steel	ρ_{ST}	*7850.00*	Kg/m^3	Unit extra weight	W_a	*0.000*	Kg/m

SOIL PROPERTIES

Grain size	d_{50}	*0.125*	mm	Soil type		Sand	-
Roughness	z_O	*1.04E-05*	m	Shear strength	S_U	*0*	N/m^2

ENVIRONMENTAL PARAMETERS

Significant wave height	H_S	*8.300*	m	Angle between wave & pipeline	θ	*90*	Degrees
Spectral peak period	T_P	*11.500*	sec	Acceleration due to gravity	g	*9.810*	m/s
Steady current	U_r	*0.690*	m/s	Coefficient of lift force	C_L	*0.750*	-
Steady current reference height	z_r	*1.500*	m	Coefficient of drag force	C_D	*0.750*	-
Water Depth	d	*32.000*	m	Coefficient of inertia force	C_M	*3.290*	-

UNIT PIPE WEIGHT [N/m]

Pipe	$\pi (D_S - t_S)\, t_S\, \rho_{ST}$	W_P	6427.811	M growth	$\pi (D_S + 2t_{CC} + 2t_{CON} + t_{MG})\, t_{MG}\, \rho_{MG}$	W_{MG}	0.000
Corrosion coating	$\pi (D_S + t_{CC})\, t_{CC}\, \rho_{CC}$	W_{CC}	253.454	Content	$0.25\, \pi\, (D_S - 2t_S)^2\, \rho_{PROD}$	W_{PROD}	9035.617
Concrete coating	$\pi (D_S + 2t_{CC} + t_{CON})\, t_{CON}\, \rho_{CON}$	W_{CON}	15162.013	Bouyancy	$0.25\pi\, (D_S + 2t_{CC} + 2t_{CON} + 2t_{MG})^2 \rho_W$	W_{BOUY}	17116.035
Total submerged weight	$W_P + W_a + W_{CC} + W_{CON} + W_{MG} + W_{PROD} - W_{BOUY}$					W_S	13762.86 N/m

VELOCITY & ACCELERATION PERPENDICULAR TO PIPELINE AND CALIBRATION FACTORS

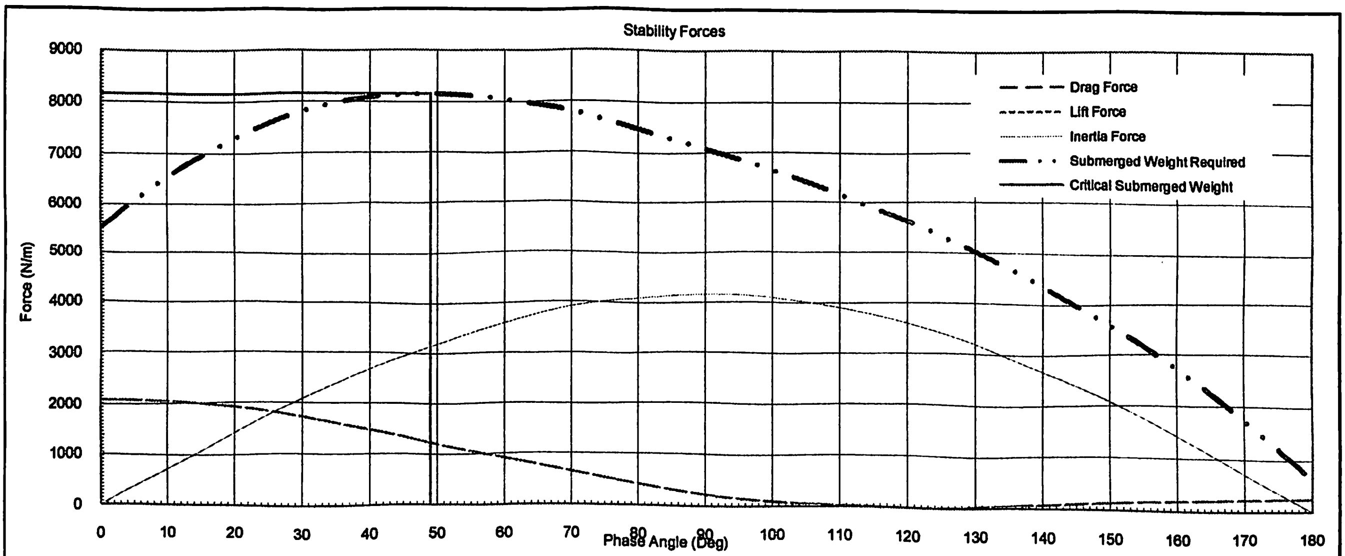
Overall outer diameter	$D_S + 2t_{CC} + 2t_{CON} + 2t_{MG}$			D	1.469	m	Reduction	R	1.000
Average current velocity	$U_r \{1/\ln(z_r/z_O+1)\, \{[1+(z_O/D)]\, \ln[D/z_O+1] - 1\}\}$			U_D	0.63	m/s	Peakedness	γ	3.30
Parameter	$[d/g]^{0.5}$	T_n	1.806	s	Sig. wave velocity	$R\, C_1\, H_S / T_n$	U_S	1.287	m/s
Ratio	T_n / T_P	-	0.16	-	From Fig 2.2	T_U / T_P	C_2	0.97	-
From Fig 2.1	$U_S\, T_n / H_S$	C_1	0.280	-	Zero upcrossing period	$C_2\, T_P$	T_U	11.16	s
Significant acceleration	$2\pi\, U_S / T_U$	A_S	0.725	m/s^2	Load parameter (KC number)		$U_S\, T_U / D$	K	9.78
Current to wave velocity ratio	U_D / U_S	M	0.49		Calibration factor from figure 5.12			F_W	1.09

