ANALYSIS OF SOIL-PIPELINE INTERACTION

AND

IT'S STABILITY IN OFFSHORE PIPELINE'S

BY

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ANALYSIS OF SOIL-PIPELINE INTERACTION ANS IT'S STABILITY IN OFFSHORE PIPELINE'S

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By

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CERTIFICATE

This is to certify that the work contained in this thesis titled "**ANALYSIS OF SOIL-PIPELINE INTERACTION AND IT'S STABILITY IN OFFSHORE PIPELINE'S**" has been carried out by **NAGAARJUN.S** under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Subsea pipeline on-bottom stability comprises both lateral and vertical stability design throughout the pipeline's operational design life.

The analysis is carried out to determine the minimum thickness of concrete of specified unit weight required for pipeline stability under installation, hydrotest and operating conditions

It has found out that a combination of 40 mm and 50 mm of concrete thickness is efficient for the stability of selected pipelines.

ACKNOWLEDGEMENT

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I also thank my teaching, non-teaching faculties and friends who have given their valuable suggestion to bring out this project in a successful manner and also thank my parents for their encouragement and support to complete this project.

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NOMENCLATURE

A_p	=	Pipe outer area including coating.
A_w	=	Orbital semi-diameter of water particles.
b	=	Pipe buoyancy per unit length.
d	=	Water depth.
d_{50}	=	Mean grain size.
D	=	Pipe outer diameter including all coating.
g	=	Acceleration of gravity (9.81m/s_2).
G	=	Transfer function.
G_c	=	Soil (clay) strength parameter .
Gs	=	Soil (sand) density parameter .
F_Y	=	Horizontal hydrodynamic (drag and inertia) load.
F_Z	=	Vertical hydrodynamic (lift) load.
F_R	=	Passive soil resistance.
F_C	=	Vertical contact force between pipe and soil
H_s	=	Significant wave height during a sea state.
$H*$	=	Maximum wave height during a sea state.
K_b	=	Equivalent sand roughness parameter = $2.5 \cdot d_{50}$.
k	=	Wave number.
k_T	=	Ratio between period of single design oscillation and design spectrum .
k_U	=	Ratio between oscillatory velocity amplitude of single design oscillation and spectrum.
k_V	=	Ratio between steady velocity component applied with single design oscillation and with design spectrum.
K	=	Significant Keulegan-Carpenter number.
$K*$	=	Keulegan-Carpenter number for single design oscillation.
L	=	Significant weight parameter.
$L*$	=	Weight parameter related to single design oscillation
M	=	Steady to oscillatory velocity ratio for design spectrum.
$M*$	=	Steady to oscillatory velocity ratio for single design oscillation $V* /U*$.

r_{tot} = Load reduction factor.

r_{pen} = Load reduction factor due to penetration.

r_{tr} = Load reduction factor due to trench.

r_{perm} = Load reduction factor due to a permeable seabed.

R_D = Reduction factor due to spectral directionality and spreading.

s = Spectral spreading exponent.

s_g = Pipe specific density .

s_u = Un-drained clay shear strength.

s_s = Relative grain density.

$S_{\eta\eta}$ = Wave spectral density

T_u = Spectrally derived mean zero up-crossing period.

T_p = Peak period for design spectrum.

T_n = Reference period .

T^* = Period associated with single design oscillation.

U_w = Wave induced water particle velocity.

U_s = Spectrally derived oscillatory velocity (significant amplitude) for design spectrum, perpendicular to pipeline.

$U_{s\theta}$ = Spectrally derived oscillatory velocity (significant amplitude) for design spectrum, at an angle θ to the pipeline.

U^* = Oscillatory velocity amplitude for single design oscillation, perpendicular to pipeline.

V = Steady current velocity associated with design spectrum, perpendicular to pipeline.

V^* = Steady current velocity associated with design oscillation, perpendicular to pipeline.

w_s = Pipe submerged weight per unit length.

y = Lateral pipe displacement

Y = Non-dimensional lateral pipe displacement.

z = Elevation above sea bed.

z_r = Reference measurement height over sea bed.

z_0 = Bottom roughness parameter.

z_p = Penetration depth.

z_t = Trench depth.

GREEK

α = Generalised Phillips' constant.

μ = Coefficient of friction.

θ = Shields parameter.

θ_c = Angle between current direction and pipe.

θ_w = Angle between wave heading and pipe.

ρ_w = Mass density of water, for sea water normally equal to 1025 kg/m3.

γ_{sc} = Safety factor.

γ_w = Safety factor.

γ_s = Dry unit soil weight. Can be taken as 18 000 N/m3 for clay.

γ'_s = Submerged unit soil weight. For sand normally in the range 7 000 (very loose) to 13 500 N/m3 (very dense).

ϕ_c = Angle of friction, cohesionless soil

τ = Number of oscillations in the design bottom velocity spectrum = T / Tu

τ_s = Shear stress applied from water flow to seabed,

ω = Wave frequency

ω_p = Peak wave frequency

CHAPTER – 1

INTRODUCTION

1.1 GENERAL

A Pipeline system is defined as a pipeline section extending from an inlet point, typically an offshore platform or an onshore compressor station, to an outlet point, typically another platform or an onshore receiver station.

In analysis and design of marine pipelines, on-bottom stability analysis is one of the scopes, besides determination of pipe size and wall thickness, free spanning and corrosion requirement. On-bottom stability analysis is performed to ensure stability of the pipeline when exposed to wave and current forces ant other internal or external loads.

Subsea pipeline on-bottom stability comprises both lateral and vertical stability design throughout the pipeline's operational design life. The analysis is carried out to determine the minimum thickness of concrete of specified unit weight required for pipeline stability under installation, hydrotest and operating conditions.

1.2 OBJECTIVES

The objectives of this study are:

i. To look into the available procedure of pipeline analysis and design
ii. To identify the mechanisms and parameters involved in on-bottom stability of pipeline
iii. To develop a spreadsheet on on-bottom stability in pipeline design
iv. To obtain the stability analysis of a pipeline based on a case study

1.3 SCOPE OF STUDY

The scope of the study is the analysis of a subsea pipeline resting on the sea bed, the forces acting on the pipeline, the parameter which affects the pipeline to be stable or move from its place. The focus will be on on-bottom stability of submarine pipeline based on code DNV-RP-F109: ON BOTTOM STABILITY DESIGN OF SUBMARINE PIPELINE. The data from a balogan project is taken for this case study as input values.

CHAPTER- 2

LITERATURE REVIEW

2.1 A PIPELINE

A pipeline is usually made up of carbon steel. In some cases it may be of carbon manganese, plastic reinforced pipelines. But in any case carbon steel makes best economical choice in the industry, because of their availability and the practices used in the field.

Fig 2.1 : Pipe with corrosion coating

A carbon steel pipeline manufacturing is based upon the code API 5L – SPECIFICATION OF LINE PIPE. Usually pipelines for offshore laying consists corrosion coating on it to reduce the corrosion due to sea water and a concrete coating over it to provide negative buoyancy. The most common loads acts on the pipeline are,

a. Internal pressure
b. External hydrostatic pressure
c. Temperature
d. Bending

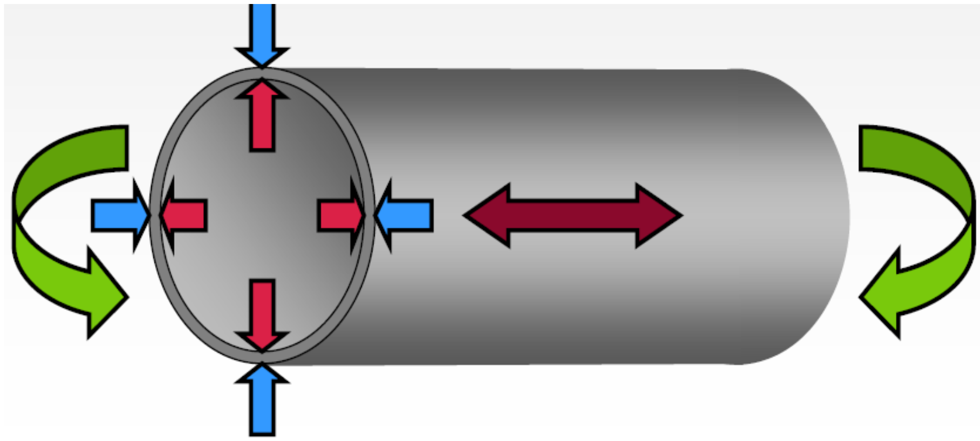

Fig 2.2 : Loads acting on the pipeline

2.2 TYPES OF PIPELINE

The pipelines are classified according to their usage or to be more precise , the stations on either sides.

a. Flow line
b. Gathering line
c. Transmission line
d. Distribution line
e. Service line

The line between the well head and manifold is flow line, the line between the manifold and ggs is called gathering line, the line between the ggs and refinery is transmission line , the line between the refinery and the gas station is distribution line and the line between the gas station and our home is called service line.

2.3 DESIGN OF SUBMARINE PIPELINES

The calculations need to be done for laying submarine pipelines are

- Wall thickness calculation
- Free span calculation
- On-bottom stability calculation
- Corrosion requirement

2.4 ON BOTTOM STABILITY DESIGN AND ANALYSIS

2.4.1 INTRODUCTION

The pipelines laid in the offshore are exposed to waves and current loads which take place in sea. Pipelines are more vulnerable to these loads which even lead to failure of the pipelines.

There is a possibility of lateral and vertical movements of the pipeline due to these loads. To overcome these loads and defects, provision of concrete on the pipeline is more suitable way and the calculation of their requirement is on bottom stability design.

To find out the degree of tolerance can be given for movement of pipeline on the seabed and in the seabed i.e. trenched & buried pipelines, these on bottom stability calculations are more efficient.

