A Project Report

On

"On Bottom Stability Analysis of a Subsea Pipeline"

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On Bottom Stability Analysis of A Subsea Pipeline

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CERTIFICATE

This is to certify that the work contained in this thesis titled "On Bottom Stability Analysis of a Subsea Pipeline" has been carried out by PRASHANT JOSHI under my supervision and has not been submitted elsewhere for a degree.

Rajeshwar Mahajan

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PRASHANT JOSHI

ABSTRACT

Design is the first and foremost important part of any cross country pipeline project. Since all most all cross country pipelines handle wide range of hydrocarbon fluid ranging from lightest natural gas to heaviest crude oil. To transport such hydrocarbon, we need to operate the pipeline at high pressures and temperatures. To withstand such critical condition, pipeline shall be designed to handle such pressure and temperature under high storm condition. The internal stresses are setup due to both internal and external pressure, high temperature, and large bending stresses due to laying operation.

This project is concerned with the design of cross country pipeline. It focuses on the fundamentals of pipe wall thickness and on bottom stability analysis of a 48" crude oil line and 14" and 24" product line between two fixed platforms in a given offshore field.

NOMENCLATURE:

SYMBOLS

B_{uoy}	Buoyancy
C_D	Drag Coefficient
C_l	Lift Force Coefficient
d	Water Depth
D	Nominal outside Diameter Of Pipe
d_{oswh}	Wave Height (Operating Condition)
d_{iswh}	Wave Height (Installation Condition)
d_{otide}	Height Of Astronomical Tide(Operation)
d_{itide}	Height Of Astronomical Tide(Installation)
d_{min}	Minimum Sea Water Depth
d_{max}	Maximum Sea Water Depth
d_{oss}	Storm Surge (Operating Condition)
d_{iss}	Storm Surge (Installation Condition)
D_{hyd}	Hydrodynamic Diameter
D_{ac}	Anticorrosion COATNG MASS
D_{coat}	Concrete Coating Diameter
CA	Corrosion Allowance
E	Young's Modulus
F_O	Design Factor
F_D	Drag Force
F_I	Inertia Force
F_L	Lift Force
FS	Factor Of Safety
H_W	Significant Wave Height
K_t	Temperature Derating Factor
M_{cont}	Content Mass
M_{steel}	Steel Mass
M_{mg}	Marine Growth Mass
P_{ioper}	Internal Design Pressure
P_{ihyd}	Hydrostatic Test Pressure
R_C	Minimum Laying Radius
SMYS	Specified Minimum Yield Strength
SG	Specific Gravity
T_d	Design Temperature
T_{min}	Minimum Sea Water Temperature
T_{max}	Maximum Sea Water Temperature
T_P	Wave Period
t_{ac}	Anticorrosion Coating Thickness
t_{coat}	Concrete Coating Thickness
U	Percentage Ovality
v	Poisson's Ratio
α	Coefficient Of Thermal Expansion
ρ_{steel}	Density Of Steel
ρ_{ac}	Anticorrosion Coating Density

ρ_{coat}	Density Of Concrete Coating
ρ_w	Density Of Water
μ	Soil Friction Factor
V_C	Steady Current Velocity
W_{sub_a}	Air Filled Submerged Weight
V_M	Specified Current Velocity
U_M	Maximum Horizontal Induced Velocity
A_M	Horizontal Particle Acceleration

CONTENTS

NOMENCLATURE:

SYMBOLS

B_{uoy}	BOUYANCY
C_D	DRAG COEFFICIENT
C_L	LIFT FORCE COEFFICIENT
d	WATER DEPTH
D	NOMINAL OUTSIDE DIAMETER OF PIPE
d_{oswh}	WAVE HEIGHT (OPERATING CONDITION)
d_{iswh}	WAVE HEIGHT (INSTALLATION CONDITION)
d_{otide}	HEIGHT OF ASTRONOMICAL TIDE(OPERATION)
d_{itide}	HEIGHT OF ASTRONOMICAL TIDE(INSTALLATION)
d_{min}	MINIMUM SEA WATER DEPTH
d_{max}	MAXIMUM SEA WATER DEPTH
d_{oss}	STORM SURGE (OPERATING CONDITION)
d_{iss}	STORM SURGE (INSTALLATION CONDITION)
D_{hyd}	HYDRODYNAMIC DIAMETER
D_{ac}	ANTICORROSION COATNG MASS
D_{coat}	CONCRETE COATING DIAMETER
CA	CORROSION ALLOWANCE
E	YOUNGS MODULUS
F_O	DESIGN FACTOR
F_D	DRAG FORCE
F_I	INERTIA FORCE
F_L	LIFT FORCE
FS	FACTOR OF SAFETY

H_w	SIGNIFICANT WAVE HEIGHT
K_t	TEMPERATURE DERATING FACTOR
M_{cont}	CONTENT MASS
M_{steel}	STEEL MASS
M_{mg}	MARINE GROWTH MASS
P_{ioper}	INTERNAL DESIGN PRESSURE
P_{ihyd}	HYDROSTATIC TEST PRESSURE
R_C	MINIMUM LAYING RADIUS
SMYS	SPECIFIED MINIMUM YIELD STRENGTH
SG	SPECIFIC GRAVITY
T_d	DESIGN TEMPERATURE
T_{min}	MINIMUM SEA WATER TEMPERATURE
T_{max}	MAXIMUM SEA WATER TEMPERATURE
T_P	WAVE PERIOD
t_{ac}	ANTICORROSION COATING THICKNESS
t_{coat}	CONCRETE COATING THICKNESS
U	PERCENTAGE OVALITY
ν	POISSON'S RATIO
α	COEFFICIENT OF THERMAL EXPANSION
ρ_{steel}	DENSITY OF STEEL
ρ_{ac}	ANTICORROSION COATING DENSITY
ρ_{coat}	DENSITY OF CONCRETE COATING
ρ_w	DENSITY OF WATER
μ	SOIL FRICTION FACTOR
V_C	STEADY CURRENT VELOCITY

W_{sub_a}	AIR FILLED SUBMERGED WEIGHT
V_M	SPECIFIED CURRENT VELOCITY
U_M	MAXIMUM HORIZONTAL INDUSED VELOCITY
A_M	HORIZONTAL PARTICLE ACCELERATION

Chapter 1
Overview to Subsea System

1.1 General

Pipelines (and risers) are used for a number of purposes in the development of offshore hydrocarbon resources (see Figure 1.1). These include e.g.:

a. Export (transportation) pipelines:
b. Flow lines to transfer product from a platform to export lines;
c. Water injection or chemical injection flow lines ;
d. Flow lines to transfer product between platforms. subsea manifolds and satellite wells;
e. Pipeline bundles.

The design process for each type of lines in general terms is the same. It is this general design approach that will be discussed in this book. Design of metallic risers is similar to pipeline design. although different analysis tools and design criteria are applied.

Marine pipelines for the transportation of oil and gas have become a safe and reliable part of the expanding infrastructure put in place for the development of the valuable resources below the world's seas and oceans. The design of these pipelines is a relatively young technology and involves a relatively small body of specialist engineers and researchers worldwide. An aspect of the marine pipeline industry. rarely understood by those engineers working in land based design and construction, is the more critical need for a 'right first time' approach in light of the expense and complexity of the materials and the installation facilities involved, and the inability to simply 'go back and fix it' after the fact when your pipeline is sitting in water depths well beyond diver depth and only accessible by robotic systems. Money spent on good engineering up front is money well spent indeed and again a specific fit for purpose modern approach is central to the best in class engineering practice requisite for this right first time philosophy.

It is well recognized that the natural gas resources in the world's ocean are gaining increasing importance as an energy source to help fuel world economic growth in the established and emerging economies alike. Pipelines carry a special role in the development and production of gas reserves since, at this point in time, they provide one of the most reliable means for transportation given that fewer options are available than for the movement of hydrocarbon liquids. Add to this the growing need to provide major transportation infrastructure between gas producing regions and countries wishing to import gas, and future oil transmission systems, then the requirement for new offshore pipelines appears to be set for several years to come. Even today, plans for pipeline transportation infrastructure are in development for regions with more hostile environments and deeper waters than would have been thought achievable even ten years ago.

Pipelines are used for a number of purposes in the development of offshore hydrocarbon resources (see Figure). These include e.g.:

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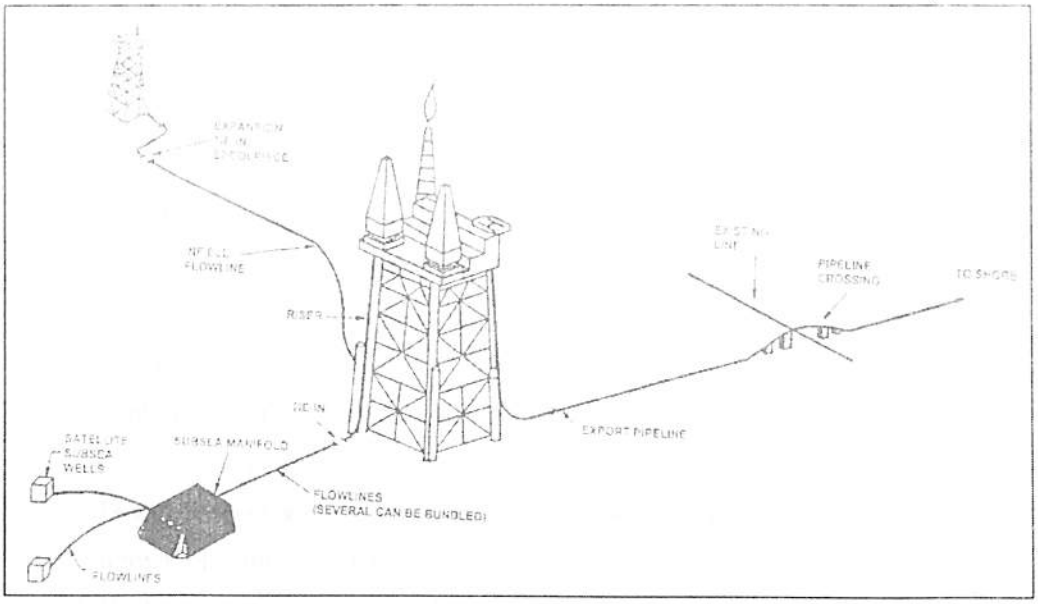
b. Pipeline bundles.
c. Flow lines to transfer product from a platform to export lines.
d. Water injection or chemical injection Flow lines.
e. Flow lines to transfer product between platforms.



1.2 Technical Terminology

1. **Offshore:** Offshore is the area seaward of the established coastline that is in direct contact with the open sea.
2. **Pipeline:** A Pipeline is a primarily horizontal pipe lying on, near or beneath the seabed, normally used for the transportation of hydrocarbon products.
3. **Pipeline System:** A Pipeline System is an integrated set of sub-sea flow lines and pipelines including pertinent instrumentation, foundations, coatings, anchors, etc.
4. **Riser:** A Riser is a conducting pipe connecting sub-sea wellheads, templates or pipelines to equipment located on a buoyant or fixed offshore structure.
5. **Riser Clamp:** Riser is supported/guided from the jacket members through clamps.
6. **MAOP:** The Maximum Allowable Operating Pressure is defined as the Design Pressure less the positive tolerance of the pressure regulation system.
7. **Hoop Stress:** Hoop stress is normal stress acting in the circumferential direction.

8. **Longitudinal Stress:** It is a normal stress acting parallel to pipe axis.
9. **Alignment Sheet:** Drawing showing a section of pipeline (in plan and profile), incorporating seabed features as well as physical pipeline properties and installation parameters.
10. **Buckle:** Deformation of pipeline as a result of local actions or stability failure of the pipe section due to external pressure. possibly in combination with bending. The buckling may lead to water entering the pipeline (wet buckle) or not (dry buckle).
11. **Collapse:** Deformation of a pipeline due to a distributed load. particularly external pressure.
12. **Design Pressure:** Maximum internal pressure occurring in the pipeline during normal operation. referred to a specific reference height.
13. **Hydrotesting:** Short for hydrostatic testing. whereby the strength and tightness of a pipeline section is documented by flooding with water and pressurizing.
14. **Incidental Pressure:** Maximum internal pressure that can occur in the pipeline during operation. referred to the same reference height as the design pressure.
15. **Internal Pressure:** Pressure of the flowing fluid inside the pipe is called as internal pressure. may be gauge pressure or absolute pressure.
16. **External Pressure:** Pressure (immediately) outside the pipe line is called as external pressure i.e.. hydrostatic pressure of water column.
17. **Over Pressure:** Difference between internal and external pressure is called as over pressure.
18. **Initiation Pressure:** External over pressure required initiating a propagating buckle from an existing local buckle or dent is called as initiation pressure.
19. **Propagation Pressure:** External over pressure required to propagate a buckle that has been initiated (at a higher pressure) is called as propagation pressure.
20. **Restrained Lines:** Pipelines which cannot expand or contract in the longitudinal direction due to fixed supports or friction between the pipe and soil.
21. **Unrestrained Lines:** Pipelines without substantial axial restraint. (Maximum one fixed support and no substantial friction).

22. **Location Class:** DNV . classification of pipelines based on failure consequences due to location. Location Class 2 are areas (near platforms or landfalls) with frequent human activity. Location Class 1 is everywhere else.
23. **Maximum Wave Height:** Maximum height of waves in a sea state, measured as the vertical distances between succeeding wave troughs and wave crests.
24. **Operating Pressure:** Internal pressure at which the pipe is normally operated.
25. **Ovality:** Difference from a circle of the pipe cross-sectional geometry, usually arising from the fabrication process or as a result of bending. The ovality may be measured in percentage terms or as the difference between maximum and minimum diameters. Also referred to as out-of-roundness.
26. **Pre Commissioning:** Activities (e.g. cleaning, de-watering, drying) which are required before a pipeline can be taken into operation (commissioned).
27. **Pressure Surge:** Increase in pipeline pressure following a flow incident. A sudden valve closure or a decreasing pump outlet will result in a pressure surge
28. **Propagation Buckling:** Collapse of a large section of a pipeline (propagation buckling), due to external pressure following local buckling.
29. **Suspended Length:** Length of the pipeline without contact with sea bottom or other support is called as suspended length.
30. **Nominal Wall Thickness:** The pipe wall thickness that is specified for supply of pipes is called as nominal wall thickness.
31. **Submerged Zone:** Submerged zone is meant the region below the splash zone including sea water, sea bottom, and buried or mud zone.
32. **Subsea Manifold:** The component to which the well fluid passed in order to move further in a single pipeline.
33. **Yield Strength:** Qualitatively this is the lowest strength where plastic strain that is permanent dominates over elastic strain that disappears as the loading is removed. For pipeline materials, standards specify the measurement of yield strength as the strength at a strain of 0.005 (0.5%) under specified conditions. Other materials may use other definitions of yield strength.

34. **Tensile Strength:** Qualitatively this is the peak strength of the material. For pipelines materials, standards specify the measurement of tensile strength as the largest strength during the test under specified conditions.
35. **Mechanical Strain:** Mechanical strain is strain created by force or moments currently acting or previously acting on a material.
36. **Thermal Strain:** Thermal strain is strain induced by a change of temperature. It is not mechanical strain, as it is induced without the action of forces. Thermal strain may induce forces and thus mechanical strain when displacement is restricted or prevented.
37. **Well Head:** The structure above the well is called as well head.
38. **Christmas Tree:** It is a mechanical component above the well or on the platform to reduce the pressure of the well fluid. It consists of series of valve arrangements.

Chapter 2

Theory of Subsea Pipelines

2.1 Introduction

Design of Subsea pipeline mainly concerts with selection of appropriate wall thickness and check in conjunction with the hydrostatic collapse/propagation buckling. Wall thickness selection is one of the most important and fundamental tasks in design of offshore pipelines. While this task involves many technical aspects related to different design scenarios, primary design loads relevant to the containment of the internal pressure are as follows:

a. the differential pressure loads
b. longitudinal functional loads
c. external impact loads

The current design practice is to limit the hoop stress for design against the differential pressure, and to limit the equivalent stress for design against combined loads. This practice has proved to be very safe in general, except when external impact loads are critical to the integrity of the pipeline. Nevertheless, this practice has been used by the pipeline industry for decades with little change, despite significant improvements and developments in the pipeline technology see **Sotberg and Bruschi (1992)** and **Verley et al. (1994).**

Considering the precise design and effective quality and operational control achieved by modern industry, and with the availability of new materials, it has been realized that there is a need to rationalize the wall thickness sizing practice for a safe and cost-effective design, see **Jiao et al. (1996)**. New design codes provide guidance on application of high strength and new materials, as well as design of high pressure and high temperature pipelines.

2.2 Design Stages and Design Codes

There are typically three phases in offshore pipeline designs: conceptual study (or Pre-FEED: front end engineering & design), preliminary design (or FEED), and detail engineering.

a. **Conceptual study (Pre-FEED)** – defines technical feasibility, system constraints, required information for design and construction, rough schedule and cost estimate

b. **Preliminary design (FEED)** – defines pipe size and grade to order pipes and prepares permit applications.

c. **Detail engineering** – defines detail technical input to prepare procurement and construction tendering.

The pipeline design procedures may vary depending on the design phases above. Tables 2.1 and 2.2 show a flowchart for preliminary design phase and detail engineering phase, respectively. Design basis is an on-going document to be updated as needed as the project proceeds, especially in conceptual and preliminary design phases. The design basis should contain:

a. Pipe Size
b. Design Pressure (@ wellhead or platform deck)
c. Design Temperature
d. Pressure and Temperature Profile
e. Max/Min Water Depth
f. Corrosion Allowance
g. Required overall heat transfer coefficient (OHTC) Value
h. Design Code (ASME, API, or DNV)
i. Installation Method (S, J, Reel, or Tow)
j. Met ocean Data
k. Soil Data
l. Design Life, etc.

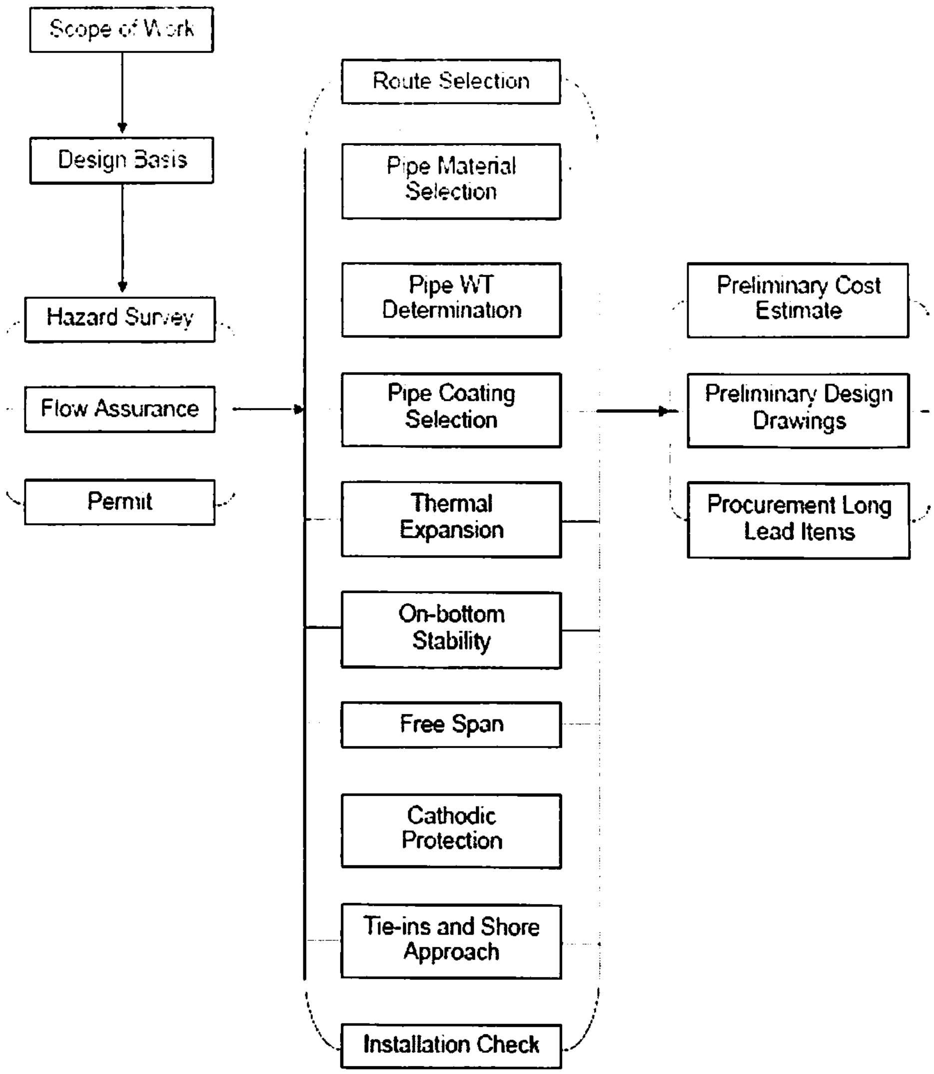


Table 2.1 PRELIMINARY DESIGN FLOWCHART

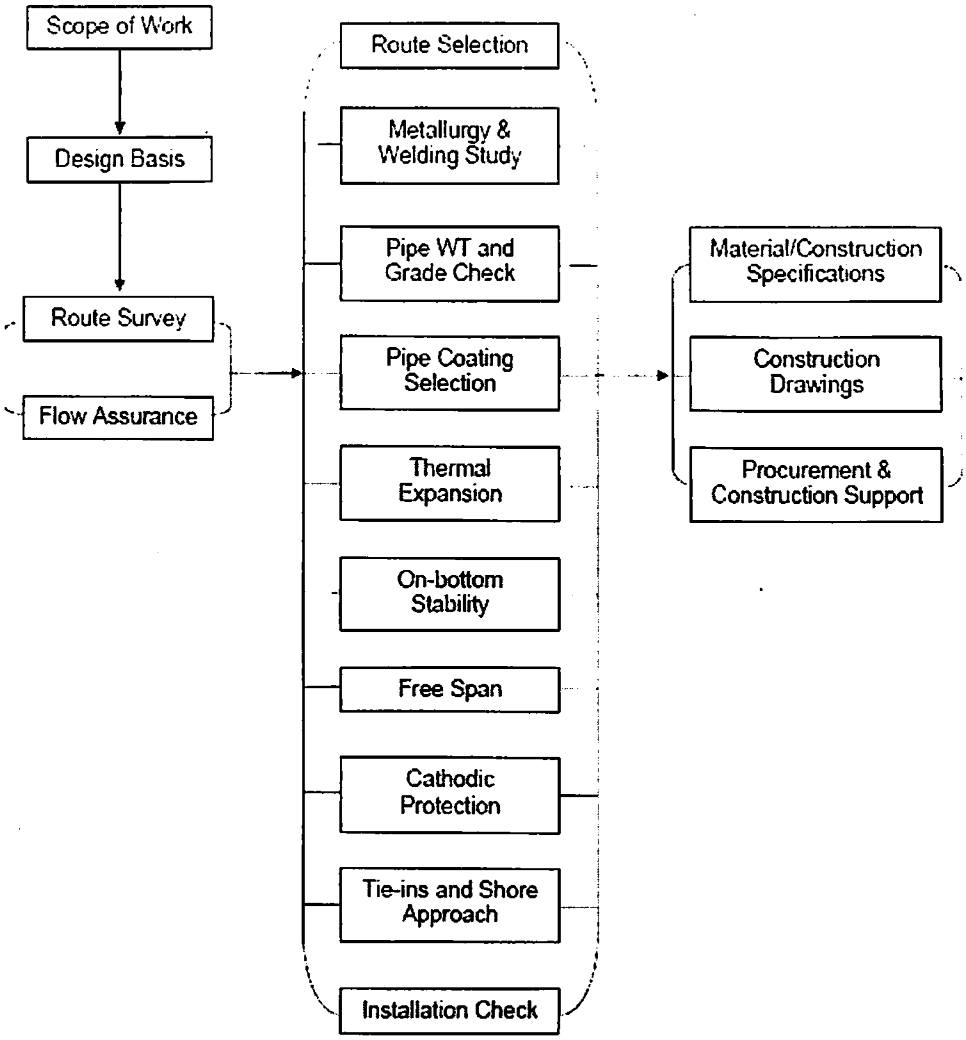


Table 2.2 <u>DETAIL ENGINEERING FLOWCHART</u>

The following international codes, standards, and regulations are used for the design of offshore pipelines and risers.