SUMMARY OF HYDRODYNAMIC LOADING

Current velocity	U_D	0.630	m/s	Wave acceleration	A_S	0.725	m/s^2
Wave velocity	U_S	1.287	m/s	Critical phase angle	θ	49.0	Deg
Lift force $0.5\rho_W D C_L\, [U_S \cos\theta + U_D]^2$	F_L	1233.4	N/m	Inertia force $0.25\pi\, D^2 \rho_W C_M A_S \sin\theta$	F_I	3142.6	N/m
Drag force $0.5\, \rho_W\, D\, C_D\, \lvert U_S \cos\theta + U_D \rvert\, [U_S \cos\theta + U_D]$	F_D	1233.4	N/m				

CHECK FOR SUBMERGED WEIGHT

Friction factor	μ	0.700	Submerged weight required	$\{[(F_D+F_I)+\mu\, F_L] / \mu\}\, F_W$	W_{SR}	8158.31 N/m
W_{SR} < W_S		Ok				



GRAPHS

Fig 2.1 Significant Water Velocity, Us

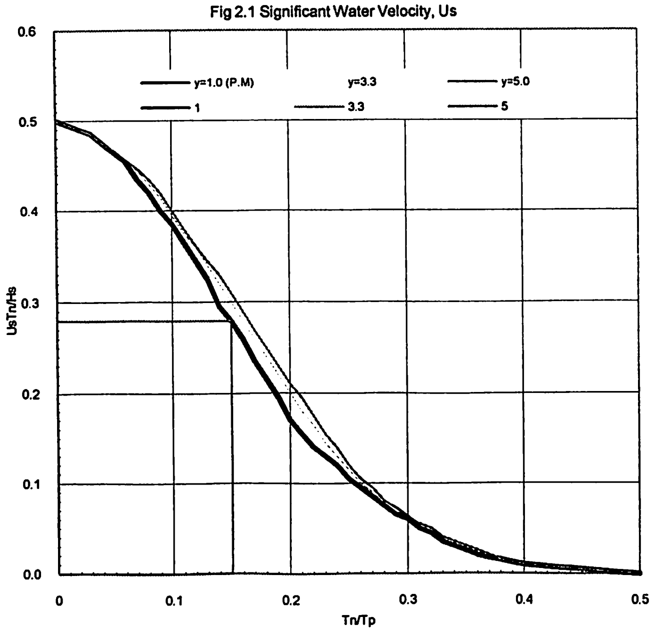


Fig 2.2 Zero-Up-Crossing Period, Tu

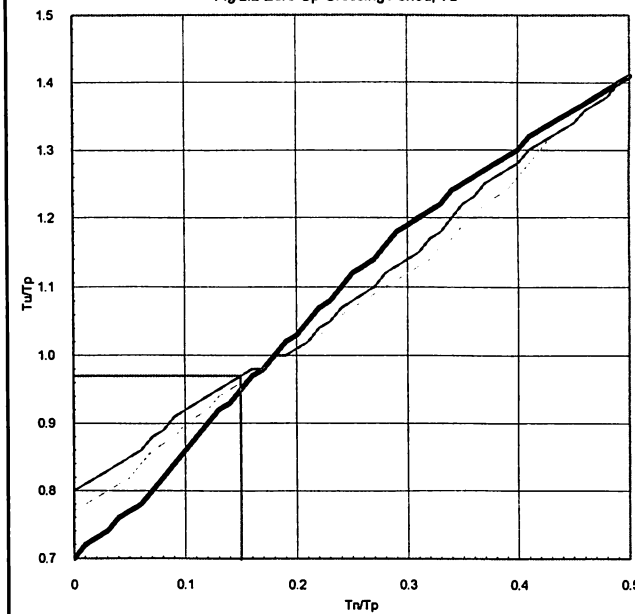


Fig.5.12 Calibration Factor, Fw as Function of K and M

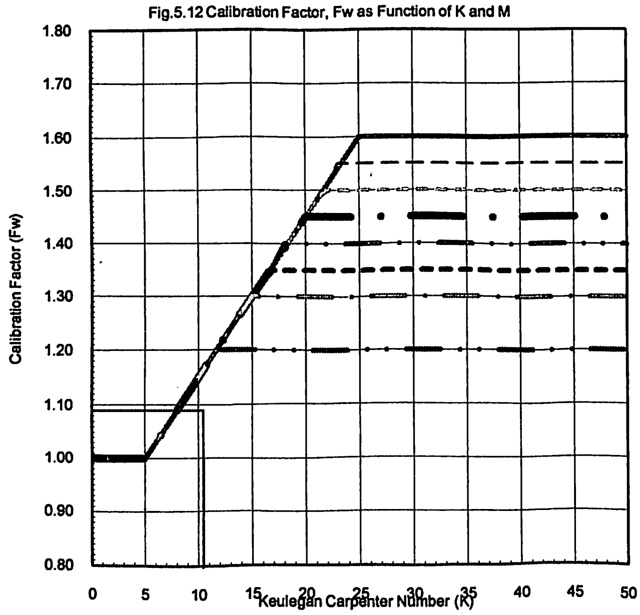
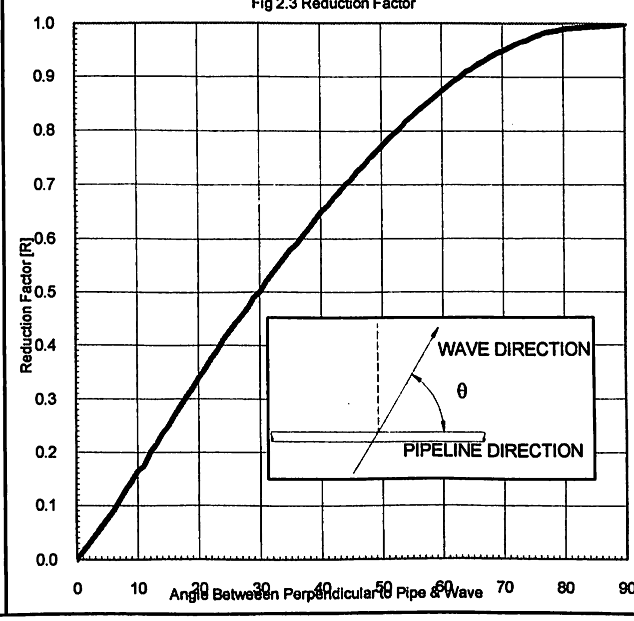


Fig 2.3 Reduction Factor



APPENDIX 3

CATHODIC PROTECTION CALCULATIONS

DESIGN AIDE PIPELINE ENGINEERING	DAcpdes Ver 1.0.1	CATHODIC PROTECTION DESIGN - BRACE ANODES

PROJECT	*subsea pipeline design*
TITLE	*subsea pipeline design for a length of 20.5 km from SPM to LFP*

INPUT

Anode type designation	A_{TYPE}	A	-	Electrochemical efficiency	ε	1325	A-hr/Kg
Pipeline OD	D	1219.00	mm	Protective potential	V_P	-900	mV