2.4.2 CODES AND STANDARDS

The pipeline codes that are used in this project are:

- DNV-OS-F101 SUBMARINE PIPELINE SYSTEMS
- DNV-RP-F109 ON-BOTTOM STABILITY DESIGN OF SUBMARINE PIPELINES
- DNV-RP-F105 FREE SPANNING PIPELINE

2.4.3 METHODS

The purpose of this section is to provide design methods and acceptance criteria for vertical and lateral stability of pipelines. A design equation is presented for vertical stability, i.e. sinking in sea. For lateral on-bottom stability, three design methods are presented in detail

- Dynamic lateral stability analysis
- A Generalised lateral stability method based on data base results from dynamic analyses/simulation
- An absolute lateral static stability method

The dynamic lateral stability analysis gives general requirements to a time domain simulation of pipe response, including hydrodynamic loads from an irregular sea-state and soil resistance forces.

The generalized lateral stability method and the absolute lateral static stability method give detailed specific design results for two approaches to stability design.

The generalized lateral stability method is based on an allowance displacement in a design spectrum of oscillatory wave induced velocities perpendicular to the pipeline at the pipeline level. The design spectrum is characterized by spectrally derived characteristics U_s (oscillatory velocity), T_u (period)and the associated steady current velocity V. As a special case a "virtually stable" case is considered whereby the displacement is limited to about one half piope diameter and is such that it does not reduce the soil resistance and the displacement do not increase no matter how long the sea-state is applied for.

The absolute lateral static stability method is a "design wave" approach, i.e. it ensures absolute static stability for a single design (extreme) wave-induced oscillation. The design oscillation is characterized by oscillatory velocity amplitude U* and period T* and the associated steady component V*. Often V*=V, however some hydrodynamic models account for a local mean velocity V* within a wave-induced oscillation and this may be different to the overall mean velocity V.

2.4.4 DESIGN CONDITIONS

The following design conditions are identified for on-bottom stability analysis of the subsea pipeline:

- Installation
- Hydrotest
- Operation

The installation condition refers to the conditions applicable to the pipelines during its installation phase, when the pipeline is air-filled and on the seabed and subjected to the worst case of the following design storm loading combinations:

- 1-Year significant wave + 1-Year current

The hydrotest condition refers to when the pipeline is water-filled, either on the seabed or trench bottom, and undergoing hydrostatic pressure testing and subjected to the same design storm loadings as for the installation phase stated above.

The operation condition commences when the installation and hydrotest activities are completed and the pipeline is placed in service. The pipeline will then be filled with product and is either on the seabed or trench bottom, subjected to design operating internal pressure and temperature and subjected to the worst case of the following design storm loading combinations:

- 100-Year significant wave + 100-year current

2.5 DESIGN LOADS

2.5.1 FUNCTIONAL LOADS

The functional loads refer to the following loads listed below:

- Self-weight, including pipe, coatings and contents
- Buoyancy effects
- Internal and external pressure
- Pipeline-soil frictional effects

2.5.2 ENVIRONMENTAL LOADS

Environmental load refers to the following loads listed below:

- Hydrodynamic forces (wave and current)
  - ✓ Tidal current
  - ✓ Wind induced current,
  - ✓ Storm surge induced current
  - ✓ Density driven currents

2.5.3 ACCIDENTAL LOADS

Accidental loads are defined which have a low probability of occurrence. For submarine pipelines, such loads may be grouped into the following:

- Natural hazards such as earthquakes and mudslides
- Third party hazards such as dropped objects (near platforms), fishing activities (trawling), shipping (anchoring, sinking) and military activities (firing)

2.5.4 INSTALLATION LOADS

Installation of marine pipelines is to great extent weather dependant, and part of the installation engineering is the determination of the acceptable limits (wind speed, wave height, current) for the installation to take place. Apart from the pipeline self weight and the normal environmental loads, specific actions during installation will mostly be imposed static and dynamic force (from laybarge stingers, tie-in tools, trenching equipment, etc..) The actions are,

- Installation of pipe strings (laying, reeling, towing, pulling)
- Tie-in
- Trenching and backfilling
- Hydrostatic testing

2.6 ON-BOTTOM STABILITY APPROACHES

On-bottom stability may follow one of three distinct approaches:

1) Ensuring absolute stability. This approach is based on force equilibrium that the hydrodynamic loads are less than the soil resistance under a design extreme oscillatory cycle in the sea state considered for design.
2) Ensuring no break-out. This approach allows some small displacements under the largest waves in a sea state. However, maximum displacement is small, less than about one half diameter which ensures that the pipe does not move out its cavity, i.e. the pipe is virtually stable. This approach may take advantage of the buildup of passive resistance during the small displacements that the pipe will experience. There will be no accumulated displacement and maximum can be considered to be independent of time.
3) Allowing accumulated displacement. In this approach one specifies a certain, larger, allowable displacement during the sea state considered in design. The pipe will then several times during the sea state break out of its cavity and the calculated displacement should be assumed to be proportional with time, i.ie. number of waves in the sea state considered. One should also in this context note that the displacement is an accumulated damage and that a sea state less severe than the one considered in design may also move the pipe, i.e. add to the damage.

2.7 VERTICAL PENETRATION AND PIPE-SOIL INTERACTION

For pipe-soil interaction the following functional requirements are need to be considered for the modeling of soil resistance

- The seabed topography along the pipeline route must be represented
- The modeling of soil resistance must account for non-linear contact forces vertical to the pipeline, e.g. lift off.
- The modeling of soil resistance must account for sliding in the axial direction. For force models this also applies in the lateral direction
- Appropriate (different) short- and long-term characteristics for stiffness and damping shall be applied, i.e. static and dynamic stiffness and damping.

The vertical soil penetration is need to find out to ensure the pipe's penetration depth is within the allowable limit i.e. no break out of pipeline in seabed.

CHAPTER-3

METHODOLOGY

3.1 ASSUMPTIONS AND CONSIDERATIONS:

3.1.1 LATERAL STABILITY ANALYSIS CONDITIONS

- Installation conditions:
  - ✓ Pipeline is empty (zero content density)
  - ✓ Pipeline is assumed to be uncorroded (maximum pipe steel weight)
  - ✓ Combination of 1-year RPD significant wave + 1-yearr RPD current are used
  - ✓ 0% water absorption
  - ✓ 5% pipeline embedment due to pipe laying
  - ✓ 0.5% pipeline embedment due to pipe movement

- Hydrotest condition:
  - ✓ Pipeline is filled with water (1025 kg/m^3 content density)
  - ✓ Pipeline is assumed to be uncorroded (zero corrosion allowance)
  - ✓ Combination of 1-year RPD significant wave + 1-year RPD current are used
  - ✓ 0% water absorption
  - ✓ 5% pipeline embedment due to pipe laying
  - ✓ 0.5% pipeline embedment due to pipe movement

- Operating condition:
  - ✓ Pipeline is filled with product of minimum product density (860 Kg/m^3)
  - ✓ 1.6mm corrosion is assumed to be present at end of pipeline design life
  - ✓ Combination of 100-year RPD significant wave + 100-year RPD current are used
  - ✓ 3% water absorption
  - ✓ 7% pipeline embedment due to pipe penetration during design life
  - ✓ 0.5% pipeline embedment due to pipe movement

3.1.2 TRENCH CONDITIONS

- Trench slope angle is assumed to be 14^{o} (1:4 trench ratio) and trench depth of 2.4m to calculate the pipeline hydrodynamic load reduction for trenched sections.
- The soil surface is clay which allows the pipeline to embed and thereby require a 'break-out' force before lateral movement is poosible. In soft clay the embedment will occur primarily during pipelay. Therefore, a calculated embedment of 7% is used for the operation cases.
- The dredged trench bottom surface penetration due to pipe laying is assumed to be 5% of total outside diameter for installation and hydrotest cases.
- Shoaling and refraction is used to determine significant wave height for appropriate water depth for sections with shallow water depth.
- Current calculated using 1/7 power law to get a current at 1 meter reference height

3.2 DESIGN METHODS

3.2.1 VERTICAL STABILITY IN WATER

In order to avoid floatation in water, the submerged weight of the pipeline shall meet the following criterion:

$$\gamma_W \cdot \frac{b}{w_s + b} = \frac{\gamma_W}{s_g} \leq 1.00$$

If a sufficiently low probability of negative buoyancy is not documented, the safety factor as 1.1 can be applied.

3.2.2 VERTICAL STABILITY ON AND IN SOIL

Pipes that are intended to be buried should be checked for possible sinking or floatation. Sinking should be considered with maximum content density, e.g. water filled, and floatation should be considered with minimum density, e.g. air filled.

If the specific weight of the pipe is less than that the soil (including water content), no further analysis is required to document the pipeline's safety against sinking.

To mitigate the possibility for pipeline floatation in liquefied soil, it is highly recommended that the pipeline be water flooded as soon as practicable after the pipeline is laid, and certainly before the pipeline is buried.

3.2.3 VERTICAL SOIL REACTION AND PENETRATION

The contact force per unit length experienced during pipe laying may significantly exceed the static contact force due to the weight of the pipe (typically by a factor 1.3-2.0). Also a simultaneously occurring horizontal force will increase the penetration. This may be accounted for by using bearing capacity formulae adjusted for inclined loading. Repeated horizontal oscillation will tend to further increase the penetration. If the horizontal loading is motion-controlled rather than force-controlled, such effects could be evaluated from empirical results. The bearing capacity factors N_c , N_q , N_g versus the internal friction angle φ_s may be calculated from the following formulas:

$$N_q = \exp(\text{Л} \tan \varphi_s) \tan^2 (45+ \varphi_s/2)$$

$$N_c = 5.14$$

$$N_\gamma = 1.5 (N_q - 1) \tan \varphi_s$$

For clayey soils the friction angle is set equal to 0^o.