Chapter 3

Pipeline Design

3.1 Pipeline Wall Thickness Design

For a specified carbon steel grade (SMYS), the pipeline wall thickness is primarily selected on considerations of following.

a. Allowable hoop stress
b. Pipe collapse & propagation buckling
c. Corrosion allowances (internal and external)

The selected pipe wall thickness must also satisfy the following:

a. Buckle initiation and propagation.
b. Local buckling analysis
c. Allowable pipe stress limits during pipeline installation, operation and hydrostatic pressure etc.
d. On-bottom pipe stability requirements.
e. Fatigue analysis, if required.

3.2 Pressure Containment (hoop stress) Design

The hoop stress criterion limits the characteristic tensile hoop stress, $\sigma_{h\,o}$, due to a pressure differential between internal and external pressures.

The design pressure used in the analysis is based upon the maximum operating pressure occurring at any point in the pipeline system. The maximum pressure will be limited by pump capacity or reservoir pressure and determined during a hydraulic analysis of the system.

$$\sigma_{h\,o} \leq F_o \times SMYS \times k_t \qquad (3.1)$$

Where,

F_o	=	Design usage factor. See Table 3.1.
SMYS	=	Specified Minimum Yield Strength.
k_t	=	Material temperature derating factor.

The hoop stress equation is commonly expressed in the following simple form:

$$\sigma_{ho} = (P_i - P_e) \times D / (2 \times t) \tag{3.2}$$

Where,

P_i	=	Pipeline internal pressure.
P_e	=	Pipeline external pressure.
D	=	External Diameter.
t	=	Pipeline wall thickness.

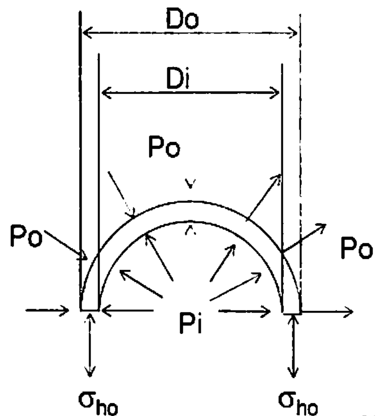


Figure 3.1 Hoop stress in pipeline

The usage factor F_o which is to be applied in the hoop stress formulae is specified by the application design code and the zone or classification of the pipeline for submarine pipelines the code requirements governing design usage factor are summarized in the following table 3.1

Table 3.1 Usage Factor For Internal Pressure		
Design Code	**Usage factor (F_u)**	
	Riser	**Linepipe**
Det Norske Veritas. DNV '81	0.5*	0.72*
Institute of petroleum. IP6	0.6	0.72
ANSI/ASME 31.4 & 49 CFR195	0.6	0.72
ANSI/ASME 31.8 & 49 CFR192	0.5#	0.72#
British Standard 8010. Part 3	0.6	0.72

Note:

- DNV 1981 specifies the riser (zone 2) as the part of the pipeline less than 500 m from any platform or building and the pipeline (zone 1) as the part of the pipeline greater than 500m from any platform building.

Furthermore. definition of diameter and thickness used in Eq. (3.2) varies between the codes. see Table 3.2. In recent codes. such as NPD (1990) and BS 8010 (1993). the minimum wall thickness is used rather than the nominal wall thickness while the usage factor remains unchanged. This may result in a considerably higher steel cost. indicating such codes are relatively more conservative despite of the significant improvements and developments in pipeline technology.

Table 3.2 Characteristic Thicknesses And Diameter Used In Various Pipeline Codes.

Code	Thickness	Diameter
DNV (1981)	Minimum	External
BS 8010(1993)	Minimum	External close to mean for $D/t \leq 20$
ABS (2000)	Minimum	Mean
ASME B31.1(1951)	Minimum	External-0.8tmin
ASME B31.3(1993)	Minimum	External. Mean or External-0.8tmin
ASME B31.4(1992)	Nominal	External
ASME B31.8(1992)	Nominal	External
NPD (1990)	Minimum	External

The primary requirement of the pipe wall-thickness selection is to sustain stresses for pressure containment. The tensile hoop stress is due to the difference between internal and external pressure as shown in figure 3.1, and is not to exceed the permissible value as given by the following hoop stress criterion. combining the equation 3.1 and 3.2 we get:

The nominal pipe wall thickness t is calculated from equation:

$$t_{eq} = [(P_{ioper} - P_{eso}) D/(2 \times F_o \times SMYS \times k_t)] + CA \qquad (3.3)$$

Where,

P_{ioper} = internal design operating pressure, N/mm^2

P_{eso} = external hydrostatic pressure during operation condition based on minimum water depth, N/mm^2

= $(d_{min} + d_{oss}) \times \rho_w \times g / 10^6$

d_{min} = minimum sea water depth, m

d_{oss} = storm surge-operating condition, m

ρ_w	=	density of sea water, kg/m^3
D	=	nominal pipe outside diameter, mm
SMYS	=	Specified Minimum Yield Strength of pipe material, N/mm^2
CA	=	(internal) Corrosion Allowance on the pipe wall thickness, mm

The nominal pipeline thickness of pipeline is selected from the standard API 5L line specification.

3.3 Pipe Stresses

The pipeline stresses will be evaluated for the following design conditions:

a. installation
b. operating
c. hydro test

For each design condition, the following pipe stresses will be calculated to confirm compliance to Design Specification:

a. hoop stress
b. longitudinal stress
c. Von Mises equivalent stress

3.3.1 Hoop Stress

The circumferential hoop stress σH. in the pipe is given by:

$$\sigma_{h\,o} = (P_i - P_e) \times D/(2t) \qquad (3.5)$$

P_i	=	Pipeline internal pressure.	
P_e	=	Pipeline external pressure.	
D	=	External Diameter.	
t	=	Pipeline wall thickness to be considered during calculation of hoop stress.	
	=	$t_{oper} = t_{nom} - CA$	(Operation condition)
	=	$t_{inst} = t_{nom}$	(Installation condition)

3.3.2 Longitudinal Stress

A pipeline in operation carries longitudinal stress as well as hoop stress. Longitudinal stresses arise primarily from two effects. **Poisson's effect and temperature.**

Poisson's effects: a bar of metal loaded in tension extends in the tension direction and contacts transversely. If transverse contraction is prevented. a transverse tensile stress will set up. and internal pressure will induces circumferential tensile stress. It there were only circumferential stress and no longitudinal stress. the pipe would extend circumferentially (so that its diameter increase) but would contract longitudinally (so that it would get shorter). If friction against the seabed or attachment to fixed objects such as platform prevents longitudinal contraction. a longitudinal tensile stress occurs.

The second effect that tends to introduce longitudinal stress is temperature. If the temperatures of a pipeline is increased and if the pipeline is free to expand in all directions. it expands both circumferentially and axially. Circumferential expansion is usually completely unconstrained. but longitudinal expansion is constrained by seabed friction and attachments. If follows that if expansion is prevented. a longitudinal compressive stress will be induced in the pipe.

a. Restrained Section

For restrained sections (if applicable) of a pipeline. the longitudinal stress is not statically determinate but depends on the extent to which longitudinal movement is constrained. If it is complete axial constraint i.e.. ε_l =0. Then longitudinal stress due to internal design pressure. Thermal stress and bending stress due to pipe laying operation is given by:

$$\sigma_l = +\nu\sigma_{h\,o} - E\alpha\,(T_2 - T_1) \pm ED/2R \qquad (3.5)$$

Where,

α = linear coefficient of thermal expansion of steel. 1/° C

T_2 = Virtual anchor point temperature (during operation condition). ° C

or

T_2 = maximum seawater temp (during hydro testing condition).° C

T_1 = minimum ambient seawater temperature. degrees centigrade *b. Unrestrained Section*

A different situation occurs in unrestrained sections of a pipeline. both circumferential stress and the longitudinal stress are statically determinate. and the longitudinal stress due to internal design pressure and bending stress due to pipe laying operation is given by:

$$\sigma_l = 0.5\ \sigma_{ho} \pm ED/2R \qquad (3.6)$$

Where.

R	=	radius of curvature considered for wall thickness and stress calculations.
E	=	Young's modulus, N/mm^2
D	=	nominal pipe outside diameter. mm

3.3.3 Equivalent Stress

The pipe wall is in a state of biaxial stress. with both circumferential and longitudinal stress components. Strictly. in fact. the state of stress is triaxial. The third principal stress in the radial direction changes from (-internal pressure) at the inside to (-external pressure) at the outside. The third principal stress is usually ignored. and this is consistent with the thin-walled shell idealization.

When tangential shear stress is ignored. the Von Mises equivalent stress σ_e according to Von Mises Theory: The failure or yielding occurs at a point in a member when the distortion strain energy (shear strain energy) per unit volume in a biaxial stress system reaches the limiting distortion energy (i.e.. distortion energy at yield point) per unit volume as determined from a simple tension test. Mathematically the max distortion energy theory for yielding is expressed as:

$$\sigma_e = (\sigma_{ho}^2 + \sigma_l^2 - \sigma_{ho}\sigma_L)^{1/2} \qquad (3.7)$$

DNV specify a limit of 72 percent SMYS for the equivalent stress.

3.4 Pipe Collapse

A large external pressure tends to make a pipeline ovalize (take on an oval shape because the pipe loses it stiffness due to plastic hinge mechanism formation at the onset of local buckling) refer figure 3.2 and collapse. A perfectly round pipeline loaded by a steadily increasing internal pressure would remain circular until the pressure reached the Elastic buckling pressure (Elastic critical pressure). And the pipeline would suddenly collapse. For most marine pipeline elastic buckling pressure is quite high. Circumferential pressure yield is possible, but elastic collapse occurs first expect for very tick pipeline.

Reel pipeline are not perfectly circular but are always out-of-round to some extent. When an out-of-round pipeline is subject to external pressure, the out-of-roundness progressively increases and becomes very large at the pressure give by the equation 3.8 before the elastic critical pressure reached the combination of hoop and circumferential bending stress reaches yield, beyond that the pressure can only increase slightly before collapse occurs

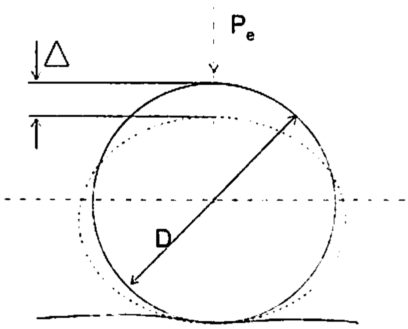


Figure 3.2 Ovality of pipe cross section

For a pipe with out-of-roundness, the limiting external hydrostatic collapse pressure P_{col}, is given by:

$$P^2_{col} - \left[\frac{SMYS\ t_c}{R_m} + P_{cr}\left(1 + \frac{3R_mU}{100t_c}\right)\right]P_{col} + \frac{SMYS\ t_cP_{cr}}{R_m} = 0 \qquad (3.8)$$

Where,

SMYS	=	Specified Minimum Yield strength, N/mm²		
tc	=	corroded pipe wall thickness, mm		
	=	t_{inst}	$= t_{nom}$	(Installation condition)
	=	t_{oper}	$= t_{nom} - CA$	(operation condition)

R_m = pipe mean radius, mm

= $(D-t_c)/2$

P_{cr} = Elastic buckling pressure, N/mm²

= $E\,(t_c/R_m)^3/4\,(1-v^2)$.

U = pipe out-of-roundness, Percent

E = modulus of elasticity of pipe steel, N/mm²

v = Poisson's ratio for steel

The value of P_{col}, as calculated above, should not be less than twice the maximum external hydrostatic pressure (Buckling check pressure), P_{eb} expected along the pipeline route. Allowable out-of-roundness of the pipe to be used for the analysis will be 2%.

Maximum external hydrostatic pressure (Buckling check pressure), P_{eb}

Installation condition

$$P_{ebi} = (d_{max} + d_{itide} + d_{iss} + 0.67 d_{iswh}) \times \rho_w \times g / 10^6 \qquad (3.9)$$

Operation condition:

$$P_{ebo} = (d_{max} + d_{otide} + d_{oss} + 0.67 d_{oswh}) \times \rho_w \times g / 10^6 \qquad (3.10)$$

Where,

d_{iswh}, d_{oswh} = Significant wave height during installation and operation condition respectively.

d_{iss}, d_{oss} = Storm surge during installation and operation condition respectively.

d_{itide}, d_{otide} = Height of Astronomical tide during installation and operation condition respectively.

d_{max} = Maximum sea water depth along the route.

Pipe collapse is checked during installation and operation condition. and in both the cases P_{col}. as calculated above. should be not less than twice the maximum external hydrostatic pressure. Hydrostatic pressure in installation and operation condition will be the based on maximum water depth including astronomical tide. storm surge. and significant wave height respectively.

3.5 Buckle Initiation and Propagation

An important consideration for the subsea pipelines is the phenomenon of buckling initiation and buckle propagation. The minimum water depth which is required to initiate a buckle under a certain pipe out-of-roundness and external load conditions is called the buckle initiation depth. Once a buckle is initiated. the buckle will be driven by the external hydrostatic head until it reaches a much shallower water depth called the buckle propagation depth.

The wall thickness required to resist a buckle can be calculated using various code such as DNV and BS 8010.

A comparison of the results from each of the buckle propagation criteria is shown in the figure 3.3. The selection of buckle propagation criteria depends on individual company practice. Generally. however. the DNV formula is marginally more conservative than the shell development corporation formula and they are more conservative than the Battelle formula. The degree of conservatism required depends on the installation technique in terms of risk. the length and cost of the line. the water depth in terms of how easily a repair can be made. In practical terms changing of any criteria will change the required wall thickness.

However. since designers are normally limited to selecting from API pipe sizes. there is quite often no actual change in the pipe specified.

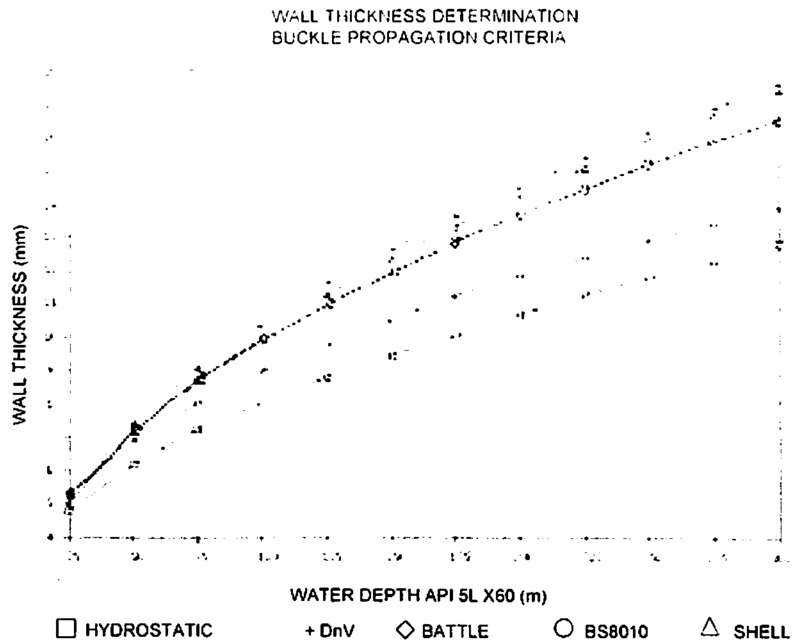


Figure 3.3: Comparison of the required wall thickness calculated to resist buckle propagation according to the DNV, Battelle, Shell and BS8010 criterion

If during design, a pipeline is found to be governed by buckle propagation criteria then there are two options open to the designer.

1) The first option is to make the wall thickness of the pipe sufficient so that a buckle once initiated will not propagate.
2) The second option is to make the wall thickness of the pipe sufficient to only withstand external pressure (hydrostatic collapse) and to use buckle arresters. Buckle arresters consists of thick sections of pipe or welded fittings which a buckle cannot propagate through. If buckle arresters are fitted, damage will be limited to the length of the pipeline between arresters should a buckle initiate.

The risk however, is considerably reduced after installation. The choice between the two is determined by considering the potential cost saving in wall thickness and possibly installation benefits due to the reduced submerged weights. This is paid off against the risk of having to replace a relatively large section of pipe possibly in deep water. However the buckle arresters are not used due to high cost involved in installation and maintaining.

The buckle initiation pressure P_{in} is calculated by the following formula based on Battelle's' equation[21].

$$P_{in} \quad = \quad 0.02\,E\left(\frac{t}{D}\right)^{2.064} \qquad (3.11)$$

A propagation buckle cannot be initiated in or propagate into a portion of the pipe where the maximum external hydrostatic pressure is less than the propagation pressure (Ppr) of the pipe.

$$P_{pr} \quad = \quad 1.15\,\pi\ \text{SMYS}\,[t/(D-t)]^{2} \qquad (3.12)$$

Where,

E	=	Young's modulus, N/mm²		
t	=	Pipe wall thickness, mm		
	=	t_{inst}	$= t_{nom}$	(Installation condition)
	=	t_{oper}	$= t_{nom} - CA$	(operation condition)
D	=	nominal pipe outside diameter, mm		

It shall be ensured that the propagation pressure (P_{pr}) is greater than external hydrostatic pressure by selecting suitable wall thickness for the pipelines. Allowable out-of-roundness of the pipe to be used for the analysis will be 2%.

Buckle Initiation and Propagation check is done in both installation and operation condition and the water depth corresponding to buckling initiation pressure should be greater than maximum possible water depth along the pipeline route considering astronomical tide, storm surge, and significant wave height as given in the equation 3.13 & 3.14, and bucking propagation pressure should be greater than external hydrostatic pressure during installation and operation condition.