Length of pipeline	L_P	20.500	Km	Closed circuit anode potential	V_A	-1050	mV
Pipe joint length	L_J	12.192	m	Current density [Average]	C_A	128	mA/m²
Design life	T	30.0	Years	Current density [Final]	C_F	128	mA/m²
Design temperature	t	60.0	°C	Electrochemical resistivity	ξ	30	Ohm-cm
Corrosion coating thickness	t_C	4.8	mm	Anode utilization factor	U	0.8	-
Coating breakdown factor [Avg]	b_A	0.05	-	Anode length	L_A	450	mm
Coating breakdown factor [Final]	b_F	0.11	-	Anode thickness	t_A	120	mm
Anode material	A_M	Al-Zn-In	-	Gap between half shells	G	100	mm
Anode material density	ρ	2700	Kg/m³	Anode spacing	S	3	Joints

CALCULATIONS

ID of anode	D_I	$D + 2 t_C$	1228.60	mm
Spacing	S_L	$S L_J$	36.576	m
Number of anodes	N	L_P / S_L	561	-
Net mass of each anode	M_A	$[0.25 \pi [(D_I + 2 t_A)^2 - D_I^2) - 2 G t_A] L_A \rho$	588.6	Kg
Total anode mass	M	$N M_A$	330204.6	Kg
Mean current output	I_{MO}	$\varepsilon U M / T$	1330.964	A
Mean current required	I_{MR}	$C_A b_A \pi D L_P$	502.444	A
Final surface area per anode	A_F	$[\pi [D_I + 2 (1 - U) t_A] - 2 G] L_A$	1.715	m²
Resistance of each anode	R_A	$0.315 \xi / [A_F]^{0.5}$	0.072	ohm
Final current output	I_{FO}	$N [V_P - V_A] / R_A$	1168.750	A
Final current required	I_{FR}	$C_F b_F \pi D L_P$	1105.376	A

RESULTS

Mass requirement	I_{MO} / I_{MR}	2.65	> 1, Ok	Final current requirement	I_{FO} / I_{FR}	1.06	> 1, Ok