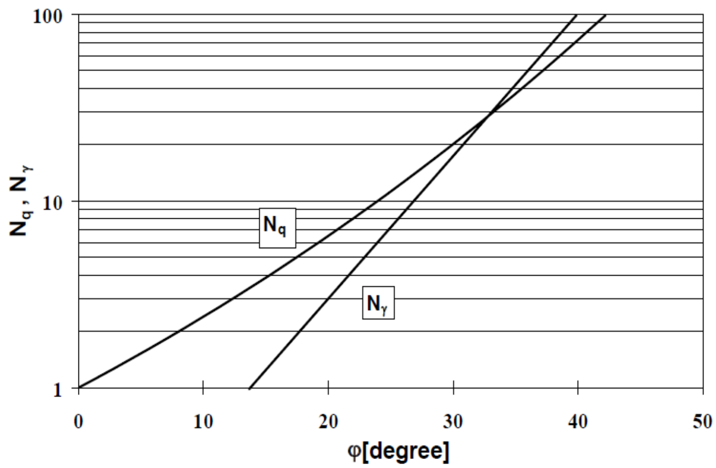

Fig: 3.1 Bearing capacity factors N_c , N_q , N_γ versus the internal friction angle φ_s

3.3 DYNAMIC LATERAL STABILITY ANALYSIS

3.3.1 SHORT TERM WAVE CONDITIONS

The wave induced oscillatory flow condition at the pipe level may be calculated using numerical or analytical wave theories. The wave theory shall be capable of describing the conditions at the pipe location, including effects due to shallow water, if applicable.

The short term, stationary, irregular sea states may be described by a wave spectrum $S_{hh}(w)$ i.e. the power spectral density function of the sea surface elevation. Wave spectral may be given in table form, as measured spectra, or in an analytical form.

For the JONSWAP spectrum, which is often appropriate, the spectral density function reads:

$$S_{\eta\eta}(\omega) = \alpha \cdot g^2 \cdot \omega^{-5} \cdot \exp\left(-\frac{5}{4} \left(\frac{\omega}{\omega_p} \right)^{-4} \right) \cdot \gamma^{\exp\left(-0.5 \left(\frac{\omega - \omega_p}{\sigma \cdot \omega_p} \right)^2 \right)}$$

The generalized phillip's constant is given by:

$$\alpha = \frac{5}{16} \cdot \frac{H_s^2 \cdot \omega_p^4}{g^2} \cdot (1 - 0.287 \cdot \ln \gamma)$$

The spectral width parameter is given by:

$$\sigma = \begin{cases} 0.07 & if \ \omega \leq \omega_p \\ 0.09 & else \end{cases}$$

In lieu of other information, the peak-enhancement factor may be taken as:

$$\gamma = \begin{cases} 5.0 & \varphi \leq 3.6 \\ \exp(5.75 - 1.15\varphi) & 3.6 < \varphi < 5.0; \\ 1.0 & \varphi \geq 5.0 \end{cases} \quad \varphi = \frac{T_p}{\sqrt{H_s}}$$

The wave induced velocity spectrum at the sea bed $S_{uu}(w)$ may be obtained through a spectral transformation of the waves at sea level using a first order wave theory :

$$S_{UU}(\omega) = G^2(\omega) \cdot S_{\eta\eta}(\omega)$$

The transfer function G transforms sea surface elevation to wave induced flow velocities at sea bed and is given by:

$$G(\omega) = \frac{\omega}{\sinh(k \cdot d)}$$

Where d is the water depth and k is the wave number established by iteration from the transcendental equation:

$$\frac{\omega^2}{g} = k \cdot \tanh(k \cdot d)$$

The spectral moments of order n is defined as:

$$M_n = \int_0^{\infty} \omega^n \cdot S_{UU}(\omega) \mathrm{d}\omega$$

Significant flow velocity amplitude at pipe level is:

$$U_s = 2\sqrt{M_0}$$

It is not recommended to consider any boundary layer effect on the wave induced velocity.

Mean zero up-crossing period oscillating flow at pipe level is:

$$T_u = 2\pi \sqrt{\frac{M_0}{M_2}}$$

Assuming linear wave theory, U_s may be taken from figure 3-2 and T_u from figure 3-3 in which:

$$T_n = \sqrt{\frac{d}{g}}$$

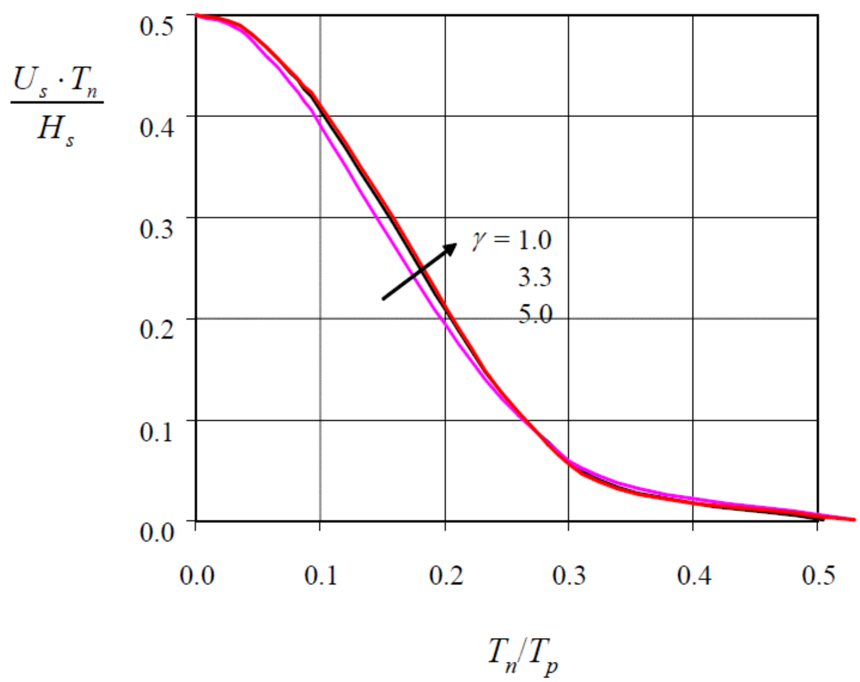

Fig 3.2: Significant flow velocity amplitude U_s at sea bed level

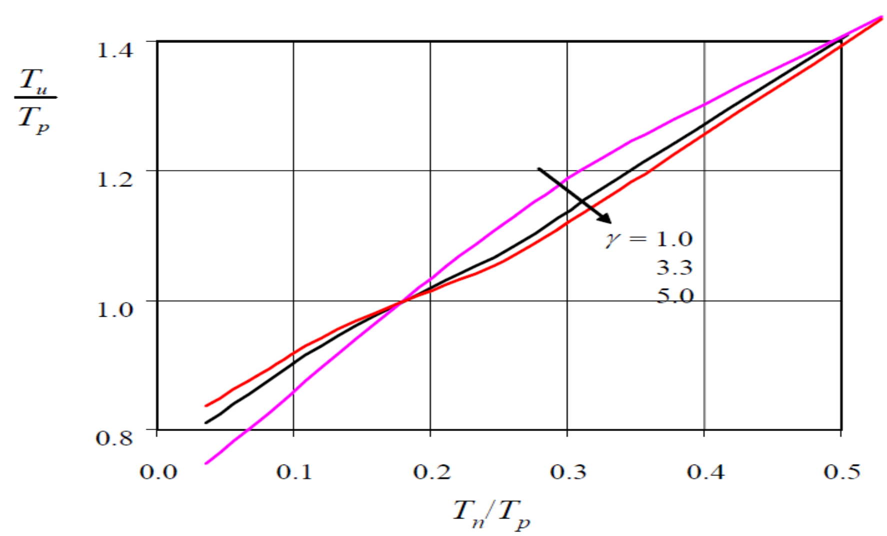

Fig 3.3: Mean zero up-crossing period of oscillating flow T_u at sea bed level

The ratio between the design single oscillation velocity amplitude and the design spectral velocity amplitude for ح oscillation is :

$$k_U = \frac{U^*}{U_s} = \frac{1}{2}\cdot\left(\sqrt{2\cdot\ln\tau} + \frac{0.5772}{\sqrt{2\cdot\ln\tau}}\right)$$

The ratio between design single oscillation velocity period and the average zero up-crossing period (both at seabed level) is site specific. In absence of other data, this can be taken as:

$$k_T = \frac{T^*}{T_u} = \begin{cases} k_t - 5\cdot(k_t - 1)\cdot T_n / T_u & \text{for} \quad T_n / T_u \le 0.2 \\ 1 & \text{for} \quad T_n / T_u > 0.2 \end{cases}$$

$$k_t = \begin{cases} 1.25 & \text{for} \quad \gamma = 1.0 \\ 1.21 & \text{for} \quad \gamma = 3.3 \\ 1.17 & \text{for} \quad \gamma = 5.0 \end{cases}$$

3.3.2 WAVE DIRECTIONALITY AND SPREADING

The effect of main wave directionality and wave spreading is introduced in the form of a reduction factor on the significant flow velocity, i.e. projection onto the velocity normal to the pipe and effect of wave spreading.

$$U_w = R_D\, U_{w\Theta}$$

The reduction factor is given by

$$R_D = \sqrt{\int_{-\pi/2}^{\pi/2} D_w(\theta)\,\mathrm{d}\theta}$$

Where the wave energy spreading directional function is given by a frequency independent cosine power function:

$$D_w = \begin{cases} \dfrac{1}{\sqrt{\pi}} \cdot \dfrac{\Gamma(1+s/2)}{\Gamma(0.5+s/2)} \cdot \cos^s \theta \cdot \sin^2(\theta_w - \theta) & |\theta| < \dfrac{\pi}{2} \\ 0 & \text{else} \end{cases}$$

The angle Θ_w is the angle between wave heading and pipe. S is a site specific spreading parameter

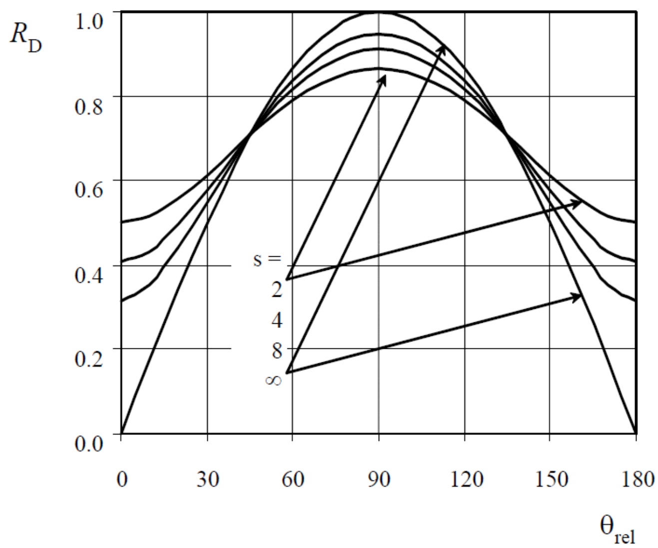

Fig 3.4:Reduction factor due to wave spreading and directionality

3.3.3 DETERMINATION OF CURRENT SPEED VELOCITY

The mean perpendicular current velocity over a pipe diameter applies:

$$V_c = V_c(z_r) \cdot \left(\frac{\left(1 + \frac{z_0}{D}\right) \cdot \ln\left(\frac{D}{z_0} + 1\right) - 1}{\ln\left(\frac{z_r}{z_0} + 1\right)} \right) \cdot \sin \theta_c$$

Where, the directionality of the current velocity is accounted for through Θ_c that is the angle between current velocity and the pipeline axis. If information on directionality is unavailable, the current should be assumed to act perpendicular to the pipeline.