Maximum possible water depth along the pipeline route:

Installation condition

$$d_i = (d_{max} + d_{itide} + d_{iss} + 0.67 d_{iswh}) \qquad (3.13)$$

Operation condition

$$d_o = (d_{max} + d_{otide} + d_{oss} + 0.67 d_{oswh}) \qquad (3.14)$$

Chapter 4
On Bottom Stability Analysis

4.1 General

Pipeline laid on the sea floor should be stable during installation. after installation. and during operation. If the pipe is too light during installation. it will be hard to control the pipe since it behaves like a noodle due to waves & current and installation vessels motion. Most installation contractors require a minimum 1.15 pipe SG (specific gravity) to avoid pipe buckling which may occur due to pipes excessive movement during installation. After installation. before the pipe is filled with water or product fluid. the pipe should be checked for 1 year return period waves and current conditions. If the pipe is laid as empty for a long period before commissioning. a 2-year. 5-year. or 10-year return period met ocean data should be used. During operation. the pipe should be stable for a 100- year return period met ocean data. The soil data is very important to estimate the pipeline on-bottom stability. If no soil data is available. use the following data for the pipe-soil lateral friction coefficients per DnV-RP-F109. On Bottom Stability of Offshore Pipeline Systems:

a. Clay 0.2
b. Sand 0.6
c. Gravel 0.8

To keep the pipeline stable. the soil resistance should be greater than the hydrodynamic force induced on the pipeline.

$$\mu(W_s - F_L) \geq (F_D + F_I)$$

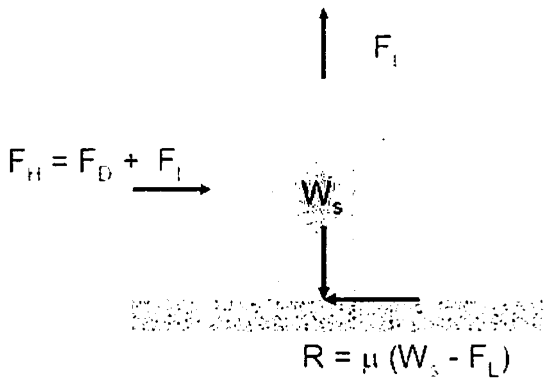


Fig 4.1

Where

$$F_L = \frac{1}{2} \rho_w D C_L V^2 \quad \text{Lift Force}$$

$$F_D = \frac{1}{2} \rho_w D C_D |V| V \quad \text{Drag Force}$$

$$F = \frac{\pi D^2}{4} \rho_w C_M A \quad \text{Inertia Force}$$

. is the soil friction coefficient as mentioned in the previous paragraph; W_s is the pipe submerged weight (lb/ft); ρ_w is the water mass density (64 lb/ft3); V is the near-bottom wave & current velocity; and A is the water particle acceleration corresponding to the V. The recommended lift, drag, and inertia force coefficient (C_L, C_D, and C_M) is 0.9, 0.7, and 3.29 respectively. The AGA pipeline on-bottom stability program [1] is widely used by industries. The program has three modules:

Level 1 – Simple and quick static analysis using a linear wave theory and Morison equations as above, without accounting for pipe movement or self-embedment.

Level 2 - Reliable quasi-static analysis using a non-linear wave theory and numerous model test results considering pipes self-embedment.

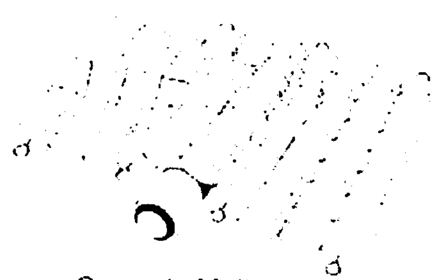
Level 3 - Complicated dynamic time domain analysis using series of linear waves and allowing some pipeline movements. Compare the computed pipe stresses and deflections with allowable limits.

Level 2 is recommended for most cases. Level 3 can be used to predict pipeline movements especially for dense sand or stiff clay where the pipe embedment does not take a big role. However, Level 3 takes a long computer running time and it is difficult to estimate how far the pipeline will move over the design life. Therefore, Level 3 is not recommended unless small savings of concrete coating can affect the project cost significantly. In Level 2 analysis, it is noted that the vertical safety factor in the output should be treated as a reference use only. This is because the lift force is already considered in the horizontal stability check and the lift force is calculated based on the pipe sitting on the seabed. Once the pipe is lifted off the seabed, the water will start to flow underneath the pipe. The underneath flow velocity is faster than the upper flow, thus the underneath pressure is less than the upper pressure. This pressure differential tends to push the pipeline back to the seabed and drastically reduces the lift force.

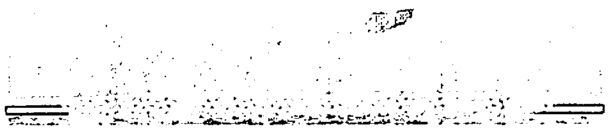
The following methods can be adopted to keep the pipeline stable on the sea floor:

a. Heavy (thick) wall pipe
b. Concrete weight coating
c. Trenching
d. Burial
e. Rock dumping (covering)
f. Concrete mattress or bitumen blanket
g. Concrete block

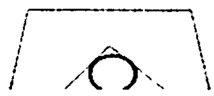
Trenching



Concrete Mattress



Rock Dumping



Concrete Block

4.2 Design

Pipeline stability analysis shall be carried out in accordance with DNV RP E 305.

Three methods are provided for the stability check:

a. Dynamic analysis method
b. Generalized method
c. 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 is based on quasi-static equilibrium approach.

The calibration factor, F_w , the classical static design approach to the generalized stability method. A safety factor of 1.1 is inherent in the calibration factor F_w .

The equilibrium condition in vertical direction is not always studied . the equilibrium condition is of interest for finding the expected penetration of a pipeline only in the case of a very soft seabed. Thus, it is restricted to examination of equilibrium in horizontal direction.

4.3 Stability Criteria

4.3.1 Minimum Pipeline Submerged Weight

The minimum submerged weight required to prevent any horizontal movement of the pipeline under the extreme environmental loading, is calculated by a simple static force balance of the horizontal hydrodynamic and soil frictional forced. The stability criteria may be expressed as based on DNV RP E305.

$$W_{SUB} = [(F_D + F_I) + \mu F_L] F_W / \mu \qquad (4.1)$$

Where:

W_{SUB}	=	Submerged weight of pipeline.(N/m)
F_L	=	Hydrodynamic lift force per unit length (N/m)
F_D	=	hydrodynamic drag force per unit length (N/m)
F_I	=	hydrodynamic inertia force per unit length (N/m)
μ	=	Coefficient of friction between pipe and soil
F_W	=	Calibration factor

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

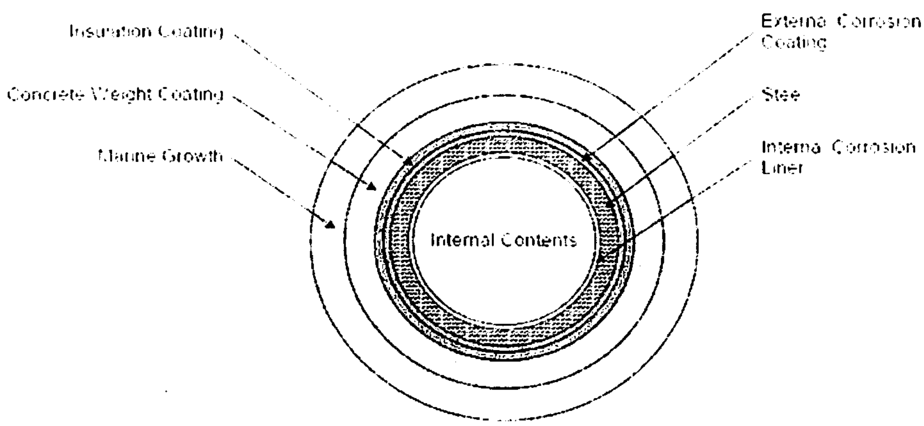
a. Pipe movements are not allowed, requiring equilibrium between loads (hydrodynamic forces) and reactions (soil resistance force).
b. Near bed wave flow is time varying and only the component perpendicular to the pipe axis is considered.
c. Soil resistance is calculated based on two dimensional assumptions, and may include simple friction as well as passive soil resistance.

4.3.2 Pipeline Submerged Weight

Submerged weight shall consider the weight of the following components:

a. Steel
b. Internal corrosion liner (if any)
c. Corrosion coating
d. Insulation coating

e. Concrete coating
f. Marine growth
g. Internal contents
h. Metal loss through internal / external corrosion.



Pipeline cross section

The hydrodynamic diameter of the pipe is given by:

$$D = D_{ST} + 2(t_{cc} + t_{ic} + t_c + t_{mg}) \quad (4.2)$$

The weight of the component (in air) are calculated as follows:

a) Carbon steel weight $W_{CS} = \pi\,(D_{ST} - t)\, t\, \rho_{st}$ (4.3)

b) Internal corrosion liner weight $W_L = \pi\,(D_{ST} - 2t - t_L) t_L\, \rho_L$ (4.4)

c) Corrosion coating weight $W_{CC} = \pi\,(D_{ST} + t_{CC})\, t_{cc}\, \rho_{cc}$ (4.5)

d) Insulation coating weight $W_{IC} = \pi\,(D_{ST} + 2t_{CC} + t_{ic}) t_{IC}\, \rho_{IC}$ (4.6)

e) Concrete coating thickness $W_C = \pi\,(D_{ST} + 2t_{CC} + 2t_{ic} + t_C) t_C\, \rho_C$ (4.7)

f) Marine growth weight $W_{MG} = \pi\,(D_{ST} + 2t_{CC} + 2t_{ic} + 2t_C + t_{MG}) t_{MG}\, \rho_{MG}$ (4.8)

g) Internal diameter of pipe $ID = D_{ST} - 2t - t_L$ (4.9)

h) Weight of content $W_i = \pi/4\, (ID)^2\, \rho_i$ (4.10)

i) Weight of corroded material $W_{CORR} = [\pi\{D - 2t + t_{CA}\} t_{CA}] \rho_{st}\, \eta_{CA}$ (4.11)

η_{CA} = Corrosion allowance usage factor

Four case are of interests:

a) Operational pristine – no marine growth or metal loss to corrosion included.
b) Operational end of life –marine growth included and η_{ca} of corrosion allowance has been lost to corrosion.
c) Installation – pipeline empty, no marine growth and no loss of corroded material.
d) Hydro test – as for installation but pipe full of hydro test water.

Table 4.1 weight of pipe for different cases

Case	Outer Diameter, *OD*	Weight of Pipe, *W*
Operational – Pristine	$D + 2t_{cc} + 2t_{ic} + 2t_c$	$Wcs - W_L + Wcc + Wic + Wc - Wi$
Operational – End of Life	$D + 2t_{cc} + 2t_{ic} + 2t_c + 2t_{mg}$	$Wcs - W_L + Wcc - Wic + Wc - Wmg - Wi - Wcorr$
Installation / Hydrotest	$D + 2t_{cc} + 2t_{ic} + 2t_c$	$Wcs - W_L + Wcc - Wic + Wc + Wi$

Pipeline's buoyancy, submerged weight and specific gravity are calculated as follow

Pipeline buoyancy $B = \pi/4 \, [OD^2 \rho_{SW}]$ (4.12)

Pipeline submerged weight $W_S = W - B$ (4.13)

Pipeline specific gravity $SG = W/B = W_S/B + 1$ (4.14)

4.3.3 Environmental Parameter

The defining sea-state parameters are H_S and T_P, which are used to calculate the significant wave velocity perpendicular to the pipe (U_S).

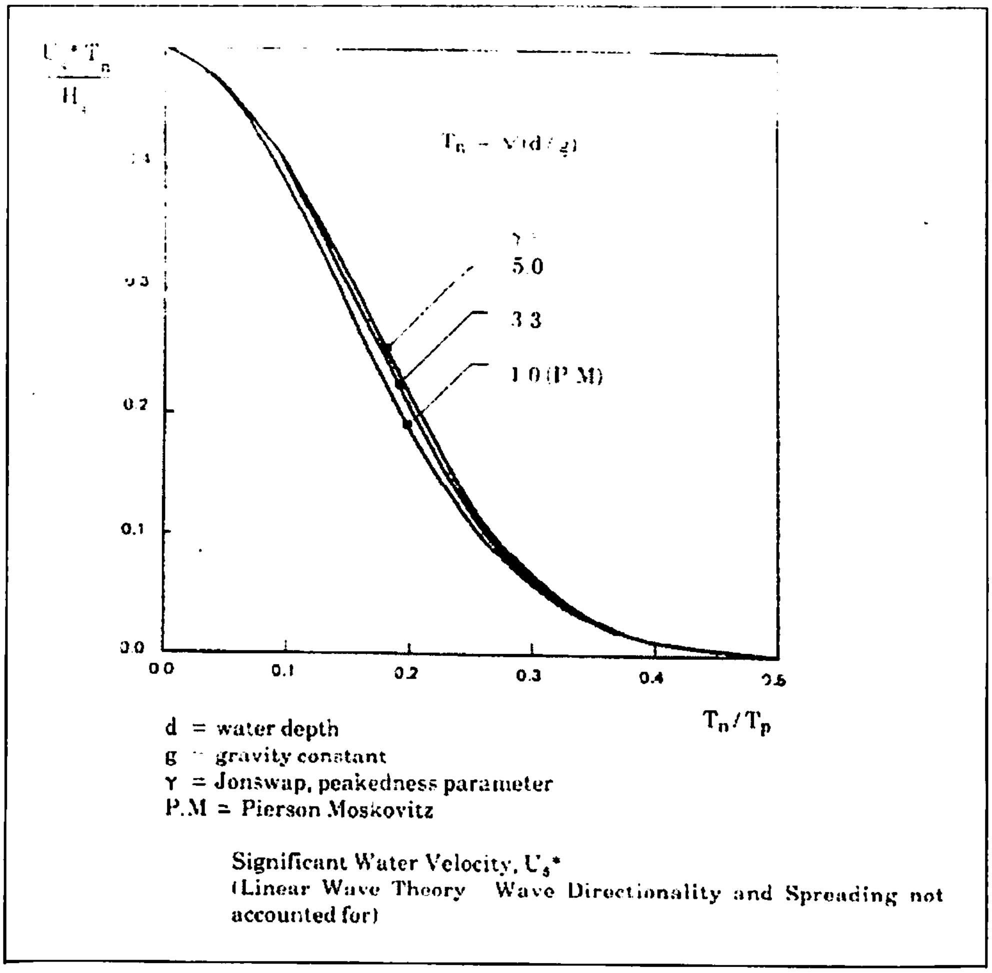


FIG.4.4: Determination of significant wave velocity (DNV RP E305)

The T_n and T_p are determined using following relationship.

$$T_n = \sqrt{\frac{d}{g}} \quad \text{and} \quad T_p = \sqrt{250 H_s g} \tag{4.15}$$

From fig. 4.4 $(U_S{*}T_n)/H_S$ is determined for the given T_n/T_P. Then, significant wave velocity perpendicular to the pipe (U_S) is determined.

Table 4.2: Grain size for seabed materials (DNV RP E305)

Seabed	Grain Size d50 (mm)	Roughness zo (m)
Silt	0.0625	5.21E-06
Very Fine Sand	0.125	1.04E-05
Fine Sand	0.25	2.08E-05
Medium Sand	0.5	4.17E-05
Coarse Sand	1	8.33E-05
Very Coarse Sand	2	1.67E-04
Gravel	4	3.33E-04
Pebble	10	8.33E-04
	25	2.08E-03
	50	4.17E-03
Cobble	100	8.33E-03
	250	2.08E-02
Boulder	500	4.17E-02

Grain size (d_{50}) and roughness (z_0) of the seabed is determined based Table 4.2

$$U_{avg} = \frac{1}{\ln\left(\frac{z_r}{z_o}+1\right)}\left[\left(1+\frac{z_o}{D}\right)\ln\left(1+\frac{D}{z_o}\right)-1\right] \quad (4.16)$$

U_{avg} = U_D/U_r

U_r = current velocity at reference height

Z_r = reference height for the current velocity, assumed 3 mm

Z_0 = bottom roughness parameter

d_{50} = mean grain size

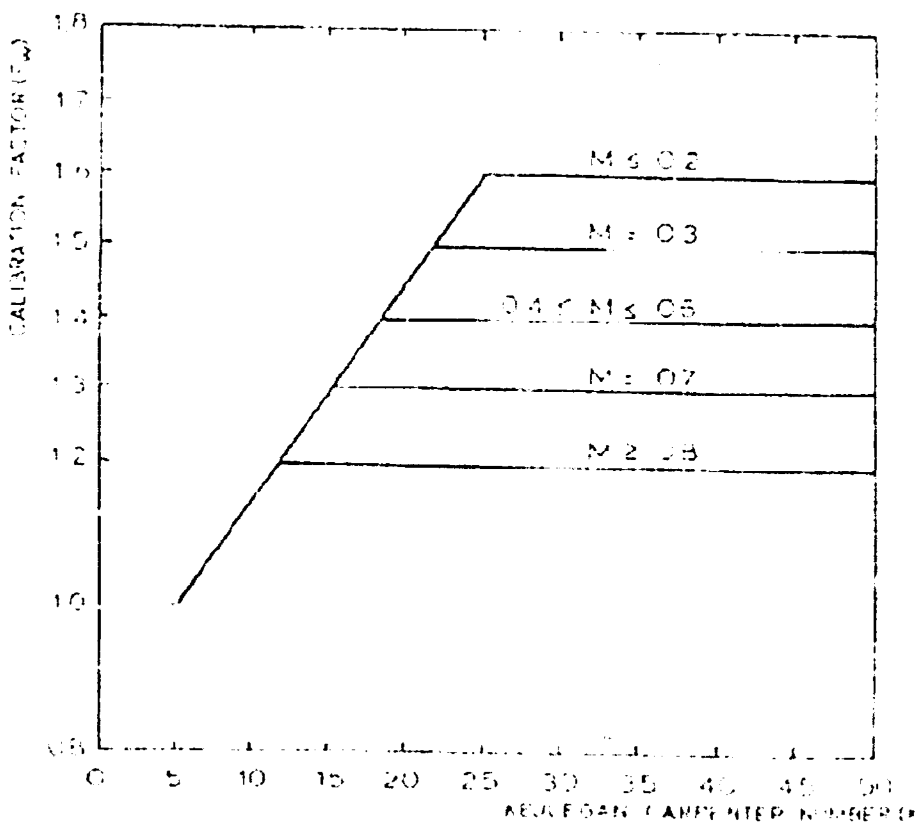


Fig. 4.5: calibration factor. F_W

Current to wave velocity ratio.	$M = U_D/U_S$
Keulegan carpenter number.	$K = (U_S T_P) / D$

From fig. 4.5. the calibration factor can be obtained after determining the value of M and K. Calibration factor is used in the calculation of pipeline submerged weight.

4.3.4 Hydrodynamic Forces

When using the calibration factor F_w to calculate W_{SUB} the hydrodynamic loading on pipe is determined using the following relationship.

Drag force. $F_D = (1/2)\rho D C_D |U_n| U_n$ (4.17)

Inertia force. $F_I = \pi \rho D^2 C_M U_n /4$ (4.18)

Lift force. $F_L = (1/2)\rho D C_L U_n^2$ (4.19)

$$|U_n| = (U_n^2 + V_n^2)^{1/2} \qquad (4.20)$$

Where.

D	=	the total outside diameter
ρ	=	density of seawater
C_l	=	0.9. is the lift force coefficient
C_D	=	0.7. is drag force coefficient
C_M	=	3.29. IS THE INERTIA FORCE COEFFICIENT
U_n	=	water particle horizontal velocity
V_n	=	water particle vertical velocity

4.3.4.1 Drag Loads

As fluid passed over a body a shear layer develops in the fluid flow. The body experiences a force caused by skin friction due to the tangential viscous shear layer between body and flow. In addition, it experiences a "pressure" or "form" drag from the pressure on the body.

Thus.

$$F_D = F_F + F_P \qquad (4.21)$$

F_D = Total drag

F_F = Fiction drag

F_P = pressure

4.3.4.2 Inertia Load

A body immersed in fluid is generally associated with an entrained mass of watt called the added mass. In some cases the added mass is directly proportional to the immersed of the body. This is often assumed

4.3.5 Gravity Waves (Linear Wave Theory)

The simplest mathematical description of a gravity (ocean) wave is given by linear wave theory.

Important parameters in linear wave theory.

a. Wave height. (H)

b. Mean water depth (d)
c. Wave period. (T)

All the other values are calculated using these three values.

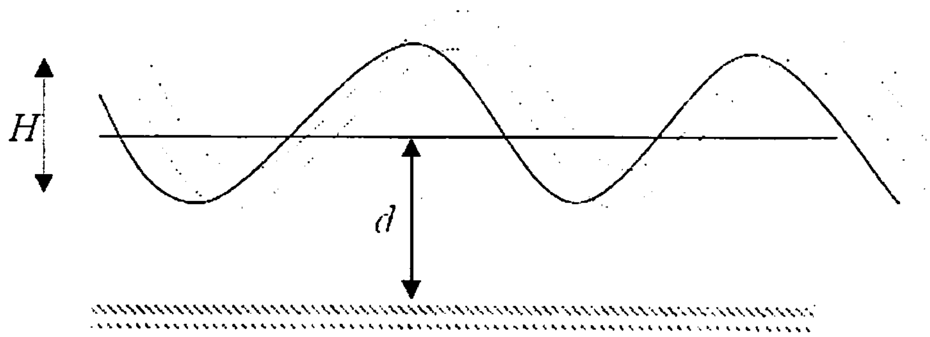


Fig.4.6 Rest frame

A few assumptions have to be made which are.

a) Ignore surface tension and viscosity
b) Two dimensional small amplitude waves permanent form
c) Wave propagate through initially still water
d) Irrotational and incompressible

The wavelength, L is calculated based on the formula below:

$$L = \frac{gT^2}{2\pi} \tanh\left[\frac{2\pi d}{L}\right] \quad (4.22)$$

In order to calculate the force on a structure immersed in moving fluid we need to determine the particle kinematics.(i.e. velocity and acceleration)

Particle velocities:

Horizontal Velocity, $U = \frac{H\pi}{T} \frac{\cosh[2\pi(y-d)/L]}{\sinh(2\pi d/L)} \cdot \cos\left(2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right)$ (4.23)

Vertical Velocity, $V = \frac{H\pi}{T} \frac{\sinh[2\pi(y-d)/L]}{\sinh(2\pi d/L)} \cdot \sin\left(2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right)$ (4.24)

***Particle acceleration*:**

Horizontal Acceleration, $U' = \frac{2H\pi^2}{T^2} \frac{\cosh[2\pi(y-d)/L]}{\sinh(2\pi d/L)} \cdot \sin\left(2\pi\left(\frac{x}{L} - \frac{t}{T}\right)\right)$ (4.25)

Therefore linear wave theory is most suitable for dealing with deep water wave of small amplitude.