The reference current should be measured at a depth where the mean current vary only slightly in the horizontal direction. On a relatively flat seabed, this reference height should be larger than 1m depending on the seabed roughness.

The non-linear interaction between wave and current flow may be accounted for by modification of the steady velocity profile.

3.3.4 STEADY TO OSCILLATORY VELOCITY RATIO OF THE DESIGN SPECTRUM & THE SIGNIFICANT KEULEGAN-CARPENTER NUMBER

The ratio between the product of drag force and period to the characteristic length of the measurement is called keulegan carpenter number

$$M := \frac{V_c}{U_s} \qquad\qquad K_s := \frac{U_s \cdot T_u}{D_{oc}}$$

Peak load coefficients C_y and C_z are taken from the tables and . Load reductions due to a permeable seabed, soil penetration and trenching can be calculated.

C_y		K										
		2.5	5	10	20	30	40	50	60	70	100	$\geq$140
M	0.0	13.0	6.80	4.55	3.33	2.72	2.40	2.15	1.95	1.80	1.52	1.30
	0.1	10.7	5.76	3.72	2.72	2.2	1.90	1.71	1.58	1.49	1.33	1.22
	0.2	9.02	5.00	3.15	2.30	1.85	1.58	1.42	1.33	1.27	1.18	1.14
	0.3	7.64	4.32	2.79	2.01	1.63	1.44	1.33	1.26	1.21	1.14	1.09
	0.4	6.63	3.80	2.51	1.78	1.46	1.32	1.25	1.19	1.16	1.10	1.05
	0.6	5.07	3.3	2.27	1.71	1.43	1.34	1.29	1.24	1.18	1.08	1.00
	0.8	4.01	2.7	2.01	1.57	1.44	1.37	1.31	1.24	1.17	1.05	1.00
	1.0	3.25	2.30	1.75	1.49	1.40	1.34	1.27	1.20	1.13	1.01	1.00
	2.0	1.52	1.50	1.45	1.39	1.34	1.20	1.08	1.03	1.00	1.00	1.00
	5.0	1.11	1.10	1.07	1.06	1.04	1.01	1.00	1.00	1.00	1.00	1.00
	10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 3.1: Peak horizontal load coefficients C_y

C_z		K										
		$\leq$2.5	5	10	20	30	40	50	60	70	100	$\geq$140
M	0.0	5.00	5.00	4.85	3.21	2.55	2.26	2.01	1.81	1.63	1.26	1.05
	0.1	3.87	4.08	4.23	2.87	2.15	1.77	1.55	1.41	1.31	1.11	0.97
	0.2	3.16	3.45	3.74	2.60	1.86	1.45	1.26	1.16	1.09	1.00	0.90
	0.3	1.01	3.25	3.53	2.14	1.52	1.26	1.10	1.01	0.99	0.95	0.90
	0.4	2.87	3.08	3.35	1.82	1.29	1.11	0.98	0.90	0.90	0.90	0.90
	0.6	2.21	2.36	2.59	1.59	1.20	1.03	0.92	0.90	0.90	0.90	0.90
	0.8	1.53	1.61	1.80	1.18	1.05	0.97	0.92	0.90	0.90	0.90	0.90
	1.0	1.05	1.13	1.28	1.12	0.99	0.91	0.90	0.90	0.90	0.90	0.90
	2.0	0.96	1.03	1.05	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	5.0	0.91	0.92	0.93	0.91	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	10	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

Table 3.2: Peak vertical load coefficients C_z

3.3.5 SOIL RESISTANCE

Soil resistance consists in general of two parts:

- pure Coulomb friction part
- passive resistance F_R (due to the build up of soil penetration as the pipe moves laterally)

Sand is here defined as a soil that is permeable and with negligible cohesive effects. The most important parameters for describing pipe sand interaction on sand are the coefficient friction and submerged sand weight. Special considerations should be made if the sand contains a high fraction of calcium carbonate.

Clay is here defined as a soil that is not permeable and with significant cohesive effects. Rock is here defined as crushed rocks with a 50 per cent diameter fractile larger than 50 mm. The coefficient of friction μ can normally, for a concrete coated pipe, be taken as 0.6 on sand, 0.2 on clay and 0.6 on rock.

A model for passive resistance on sand and clay is described below whereas this effect should be neglected on rock. A typical model for passive soil resistance consists of four distinct regions:

- An elastic region where the lateral displacement is less than typically 2% of the pipe diameter.
- A region where significant displacement may be experienced, up to half the pipe diameter for sand and clay soils in which the pipe soil interaction causes an increase in the penetration and thus in the passive soil resistance.
- After break-out where the resistance and penetration decrease.
- When the displacement exceeds typically one pipe diameter, the passive resistance and penetration may be assumed constant.

$$\frac{F_R}{F_C} = \begin{cases} \left(5.0 \cdot \kappa_s - 0.15 \cdot \kappa_s^2\right) \cdot \left(\dfrac{z_p}{D}\right)^{1.25} & \text{if } \kappa_s \leq 26.7 \\ \kappa_s \cdot \left(\dfrac{z_p}{D}\right)^{1.25} & \text{if } \kappa_s > 26.7 \end{cases}$$

$$\kappa_s = \frac{\gamma_s' \cdot D^2}{w_s - F_Z} = \frac{\gamma_s' \cdot D^2}{F_C} \quad , \quad F_C = w_s - F_Z$$

Passive resistance on clay can be taken as

$$\frac{F_R}{F_C} = \frac{4.1 \cdot \kappa_c}{G_C^{\ 0.39}} \cdot \left(\frac{z_p}{D} \right)^{1.31}$$

$$G_C = \frac{s_u}{D \cdot \gamma_s} \qquad\qquad \kappa_c = \frac{s_u \cdot D}{w_s - F_Z} = \frac{s_u \cdot D}{F_C}$$

It must be documented that the soil parameters used in the calculation of passive resistance are valid within the actual pipe penetration. Total penetration can be taken as the sum of initial penetration and penetration due to pipe movement:

$$Z_p = Z_{pi} + Z_{pm}$$

Initial penetration on sand can be taken as

$$\frac{z_{pi}}{D} = 0.037 \cdot \kappa_s^{\ -0.67}$$

Initial penetration on clay can be taken as

$$\frac{z_{pi}}{D} = 0.0071 \cdot \left(\frac{G_c^{0.3}}{\kappa_c} \right)^{3.2} + 0.062 \cdot \left(\frac{G_c^{0.3}}{\kappa_c} \right)^{0.7}$$

It must be documented that the soil parameters used in the calculation of passive resistance are valid within the actual pipe penetration. Total penetration can be taken as the sum of

- initial penetration due to self weight
- piping
- penetration due dynamics during laying and
- penetration due to pipe movement under the action of waves and current.

PIPING

Piping is here defined as a phenomenon where a layer of sand is moved from its position immediately under the pipeline due to the hydrodynamic pressure difference on each side of the pipeline. This will lower the pipe and the increased resistance may be accounted for in stability design. A clay layer will prevent piping.

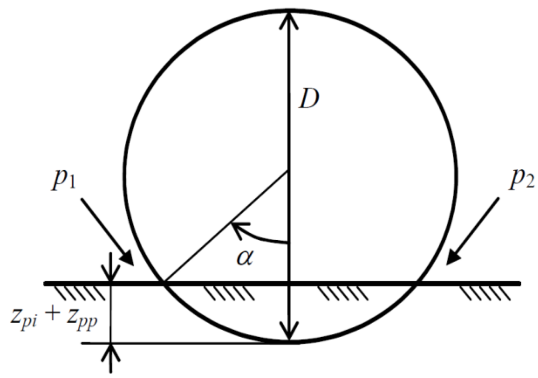

Fig 3.5:piping parameter

3.4 ABSOLUTE LATERAL STATIC STABILITY METHOD

3.4.1 LOAD REDUCTION DUE TO PIPE-SOIL INTERACTION

The hydrodynamic loads may be reduced due:

- Permeable seabed $r_{\mathrm{perm,i}}$,
- Pipe penetrating the seabed $r_{\mathrm{pen,i}}$
- Trenching $r_{\mathrm{trench,i}}$

Total load reduction is then:

$$r_{tot,i} = r_{perm,i}\ r_{pen,i}\ r_{tr,i}$$

The subscript "*i*" takes the value *y* for the horizontal load and *z* for the vertical load.