4.3.6 Assumptions for On-Bottom Stability Analysis

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

a. No pipe burial has been considered.
b. No water absorption on the concrete is considered.
c. No marine growth on the pipeline is taken into consideration.
d. Currents and wave acting perpendicular to the pipeline.
e. No pipe burial has been considered.
f. No water absorption on the concrete is considered.
g. The soil friction for clay is calculated based on fig. 4.11 in DNV RP E 305.
h. The 1 year significant wave height and peak period plus 1 year currents are considered for the installation condition. Pipeline is assumed to empty during this condition.
i. The 100 year significant wave height and peak period plus 100 year currents are considered for the installation condition.

Chapter 5
Input Design Data

5.1 Introduction

Nagarjuna Oil Corporation limited (NOCL) is developing refinery at Thiruchopuram. 24 km south of Cuddalore and about 175 km from Chennai. As part of the refinery project. NOCL has plans to include a marine terminal for import of crude oil and export of products such as Euro IV auto fuels . like petrol. diesel apart from the products like LPG. bitumen etc. NOCL has mandated Cuddalore Port Client Pvt. Ltd. (CPCPL) to construct the port on a boo basis. CPCL has engaged KONSORTIUM PORTS PTE LIMITED (KPPL) on a turnkey basis to set up the port.

The crude oil import terminal is planned at water depth of 30 m using VLCC tankers at distance of 11km from coast line and a export terminal at 6.5 km from coast line. The planned terminal uses the concept of single point mooring system (SPM) for import terminal and Conventional Buoy Mooring system (CBM) for export terminal. The import and export terminals are connected to the onshore refinery by submarine pipelines

The import of crude from VLCC tankers via SPM terminal is by 48" pipeline and the export of products is expected by Panamax class tankers (65000 DWT) from CBM terminal. The export of products is expected through 3 x 24" pipeline and 1 x 14" pipeline for different products. All the pipelines from the SPM/CBM terminal PLEM are planned to be buried below seabed by at least 1.5m soil cover to the top of the pipeline .

This document forms the basis of design for the following subsea pipelines:

a. 48" Crude oil import pipeline from SPM terminal to the Land Fall Point (LFP).
b. 2x24" export product pipeline from SPM terminal to the Land Fall Point (LFP).
c. 1x14" export product pipeline from SPM terminal to the Land Fall Point (LFP).

5.2 Codes and Standards

Code	Description
ASME B31.4	Pipeline transportation system for liquid hydrocarbons.
API SPEC 5L	Specification for line pipe.
API RP 1104	Welding of pipelines and related facilities.
NACE RP-06-75	Recommended practice for control of corrosion on offshore steel pipelines.
DNV 1981	
DNV RP E 305	On bottom stability of submarine pipelines
DNV RP B401	Cathodic protection design

5.3 Marine Terminal Description

The overall marine terminal consists of the following facilities intended to serve the NOCL refinery for import of crude oil and export of products.

a. A SPM terminal for mooring and unloading crude for vessels up to a size of 300000 DWT tankers.
b. A CBM terminal for mooring vessels up to 65000 DWT tankers for loading export products.
c. A 48" submarine pipeline for import of crude oil from SPM to the refinery.
d. 3x24" and 1x14" export product pipelines from refinery to the CBM terminal.

5.3.1 SPM Terminal

The SPM terminal connected to onshore facilities via a 48" diameter crude oil import pipeline. The SPM will be designed to accommodate tankers upto a size of 300000 DWT. and will be located in approximately 30m water depth (below CD). A pipeline end manifold will be located close to the SPM. The SPM terminal will consists of following major components.

a. A Buoy complete with piping assembly for fluid transfer, and mooring of the vessel.
b. A system of chain mooring system complete with anchors.
c. Floating hose strings (2 no's of 24").
d. Chinese lantern risers (2 no's of 24").

e. A PLEM with valve control.

5.3.2 CBM Terminal

The CBM terminal is a multi buoy mooring system with a PLEM located near the vessel. Mooring location will be used to connect the loading hoses for transfer of liquid to the tankers. The CBM will be designed to accommodate tankers up to a size of 65000 DWT . and will be located in approximately 15 m water depth. A pipeline end manifold will be located close to the CBM. The CBM terminal will consist of following major components.

a. A buoy mooring system
b. A system of chain mooring system complete with anchors.
c. Hose strings foe each pipeline with end couplings.
d. A PLEM with valve controls.

Tankers will be able to load cargo from any pipeline (3x24" and 1x14") dedicated for various export products. These offshore pipelines will tie-in to a on shore pipeline to tank farm situated at crude oil terminal area situated inside NOCL refinery.

5.3.3 Loading/Unloading Facility

The function of the ship loading/unloading system is to transfer the products from the storage tanks into the ship and vice versa. At the ship loading/unloading area . the ships are loaded with the following products:

1. Naphtha / motor spirit
2. Kerosene/ ATF
3. High speed diesel
4. Low sulfur crude oil (import)

Product	Pump Capacity (m^3/h)
Naphtha	2000
Motor spirit	4000
Kerosene/ ATF	3500
HSD	3500

Detail of pump capacity

5.3.4 Annual Throughput

Ship loading facilities are to be designed based on the following maximum annual throughputs.

Product	Annual Through Put (KTPA)
NAPTHA	212
MOTOR SPIRIT	
• EURO IV	578
• PREMIUM	317
KEROSENE/ATF	450
HSD	
• EURO-III	1836
• EURO-IV	1056

Annual Throughput

The maximum quantity of low sulfur fuel oil to be unloaded is 225 KTPA.

5.3.5 Tanker Sizes

For each product the maximum tanker size expected is provided in the following table.

Product	Tanker size (DWT)
Low sulfur fuel oil	30000
Kerosene/ATF/HSD/Motor spirit	65000
Naphtha	30000
Crude oil (import)	300000

5.4 Design Data

This section presents the data and design parameters for the engineering design of the pipelines.

5.4.1 Datum Level

Unless noted otherwise, all levels shall be referenced to the chart datum.

5.4.2 Design Life

The pipelines shall be designed for a design life of 30 years.

5.4.3 Material Properties

The material properties to be considered in rigid pipeline design are as follow:

Description	Unit	Value
Steel Grade	API 5L	X65
SMYS	MPa	448
Steel Density	Kg/m³	7850
Concrete Coating-High Density	Kg/m³	3040
Young's Modulus Of Steel (E)	MPa	207 x 10
Poisson's Ratio		0.3
Coefficient Of Thermal Expansion ()	(1/°C)	11.7×10^{-6}
Thermal Conductivity	Btu/hr-ft°F	26

5.4.4 Pipeline Functional Parameters

The functional parameters to be considered for pipeline systems are as follows. The hydro test pressure for all the pipelines shall be at least 1.4 times the design pressure.

S.No.	Service	Flowrate (m^3/h)	Operating Pressure(bar)	Condition Temp.(°C)	Design Pressure(bar)	Condition Temp.(°C)
1	Crude oil	2000	20	33	20	33
2	Naphtha	2000	20	33	20	33
3	Motor spirit	4000	20	33	20	33
4	Kerosene/ jet fuel	3500	20	33	20	33
5	Diesel	3500	20	33	20	33

5.4.5 Pipeline Data

The details of pipelines to be installed are listed in table below. The design wall thickness and length is based on estimate and shall be confirmed during detailed engineering.

The diameter of the pipeline has been arrived at based on flow rate given by client and cannot be altered. The diameter specified is outer diameter.

S.No.	Service	Purpose	Grade	Length	Outer dia.
1	Crude oil	Import	X65	11000	48"

2	Naphtha	Export	X65	6500	24"
3	Motor spirit	Export	X65	6500	24"
4	Kerosene / jet fuel	Export	X65	6500	24"
5	Diesel	Export	X65	6500	14"

5.4.6 Fluid Properties

The properties of import crude oil and export products are summarized in the following tables:

Fluid	Sp. Gravity (15.56/15.56°C)	Viscosity (cSt)	Pour point (°C)	RVP (psi)	Sulphur content (wt%)	water content (vol %)
Arab heavy	0.8888	40.5 @21.1°C 20.1 @37.8°C	-17.8	.57	2.85	Trace
Arab medium	0.8718	18.4 @21.1°C 9.2 @37.8°C	-17.8	.45	1.82	Trace
Arab light	0.8591	10.82 @21.1°C 6.2 @37.8°C	<<-317	.45	1.82	Trace
Nigerion	0.8413	5.57 @ 20°C 3.28 @38°C	2	.57	0.13	0.15
Bombay high	0.8282	3.75 @37.8°C 3.28 @40°C	+30	.34	0.17	0.15

Import fluids (SPM system)

Fluid	Density (Kg/m^3)	Viscosity (cSt)	Pour point (°C)	RVP (psi)	Sulphur content (wt%)	water content (vol %)
Naphtha	-	-	N/A	10	0.15	-
Gasoline	720-775	-	N/A	N/A	0.015	-
Kerosene	775-840	8.0	N/A	N/A	0.25	N/A
HSD	820-845	2.0-4.5	N/A	N/A	0.035	0.02

5.4.7 Water Depth

Design water level including storm surge is summarized below.

Mean High Water Spring	+1.10m CD
Mean High Water Neap	+0.90m CD
Mean Sea Level	+0.70m CD
Mean Low Water Neap	+0.60m CD
Mean Low Water Spring	+0.30m CD
Storm Surge	2.0m

5.4.8 Wave Parameters

Description	Operating	Storm
Wave height H_{max} (m)	2.5	16.75
Wave period T_p (sec)	9	12

Wave data for SPM location (30 m water depth)

Description	Operating	Storm
Wave height H_{max} (m)	2.5	7.2
Wave period T_p (sec)	9	12

Wave data for CBM location (16 m water depth)

Wave height along the pipeline route below a water depth of 5m can be limited to limiting wave height based on wave breaking limit of 0.78 times the water depth.

5.4.9 Current Parameters

The surface current at the location is considered as 1m/sec.

5.4.10 Wind Parameters

The wind speed to be used for the design shall be as per table below.

Description	units	1 year return period	100 year return period
1-hour sustained wind speed	m/s (km/hr)	30 (80)	55.5 (200)

5.4.11 Sea Water Properties

The following sea water properties are used throughout the design.

Sea water temp. °C	Minimum	Maximum	Mean
Surface	20.3	30.3	27.6
Mid depth	20.4	29.4	26.8
Bottom	19.3	28.9	25.7
Sea water density , kg/m^3	1025 (64)		
Sea water kinematics viscosity, m^2/s	$1{,}03 \times 10^{-6}$		
Sea water resistivity (ohm-m)	0.20		

5.4.12 Marine Growth

The marine growth is not applicable to buried pipelines. However, a marine growth of 100 mm shall be considered for the risers and floating buoys.

5.4.13 Soil Data

Geotechnical investigation for SPM location and along the pipeline route was carried out and the details of soil information can be found from the following report.

Final report on geotechnical investigation for SPM and submarine pipeline at south of cuddalore. Tamilnadu by Coastal Marine Construction And Engineering Limited .

5.4.14 Friction Factors

Following friction factor will be considered between the pipeline and soil

	Lateral	Longitudinal
Friction Factor	0.5 TO 0.7	0.5

5.4.15 Pipeline Burial And Fill

All the pipelines shall be buried below existing seabed with a minimum cover of 1.5 m. Fill material shall be natural fill.

5.4.16 Pipeline Corrosion Allowance

A minimum of 3 mm on wall thickness shall be considered as allowance against internal corrosion. However, a corrosion assessment study shall be carried out to determine the internal corrosion allowance during the detailed design stage.

Pipeline Wall Thickness Calculation of 48" Pipeline

PIPE DATA

NOMINAL OUTSIDE DIA OF PIPE: $D := 48in$

CORROSION ALLOWANCE: $CA := 3mm$

PERCENTAGE OVALITY: $U := 2\%$

MINIMUM LAYING RADIUS: $R_c := 2500m$

MATERIAL DATA:

YOUNGS MODULUS: $E := 2.07 \cdot (10)^5 \frac{N}{mm^2}$

POISSONS RATIO: $\nu := .30$

COEFFICIENT OF THERMAL EXPANSION: $\alpha := \frac{\left(1.17 \cdot 10^{-5}\right)}{\Delta °C}$

SPECIFIED MINIMUN YIELD STRENGTH: $SMYS := 448MPa$

PROCESS DATA:

INTERNAL DESIGN PRESSURE (OPERATING CONDITION): $P_{ioper} := 20.bar = 2 \times 10^6 Pa$

HYDROSTATIC TEST PRESSURE: $P_{ihyd} := 1.4 \cdot P_{ioper} = 2.8 \times 10^6 Pa$

DESIGN TEMPERATURE (OPERATING CONDITION:) $T_d := 33 °C$

DESIGN PARAMETERS:

CODE FOLLOWED FOR DESIGN CALCULATIONS: DnV 1981

DESIGN FACTOR: $F_0 := 0.72$

TEMPERATURE DERATING FACTOR: $k_t := 1$

ENVIRONMENTAL DATA:

MINIMUM SEA WATER DEPTH: $d_{min} := 1m$

MAXIMUM SEA WATER DEPTH: $d_{max} := 30m$

STORM SURGE (OPERATING CONDITION): $d_{oss} := 2m$

STORM SURGE (INSTALLATION CONDITION): $d_{iss} := 2m$

MINIMUM SEA WATER TEMPERATURE: $T_{min} := 22.8\,°C$

MAXIMUM SEA WATER TEMPERATURE: $T_{max} := 30.3\,°C$

WAVE HEIGHT (OPERATING CONDITION): $d_{oswh} := 16m$

WAVE HEIGHT (INSTALLATION CONDITION): $d_{iswh} := 2.5m$

HEIGHT OF ASTRONOMICAL TIDE (OPERATING CONDITION): $d_{otide} := 2m$

HEIGHT OF ASTRONOMICAL TIDE (INSTALLATION CONDITION): $d_{itide} := 2m$

DENSITY OF SEA WATER: $\rho_{wg} := 1025\frac{kg}{m^3}$

CALCULATIONS :

EXTERNAL PRESSURE:

1. INSTALLATION CONDITION:

FOR BUCKLING CHECK:

$$P_{ebi} := \left(d_{max} - d_{itide} - d_{iss} + .67 d_{iswh}\right) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{ebi} = 0.359\,Pa$$

FOR STRESS AND STABILITY CHECK:

$$P_{esi} := d_{min} \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{esi} = 0.01\,Pa$$

2. HYDROTESTING CONDITION

FOR STRESS AND STABILITY CHECK:

$$P_{esh} := d_{min} \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{esh} = 0.01\,Pa$$

3. OPERATING CONDITION:

FOR BUCKLING CHECK:

$$P_{ebo} := \left(d_{max} + d_{otide} + d_{oss} + .67 d_{oswh}\right) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{ebo} = 0.45\,Pa$$

WALL THICKNESS CALCULATION:

external hydrostatic condition:
(during operating condition)

$$P_{eso} := (d_{min} + d_{oss}) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{eso} = 0.03\,Pa$$

EQUIVALENT WALL THICKNESS:

$$t_{eq} := \left[(P_{ioper} - P_{eso}) \frac{D}{2 \cdot E_0 \cdot SMYS \cdot k_t} \right]$$

$$t_{eq} = 3.78 \cdot mm$$

WALL THICKNESS:

$$t := t_{eq} + CA = 6.78 \cdot mm$$

CORRESPONDINGN NOMINAL WALL THICKNESS FROM API 5L

$$t_{nom} := 20.6mm$$

$$t_{inst} := t_{nom}$$

STRESS CHECK:

1) FOR OPERATING CONDITION:

HOOP STRESS CALCULATION:

WALL THICKNESS FOR OPERATING CONDITION: $t_{oper} := t_{nom} - CA = 17.6 \cdot mm$

HOOP STRESS IN PIPE: $\sigma_{ho} := (P_{ioper} - P_{eso}) \cdot \frac{D}{2 \cdot t_{oper}}$

$\sigma_{ho} = 69.273 \cdot MPa$

ALLOWABLE HOOP STRESS: $\sigma_{aho} := 0.72 \cdot SMYS$

$\sigma_{aho} = 322.56 \cdot MPa$

CHECK_FOR_HOOP_STRESS_OPER := if($\sigma_{aho} > \sigma_{ho}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_FOR_HOOP_STRESS_OPER = "DESIGN IS SAFE"

LONGITUDINAL STRESS CALCULATIONS:

1. LONGITUDINAL STRESS CHECK FOR RESTRAINED SECTION

LONGITUDINAL STRESS DUE TO INTERNAL PRESSURE: $\sigma_{lop} := \nu \cdot \sigma_{ho}$

$\sigma_{lop} = 20.782 \cdot MPa$

LONGITUDINAL STRESS DUE TO TEMPERATURE:

$$\sigma_{lot} := E \cdot \alpha \cdot (T_d - T_{min})$$

$$\sigma_{lot} = 24.703 \cdot MPa$$

MAXIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTIONS:

$$\sigma_{lomaxr} := \sigma_{lop} - \sigma_{lot} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lomaxr} = 46.553 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTION:

$$\sigma_{lominr} := \sigma_{lop} - \sigma_{lot} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lominr} = -54.396 \cdot MPa$$

2. LONGITUDINAL STRESS CHECK FOR UN-RESTRAINED SECTION

MAXIMUM LONGITUDINAL STRESS FOR UN RESTRAINED SECTION:

$$\sigma_{lomaxu} := 0.5\sigma_{ho} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lomaxu} = 85.111 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS FOR UN-RESTRAINED SECTION

$$\sigma_{lominu} := 0.5\sigma_{ho} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lominu} = -15.839 \cdot MPa$$

ABSOLUTE MAXIMUM LONGITUDINAL STRESS IS THE MAXIMUM AMONG ABOVE 4 VALUES:

$$\sigma_{lomax} := \max(\sigma_{lomaxr}, \sigma_{lominr}, \sigma_{lomaxu}, \sigma_{lominu})$$

$$\sigma_{lomax} = 85.111 \cdot MPa$$

EQUIVALENT STRESS CALCULATIONS

VON MISES COMBINED STRESS CRITERIA

MAXIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{comaxr} := \left(\sigma_{ho}^{2} + \sigma_{lomaxr}^{2} - \sigma_{ho} \cdot \sigma_{lomaxr}\right)^{\frac{1}{2}}$$

$$\sigma_{comaxr} = 61.164 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{cominr} := \left(\sigma_{ho}^{2} + \sigma_{lominr}^{2} - \sigma_{ho} \cdot \sigma_{lominr}\right)^{\frac{1}{2}}$$

$$\sigma_{cominr} = 107.359 \cdot MPa$$

MAXIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{comaxu} := \left(\sigma_{ho}^{2} + \sigma_{lomaxu}^{2} - \sigma_{ho} \cdot \sigma_{lomaxu}\right)^{\frac{1}{2}}$$

$$\sigma_{comaxu} = 78.401 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{cominu} := \left(\sigma_{ho}^{2} + \sigma_{lominu}^{2} - \sigma_{ho} \cdot \sigma_{lominu}\right)^{\frac{1}{2}}$$

$$\sigma_{cominu} = 78.401 \cdot MPa$$

ABSOLUTE MAXIMUM EQUIVALENT
STRESS IS MAX. OF ABOVE 4 VALUES:

$$\sigma_{eabsoluteo} := \max\left(\sigma_{comaxr}, \sigma_{cominr}, \sigma_{comaxu}, \sigma_{cominu}\right)$$

$$\sigma_{eabsoluteo} = 107.359 \cdot MPa$$

ALLOWABLE EQUIVALENT STRESS IN
OPERATING CONDITION:

$$\sigma_{eallow} := 0.72 \cdot SMYS = 3.226 \times 10^{8} \, Pa$$

CHK_FOR_L_STRESS_OPER := if($\sigma_{eallow} > \sigma_{eabsoluteo}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE

CHK_FOR_L_STRESS_OPER = "DESIGN IS SAFE"

2.) FOR HYDROTEST CONDITION:

HOOP STRESS CALCULATION:

WALL THICKNESS FOR HYDROTEST CONDITION:

$t_h := t_{nom} = 0.021\,m$

HOOP STRESS IN PIPE :