LOAD REDUCTION DUE TO PERMEABLE SEABED

A permeable seabed will allow flow in the seabed underneath the pipe and thus reduce the vertical load. If the vertical hydrodynamic load used in an analysis are based on load coefficients derived from the assumption of a non-permeable seabed, the following load reduction applies:

$$r_{perm,z} = 0.7$$

LOAD REDUCTION DUE TO PENETRATION

Load reduction factors due to penetration are in the horizontal and vertical directions, respectively

$$r_{pen,y} = 1.0 - 1.4 \cdot \frac{z_p}{D}$$

$$r_{pen,z} = 1.0 - 1.3 \cdot \left(\frac{z_p}{D} - 0.1 \right)$$

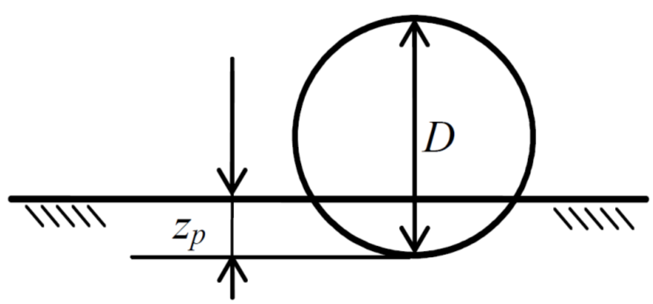

Fig 3.6:Definition of penetration

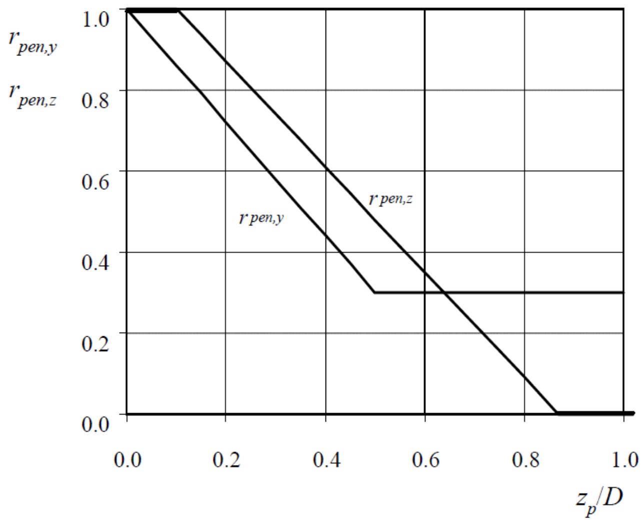

Fig 3.7:Peak load reduction due to penetration

LOAD REDUCTION DUE TO TRENCHING

Load reduction factors due to trenching are in the horizontal and vertical directions, respectively

$$r_{tr,y} = 1.0 - 0.18 \cdot (\theta - 5)^{0.25} \cdot \left(\frac{z_t}{D}\right)^{0.42} \quad , \quad 5 \le \theta \le 45$$

$$r_{tr,z} = 1.0 - 0.14 \cdot (\theta - 5)^{0.43} \cdot \left(\frac{z_t}{D}\right)^{0.46} \quad , \quad 5 \le \theta \le 45$$

The trench depth is to be taken relative to the seabed level at a width not greater than $3 \cdot D$ away from the pipe.

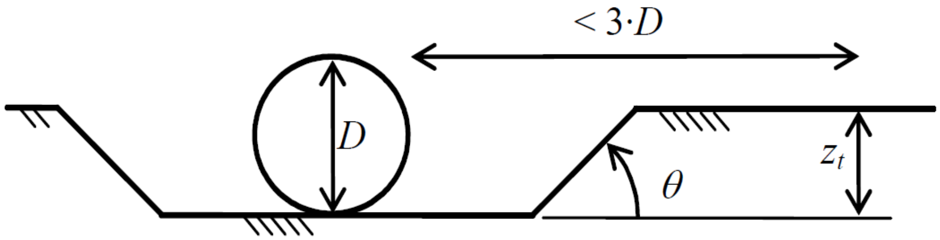

Fig 3.8:Definition of trench parameters

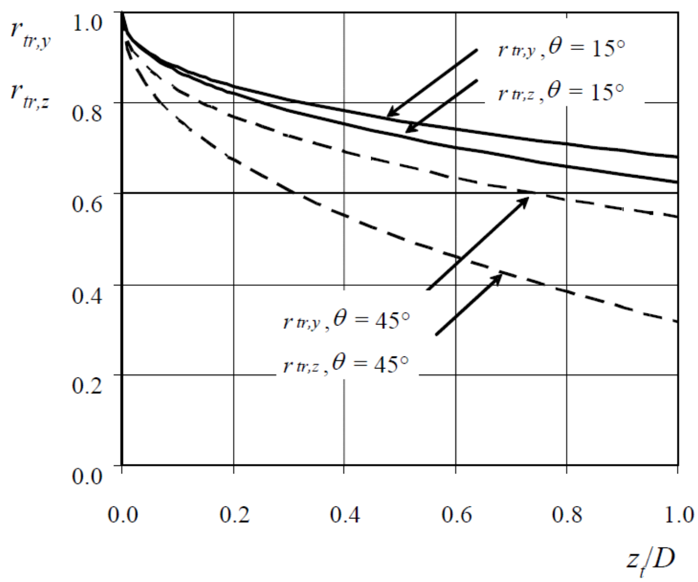

Fig 3.9:Peak load reduction due to trenching

3.4.2 LOADS

Peak horizontal and vertical loads are,

$$F_Y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Y^* \cdot \left(U^* + V^*\right)^2$$

$$F_Z^* = r_{tot,z} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Z^* \cdot \left(U^* + V^*\right)^2$$

3.4.3 DESIGN CRITERION

A pipeline can be considered to satisfy the absolute static stability requirement if:

$$\gamma_{SC} \cdot \frac{F_Y^* + \mu \cdot F_Z^*}{\mu \cdot w_s + F_R} \leq 1.0$$

$$\gamma_{SC} \cdot \frac{F_Z^*}{w_s} \leq 1.0$$

CHAPTER – 4

EXPERIMENTAL DETAILS

4.0 DESIGN DATA

4.1 GENERAL

The design data and parameters utilized in the pipeline on-bottom stability analysis are extracted from Project Design Basis for 12 inch Offshore Pipelines from XAP Platform to LFP Platform of BALONGAN PROJECT, for various water depth, hydrodynamic forces and pipeline condition on seabed.

4.2 DESIGN LIFE

The pipelines shall have a design life of 20 years.

4.3 SAFETY CLASS DESIGNATION

The pipeline system is classified based on location and safety class as shown in Table 4.1

Design condition	**Location class 1**	**Location class 2**
Installation	Low	
Hydrotest	Low	
Operation	Medium	High

Table 4.1 : Classification of safety Classes

4.4 PIPELINE PROCESS DATA

The principle design parameters of the 12-inch pipeline are summarized in Table 4.2

Description	Units	Parameters
Service	-	Oil
Design pressure	Barg	17.2
Max operation pressure	Barg	10.3
Hydrotest pressure	Barg	21.5
Design temperature	^oC	93.3
Maximum operating Temperature	^oC	65.6
Product densities	Kg/m^3	860

Table 4.2 : Pipeline process data

4.5 OFFSHORE PIPELINE MATERIAL PROPERTIES

4.5.1 LINE PIPE MATERIAL PROPERTIES

Line pipe material properties considered in the on-bottom stability analysis are summarized in Table 4.3

Description	Units	Parameters
Steel young's Modulus	GPa	207
Poisson ratio	-	0.3
Density of steel	Kg/m^3	7850
SMYS of steel	MPa	360
SMTS of steel	MPa	460
Coefficient of linear expansion	$/^oC$	1.17×10^{-5}
Steel thermal conductivity	W/m.C	45
Corrosion allowance	Mm	3.175
Pipeline burial condition	-	Buried for WD less than 13m otherwise laid on seabed

Table 4.3: Line pipe material properties

4.5.2 SUBSEA PIPELINE EXTERNAL COATING AND CONCRETE COATING PROPERTIES

3-Layer Polyethylene (3LPE) anti-corrosion coating will be provided for the pipeline. The physical properties of external anti-corrosion coating considered in the design are summarized in Table 4.4.

Concrete weight coating will act to provide negative buoyancy to the pipeline as well as provide mechanical protection to the anti-corrosion coating during installation and pipeline operational life. The external coating and concrete coating properties considered in the on-bottom stability analysis are summarized in Table 4.4 below.

Description	Units	Parameters
External anti-corrosion coating type	-	3LPE
External anti-corrosion coating thickness	mm	3.2
External anti-corrosion coating density	Kg/m^3	932.2
External anti-corrosion coating cutback	Mm	150 +/- 20
Concrete coating density	Kg/m^3	3040
Concrete coating cutback	mm	305 +/- 25
Absorption	%	3-5

Table 4.4: Pipeline coating properties

4.6 ENVIRONMENTAL DATA

4.6.1 BATHYMETRY

Bathymetry, i.e. water depth and seabed profile, is determined using echo sounders. Multi-beam systems towed close to the seabed can be used to produce 3-D images of the seabed.

Swathe bathymetry uses a downward-pointing beam and is good for measuring depths accurately. Sides scan sonar directs the sound beam sideways and downwards, detecting obstructions such as wrecks or pinnacles which may snag anchor wires.

- **Medium resolution**
  - ✓ Single beam echo sounder
  - ✓ Hull mounted
  - ✓ Swathe
  - ✓ 750 m (2460 ft) wide
  - ✓ Corresponding resolution
  - ✓ 8 m (26 ft) footprint size
- **High resolution**
  - ✓ Multi beam
  - ✓ Towed close to seabed
  - ✓ Much narrower swathe

Based on the offshore pipeline alignment sheet the minimum water depth for each section is shown in Table 4.5 below. The minimum WD shown in alignment sheet is assumed at LAT

Parameters		**Units**	**Parameters**
Minimum WD along pipeline route	KP0-KP17	M	14
	KP17-KP19.7		13
	KP19.7-KP23.3		10
	KP23.3-KP26.7		5
	KP26.7-LFP		1.4
Seawater density		Kg/m^3	1025

Table 4.5: Water depth profile

4.6.2 TIDAL DATA

The tidal data from Basis of Design, unless specified otherwise are summarized in Table 4.6 below. Tidal data given are with respect to Chart Datum

Parameters	Units	Return period	
		1year	100 year
Highest Astronomical tide (HAT)	M	0.52	
Mean sea level (MSL)	M	0.0	
Lowest astronomical tide (LAT)	M	-0.47	
Maximum storm surge	M	0.1	0.45

Table 4.6: Tidal data

4.6.3 SEAWATER PARAMETER

Seawater parameter is presented in Table 4.7 below.

Description	Units	Parameters
Seawater density	Kg/m^3	1025
Kinematic viscosity	m (ft)	1.96×10^{-6}
Sea floor temperature		
Maximum	^oC	26.7
Minimum	^oC	15

Table 4.7: Seawater Data

4.6.4 GEOTECHNICAL DATA

The Geotechnical data used is obtained from the Offshore Pipelines Design Basis as listed below on Table 4.8. Dry soil weight assumed to be $16000 N/m^3$

Description	Units	Parameters
Soil type	-	Very soft to very stiff clay
Undrained shear strength	kPa	12.45
Angle of friction	Degree	-
Submerged soil density	N/m^3	14139

Table 4.8: Soil data

4.6.5 Marine Growth

Marine growth has not been considered in on-bottom stability analysis.

4.6.6 Wave Data

The wave and current data extracted from the Offshore Pipelines Design Basis is presented in Table 4.9. Current calculated using 1/7 power law to get current at 1 meter reference height. Shoaling and refraction used for wave height at shallow regions

Item	**Notation**	**Unit**	**Return period**	
			1 year	**100 year**
Maximum individual waves				
Height	H_{max}	m	2.2	5.4
Period	T_{max}	s	5.6	8.7
Length	L_{max}	m	46.7	91.4
Significant wave				
Height	H_s	m	1.2	3
Period	T_s	s	5.5	8
Length	L_s	m	45.8	82.2
Current speed (wind and tide induced)				
0% of Depth	V_0	m/s	0.8	1.22
10% of Depth	V_{10}	m/s	0.69	1.00
20% of Depth	V_{20}	m/s	0.61	0.84
30% of Depth	V_{30}	m/s	0.55	0.72
40% of Depth	V_{40}	m/s	0.51	0.63
50% of Depth	V_{50}	m/s	0.48	0.57
60% of Depth	V_{60}	m/s	0.46	0.52
70% of Depth	V_{70}	m/s	0.44	0.48
80% of Depth	V_{80}	m/s	0.40	0.42
90% of Depth	V_{90}	m/s	0.36	0.38
100% of Depth	V_{100}	m/s	0.32	0.34

Table 4.9: Metocean Data

CHAPTER – 5

ANALYSIS

5.1 INTRODUCTION

The fig 5.1 shows the calculation sheet with input details to find out the vertical penetration depth of a pipeline in offshore. The Input details are according to the conditions.

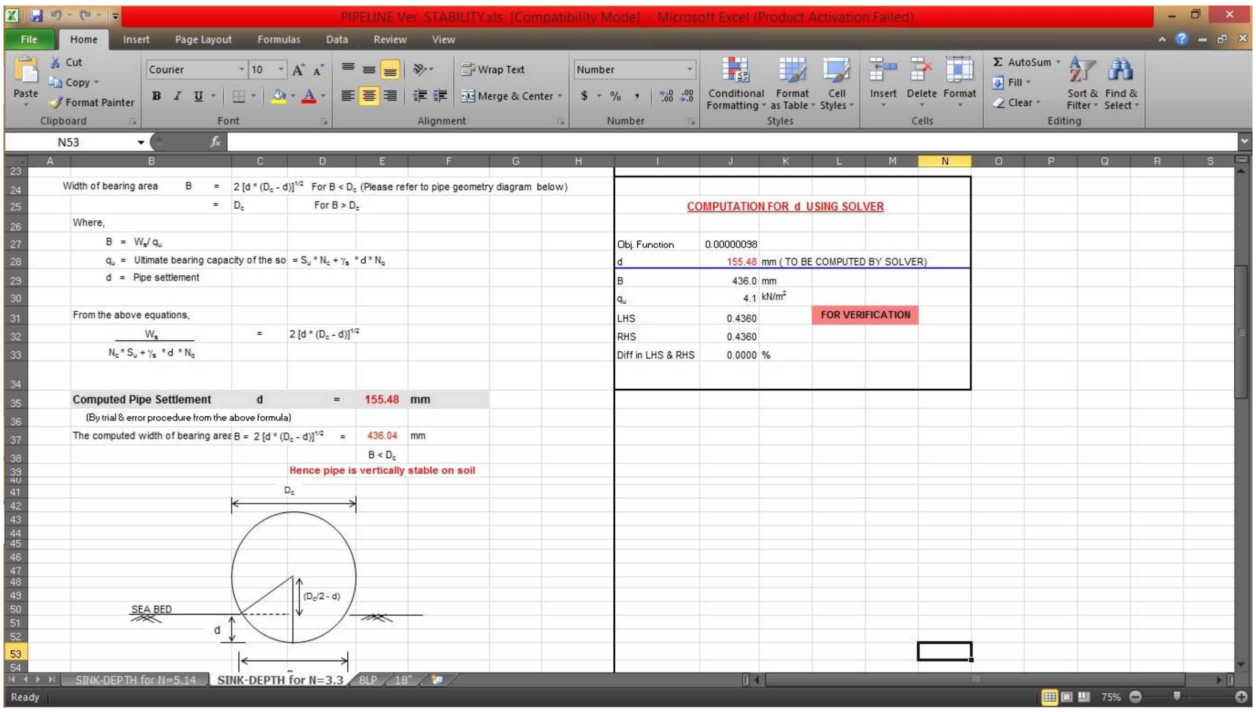

Fig 5.1 : Calculation spread sheet

The vertical penetration depth of the pipeline should be checked for the approval. It is based on DNV-RP-F105 FREE SPANNING OF PIPELINES. The vertical penetration depth should be within half the diameter of the final coated pipeline. In case of sinking, if the maximum submerged specific weight-water filled is greater than specific weight of soil including water then the result of vertical penetration depth should be used as the result for sinking.

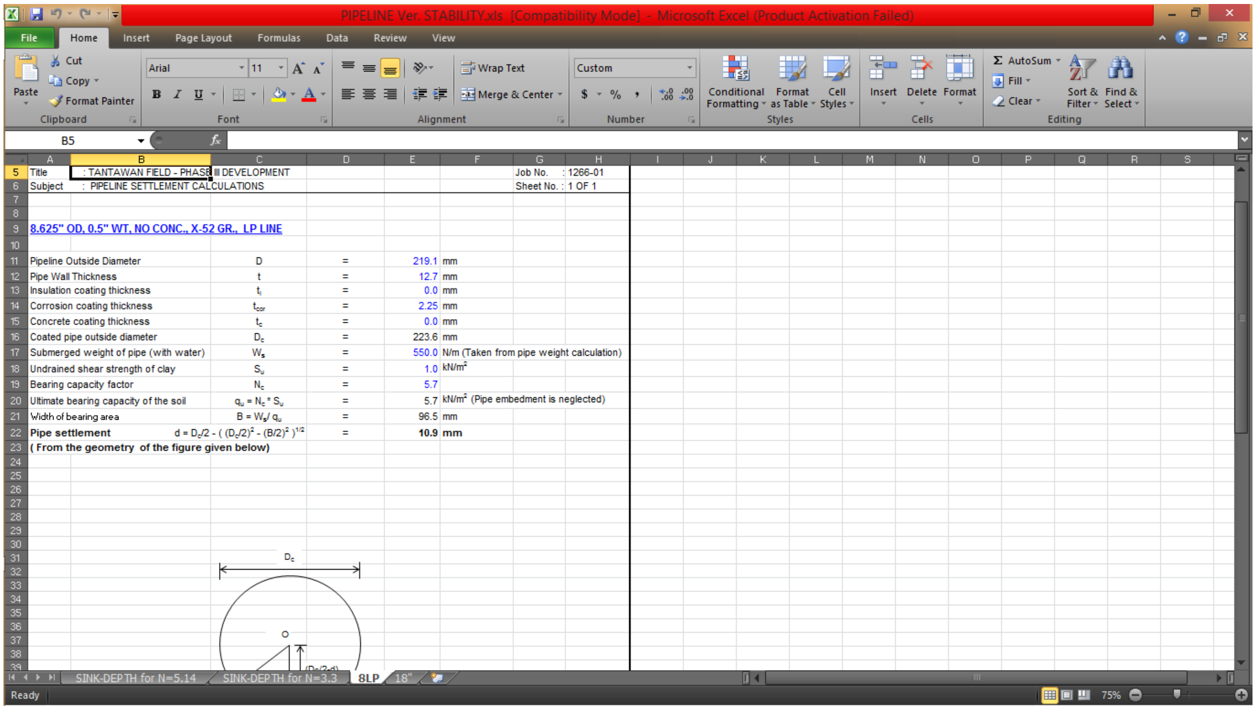

Fig 5.2 : Spread sheet (vertical penetration depth)

CHAPTER - 6

RESULTS AND DISCUSSIONS

6.1 INTRODUCTION

The four major results need to be checked in this on-bottom stability project are

- Submerged weight check
- Vertical soil penetration requirement
- Vertical stability requirement – sinking
- Absolute static stability requirement

6.2 RESULTS

The major results are checked for all conditions, and found for some cases increase in concrete thickness more than DNV-OS-F101 specified minimum concrete thickness is required to get pass.