$\sigma_{hh} := \left[(P_{ihyd} - P_{esh}) \cdot \frac{D}{2 \cdot t_h} \right]$

$\sigma_{hh} = 82.858 \cdot MPa$

ALLOWABLE HOOP STRESS FOR HYDROTEST:

$\sigma_{ahh} := 0.9SMYS = 4.032 \times 10^8 Pa$

CHECK_FOR_HOOP_STRESS_HYD := if($\sigma_{ahh} > \sigma_{hh}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_FOR_HOOP_STRESS_HYD = "DESIGN IS SAFE"

LONGITUDINAL STRESS CALCULATIONS:

1. LONGITUDINAL STRESS CHECK FOR RESTRAINED SECTION

LONGITUDINAL STRESS DUE TO INTERNAL PRESSURE:

$\sigma_{lhp} := \nu \cdot \sigma_{hh}$

$\sigma_{lhp} = 24.857 \cdot MPa$

LONGITUDINAL STRESS DUE TO TEMPERATURE:

$\sigma_{lht} := E \cdot \alpha \cdot (T_{max} - T_{min})$

$\sigma_{lht} = 18.164 \cdot MPa$

MAXIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTION:

$\sigma_{lhmaxr} := \sigma_{lhp} - \sigma_{lht} + E \cdot \frac{D}{2 \cdot R_c}$

$\sigma_{lhmaxr} = 57.168 \cdot MPa$

MINIMUM LONGITUDINAL STRESS
FOR RESTRAINED SECTION:

$$\sigma_{lhminr} := \sigma_{lhp} - \sigma_{lht} - E\cdot\frac{D}{2\cdot R_c}$$

$$\sigma_{lhminr} = -43.782\cdot MPa$$

2. LONGITUDINAL STRESS CHECK FOR UN-RESTRAINED SECTION

MAXIMUM LONGITUDINAL STRESS
FOR UN RESTRAINED SECTION:

$$\sigma_{lhmaxu} := 0.5\sigma_{hh} + E\cdot\frac{D}{2\cdot R_c}$$

$$\sigma_{lhmaxu} = 9.19\times 10^{7}\,Pa$$

MINIMUM LONGITUDINAL STRESS
FOR UN RESTRAINED SECTION:

$$\sigma_{lhminu} := 0.5\sigma_{hh} - E\cdot\frac{D}{2\cdot R_c}$$

$$\sigma_{lhminu} = -9.046\cdot MPa$$

ABSOLUTE MAXIMUM LONGITUDINAL STRESS:
(MAX. OF ABOVE 4 - VALUES)

$$\sigma_{lhmax} := \max(\sigma_{lhmaxr}, \sigma_{lhminr}, \sigma_{lhmaxu}, \sigma_{lhminu})$$

$$\sigma_{lhmax} = 91.904\cdot MPa$$

EQUIVALENT STRESS CALCULATIONS:

VON MISES COMBINED STRESS CRITERIA

MAXIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{ehmaxr} := \left(\sigma_{hh}^{2} + \sigma_{lhmaxr}^{2} - \sigma_{hh}\cdot\sigma_{lhmaxr}\right)^{\frac{1}{2}}$$

$$\sigma_{ehmaxr} = 73.463\cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{ehminr} := \left(\sigma_{hh}^{2} + \sigma_{lhminr}^{2} - \sigma_{hh} \cdot \sigma_{lhminr}\right)^{\frac{1}{2}}$$

$$\sigma_{ehminr} = 111.4 \cdot MPa$$

MAXIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{ehmaxu} := \left(\sigma_{hh}^{2} + \sigma_{lhmaxu}^{2} - \sigma_{hh} \cdot \sigma_{lhmaxu}\right)^{\frac{1}{2}}$$

$$\sigma_{ehmaxu} = 87.732 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{ehminu} := \left(\sigma_{hh}^{2} + \sigma_{lhminu}^{2} - \sigma_{hh} \cdot \sigma_{lhminu}\right)^{\frac{1}{2}}$$

$$\sigma_{ehminu} = 87.732 \cdot MPa$$

ABSOLUTE MAXIMUM EQUIVALENT STRESS
IS MAX. OF ABOVE 4 VALUES:

$$\sigma_{eabsoluteh} := \max\left(\sigma_{ehmaxr}, \sigma_{ehminr}, \sigma_{ehmaxu}, \sigma_{ehminu}\right)$$

$$\sigma_{eabsoluteh} = 111.4 \cdot MPa$$

ALLOWABLE EQUIVALENT STRESS
IN HYDROTEST CONDITION:

$$\sigma_{alh} := 1 \cdot SMYS = 4.48 \times 10^{8} \, Pa$$

CHECK_FOR_L_STRESS_HYD := if($\sigma_{alh} > \sigma_{eabsoluteh}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE

CHECK_FOR_L_STRESS_HYD = "DESIGN IS SAFE"

BUCKLING CHECK:

PIPE COLLAPSE (EXTERNAL PRESSURE CAPACITY):

INSTALLATION CONDITION

WALL THICKNESS FOR INSTALLATION CONDITION: $t_{inst} = 0.021\,m$

MEAN RADIUS OF THE PIPE CROSS SECTION $R_{minst} := \frac{(D - t_{inst})}{2}$

$R_{minst} = 0.599\,m$

ELASTIC BUCKLING PRESSURE:

$$P_{crinst} := E \cdot \frac{\left(\frac{t_{inst}}{R_{minst}}\right)^3}{4\left(1 - \nu^2\right)}$$

$P_{crinst} = 2.31 \cdot MPa$

$$B_{inst} := \left(SMYS \cdot \frac{t_{inst}}{R_{minst}}\right) + \left[P_{crinst} \cdot \left[1 + \left[3 \cdot R_{minst} \cdot \frac{U}{(100 \cdot t_{inst})}\right]\right]\right] = 1.775 \times 10^7\,Pa$$

$$C_{inst} := P_{crinst} \cdot SMYS \cdot \frac{t_{inst}}{R_{minst}} = 3.557 \times 10^{13}\,Pa^2$$

MINIMUM COLLAPSE PRESSURE AT INSTALLATION:

$$P_{colmininst} := \frac{\left[B_{inst} - \left(B_{inst}^{\,2} - 4 \cdot C_{inst}\right)^{\frac{1}{2}}\right]}{2}$$

$P_{colmininst} = 2.303 \cdot MPa$

MAXIMUM COLLAPSE PRESSURE
AT INSTALLATION:

$$P_{colmaxinst} := \frac{\left[B_{inst} + \left(B_{inst}^{2} - 4 \cdot C_{inst}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmaxinst} = 15.447 \cdot MPa$$

COLLAPSE PRESSURE IS MINIMUM OF ABOVE 2 VALUES

$$P_{colinst} := \min\left(P_{colmininst}, P_{colmaxinst}\right)$$

$$P_{colinst} = 2.303 \cdot MPa$$

MAXIMUM EXTERNAL HYDROSTATIC PRESSURE ALONG THE PIPELINE ROUTE:

$$P_{possibleinst} := 2 \cdot P_{ebi}$$

$$P_{possibleinst} = 7.172 \times 10^{-7} \cdot MPa$$

$CHECK\_COLPSE\_INST := if\left(P_{colinst} > P_{possibleinst}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"}\right)$

$CHECK\_COLPSE\_INST = \text{"DESIGN IS SAFE"}$

OPERATION CONDITION:

MEAN RADIUS OF THE PIPE CROSS SECTION:

$$R_{moper} := \frac{\left(D - t_{oper}\right)}{2}$$

$$R_{moper} = 0.601\, m$$

ELASTIC BUCKLING PRESSURE:

$$P_{croper} := E \cdot \frac{\left(\frac{t_{oper}}{R_{moper}}\right)^{3}}{4\left(1 - \nu^{2}\right)}$$

$$P_{croper} = 1.43 \cdot MPa$$

$$B_{oper} := \left(SMYS\cdot\frac{t_{oper}}{R_{moper}}\right) - \left[P_{croper}\cdot\left[1 + \left[3\cdot R_{moper}\cdot\frac{U}{(100\cdot t_{oper})}\right]\right]\right] = 1.458\times 10^{7}\,Pa$$

$$C_{oper} := P_{croper}\cdot SMYS\cdot\frac{t_{oper}}{R_{moper}} = 1.876\times 10^{13}\,Pa^{2}$$

MINUIMUM COLLAPSE PRESSURE
AT OPERATION:

$$P_{colminoper} := \frac{\left[B_{oper} - \left(B_{oper}^{2} - 4\cdot C_{oper}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colminoper} = 1.426\cdot MPa$$

MAXIMUM COLLAPSE PRESSURE
AT INSTALLATION:

$$P_{colmaxoper} := \frac{\left[B_{oper} + \left(B_{oper}^{2} - 4\cdot C_{oper}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmaxoper} = 13.157\cdot MPa$$

COLLAPSE PRESSURE IS MINIMUM OF ABOVE 2 VALUES:

$$Pcoloper := min\left(P_{colminoper}, P_{colmaxoper}\right)$$

$$Pcoloper = 1.426\cdot MPa$$

MAXIMUM EXTERNALHYDROSTATIC PRESSUREALONG THE PIPELINE ROUTE:

$$P_{possibleoper} := 2\cdot P_{ebo} = 0.899\,Pa$$

CHECK_COLPSE_OPER := if(Pcoloper > $P_{possibleoper}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE"

CHECK_COLPSE_OPER = "DESIGN IS SAFE"

BUCKLING INITIATION (INSTALLATION)

BUCKLE INITIATION PRESSURE

$$P_{ininst} := 0.02 \cdot E \cdot \left(\frac{t_{inst}}{D}\right)^{2.064}$$

$$P_{ininst} = 0.91 \cdot MPa$$

WATER DEPTH CORRESPONDING TO BUCKLE INITIATION PRESSURE

$$d_{ininst} := \frac{P_{ininst}}{\rho_{wg} \cdot g} = 90.556\, m$$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE

$$d_{inmax} := \left(d_{max} + d_{itide} + d_{iss} + .67 \cdot d_{iswh}\right)$$

$$d_{inmax} = 35.675\, m$$

CHECK_BI_INST := if($d_{ininst} > d_{inmax}$, "DESIGN IS SAFE." , "DESIGN IS NOT SAFE")

CHECK_BI_INST = "DESIGN IS SAFE."

BUCKLE PROPOGATION (INSTALLATION):

BUCKLE PROPOGATION PRESSURE

$$P_{prinst} := 1.15 \cdot \pi \cdot SMYS \cdot \left[\frac{t_{inst}}{(D - t_{inst})}\right]^2$$

$$P_{prinst} = 0.478 \cdot MPa$$

WATER DEPTH CORRESPONDING TO THE BUCKLING PROPOGATION PRESSURE:

$$d_{prinst} := \frac{P_{prinst}}{(\rho_{wg} \cdot g)} = 47.563\, m$$

MAXIMUM POSSIBLE WATER DEPTH
ALONG THE PIPELINE ROUTE

$d_{inmax} = 35.675\,m$

$CHECK\_BP\_INST := if(d_{prinst} > d_{inmax}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"})$

$CHECK\_BP\_INST = \text{"DESIGN IS SAFE"}$

BUCKLING INITIATION (OPERATION)

BUCKLE INITIATION PRESSURE

$$P_{inoper} := 0.02 \cdot \left[E \cdot \left(\frac{t_{oper}}{D} \right)^{2.064} \right]$$

$P_{inoper} = 0.658 \cdot MPa$

WATER DEPTH CORRESPONDING
TO BUCKLE INITIATION PRESSURE

$$d_{inoper} := \frac{P_{inoper}}{\rho_{wg} \cdot g} = 65.439\,m$$

MAXIMUM POSSIBLE WATER DEPTH
ALONG THE PIPELINE ROUTE

$$d_{opermax} := \left(d_{max} + d_{otide} + d_{oss} + .67 \cdot d_{oswh} \right)$$

$d_{opermax} = 44.72\,m$

$CHECK\_BI\_OPER := if(d_{inoper} > d_{opermax}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"})$

$CHECK\_BI\_OPER = \text{"DESIGN IS SAFE"}$

BUCKLE PROPOGATION (OPERATION):

BUCKLE PROPOGATION PRESSURE

$$P_{proper} := 1.15 \cdot \pi \cdot SMYS \cdot \left(\frac{t_{oper}}{D - t_{oper}} \right)^2 = 3.472 \times 10^5 \, Pa$$

$$P_{proper} = 0.347 \cdot MPa$$

WATER DEPTH CORRESPONDING TO THE
BUCKLING PROPOGATION PRESSURE:

$$d_{proper} := \frac{P_{proper}}{(\rho_{wg} \cdot g)} = 34.545 \, m$$

MAXIMUM POSSIBLE WATER DEPTH
ALONG THE PIPELINE ROUTE

$$d_{opermax} = 44.72 \, m$$

CHECK_BP_OPER := if($d_{proper} > d_{opermax}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_BP_OPER = "DESIGN IS NOT SAFE"

Pipeline Wall Thickness Calculation of 24” Pipeline

PIPE DATA

NOMINAL OUTSIDE DIA OF PIPE:	$D := 24in$
CORROSION ALLOWANCE:	$CA := 3mm$
PERCENTAGE OVALITY:	$U := 2\%$
MINIMUM LAYING RADIUS:	$R_c := 1600m$

MATERIAL DATA:

YOUNGS MODULUS:	$E := 2.07\cdot(10)^5 \frac{N}{mm^2}$
POISSONS RATIO:	$\nu := .30$
COEFFICIENT OF THERMAL EXPANSION:	$\alpha := \frac{\left(1.17\cdot 10^{-5}\right)}{\Delta °C}$
SPECIFIED MINIMUN YIELD STRENGTH:	$SMYS := 448MPa$

PROCESS DATA:

INTERNAL DESIGN PRESSURE (OPERATING CONDITION):	$P_{ioper} := 20\cdot bar = 2 \times 10^6 Pa$
HYDROSTATIC TEST PRESSURE:	$P_{ihyd} := 1.4\cdot P_{ioper} = 2.8 \times 10^6 Pa$
DESIGN TEMPERATURE (OPERATING CONDITION:)	$T_d := 33 °C$

DESIGN PARAMETERS:

CODE FOLLOWED FOR DESIGN CALCULATIONS: DnV 1981

DESIGN FACTOR: $F_o := 0.72$

TEMPERATURE DERATING FACTOR: $k_t := 1$

ENVIRONMENTAL DATA:

MINIMUM SEA WATER DEPTH: $d_{min} := 1m$

MAXIMUM SEA WATER DEPTH: $d_{max} := 20m$

STORM SURGE (OPERATING CONDITION): $d_{oss} := 2m$

STORM SURGE (INSTALLATION CONDITION): $d_{iss} := 2m$

MINIMUM SEA WATER TEMPERATURE: $T_{min} := 22.8\,°C$

MAXIMUM SEA WATER TEMPERATURE: $T_{max} := 30.3\,°C$

WAVE HEIGHT (OPERATING CONDITION): $d_{oswh} := 16m$

WAVE HEIGHT (INSTALLATION CONDITION): $d_{iswh} := 2.5m$

HEIGHT OF ASTRONOMICAL TIDE (OPERATING CONDITION): $d_{otide} := 2m$

HEIGHT OF ASTRONOMICAL TIDE (INSTALLATION CONDITION): $d_{itide} := 2m$

DENSITY OF SEA WATER: $\rho_{wg} := 1025\,\frac{kg}{m^3}$

CALCULATIONS :

EXTERNAL PRESSURE:

1. INSTALLATION CONDITION:

FOR BUCKLING CHECK:

$$P_{ebi} := \left(d_{max} + d_{itide} + d_{iss} + .67 d_{iswh}\right) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{ebi} = 0.258\,Pa$$

FOR STRESS AND STABILITY CHECK:

$$P_{esi} := d_{min} \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{esi} = 0.01\,Pa$$

2. HYDROTESTING CONDITION

FOR STRESS AND STABILITY CHECK:

$$P_{esh} := d_{min} \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{esh} = 0.01\,Pa$$

3. OPERATING CONDITION:

FOR BUCKLING CHECK:

$$P_{ebo} := \left(d_{max} + d_{otide} + d_{oss} + .67 d_{oswh}\right) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{ebo} = 0.349\,Pa$$

WALL THICKNESS CALCULATION:

External hydrostatic condition:
(during operating condition)

$$P_{eso} := (d_{min} + d_{oss}) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{eso} = 0.03\,Pa$$

EQUIVALENT WALL THICKNESS:

$$t_{eq} := \left[(P_{ioper} - P_{eso}) \frac{D}{2 \cdot F_o \cdot SMYS \cdot k_t}\right]$$

$$t_{eq} = 1.89 \cdot mm$$

WALL THICKNESS:

$$t := t_{eq} + CA = 4.89 \cdot mm$$

CORRESPONDINGN NOMINAL WALL THICKNESS FROM API 5L

$$t_{nom} := 11.9mm$$

$$t_{inst} := t_{nom}$$

STRESS CHECK:

1) FOR OPERATING CONDITION:

HOOP STRESS CALCULATION:

WALL THICKNESS FOR OPERATING CONDITION: $t_{oper} := t_{nom} - CA = 8.9 \cdot mm$

HOOP STRESS IN PIPE: $\sigma_{ho} := (P_{ioper} - P_{eso}) \cdot \frac{D}{2 \cdot t_{oper}}$

$\sigma_{ho} = 68.494 \cdot MPa$

ALLOWABLE HOOP STRESS: $\sigma_{aho} := 0.72 \cdot SMYS$

$\sigma_{aho} = 322.56 \cdot MPa$

CHECK_FOR_HOOP_STRESS_OPER := if($\sigma_{aho} > \sigma_{ho}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_FOR_HOOP_STRESS_OPER = "DESIGN IS SAFE"

LONGITUDINAL STRESS CALCULATIONS:

1. LONGITUDINAL STRESS CHECK FOR RESTRAINED SECTION

LONGITUDINAL STRESS DUE TO INTERNAL PRESSURE: $\sigma_{lop} := \nu \cdot \sigma_{ho}$

$\sigma_{lop} = 20.548 \cdot MPa$

LONGITUDINAL STRESS DUE TO TEMPERATURE:

$$\sigma_{lot} := E \cdot \alpha \cdot (T_d - T_{min})$$

$$\sigma_{lot} = 24.703 \cdot MPa$$

MAXIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTIONS:

$$\sigma_{lomaxr} := \sigma_{lop} - \sigma_{lot} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lomaxr} = 35.278 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTION:

$$\sigma_{lominr} := \sigma_{lop} - \sigma_{lot} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lominr} = -43.589 \cdot MPa$$

2. LONGITUDINAL STRESS CHECK FOR UN-RESTRAINED SECTION

MAXIMUM LONGITUDINAL STRESS FOR UN RESTRAINED SECTION:

$$\sigma_{lomaxu} := 0.5\sigma_{ho} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lomaxu} = 73.681 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS FOR UN-RESTRAINED SECTION

$$\sigma_{lominu} := 0.5\sigma_{ho} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lominu} = -5.186 \cdot MPa$$

ABSOLUTE MAXIMUM LONGITUDINAL STRESS IS THE MAXIMUM AMONG ABOVE 4 VALUES:

$$\sigma_{lomax} := \max(\sigma_{lomaxr}, \sigma_{lominr}, \sigma_{lomaxu}, \sigma_{lominu})$$

$$\sigma_{lomax} = 73.681 \cdot MPa$$

EQUIVALENT STRESS CALCULATIONS

VON MISES COMBINED STRESS CRITERIA

MAXIMUM EQUIVALENT STRESS FOR RESTRAINED SECTION:

$$\sigma_{eomaxr} := \left(\sigma_{ho}^{2} + \sigma_{lomaxr}^{2} - \sigma_{ho} \cdot \sigma_{lomaxr}\right)^{\frac{1}{2}}$$

$$\sigma_{eomaxr} = 59.327 \cdot MPa$$

MINIMUM EQUIVALENT STRESS FOR RESTRAINED SECTION:

$$\sigma_{eominr} := \left(\sigma_{ho}^{2} + \sigma_{lominr}^{2} - \sigma_{ho} \cdot \sigma_{lominr}\right)^{\frac{1}{2}}$$

$$\sigma_{eominr} = 97.862 \cdot MPa$$

MAXIMUM EQUIVALENT STRESS FOR UN-RESTRAINED SECTION:

$$\sigma_{eomaxu} := \left(\sigma_{ho}^{2} + \sigma_{lomaxu}^{2} - \sigma_{ho} \cdot \sigma_{lomaxu}\right)^{\frac{1}{2}}$$

$$\sigma_{eomaxu} = 71.229 \cdot MPa$$

MINIMUM EQUIVALENT STRESS FOR UN-RESTRAINED SECTION:

$$\sigma_{eominu} := \left(\sigma_{ho}^{2} + \sigma_{lominu}^{2} - \sigma_{ho} \cdot \sigma_{lominu}\right)^{\frac{1}{2}}$$

$$\sigma_{eominu} = 71.229 \cdot MPa$$

ABSOLUTE MAXIMUM EQUIVALENT STRESS IS MAX. OF ABOVE 4 VALUES:

$$\sigma_{eabsoluteo} := \max\left(\sigma_{eomaxr}, \sigma_{eominr}, \sigma_{eomaxu}, \sigma_{eominu}\right)$$

$$\sigma_{eabsoluteo} = 97.862 \cdot MPa$$

ALLOWABLE EQUIVALENT STRESS IN OPERATING CONDITION:

$$\sigma_{eallow} := 0.72 \cdot SMYS = 3.226 \times 10^{8} Pa$$

CHK_FOR_L_STRESS_OPER := if($\sigma_{eallow} > \sigma_{eabsoluteo}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE

CHK_FOR_L_STRESS_OPER = "DESIGN IS SAFE"

2.) FOR HYDROTEST CONDITION:

HOOP STRESS CALCULATION:

WALL THICKNESS FOR HYDROTEST CONDITION:

$$t_h := t_{nom} = 0.012\,m$$

HOOP STRESS IN PIPE :

$$\sigma_{hh} := \left[\left(P_{ihyd} - P_{esh} \right) \cdot \frac{D}{2 \cdot t_h} \right]$$

$$\sigma_{hh} = 71.718 \cdot MPa$$

ALLOWABLE HOOP STRESS FOR HYDROTEST:

$$\sigma_{ahh} := 0.9 SMYS = 4.032 \times 10^{8}\,Pa$$

CHECK_FOR_HOOP_STRESS_HYD := if($\sigma_{ahh} > \sigma_{hh}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_FOR_HOOP_STRESS_HYD = "DESIGN IS SAFE"

LONGITUDINAL STRESS CALCULATIONS:

1. LONGITUDINAL STRESS CHECK FOR RESTRAINED SECTION

LONGITUDINAL STRESS DUE TO INTERNAL PRESSURE:

$$\sigma_{lhp} := \nu \cdot \sigma_{hh}$$

$$\sigma_{lhp} = 21.515 \cdot MPa$$

LONGITUDINAL STRESS DUE TO TEMPERATURE:

$$\sigma_{lht} := E \cdot \alpha \cdot \left(T_{max} - T_{min} \right)$$

$$\sigma_{lht} = 18.164 \cdot MPa$$

MAXIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTION:

$$\sigma_{lhmaxr} := \sigma_{lhp} - \sigma_{lht} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhmaxr} = 42.785 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS
FOR RESTRAINED SECTION:

$$\sigma_{lhminr} := \sigma_{lhp} - \sigma_{lht} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhminr} = -36.082 \cdot MPa$$

2. LONGITUDINAL STRESS CHECK FOR UN-RESTRAINED SECTION

MAXIMUM LONGITUDINAL STRESS
FOR UN RESTRAINED SECTION:

$$\sigma_{lhmaxu} := 0.5\sigma_{hh} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhmaxu} = 7.529 \times 10^{7} Pa$$

MINIMUM LONGITUDINAL STRESS
FOR UN RESTRAINED SECTION:

$$\sigma_{lhminu} := 0.5\sigma_{hh} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhminu} = -3.575 \cdot MPa$$

ABSOLUTE MAXIMUM LONGITUDINAL STRESS:
(MAX. OF ABOVE 4 - VALUES)

$$\sigma_{lhmax} := \max(\sigma_{lhmaxr}, \sigma_{lhminr}, \sigma_{lhmaxu}, \sigma_{lhminu})$$

$$\sigma_{lhmax} = 75.292 \cdot MPa$$

EQUIVALENT STRESS CALCULATIONS:

VON MISES COMBINED STRESS CRITERIA

MAXIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{ehmaxr} := \left(\sigma_{hh}^{2} + \sigma_{lhmaxr}^{2} - \sigma_{hh} \cdot \sigma_{lhmaxr}\right)^{\frac{1}{2}}$$

$$\sigma_{ehmaxr} = 62.494 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{ehminr} := \left(\sigma_{hh}^{2} + \sigma_{lhminr}^{2} - \sigma_{hh} \cdot \sigma_{lhminr}\right)^{\frac{1}{2}}$$

$$\sigma_{ehminr} = 95.043 \cdot MPa$$

MAXIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{ehmaxu} := \left(\sigma_{hh}^{2} + \sigma_{lhmaxu}^{2} - \sigma_{hh} \cdot \sigma_{lhmaxu}\right)^{\frac{1}{2}}$$

$$\sigma_{ehmaxu} = 73.57 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{ehminu} := \left(\sigma_{hh}^{2} + \sigma_{lhminu}^{2} - \sigma_{hh} \cdot \sigma_{lhminu}\right)^{\frac{1}{2}}$$

$$\sigma_{ehminu} = 73.57 \cdot MPa$$

ABSOLUTE MAXIMUM EQUIVALENT STRESS
IS MAX. OF ABOVE 4 VALUES:

$$\sigma_{eabsoluteh} := \max\left(\sigma_{ehmaxr}, \sigma_{ehminr}, \sigma_{ehmaxu}, \sigma_{ehminu}\right)$$

$$\sigma_{eabsoluteh} = 95.043 \cdot MPa$$

ALLOWABLE EQUIVALENT STRESS
IN HYDROTEST CONDITION:

$$\sigma_{alh} := 1 \cdot SMYS = 4.48 \times 10^{8} \, Pa$$

CHECK_FOR_L_STRESS_HYD := if($\sigma_{alh} > \sigma_{eabsoluteh}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE

CHECK_FOR_L_STRESS_HYD = "DESIGN IS SAFE"

BUCKLING CHECK:

PIPE COLLAPSE (EXTERNAL PRESSURE CAPACITY):

INSTALLATION CONDITION

WALL THICKNESS FOR INSTALLATION CONDITION: $t_{inst} = 0.012\,m$

MEAN RADIUS OF THE PIPE CROSS SECTION

$$R_{minst} := \frac{(D - t_{inst})}{2}$$

$$R_{minst} = 0.299\,m$$

ELASTIC BUCKLING PRESSURE:

$$P_{crinst} := E \cdot \frac{\left(\frac{t_{inst}}{R_{minst}}\right)^3}{4\left(1 - \nu^2\right)}$$

$$P_{crinst} = 3.59 \cdot MPa$$

$$B_{inst} := \left(SMYS \cdot \frac{t_{inst}}{R_{minst}}\right) + \left[P_{crinst} \cdot \left[1 + \left[3 \cdot R_{minst} \cdot \frac{U}{(100 \cdot t_{inst})}\right]\right]\right] = 2.148 \times 10^7\,Pa$$

$$C_{inst} := P_{crinst} \cdot SMYS \cdot \frac{t_{inst}}{R_{minst}} = 6.405 \times 10^{13}\,Pa^2$$

MINIMUM COLLAPSE PRESSURE AT INSTALLATION:

$$P_{colmininst} := \frac{\left[B_{inst} - \left(B_{inst}^2 - 4 \cdot C_{inst}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmininst} = 3.577 \cdot MPa$$

MAXIMUM COLLAPSE PRESSURE AT INSTALLATION:

$$P_{colmaxinst} := \frac{\left[B_{inst} + \left(B_{inst}^{2} - 4 \cdot C_{inst}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmaxinst} = 17.907 \cdot MPa$$

COLLAPSE PRESSURE IS MINIMUM OF ABOVE 2 VALUES

$$P_{colinst} := \min\left(P_{colmininst}, P_{colmaxinst}\right)$$

$$P_{colinst} = 3.577 \cdot MPa$$

MAXIMUM EXTERNAL HYDROSTATIC PRESSURE ALONG THE PIPELINE ROUTE:

$$P_{possibleinst} := 2 \cdot P_{ebi}$$

$$P_{possibleinst} = 5.162 \times 10^{-7} \cdot MPa$$

CHECK_COLPSE_INST := if($P_{colinst} > P_{possibleinst}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_COLPSE_INST = "DESIGN IS SAFE"

OPERATION CONDITION:

MEAN RADIUS OF THE PIPE CROSS SECTION:

$$R_{moper} := \frac{\left(D - t_{oper}\right)}{2}$$

$$R_{moper} = 0.3\,m$$

ELASTIC BUCKLING PRESSURE:

$$P_{croper} := E \cdot \frac{\left(\frac{t_{oper}}{R_{moper}}\right)^{3}}{4\left(1 - \nu^{2}\right)}$$

$$P_{croper} = 1.48 \cdot MPa$$

$$B_{oper} := \left(SMYS \cdot \frac{t_{oper}}{R_{moper}}\right) + \left[P_{croper} \cdot \left[1 + \left[3 \cdot R_{moper} \cdot \frac{U}{(100 \cdot t_{oper})}\right]\right]\right] = 1.478 \times 10^{7}\,Pa$$

$$C_{oper} := P_{croper} \cdot SMYS \cdot \frac{t_{oper}}{R_{moper}} = 1.964 \times 10^{13}\,Pa^{2}$$

MINUIMUM COLLAPSE PRESSURE AT OPERATION:

$$P_{colminoper} := \frac{\left[B_{oper} - \left(B_{oper}^{2} - 4 \cdot C_{oper}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colminoper} = 1.476 \cdot MPa$$

MAXIMUM COLLAPSE PRESSURE AT INSTALLATION:

$$P_{colmaxoper} := \frac{\left[B_{oper} + \left(B_{oper}^{2} - 4 \cdot C_{oper}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmaxoper} = 13.309 \cdot MPa$$

COLLAPSE PRESSURE IS MINIMUM OF ABOVE 2 VALUES:

$$Pcoloper := \min\left(P_{colminoper}, P_{colmaxoper}\right)$$

$$Pcoloper = 1.476 \cdot MPa$$

MAXIMUM EXTERNALHYDROSTATIC PRESSUREALONG THE PIPELINE ROUTE:

$$P_{possibleoper} := 2 \cdot P_{ebo} = 0.698\,Pa$$

CHECK_COLPSE_OPER := if(Pcoloper > $P_{possibleoper}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE"

CHECK_COLPSE_OPER = "DESIGN IS SAFE"

BUCKLING INITIATION (INSTALLATION)

BUCKLE INITIATION PRESSURE

$$P_{ininst} := 0.02 \cdot E \cdot \left(\frac{t_{inst}}{D} \right)^{2.064}$$

$$P_{ininst} = 1.226 \cdot MPa$$

WATER DEPTH CORRESPONDING TO BUCKLE INITIATION PRESSURE

$$d_{ininst} := \frac{P_{ininst}}{\rho_{wg} \cdot g} = 121.998\,m$$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE

$$d_{inmax} := \left(d_{max} + d_{itide} + d_{iss} + .67 \cdot d_{iswh} \right)$$

$$d_{inmax} = 25.675\,m$$

CHECK_BI_INST := if($d_{ininst} > d_{inmax}$, "DESIGN IS SAFE." , "DESIGN IS NOT SAFE")

CHECK_BI_INST = "DESIGN IS SAFE."

BUCKLE PROPOGATION (INSTALLATION):

BUCKLE PROPOGATION PRESSURE

$$P_{prinst} := 1.15 \cdot \pi \cdot SMYS \cdot \left[\frac{t_{inst}}{(D - t_{inst})} \right]^2$$

$$P_{prinst} = 0.642 \cdot MPa$$

WATER DEPTH CORRESPONDING TO THE BUCKLING PROPOGATION PRESSURE:

$$d_{prinst} := \frac{P_{prinst}}{(\rho_{wg} \cdot g)} = 63.828\,m$$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE

$d_{inmax} = 25.675\,m$

$CHECK\_BP\_INST := if(d_{prinst} > d_{inmax}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"})$

$CHECK\_BP\_INST = \text{"DESIGN IS SAFE"}$

BUCKLING INITIATION (OPERATION)

BUCKLE INITIATION PRESSURE

$$P_{inoper} := 0.02 \cdot \left[E \cdot \left(\frac{t_{oper}}{D} \right)^{2.064} \right]$$

$P_{inoper} = 0.673 \cdot MPa$

WATER DEPTH CORRESPONDING TO BUCKLE INITIATION PRESSURE

$$d_{inoper} := \frac{P_{inoper}}{\rho_{wg} \cdot g} = 66.983\,m$$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE

$$d_{opermax} := (d_{max} + d_{otide} + d_{oss} + .67 \cdot d_{oswh})$$

$d_{opermax} = 34.72\,m$

$CHECK\_BI\_OPER := if(d_{inoper} > d_{opermax}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"})$

$CHECK\_BI\_OPER = \text{"DESIGN IS SAFE"}$

BUCKLE PROPOGATION (OPERATION):

BUCKLE PROPOGATION PRESSURE $P_{proper} := 1.15 \cdot \pi \cdot SMYS \cdot \left(\frac{t_{oper}}{D - t_{oper}} \right)^2 = 3.553 \times 10^5 \, Pa$

$P_{proper} = 0.355 \cdot MPa$

WATER DEPTH CORRESPONDING TO THE BUCKLING PROPOGATION PRESSURE: $d_{proper} := \frac{P_{proper}}{(\rho_{wg} \cdot g)} = 35.346 \, m$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE $d_{opermax} = 34.72 \, m$

CHECK_BP_OPER := if($d_{proper} > d_{opermax}$, "DESIGN IS SAFE", "DESIGN IS NOT SAFE")

CHECK_BP_OPER = "DESIGN IS SAFE"

Pipeline Wall Thickness Calculation of 14" Pipeline

PIPE DATA

NOMINAL OUTSIDE DIA OF PIPE: $D := 14in$

CORROSION ALLOWANCE: $CA := 3mm$

PERCENTAGE OVALITY: $U := 2\%$

MINIMUM LAYING RADIUS: $R_c := 1600m$

MATERIAL DATA:

YOUNGS MODULUS: $E := 2.07 \cdot (10)^5 \frac{N}{mm^2}$

POISSONS RATIO: $\nu := .30$

COEFFICIENT OF THERMAL EXPANSION: $\alpha := \frac{\left(1.17 \cdot 10^{-5}\right)}{\Delta°C}$

SPECIFIED MINIMUN YIELD STRENGTH: $SMYS := 448MPa$

PROCESS DATA:

INTERNAL DESIGN PRESSURE
(OPERATING CONDITION): $P_{ioper} := 20.bar = 2 \times 10^6 Pa$

HYDROSTATIC TEST PRESSURE: $P_{ihyd} := 1.4 \cdot P_{ioper} = 2.8 \times 10^6 Pa$

DESIGN TEMPERATURE
(OPERATING CONDITION:) $T_d := 33°C$

DESIGN PARAMETERS:

CODE FOLLOWED FOR DESIGN CALCULATIONS: DnV 1981

DESIGN FACTOR: $F_o := 0.72$

TEMPERATURE DERATING FACTOR: $k_t := 1$

ENVIRONMENTAL DATA:

MINIMUM SEA WATER DEPTH: $d_{min} := 1m$

MAXIMUM SEA WATER DEPTH: $d_{max} := 16m$

STORM SURGE (OPERATING CONDITION): $d_{oss} := 2m$

STORM SURGE (INSTALLATION CONDITION): $d_{iss} := 2m$

MINIMUM SEA WATER TEMPERATURE: $T_{min} := 22.8\,°C$

MAXIMUM SEA WATER TEMPERATURE: $T_{max} := 30.3\,°C$

WAVE HEIGHT (OPERATING CONDITION): $d_{oswh} := 16m$

WAVE HEIGHT (INSTALLATION CONDITION): $d_{iswh} := 2.5m$

HEIGHT OF ASTRONOMICAL TIDE
(OPERATING CONDITION): $d_{otide} := 2m$

HEIGHT OF ASTRONOMICAL TIDE
(INSTALLATION CONDITION): $d_{itide} := 2m$

DENSITY OF SEA WATER: $\rho_{wg} := 1025\,\frac{kg}{m^3}$

CALCULATIONS :

EXTERNAL PRESSURE:

1. INSTALLATION CONDITION:

FOR BUCKLING CHECK:

$$P_{ebi} := \left(d_{max} + d_{itide} + d_{iss} + .67 d_{iswh}\right) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{ebi} = 0.218\,Pa$$

FOR STRESS AND STABILITY CHECK:

$$P_{esi} := d_{min} \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{esi} = 0.01\,Pa$$

2. HYDROTESTING CONDITION

FOR STRESS AND STABILITY CHECK:

$$P_{esh} := d_{min} \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{esh} = 0.01\,Pa$$

3. OPERATING CONDITION:

FOR BUCKLING CHECK:

$$P_{ebo} := \left(d_{max} + d_{otide} + d_{oss} + .67 d_{oswh}\right) \cdot \rho_{wg} \cdot \frac{g}{10^6}$$

$$P_{ebo} = 0.309\,Pa$$

WALL THICKNESS CALCULATION:

External hydrostatic condition:
(during operating condition)

$$P_{eso} := \left(d_{min} + d_{oss}\right)\cdot \rho_{wg}\cdot \frac{g}{10^{6}}$$

$$P_{eso} = 0.03\,Pa$$

EQUIVALENT WALL THICKNESS:

$$t_{eq} := \left[\left(P_{ioper} - P_{eso}\right)\frac{D}{2\cdot E_{0}\cdot SMYS\cdot k_{t}}\right]$$

$$t_{eq} = 1.102\cdot mm$$

WALL THICKNESS:

$$t := t_{eq} + CA = 4.102\cdot mm$$

CORRESPONDINGN NOMINAL WALL THICKNESS FROM API 5L

$$t_{nom} := 7.9mm$$

$$t_{inst} := t_{nom}$$

STRESS CHECK:

1) FOR OPERATING CONDITION:

HOOP STRESS CALCULATION:

WALL THICKNESS FOR OPERATING CONDITION: $t_{oper} := t_{nom} - CA = 4.9 \cdot mm$

HOOP STRESS IN PIPE: $\sigma_{ho} := \left(P_{ioper} - P_{eso}\right) \cdot \frac{D}{2 \cdot t_{oper}}$

$\sigma_{ho} = 72.571 \cdot MPa$

ALLOWABLE HOOP STRESS: $\sigma_{aho} := 0.72 \cdot SMYS$

$\sigma_{aho} = 322.56 \cdot MPa$

CHECK_FOR_HOOP_STRESS_OPER := if($\sigma_{aho} > \sigma_{ho}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_FOR_HOOP_STRESS_OPER = "DESIGN IS SAFE"

LONGITUDINAL STRESS CALCULATIONS:

1. LONGITUDINAL STRESS CHECK FOR RESTRAINED SECTION

LONGITUDINAL STRESS DUE TO INTERNAL PRESSURE: $\sigma_{lop} := \nu \cdot \sigma_{ho}$

$\sigma_{lop} = 21.771 \cdot MPa$

LONGITUDINAL STRESS DUE TO TEMPERATURE:

$$\sigma_{lot} := E \cdot \alpha \cdot (T_d - T_{min})$$

$$\sigma_{lot} = 24.703 \cdot MPa$$

MAXIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTIONS:

$$\sigma_{lomaxr} := \sigma_{lop} - \sigma_{lot} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lomaxr} = 20.071 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTION:

$$\sigma_{lominr} := \sigma_{lop} - \sigma_{lot} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lominr} = -25.935 \cdot MPa$$

2. LONGITUDINAL STRESS CHECK FOR UN-RESTRAINED SECTION

MAXIMUM LONGITUDINAL STRESS FOR UN RESTRAINED SECTION:

$$\sigma_{lomaxu} := 0.5\sigma_{ho} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lomaxu} = 59.289 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS FOR UN-RESTRAINED SECTION

$$\sigma_{lominu} := 0.5\sigma_{ho} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lominu} = 13.283 \cdot MPa$$

ABSOLUTE MAXIMUM LONGITUDINAL STRESS IS THE MAXIMUM AMONG ABOVE 4 VALUES:

$$\sigma_{lomax} := \max(\sigma_{lomaxr}, \sigma_{lominr}, \sigma_{lomaxu}, \sigma_{lominu})$$

$$\sigma_{lomax} = 59.289 \cdot MPa$$

EQUIVALENT STRESS CALCULATIONS

VON MISES COMBINED STRESS CRITERIA

MAXIMUM EQUIVALENT STRESS FOR RESTRAINED SECTION:

$$\sigma_{comaxr} := \left(\sigma_{ho}^{2} + \sigma_{lomaxr}^{2} - \sigma_{ho} \cdot \sigma_{lomaxr}\right)^{\frac{1}{2}}$$

$$\sigma_{comaxr} = 64.907 \cdot MPa$$

MINIMUM EQUIVALENT STRESS FOR RESTRAINED SECTION:

$$\sigma_{cominr} := \left(\sigma_{ho}^{2} + \sigma_{lominr}^{2} - \sigma_{ho} \cdot \sigma_{lominr}\right)^{\frac{1}{2}}$$

$$\sigma_{cominr} = 88.438 \cdot MPa$$

MAXIMUM EQUIVALENT STRESS FOR UN-RESTRAINED SECTION:

$$\sigma_{comaxu} := \left(\sigma_{ho}^{2} + \sigma_{lomaxu}^{2} - \sigma_{ho} \cdot \sigma_{lomaxu}\right)^{\frac{1}{2}}$$

$$\sigma_{comaxu} = 66.926 \cdot MPa$$

MINIMUM EQUIVALENT STRESS FOR UN-RESTRAINED SECTION:

$$\sigma_{cominu} := \left(\sigma_{ho}^{2} + \sigma_{lominu}^{2} - \sigma_{ho} \cdot \sigma_{lominu}\right)^{\frac{1}{2}}$$

$$\sigma_{cominu} = 66.926 \cdot MPa$$

ABSOLUTE MAXIMUM EQUIVALENT STRESS IS MAX. OF ABOVE 4 VALUES:

$$\sigma_{cabsoluteo} := \max\left(\sigma_{comaxr}, \sigma_{cominr}, \sigma_{comaxu}, \sigma_{cominu}\right)$$

$$\sigma_{cabsoluteo} = 88.438 \cdot MPa$$

ALLOWABLE EQUIVALENT STRESS IN OPERATING CONDITION:

$$\sigma_{callow} := 0.72 \cdot SMYS = 3.226 \times 10^{8}\,Pa$$

$$CHK\_FOR\_L\_STRESS\_OPER := if\left(\sigma_{callow} > \sigma_{cabsoluteo}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE}\right.$$

$$CHK\_FOR\_L\_STRESS\_OPER = \text{"DESIGN IS SAFE"}$$

2.) FOR HYDROTEST CONDITION:

HOOP STRESS CALCULATION:

WALL THICKNESS FOR HYDROTEST CONDITION:

$$t_h := t_{nom} = 7.9 \times 10^{-3}\,m$$

HOOP STRESS IN PIPE :

$$\sigma_{hh} := \left[\left(P_{ihyd} - P_{esh} \right) \cdot \frac{D}{2 \cdot t_h} \right]$$

$$\sigma_{hh} = 63.018 \cdot MPa$$

ALLOWABLE HOOP STRESS FOR HYDROTEST:

$$\sigma_{ahh} := 0.9 SMYS = 4.032 \times 10^{8}\,Pa$$

CHECK_FOR_HOOP_STRESS_HYD := if($\sigma_{ahh} > \sigma_{hh}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_FOR_HOOP_STRESS_HYD = "DESIGN IS SAFE"

LONGITUDINAL STRESS CALCULATIONS:

1. LONGITUDINAL STRESS CHECK FOR RESTRAINED SECTION

LONGITUDINAL STRESS DUE TO INTERNAL PRESSURE:

$$\sigma_{lhp} := \nu \cdot \sigma_{hh}$$

$$\sigma_{lhp} = 18.905 \cdot MPa$$

LONGITUDINAL STRESS DUE TO TEMPERATURE:

$$\sigma_{lht} := E \cdot \alpha \cdot \left(T_{max} - T_{min} \right)$$

$$\sigma_{lht} = 18.164 \cdot MPa$$

MAXIMUM LONGITUDINAL STRESS FOR RESTRAINED SECTION:

$$\sigma_{lhmaxr} := \sigma_{lhp} - \sigma_{lht} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhmaxr} = 23.744 \cdot MPa$$

MINIMUM LONGITUDINAL STRESS
FOR RESTRAINED SECTION:

$$\sigma_{lhminr} := \sigma_{lhp} - \sigma_{lht} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhminr} = -22.262 \cdot MPa$$

2. LONGITUDINAL STRESS CHECK FOR UN-RESTRAINED SECTION

MAXIMUM LONGITUDINAL STRESS
FOR UN RESTRAINED SECTION:

$$\sigma_{lhmaxu} := 0.5\sigma_{hh} + E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhmaxu} = 5.451 \times 10^{7} Pa$$

MINIMUM LONGITUDINAL STRESS
FOR UN RESTRAINED SECTION:

$$\sigma_{lhminu} := 0.5\sigma_{hh} - E \cdot \frac{D}{2 \cdot R_c}$$

$$\sigma_{lhminu} = 8.506 \cdot MPa$$

ABSOLUTE MAXIMUM LONGITUDINAL STRESS:
(MAX. OF ABOVE 4 - VALUES)

$$\sigma_{lhmax} := \max(\sigma_{lhmaxr}, \sigma_{lhminr}, \sigma_{lhmaxu}, \sigma_{lhminu})$$

$$\sigma_{lhmax} = 54.512 \cdot MPa$$

EQUIVALENT STRESS CALCULATIONS:

VON MISES COMBINED STRESS CRITERIA

MAXIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{ehmaxr} := \left(\sigma_{hh}^{2} + \sigma_{lhmaxr}^{2} - \sigma_{hh} \cdot \sigma_{lhmaxr}\right)^{\frac{1}{2}}$$

$$\sigma_{ehmaxr} = 55.125 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR RESTRAINED SECTION:

$$\sigma_{ehminr} := \left(\sigma_{hh}^{2} + \sigma_{lhminr}^{2} - \sigma_{hh} \cdot \sigma_{lhminr}\right)^{\frac{1}{2}}$$

$$\sigma_{ehminr} = 76.614 \cdot MPa$$

MAXIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{ehmaxu} := \left(\sigma_{hh}^{2} + \sigma_{lhmaxu}^{2} - \sigma_{hh} \cdot \sigma_{lhmaxu}\right)^{\frac{1}{2}}$$

$$\sigma_{ehmaxu} = 59.225 \cdot MPa$$

MINIMUM EQUIVALENT STRESS
FOR UN-RESTRAINED SECTION:

$$\sigma_{ehminu} := \left(\sigma_{hh}^{2} + \sigma_{lhminu}^{2} - \sigma_{hh} \cdot \sigma_{lhminu}\right)^{\frac{1}{2}}$$

$$\sigma_{ehminu} = 59.225 \cdot MPa$$

ABSOLUTE MAXIMUM EQUIVALENT STRESS
IS MAX. OF ABOVE 4 VALUES:

$$\sigma_{eabsoluteh} := \max\left(\sigma_{ehmaxr}, \sigma_{ehminr}, \sigma_{ehmaxu}, \sigma_{ehminu}\right)$$

$$\sigma_{eabsoluteh} = 76.614 \cdot MPa$$

ALLOWABLE EQUIVALENT STRESS
IN HYDROTEST CONDITION:

$$\sigma_{alh} := 1 \cdot SMYS = 4.48 \times 10^{8}\,Pa$$

CHECK_FOR_L_STRESS_HYD := if($\sigma_{alh} > \sigma_{eabsoluteh}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE

CHECK_FOR_L_STRESS_HYD = "DESIGN IS SAFE"

BUCKLING CHECK:

PIPE COLLAPSE (EXTERNAL PRESSURE CAPACITY):

INSTALLATION CONDITION

WALL THICKNESS FOR INSTALLATION CONDITION: $t_{inst} = 7.9 \times 10^{-3}\,m$

MEAN RADIUS OF THE PIPE CROSS SECTION

$$R_{minst} := \frac{(D - t_{inst})}{2}$$

$$R_{minst} = 0.174\,m$$

ELASTIC BUCKLING PRESSURE:

$$P_{crinst} := E \cdot \frac{\left(\frac{t_{inst}}{R_{minst}}\right)^3}{4\left(1 - \nu^2\right)}$$

$$P_{crinst} = 5.336 \cdot MPa$$

$$B_{inst} := \left(SMYS \cdot \frac{t_{inst}}{R_{minst}}\right) + \left[P_{crinst} \cdot \left[1 + \left[3 \cdot R_{minst} \cdot \frac{U}{(100 \cdot t_{inst})}\right]\right]\right] = 2.576 \times 10^7\,Pa$$

$$C_{inst} := P_{crinst} \cdot SMYS \cdot \frac{t_{inst}}{R_{minst}} = 1.086 \times 10^{14}\,Pa^2$$

MINIMUM COLLAPSE PRESSURE AT INSTALLATION:

$$P_{colmininst} := \frac{\left[B_{inst} - \left(B_{inst}^{\ 2} - 4 \cdot C_{inst}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmininst} = 5.311 \cdot MPa$$

MAXIMUM COLLAPSE PRESSURE
AT INSTALLATION:

$$P_{colmaxinst} := \frac{\left[B_{inst} + \left(B_{inst}^2 - 4\cdot C_{inst}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmaxinst} = 20.453\cdot MPa$$

COLLAPSE PRESSURE IS MINIMUM OF ABOVE 2 VALUES

$$P_{colinst} := \min\left(P_{colmininst}, P_{colmaxinst}\right)$$

$$P_{colinst} = 5.311\cdot MPa$$

MAXIMUM EXTERNAL HYDROSTATIC PRESSURE ALONG THE PIPELINE ROUTE:

$$P_{possibleinst} := 2\cdot P_{ebi}$$

$$P_{possibleinst} = 4.357\times 10^{-7}\cdot MPa$$

CHECK_COLPSE_INST := if($P_{colinst} > P_{possibleinst}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_COLPSE_INST = "DESIGN IS SAFE"

OPERATION CONDITION:

MEAN RADIUS OF THE PIPE CROSS SECTION:

$$R_{moper} := \frac{\left(D - t_{oper}\right)}{2}$$

$$R_{moper} = 0.175\,m$$

ELASTIC BUCKLING PRESSURE:

$$P_{croper} := E\cdot\frac{\left(\frac{t_{oper}}{R_{moper}}\right)^3}{4\left(1 - \nu^2\right)}$$

$$P_{croper} = 1.241\cdot MPa$$

$$B_{oper} := \left(SMYS \cdot \frac{t_{oper}}{R_{moper}}\right) + \left[P_{croper} \left[1 + \left[3 \cdot R_{moper} \cdot \frac{U}{(100 \cdot t_{oper})}\right]\right]\right] = 1.379 \times 10^{7} \, Pa$$

$$C_{oper} := P_{croper} \cdot SMYS \cdot \frac{t_{oper}}{R_{moper}} = 1.553 \times 10^{13} \, Pa^{2}$$

MINUIMUM COLLAPSE PRESSURE AT OPERATION:

$$P_{colminoper} := \frac{\left[B_{oper} - \left(B_{oper}^{2} - 4 \cdot C_{oper}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colminoper} = 1.238 \cdot MPa$$

MAXIMUM COLLAPSE PRESSURE AT INSTALLATION:

$$P_{colmaxoper} := \frac{\left[B_{oper} + \left(B_{oper}^{2} - 4 \cdot C_{oper}\right)^{\frac{1}{2}}\right]}{2}$$

$$P_{colmaxoper} = 12.549 \cdot MPa$$

COLLAPSE PRESSURE IS MINIMUM OF ABOVE 2 VALUES:

$$Pcoloper := \min(P_{colminoper}, P_{colmaxoper})$$

$$Pcoloper = 1.238 \cdot MPa$$

MAXIMUM EXTERNALHYDROSTATIC PRESSUREALONG THE PIPELINE ROUTE:

$$P_{possibleoper} := 2 \cdot P_{ebo} = 0.618 \, Pa$$

CHECK_COLPSE_OPER := if(Pcoloper > $P_{possibleoper}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE"

CHECK_COLPSE_OPER = "DESIGN IS SAFE"

BUCKLING INITIATION (INSTALLATION)

BUCKLE INITIATION PRESSURE

$$P_{ininst} := 0.02 \cdot E \cdot \left(\frac{t_{inst}}{D} \right)^{2.064}$$

$$P_{ininst} = 1.601 \cdot MPa$$

WATER DEPTH CORRESPONDING TO BUCKLE INITIATION PRESSURE

$$d_{ininst} := \frac{P_{ininst}}{\rho_{wg} \cdot g} = 159.321\, m$$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE

$$d_{inmax} := \left(d_{max} + d_{itide} + d_{iss} + .67 \cdot d_{iswh} \right)$$

$$d_{inmax} = 21.675\, m$$

CHECK_BI_INST := if($d_{ininst} > d_{inmax}$, "DESIGN IS SAFE." , "DESIGN IS NOT SAFE")

CHECK_BI_INST = "DESIGN IS SAFE."

BUCKLE PROPOGATION (INSTALLATION):

BUCKLE PROPOGATION PRESSURE

$$P_{prinst} := 1.15 \cdot \pi \cdot SMYS \cdot \left[\frac{t_{inst}}{\left(D - t_{inst} \right)} \right]^2$$

$$P_{prinst} = 0.836 \cdot MPa$$

WATER DEPTH CORRESPONDING TO THE BUCKLING PROPOGATION PRESSURE:

$$d_{prinst} := \frac{P_{prinst}}{\left(\rho_{wg} \cdot g \right)} = 83.124\, m$$

MAXIMUM POSSIBLE WATER DEPTH
ALONG THE PIPELINE ROUTE

$$d_{inmax} = 21.675\,m$$

$$CHECK\_BP\_INST := if(d_{prinst} > d_{inmax}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"})$$

$$CHECK\_BP\_INST = \text{"DESIGN IS SAFE"}$$

BUCKLING INITIATION (OPERATION)

BUCKLE INITIATION PRESSURE

$$P_{inoper} := 0.02 \cdot \left[E \cdot \left(\frac{t_{oper}}{D}\right)^{2.064}\right]$$

$$P_{inoper} = 0.598 \cdot MPa$$

WATER DEPTH CORRESPONDING
TO BUCKLE INITIATION PRESSURE

$$d_{inoper} := \frac{P_{inoper}}{\rho_{wg} \cdot g} = 59.448\,m$$

MAXIMUM POSSIBLE WATER DEPTH
ALONG THE PIPELINE ROUTE

$$d_{opermax} := (d_{max} + d_{otide} + d_{oss} + .67 \cdot d_{oswh})$$

$$d_{opermax} = 30.72\,m$$

$$CHECK\_BI\_OPER := if(d_{inoper} > d_{opermax}, \text{"DESIGN IS SAFE"}, \text{"DESIGN IS NOT SAFE"})$$

$$CHECK\_BI\_OPER = \text{"DESIGN IS SAFE"}$$

BUCKLE PROPOGATION (OPERATION):

BUCKLE PROPOGATION PRESSURE $\quad P_{proper} := 1.15 \cdot \pi \cdot SMYS \cdot \left(\frac{t_{oper}}{D - t_{oper}} \right)^2 = 3.16 \times 10^5 \, Pa$

$$P_{proper} = 0.316 \cdot MPa$$

WATER DEPTH CORRESPONDING TO THE BUCKLING PROPOGATION PRESSURE: $\quad d_{proper} := \frac{P_{proper}}{(\rho_{wg} \cdot g)} = 31.434 \, m$

MAXIMUM POSSIBLE WATER DEPTH ALONG THE PIPELINE ROUTE $\quad d_{opermax} = 30.72 \, m$

CHECK_BP_OPER := if($d_{proper} > d_{opermax}$, "DESIGN IS SAFE" , "DESIGN IS NOT SAFE")

CHECK_BP_OPER = "DESIGN IS SAFE"

On Bottom Stability Analysis of 48" Pipeline

INPUT DATA

PIPELINE PARAMETERS:

STEEL PIPE OUTER DIAMETER: $OD := 48in$

WALL THICKNESS: $t := 20.6mm$

CORROSION ALLOWANCE $t_{ca} := 0mm$

DENSITY OF STEEL: $\rho_{steel} := 7850 \frac{kg}{m^3}$

ANTICORROSION COATING THICKNESS: $t_{ac} := 5mm$

ANTICORROSION COATING DENSITY: $\rho_{ac} := 1400 \frac{kg}{m^3}$

CONCRETE COATING THICKNESS: $t_{coat} := 176mm$

DENSITY OF CONCRETE COATING: $\rho_{coat} := 3040 \frac{kg}{m^3}$

CONCRETE SATURATION(%): $S_{conc} := 4$

CONTENT DENSITY: $\rho_{cont} := 0 \frac{kg}{m^3}$

MARINE GROWTH DENSITY: $\rho_{mg} := 1025 \frac{kg}{m^3}$

SEA WATER PARAMETERS

MASS DENSITY OF WATER: $\rho_w := 1025 \frac{kg}{m^3}$

KINEMATIC VISCOSITY OF SEA WATER: $\nu := 1.05 \cdot 10^{(-6)} \frac{m^2}{s}$

SOIL PARAMETERS:

MEAN GRAIN SIZE:	$d_{50} := 0.50mm$
BOTTOM ROUGHNESS PARAMETER:	$z_0 := 4.17 \cdot 10^{(-5)} m$
SOIL FRICTION FACTOR:	$\mu := 0.5$
MARINE GROWTH THICKNESS:	$t_{mg} := 0mm$

ENVIRONMENTAL PARAMETERS:

WATER DEPTH	$d := 10m$
SIGNIFICANT WAVE HEIGHT:	$H_W := 2.5m$
HEIGHT ABOVE SEABED AT WHICH VELOCITY AND ACCLERATION IS COMPUTED:	$H_Z := 48in$
WAVE PERIOD:	$T_P := 9sec$
STEADY CURRENT VELOCITY:	$V_c := 1 \frac{m}{sec}$
STEADY CURRENT HEIGHT:	$Z_{r1} := d$

CALCULATIONS

AVALIABLE WALL THICKNESS : $t := t - t_{ca} = 20.6\ mm$

HYDRODYNAMIC DIAMETER: $D_{hyd} := OD + 2\cdot(t_{ac} + t_{coat} + t_{mg}) = 1.581\times 10^{3}\ mm$

INTERNAL DIAMETER: $ID := OD - 2\cdot t = 1.178\,m$

ANTICORROSION COATING DIAMETER: $D_{ac} := OD + 2t_{ac} = 1.229\,m$

CONCRETE COATING DIAMETER: $D_{coat} := D_{ac} + 2\cdot t_{coat} = 1.581\,m$

CONTENT MASS: $M_{cont} := \pi\frac{\left(ID^{2}\cdot\rho_{cont}\right)}{4} = 0$

STEEL MASS: $M_{steel} := \frac{\pi\cdot\rho_{steel}\cdot\left(OD^{2} - ID^{2}\right)}{4} = 608.921\ \frac{kg}{m}$

ANTICORROSION COAT MASS: $M_{ac} := \pi\cdot\left(D_{ac}^{2} - OD^{2}\right)\cdot\frac{\rho_{ac}}{4} = 26.922\ \frac{kg}{m}$

COATING MASS: $M_{coat} := \pi\cdot\left(D_{coat}^{2} - D_{ac}^{2}\right)\cdot\frac{\rho_{coat}}{4} = 2.362\times 10^{3}\ \frac{kg}{m}$

SATURATED MASS: $M_{coatsat} := \left(1 + \frac{S_{conc}}{100}\right)\cdot M_{coat} = 2.456\times 10^{3}\ \frac{kg}{m}$

MARINE GROWTH MASS: $M_{mg} := \pi\cdot\left(D_{hyd}^{2} - D_{coat}^{2}\right)\cdot\frac{\rho_{mg}}{4} = 0\ \frac{kg}{m}$

BOUYANCY $B_{uoy} := \pi\cdot D_{hyd}^{2}\cdot\frac{\rho_{w}}{4} = 2.013\times 10^{3}\ \frac{kg}{m}$

AIR FILLED SUBMERGED WEIGHT:

$$W_{sub\_a} := \left(M_{steel} + M_{ac} + M_{coatsat} + M_{mg} - B_{uoy}\right) \cdot g = 1.059 \times 10^{4} \frac{kg}{s^2}$$

$$W_{sub\_a} = 1.08 \times 10^{3} \cdot \frac{kgf}{m}$$

CONTENT FILLED SUBMERGED WEIGHT:

$$W_{sub} := W_{sub\_a} + M_{cont} \cdot g = 1.059 \times 10^{4} \frac{kg}{s^2}$$

$$W_{sub} = 1.08 \times 10^{3} \cdot \frac{kgf}{m}$$

SPECIFIC GRAVITY CHECK:

$$SG := \frac{\left(W_{sub\_a} + B_{uoy} \cdot g\right)}{B_{uoy} \cdot g} = 1.536$$

STEADY CURRENT VELOCITY , (USING 1/7 TH POWER LAW): (V_M)

SELECTED HEIGHT ABOVE SEA BED: $Z_c := d$

HEIGHT ABOVE SEABED FOR SPECIFIED CURRENT VELOCITY $Z_m := 48in$

$$V_m := \frac{V_c}{\left(\frac{Z_c}{Z_m}\right)^{\left(\frac{1}{7}\right)}} = 0.74 \frac{m}{s}$$

$$V_m = 0.74 \frac{m}{s}$$

DESIGN WAVE PREDICTION USING WAVE THEORY:

AFTER PLOTTING

$\frac{H_W}{g \cdot T_P^2}$ **VERSUS** $\frac{d}{g \cdot T_P^2}$ GRAPH

WE GET WHICH THEORY TO FOLLOW

IN THIS CASE IT LIES IN **AIRY'S REGION**

DEEP WATER WAVELENGTH: $L_{DWW} := g \cdot \frac{T_P^2}{2 \cdot \pi} = 126.423 \cdot m$

LET $X := \frac{d}{L_{DWW}} = 0.079$

CORRESPONDINGLY THE VALUE OF $\frac{d}{L_{SWD}} = \cdot 0.1223$ **(FROM TABLE)**

WAVE LENGTH AT SPECIFIED WATER DEPTH

$L_{SWD} := \frac{d}{0.1223} = 81.766 m$

LET $S := \frac{d}{g \cdot T_P^2} = 0.013$

CHECK := **if** (**S** < 0.8, "IT IS NOT DEEP WATER SITUATION" , "DEEP WATER SITUATION")

CHECK = "IT IS NOT DEEP WATER SITUATION"