Submerged Weight Check:

$$\mathbf{w_{sub} = "PASS"}$$

Vertical Soil Penetration Requirement:

$$\mathbf{Soil_{limit} = "PASS"}$$

Vertical stability requirement - No Sinking:

$$\mathbf{Stab_{vertical} = "PASS"}$$

Absolute Static Stability Requirement:

Absolute_Static_Stability_Req = "PASS"

6.3 STABILITY ANALYSIS RESULT

The on-bottom stability analysis has been performed for the 12-inch pipelines in accordance with the requirements of DNV-RP-F109. Based on the analysis results, the minimum concrete thicknesses calculated and the concrete thicknesses selected for the 12-inch pipelines to be stable, both laterally and vertically, are summarized in Table 6.1. Wave attack angle of 60^{o} (south) used near LFP. Water depth at LAT inclusive of trench depth

KP Sections	**Position of Pipe**	**Min WD**	**Installation**	**Hydrotest**	**Operation**	**Selected CWC**
KP0-KP17	Exposed	14m	0mm	0mm	40mm	40mm
KP17-KP19.7	Exposed	13m	0mm	0mm	50mm	50mm
KP19.7-LFP	Post-Trench	5m	49mm	0mm	0mm	50mm
	Pre-Trench	1.4m	50mm	0mm	0mm	

Table 6.1: Concrete coating Thickness Results

6.4 MINIMUM REQUIRED CONCRETE THICKNESS FOR ALL CONDITIONS

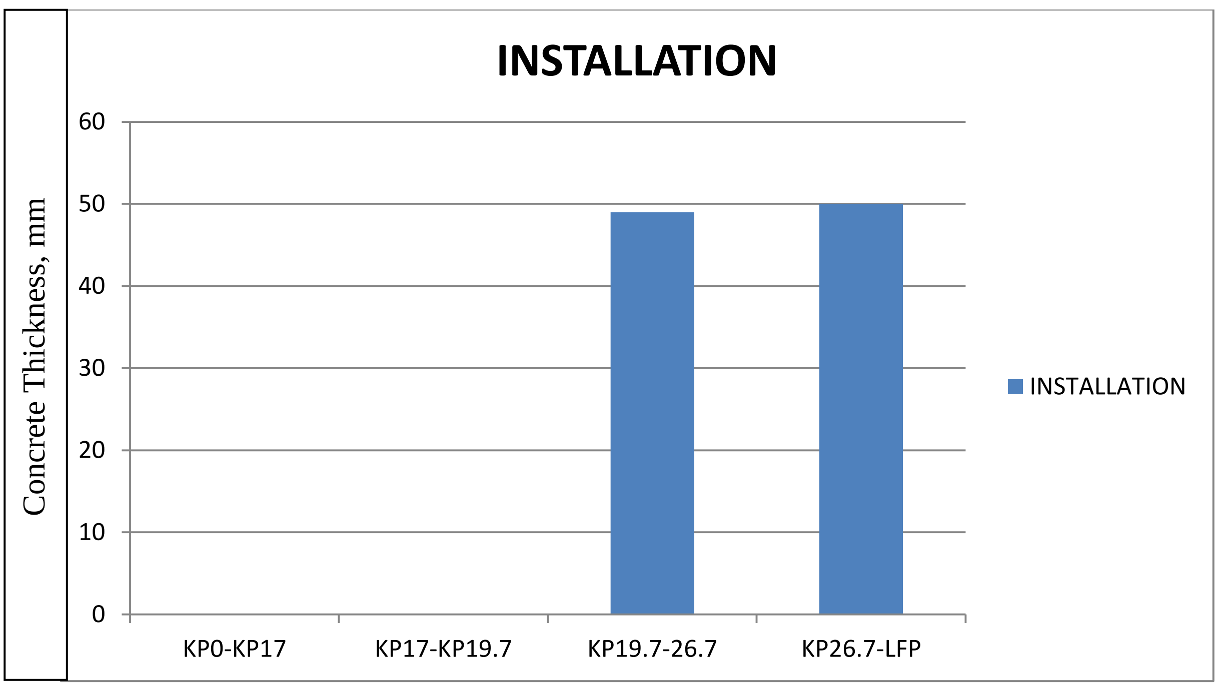

Fig 6.1: Required concrete thickness for installation condition

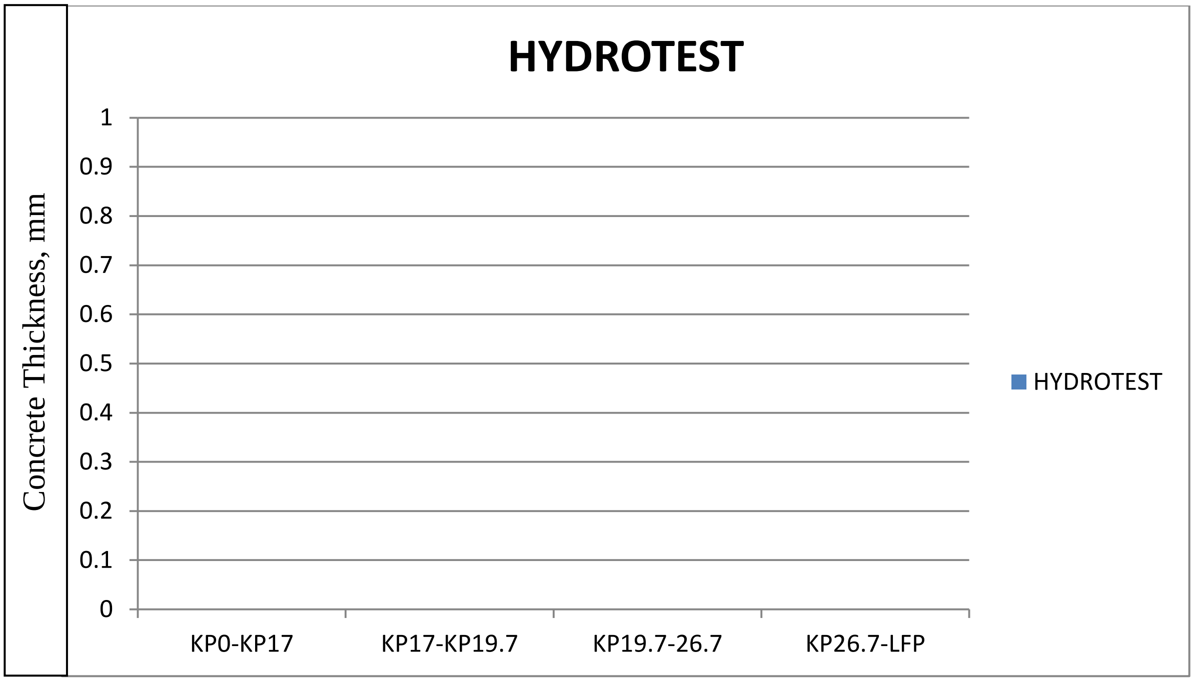

Fig 6.2: Required concrete thickness for Hydrotest condition

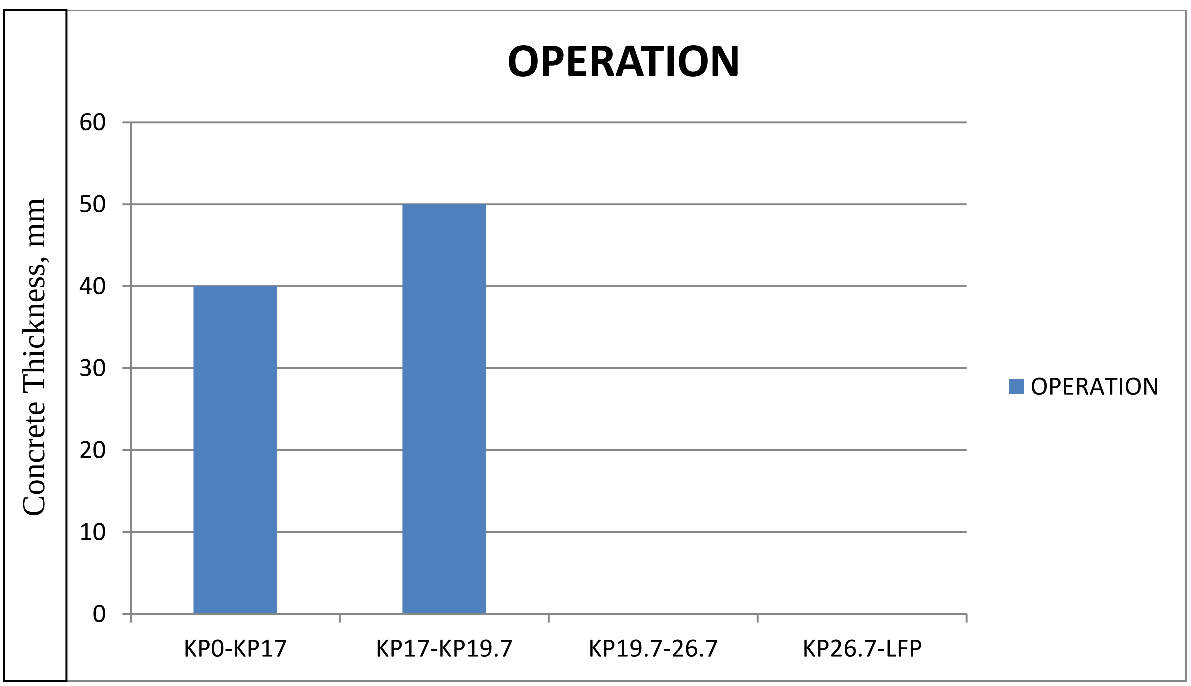

Fig 6.3: Required concrete thickness for Operation condition

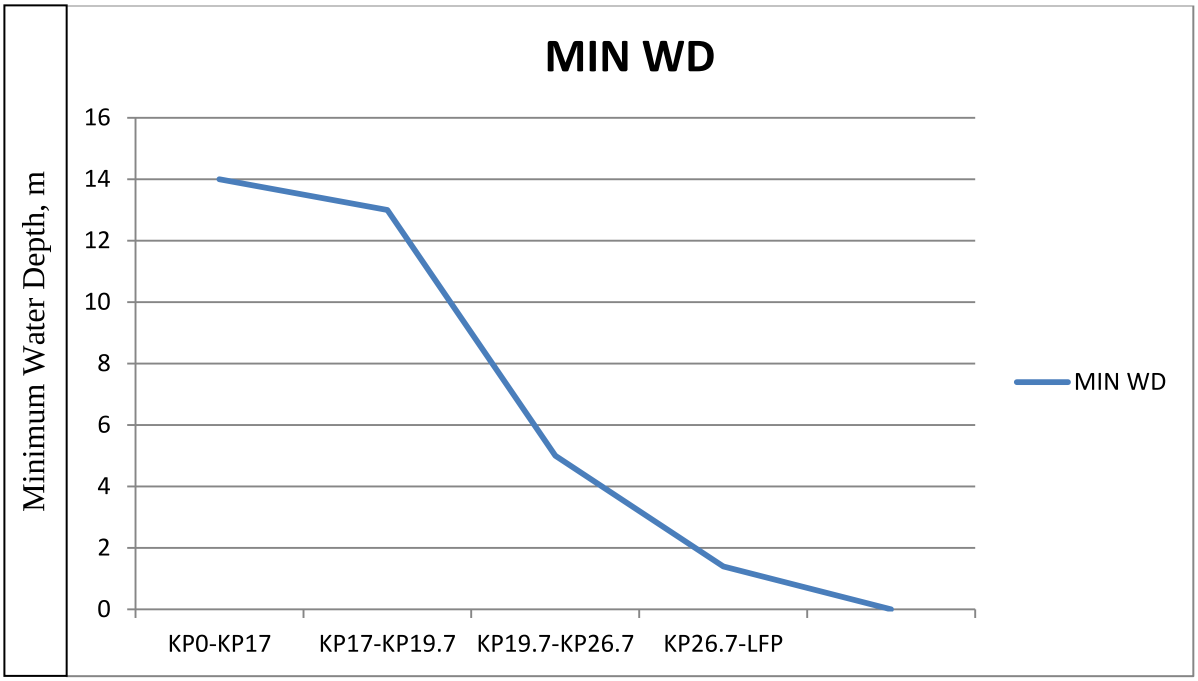

Fig 6.4: Minimum water depth along the pipeline route

6.5 STABILITY ANALYSIS

The stability has to be checked for all three cases. The actual pipeline submerged weight is bigger than the minimum pipeline submerged weight required for all three cases. So the pipeline is stable. This is supported by the fact that the pipeline specific gravity is more than 1.1 for all three cases.