MAXIMUM HORIZONTAL INDUCED VELOCITY:

$$U_M := H_W \cdot \frac{L_{SWD}}{2 \cdot T_P \cdot d} = 1.136 \frac{m}{s}$$

HORIZONTAL PARTICLE ACCLERATION:

$$A_M := 2 \cdot \pi \cdot \frac{U_M}{T_P} = 0.793 \frac{m}{s^2}$$

HYDRODYNAMIC COEFFICIENTS:

$$Re := V_m \cdot \frac{D_{hyd}}{\nu} = 1.115 \times 10^6$$

CURRENT TO WAVE RATIO:

$$M := \frac{V_m}{U_M} = 0.652$$

LOAD PARAMETER:

$$K_L := V_m \cdot \frac{T_P}{D_{hyd}} = 4.214$$

DRAG COEFFICIENT:

if Re<3000000 AND M>=0.8, OTHERWISE

$$C_D := \text{if}(Re < 300000, 1.2, 0.7)$$

$$C_D = 0.7$$

LIFT FORCE COEFFICIENT:

$$C_L := 0.8$$

DRAG FORCE:

$$V := V_m + 0.7U_M = 1.535\,\frac{m}{s}$$

$$F_D := 0.5 \cdot \rho_w \cdot C_D \cdot OD \cdot V^2 = 1.031 \times 10^3\,\frac{kg}{s^2}$$

INERTIA FORCE: $C_I := 3.29$ FOR PIPE

$$F_I := \pi \cdot OD^2 \cdot \rho_w \cdot C_I \cdot \frac{A_M}{4} = 3.121 \times 10^3\,\frac{kg}{s^2}$$

LIFT FORCE:

$$F_L := 0.5 \cdot \rho_w \cdot C_L \cdot OD \cdot V^2 = 1.178 \times 10^3\,\frac{kg}{s^2}$$

STABILITY CRITERIA:

$$FS := (W_{sub} - F_L) \cdot \frac{\mu}{(F_D + F_I)} = 1.133$$

$$CHECK_{STABILITY} := \text{if}(FS > 1.1, \text{"STABLE"}, \text{"UNSTABLE"})$$

$$CHECK_{STABILITY} = \text{"STABLE"}$$

On Bottom Stability Analysis of 24" Pipeline

INPUT DATA

PIPELINE PARAMETERS:

STEEL PIPE OUTER DIAMETER: $OD := 24in$

WALL THICKNESS: $t := 19.05mm$

CORROSION ALLOWANCE $t_{ca} := 0mm$

DENSITY OF STEEL: $\rho_{steel} := 7850 \frac{kg}{m^3}$

ANTICORROSION COATING THICKNESS: $t_{ac} := 5mm$

ANTICORROSION COATING DENSITY: $\rho_{ac} := 1400 \frac{kg}{m^3}$

CONCRETE COATING THICKNESS: $t_{coat} := 80mm$

DENSITY OF CONCRETE COATING: $\rho_{coat} := 3040 \frac{kg}{m^3}$

CONCRETE SATURATION(%): $S_{conc} := 4$

CONTENT DENSITY: $\rho_{cont} := 0 \frac{kg}{m^3}$

MARINE GROWTH DENSITY: $\rho_{mg} := 1025 \frac{kg}{m^3}$

SEA WATER PARAMETERS

MASS DENSITY OF WATER: $\rho_w := 1025 \frac{kg}{m^3}$

KINEMATIC VISCOSITY OF SEA WATER: $\nu := 1.05 \cdot 10^{(-6)} \frac{m^2}{s}$

SOIL PARAMETERS:

MEAN GRAIN SIZE:	$d_{50} := 0.50mm$
BOTTOM ROUGHNESS PARAMETER:	$z_0 := 4.17 \cdot 10^{(-5)} m$
SOIL FRICTION FACTOR:	$\mu := 0.5$
MARINE GROWTH THICKNESS:	$t_{mg} := 0mm$

ENVIRONMENTAL PARAMETERS:

WATER DEPTH	$d := 10m$
SIGNIFICANT WAVE HEIGHT:	$H_W := 2.5m$
HEIGHT ABOVE SEABED AT WHICH VELOCITY AND ACCLERATION IS COMPUTED:	$H_Z := 24in$
WAVE PERIOD:	$T_P := 9sec$
STEADY CURRENT VELOCITY:	$V_c := 1 \frac{m}{sec}$
STEADY CURRENT HEIGHT:	$Z_{r1} := d$

CALCULATIONS

AVALIABLE WALL THICKNESS : $t := t - t_{ca} = 19.05 \cdot mm$

HYDRODYNAMIC DIAMETER: $D_{hyd} := OD + 2 \cdot (t_{ac} + t_{coat} + t_{mg}) = 779.6 \cdot mm$

INTERNAL DIAMETER: $ID := OD - 2 \cdot t = 0.571\, m$

ANTICORROSION COATING DIAMETER: $D_{ac} := OD + 2t_{ac} = 0.62\, m$

CONCRETE COATING DIAMETER: $D_{coat} := D_{ac} + 2 \cdot t_{coat} = 0.78\, m$

CONTENT MASS: $M_{cont} := \pi \frac{(ID^2 \cdot \rho_{cont})}{4} = 0$

STEEL MASS: $M_{steel} := \frac{\pi \cdot \rho_{steel} \cdot (OD^2 - ID^2)}{4} = 277.441 \frac{kg}{m}$

ANTICORROSION COAT MASS: $M_{ac} := \pi \cdot (D_{ac}{}^2 - OD^2) \cdot \frac{\rho_{ac}}{4} = 13.516 \frac{kg}{m}$

COATING MASS: $M_{coat} := \pi \cdot (D_{coat}{}^2 - D_{ac}{}^2) \cdot \frac{\rho_{coat}}{4} = 534.519 \frac{kg}{m}$

SATURATED MASS: $M_{coatsat} := \left(1 + \frac{S_{conc}}{100}\right) M_{coat} = 555.9 \frac{kg}{m}$

MARINE GROWTH MASS: $M_{mg} := \pi \cdot \left(D_{hyd}^2 - D_{coat}^2\right) \frac{\rho_{mg}}{4} = 0 \frac{kg}{m}$

BOUYANCY $B_{uoy} := \pi \cdot D_{hyd}^2 \cdot \frac{\rho_w}{4} = 489.28 \frac{kg}{m}$

AIR FILLED SUBMERGED WEIGHT:

$$W_{sub\_a} := \left(M_{steel} + M_{ac} + M_{coatsat} + M_{mg} - B_{uoy}\right) \cdot g = 3.507 \times 10^3 \frac{kg}{s^2}$$

$$W_{sub\_a} = 357.577 \cdot \frac{kgf}{m}$$

CONTENT FILLED SUBMERGED WEIGHT:

$$W_{sub} := W_{sub\_a} + M_{cont} \cdot g = 3.507 \times 10^3 \frac{kg}{s^2}$$

$$W_{sub} = 357.577 \cdot \frac{kgf}{m}$$

SPECIFIC GRAVITY CHECK:

$$SG := \frac{\left(W_{sub\_a} + B_{uoy} \cdot g\right)}{B_{uoy} \cdot g} = 1.731$$

STEADY CURRENT VELOCITY , (USING 1/7 TH POWER LAW): (V_M)

SELECTED HEIGHT ABOVE SEA BED: $Z_c := d$

HEIGHT ABOVE SEABED FOR SPECIFIED CURRENT VELOCITY $Z_m := 48\,in$

$$V_m := \frac{V_c}{\left(\frac{Z_c}{Z_m}\right)^{\left(\frac{1}{7}\right)}} = 0.74\,\frac{m}{s}$$

$$V_m = 0.74\,\frac{m}{s}$$

DESIGN WAVE PREDICTION USING WAVE THEORY:

AFTER PLOTTING

$\frac{H_W}{g \cdot T_P^2}$ **VERSUS** $\frac{d}{g \cdot T_P^2}$ GRAPH

WE GET WHICH THEORY TO FOLLOW

IN THIS CASE IT LIES IN **AIRY'S REGION**

DEEP WATER WAVELENGTH: $L_{DWW} := g \cdot \frac{T_P^2}{2 \cdot \pi} = 126.423 \cdot m$

LET $X := \frac{d}{L_{DWW}} = 0.079$

CORRESPONDINGLY THE VALUE OF $\frac{d}{L_{SWD}} = 0.1223$, **(FROM TABLE)**

WAVE LENGTH AT SPECIFIED WATER DEPTH

$$L_{SWD} := \frac{d}{0.1223} = 81.766\,m$$

LET $S := \frac{d}{g \cdot T_p^{2}} = 0.013$

CHECK := **if** (**S** < 0.8, "IT IS NOT DEEP WATER SITUATION" , "DEEP WATER SITUATION")

CHECK = "IT IS NOT DEEP WATER SITUATION"

MAXIMUM HORIZONTAL INDUCED VELOCITY:

$$U_M := H_W \cdot \frac{L_{SWD}}{2 \cdot T_p \cdot d} = 1.136\,\frac{m}{s}$$

HORIZONTAL PARTICLE ACCLERATION:

$$A_M := 2 \cdot \pi \cdot \frac{U_M}{T_p} = 0.793\,\frac{m}{s^2}$$

HYDRODYNAMIC COEFFICIENTS: $Re := V_m \cdot \frac{D_{hyd}}{\nu} = 5.497 \times 10^5$

CURRENT TO WAVE RATIO: $M := \frac{V_m}{U_M} = 0.652$

LOAD PARAMETER: $K_L := V_m \cdot \frac{T_P}{D_{hyd}} = 8.547$

DRAG COEFFICIENT:

if Re<3000000 AND M>=0.8, OTHERWISE

$C_D :=$ if(Re < 300000, 1.2, 0.7)

$C_D = 0.7$

LIFT FORCE COEFFICIENT:

$C_L := 0.8$

DRAG FORCE:

$$V := V_m + 0.7U_M = 1.535\,\frac{m}{s}$$

$$F_D := 0.5\cdot\rho_W\cdot C_D\cdot OD\cdot V^2 = 515.495\,\frac{kg}{s^2}$$

INERTIA FORCE:

$C_I := 3.29$ FOR PIPE

$$F_I := \pi\cdot OD^2\cdot\rho_W\cdot C_I\cdot\frac{A_M}{4} = 780.329\,\frac{kg}{s^2}$$

LIFT FORCE:

$$F_L := 0.5\cdot\rho_W\cdot C_L\cdot OD\cdot V^2 = 589.138\,\frac{kg}{s^2}$$

STABILITY CRITERIA:

$$FS := \left(W_{sub} - F_L\right)\cdot\frac{\mu}{\left(F_D + F_I\right)} = 1.126$$

$CHECK_{STABILITY}$:= if (FS > 1.1, "STABLE", "UNSTABLE")

$CHECK_{STABILITY}$ = "STABLE"

On Bottom Stability Analysis of 14" Pipeline

INPUT DATA

PIPELINE PARAMETERS:

STEEL PIPE OUTER DIAMETER:	$OD := 14in$
WALL THICKNESS:	$t := 15.88mm$
CORROSION ALLOWANCE	$t_{ca} := 0mm$
DENSITY OF STEEL:	$\rho_{steel} := 7850 \frac{kg}{m^3}$
ANTICORROSION COATING THICKNESS:	$t_{ac} := 5mm$
ANTICORROSION COATING DENSITY:	$\rho_{ac} := 1400 \frac{kg}{m^3}$
CONCRETE COATING THICKNESS:	$t_{coat} := 56mm$
DENSITY OF CONCRETE COATING:	$\rho_{coat} := 3040 \frac{kg}{m^3}$
CONCRETE SATURATION(%):	$S_{conc} := 4$
CONTENT DENSITY:	$\rho_{cont} := 0 \frac{kg}{m^3}$
MARINE GROWTH DENSITY:	$\rho_{mg} := 1025 \frac{kg}{m^3}$

SEA WATER PARAMETERS

MASS DENSITY OF WATER:	$\rho_w := 1025 \frac{kg}{m^3}$
KINEMATIC VISCOSITY OF SEA WATER:	$\nu := 1.05 \cdot 10^{(-6)} \frac{m^2}{s}$

SOIL PARAMETERS:

MEAN GRAIN SIZE: $d_{50} := 0.50\mathrm{mm}$

BOTTOM ROUGHNESS PARAMETER: $z_0 := 4.17 \cdot 10^{(-5)}\mathrm{m}$

SOIL FRICTION FACTOR: $\mu := 0.5$

MARINE GROWTH THICKNESS: $t_{mg} := 0\mathrm{mm}$

ENVIRONMENTAL PARAMETERS:

WATER DEPTH $d := 10\mathrm{m}$

SIGNIFICANT WAVE HEIGHT: $H_W := 2.5\mathrm{m}$

HEIGHT ABOVE SEABED AT WHICH VELOCITY AND ACCLERATION IS COMPUTED: $H_Z := 14\mathrm{in}$

WAVE PERIOD: $T_p := 9\mathrm{sec}$

STEADY CURRENT VELOCITY: $V_c := 1\,\frac{\mathrm{m}}{\mathrm{sec}}$

STEADY CURRENT HEIGHT: $Z_{r1} := d$

CALCULATIONS

AVALIABLE WALL THICKNESS : $t := t - t_{ca} = 15.88 \cdot mm$

HYDRODYNAMIC DIAMETER: $D_{hyd} := OD + 2 \cdot (t_{ac} + t_{coat} + t_{mg}) = 477.6 \cdot mm$

INTERNAL DIAMETER: $ID := OD - 2 \cdot t = 0.324 m$

ANTICORROSION COATING DIAMETER: $D_{ac} := OD + 2t_{ac} = 0.366 m$

CONCRETE COATING DIAMETER: $D_{coat} := D_{ac} + 2 \cdot t_{coat} = 0.478 m$

CONTENT MASS: $M_{cont} := \pi \frac{(ID^2 \cdot \rho_{cont})}{4} = 0$

STEEL MASS: $M_{steel} := \frac{\pi \cdot \rho_{steel} \cdot (OD^2 - ID^2)}{4} = 133.043 \frac{kg}{m}$

ANTICORROSION COAT MASS: $M_{ac} := \pi \cdot (D_{ac}{}^2 - OD^2) \cdot \frac{\rho_{ac}}{4} = 7.93 \frac{kg}{m}$

COATING MASS: $M_{coat} := \pi \cdot (D_{coat}{}^2 - D_{ac}{}^2) \cdot \frac{\rho_{coat}}{4} = 225.482 \frac{kg}{m}$

SATURATED MASS: $M_{coatsat} := \left(1 + \frac{S_{conc}}{100}\right) \cdot M_{coat} = 234.501 \frac{kg}{m}$

MARINE GROWTH MASS: $M_{mg} := \pi \cdot (D_{hyd}{}^2 - D_{coat}{}^2) \cdot \frac{\rho_{mg}}{4} = 0 \frac{kg}{m}$

BOUYANCY $B_{uoy} := \pi \cdot D_{hyd}{}^2 \cdot \frac{\rho_w}{4} = 183.629 \frac{kg}{m}$

AIR FILLED SUBMERGED WEIGHT:

$$W_{sub\_a} := \left(M_{steel} - M_{ac} + M_{coatsat} + M_{mg} - B_{uoy}\right) \cdot g = 1.881 \times 10^{3}\,\frac{kg}{s^{2}}$$

$$W_{sub\_a} = 191.845 \cdot \frac{kgf}{m}$$

CONTENT FILLED SUBMERGED WEIGHT:

$$W_{sub} := W_{sub\_a} + M_{cont} \cdot g = 1.881 \times 10^{3}\,\frac{kg}{s^{2}}$$

$$W_{sub} = 191.845 \cdot \frac{kgf}{m}$$

SPECIFIC GRAVITY CHECK: $SG := \dfrac{\left(W_{sub\_a} + B_{uoy} \cdot g\right)}{B_{uoy} \cdot g} = 2.045$

STEADY CURRENT VELOCITY , (USING 1/7 TH POWER LAW): (V_M)

SELECTED HEIGHT ABOVE SEA BED: $Z_c := d$

HEIGHT ABOVE SEABED FOR SPECIFIED CURRENT VELOCITY $Z_m := 14in$

$$V_m := \frac{V_c}{\left(\dfrac{Z_c}{Z_m}\right)^{\left(\frac{1}{7}\right)}} = 0.621\,\frac{m}{s}$$

$$V_m = 0.621\,\frac{m}{s}$$

DESIGN WAVE PREDICTION USING WAVE THEORY:

AFTER PLOTTING

$$\frac{H_W}{g \cdot T_P^2} \quad \textbf{VERSUS} \quad \frac{d}{g \cdot T_P^2}$$

GRAPH

WE GET WHICH THEORY TO FOLLOW

IN THIS CASE IT LIES IN **AIRY'S REGION**

DEEP WATER WAVELENGTH:

$$L_{DWW} := g \cdot \frac{T_P^2}{2 \cdot \pi} = 126.423 \cdot m$$

LET $$X := \frac{d}{L_{DWW}} = 0.079$$

CORRESPONDINGLY THE VALUE OF $$\frac{d}{L_{SWD}} = \blacksquare \cdot 0.1223$$ **(FROM TABLE)**

WAVE LENGTH AT SPECIFIED WATER DEPTH

$$L_{SWD} := \frac{d}{0.1223} = 81.766 m$$

LET $$S := \frac{d}{g \cdot T_P^2} = 0.013$$

CHECK := **if** (**S** < 0.8, "IT IS NOT DEEP WATER SITUATION" , "DEEP WATER SITUATION")

CHECK = "IT IS NOT DEEP WATER SITUATION"

MAXIMUM HORIZONTAL INDUCED VELOCITY:

$$U_M := H_W \cdot \frac{L_{SWD}}{2 \cdot T_P \cdot d} = 1.136 \frac{m}{s}$$

HORIZONTAL PARTICLE ACCLERATION:

$$A_M := 2 \cdot \pi \cdot \frac{U_M}{T_P} = 0.793 \frac{m}{s^2}$$

HYDRODYNAMIC COEFFICIENTS: $Re := V_m \cdot \frac{D_{hyd}}{\nu} = 2.824 \times 10^5$

CURRENT TO WAVE RATIO: $M := \frac{V_m}{U_M} = 0.547$

LOAD PARAMETER: $K_L := V_m \cdot \frac{T_P}{D_{hyd}} = 11.7$

DRAG COEFFICIENT:

if Re<3000000 AND M>=0.8, OTHERWISE

$$C_D := \text{if}(Re < 300000, 1.2, 0.7)$$

$$C_D = 1.2$$

LIFT FORCE COEFFICIENT: $C_L := 0.8$

<u>DRAG FORCE:</u> $V := V_m + 0.7U_M = 1.416\,\frac{m}{s}$

$$F_D := 0.5\cdot\rho_w\cdot C_D\cdot OD\cdot V^2 = 438.376\,\frac{kg}{s^2}$$

<u>INERTIA FORCE:</u> $C_I := 3.29$ FOR PIPE

$$F_I := \pi\cdot OD^2\cdot\rho_w\cdot C_I\cdot\frac{A_M}{4} = 265.529\,\frac{kg}{s^2}$$

<u>LIFT FORCE:</u> $F_L := 0.5\cdot\rho_w\cdot C_L\cdot OD\cdot V^2 = 292.251\,\frac{kg}{s^2}$

STABILITY CRITERIA: $FS := \left(W_{sub} - F_L\right)\cdot\frac{\mu}{\left(F_D + F_I\right)} = 1.129$

$CHECK_{STABILITY} :=$ if(FS > 1.1, "STABLE", "UNSTABLE")

$CHECK_{STABILITY} =$ "STABLE"

CHAPTER 7

CONCLUSION:

The present work is aimed at On Bottom Stability analysis of a 48'' crude oil line and a 14''and 28'' product line between two fixed platforms in a given offshore field. The pipe design parameters, the environmental conditions and the fluid properties used in this work are same as that used in recently completed project at PL Engineering of which the given pipeline was part of.

1. Pipe Wall Thickness Analysis

Pipe Size (inch)	Service	Grade	Wall Thickness (mm)		Remarks
			Specified	Calculated	
48	Crude Oil	X 65	20.60	20.6	OK (note-a)
24	Naphtha	X 65	19.05	11.9	OK
24	Motor Spirit	X 65	19.05	11.9	OK
24	Kerosene/Jet Fuel	X 65	19.05	11.9	OK
14	Diesel	X 65	15.88	8.7	OK

Note:

a) Buckle Arrester may be required for water depth above 30m w.r.t. CD.

2. Pipeline Stability Analysis

a. Concrete Weight Coating Requirement

Pipe Size (inch)	Service	WT (mm)	Required Concrete Weight Coating Thickness (mm)	Remarks
			Shore Approach (WD < 10m)	Refer Notes
48	Crude Oil	20.60	176	OK
24	Naphtha	19.05	80	OK
24	Motor Spirit	19.05	80	OK
24	Kerosene/Jet Fuel	19.05	80	OK
14	Diesel	15.88	56	OK

Note:

a) The lateral stability analysis has been carried out for Installation Condition, by assuming no wave sheltering effect (due to trenching- at time of Installation) is present. Considering the fact that Five (05) Pipeline Segments are being planned to be laid in a single trench, that trench width would be large enough to justify the above mentioned assumption.

b) The more detailed stability analysis is required to be done to finalize the exact CWC thickness at both subsea portions as well as shore approach area. The above mentioned CWC thickness values for subsea portion are varying due to different water depths along the pipeline route. More information related to Environmental Conditions (wave & current data, their headings/directions details etc.) at various water depths would be required for full fledge analysis.

c) The Shore Approach Area has been considered as portion falling within water depth of 0m to 10m which forms approx. 700m portion from the Land Fall Point.

REFERENCES:

1) ***Introduction to offshore pipelines and risers: J P Kenny.***

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