From table 6.1, the minimum thickness of concrete coating is around 40mm and 50mm, based on the installation, hydrotest, operation phase. Installation phase in considered the critical phase. If the value is less than the required thickness, the pipeline would probably fail due to high stress and fatigue damage during installation.

6.6 PARAMETRIC ANALYSIS

Parametric analysis is done by varying an input parameter and the others are fixed. In this study, input parameters are varied which are the wave height, mean water depth, wave and current velocity, contents and total diameter of pipeline.

From Figure 6.1, the required minimum concrete thickness increases with decrease in distance between the pipe and the shore.

From Figure 6.2, the required minimum concrete thickness remains same with whatever the distance between the pipe and the shore.From Figure 6.3, the required minimum concrete thickness changes according to the given conditions.

If the pipeline diameter gets increased, then the pipeline submerged weight also gets increased. Pipeline diameter is not involved in the calculation of water particle kinematics.

CHAPTER- 7

CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

Based on the analysis, concrete coating and diameter of the pipeline contributes the most to the submerged weight and the stability of the pipeline. According to our case, the required minimum concrete thickness is 40mm for some case and 50 mm for some other cases. To obtain stability application of concrete coating is mandatory. A minimum concrete coating thickness of 40 mm is recommended by DNV-OS-F101. From the calculations, it is clear that the on bottom stability for this case study is “PASS” for all conditions.

7.2 RECOMMENDATION

Stability may be obtained by

- Weight coating
- Trenching
- Burial
- Mattresses
- Structural anchors
- Intermittent rock berms

In our case study, we have used weight coating i.e. concrete coating and trenching to obtain stability. In any case the provided concrete thickness should not be less than recommended required minimum concrete thickness.

REFERENCES

1. DNV Offshore Standard DNV-OS-F101, *Submarine Pipeline Systems*.
2. DNV Recommended Practice DNV-RP-F105, *Free Spanning Pipelines*, 2006.
3. DNV Recommended Practice DNV-RP-F109, *On-Bottom Stability Design of Submarine Pipelines*, 2007.
4. API 5L, *specification for line pipe, june- 2000*
5. Mohd.Ridza bin mohd. Haniffah, *on bottom stability analysis and design of submarine pipeline*, 2007
6. 135594-00-PP-03-ED-004, *A Offshore Pipeline- On-bottom stability analysis*, 2013

APPENDIX

Condition	Cond = “Installation”
Position	Pos = “seabed”
Location class [DNV OS F101]	LC = 1
Piggy-back	Piggy = “No”
Trench depth	z_t= 0m
Slope angle of trench	Θ_t = 0
Steel density	ρ_{st} = 7850kg.m3
Seawater density	ρ_w = 1025kg.m3
Marine growth density	ρ_{mg} = 0kg/m3
Field Joint Density	ρ_{field} = 1025 kg/m3

MAIN PIPE

Length per joint	l = 12m
Pipeline wall thickness	wt = 12.7mm
Corrosion allowance	t_{ca} = 1.6mm if cond=”Installation”:
	0mm otherwise
Anti-corrosion thickness	t_{cc} = 3.2mm (3PLE)
Assumed concrete thickness	t_{con} = 0mm
Concrete coating thickness	t_{conc} = tcon
Corrosion cutback	$corr_{cutback}$ = 305mm
Concrete cutback	$con_{cutback}$ =150mm

Marine growth thickness t_{mg} = 25.4 mm if cond=”operation”

(*Marine growth equal to 0mm for pipeline*) 0mm if cond=”Installation” , “hydrotest”

Contents maximum density ρ_{cmax} = 0kg.m-3 if cond=”installation”

806 kg.m-3 if cond= “operation”

1025kg.m-3 if cond= “hydrotest

Anti-corrosion coating density ρ_{cc} = 932.2kg.m-3

Concrete coating density ρ_{conc} = 3040kg.m-3

Concrete water absorption SWA = 3% if cond=”operation”

0% otherwise

SEABED AND SOIL DATA

Select seabed type form TYPE = 1

Seabed roughness			
Type	**Seabed**	**Grain size d50 (mm)**	**Roughness z_o (m)**
1	Silt and clay	0.0625	5.10-6
2	Fine sand	0.25	1.10-5
3	Medium sand	0.5	4.10-5
4	Coarse sand	1	1.10-4
5	Gravel	4	3.10-4
6	Pebble	25	2.10-3
7	Cobble	125	1.10-2
8	Boulder	500	4.10-2

Soil data = clay

	D_{50} = 6.25 x 10-5m
	Z_o= 5x 10-6m
Submerged unit soil weight for clay	γ'_c= 14139 Nm-3
Submerged unit soil weight for sand	γ'_s = 0Nm-3
Dry unit weight for clay	γ_s = 16000Nm-3
Submerged weight of soil	γ_{soil} = γ's if soil = sand
	γ'_c if soil = clay
clay shear strength	s_u = 12.45 kpa
angle of internal friction of sand	ϕ_s = o deg
Soil friction factor	μ= 0.2 if soil = clay
	0.6 if soil = sand

ENVIRONMENTAL DATA

Water depth	h= 14m
Current reference height above seabed	z_r =1m
Current velocity at reference level	v_r=0.36 m/s
Significant wave height	H_s=1.2m
Peak wave period	T_p=5.5s
Angle between current velocity and pipeline axis	Θ_c=90 deg
Angle between wave heading and pipeline axis	Θ_w=90 deg
Design sea state duration	T_{storm} = 3hr

SAFETY FACTORS

Pipeline location:

Safety classes (DNV OS F101 Table 2-4)

Normal classification of safety classes				
Phase	Fluid category A,C		Fluid category B,D and E	
	Location class		Location class	
	1	2	1	2
Temporary	Low	Low	Low	Low
Operational	Low	Normal	Normal	high

SC = "Low"

Safety factor for weight $\gamma w = 1.1$

PIPELINE WEIGHT CALCULATION

Total outside diameter $D_{oc} = D_o + 2(t_{cc} + t_{conc})$ $D_{oc} = 0.33m$

Full outside diameter main pipe including marine growth

$D_{mg} = D_{oc} + 2t_{mg}$ $D_{mg} = 0.33m$

Internal diameter $D_i = D_o - 2wt$ $D_i = 0.298m$

Steel area $A_{st} = \frac{\pi}{4} [D_o^2 - (D_i + 2t_{ca})^2]$ $A_{st} = 0.0124m^2$

Steel mass $M_{st}=A_{st}\, \rho_{st}$ $M_{st}= 97.468$ kg/m

Corrosion coating area $A_{cc}= \frac{\pi}{4}[D_o^2-(D_i+2t_{ca})^2]$ $A_{cc}=3.288x10\text{-}3\ m^2$

Corrosion coating mass $M_{cc}=A_{cc}\, \rho_{cc}$ $M_{cc}=3.065$ kg/m

Concrete coating mass $A_{con}= \frac{\pi}{4}[(D_o + 2t_{cc} + 2t_{conc})^2 - (D_o + 2t_{cc})^2]$

Field joint coating area I	$A_{field1}= \frac{\pi}{4}[(D_o+2t_{cc})^2- D_o^2]$	$A_{field1}= 3.288 \times 10\text{-}3\ m^2$
Field joint cating area II	$A_{field2}= \frac{\pi}{4}[D_{oc}^2-(D_o+2t_{cc})^2]$	$A_{field2}= 0m2$
Concrete coating mass	$M_{con} = A_{con}\ \rho_{conc}$	$M_{con} = 0$ kg/m
Marine growth area	$A_{mar}= \frac{\pi}{4}[(D_o+2t_{cc}+2t_{conc}+2t_{mg})^2- (D_o+2t_{cc}+2t_{conc})^2]$	
	$A_{mar}= 0m^2$	
Marine growth mass	$M_{mar} = A_{mar}\ \rho_{mg}$	$M_{mar}= 0$ kg/m
Content mass	$M_{cont} = (\frac{\pi}{4}D_i^2\ \rho_{cmax})$	$M_{cont}= 0$ kg/m
Field joint mass I	$M_{field1} = \rho_{field}\ A_{field}$	$M_{field1} = 3.371$ kg/m
Field joint mass II	$M_{field2} = \rho_{filed}\ A_{field2}$	$M_{field2}= 0$kg/m
Water mass	$M_w=\frac{\pi}{4}D_i^2\ \rho_w$	
	$W_{sub\_w} =\frac{\pi}{4}D_i^2\rho_{wg}$	$W_{sub\_w} = 703.434$ N/m
Concrete water absorption	$A_{SWA} = A_{con}\ SWA$	$A_{swa}= 0m^2$
Absorbed waer mass	$M_{SWA} = ASWA\ \rho_w$	$M_{SWA} = 0$ kg/m
Buoyancy force	$W_{bmgeq} = \frac{\pi}{4} D_{oc}^2\ \rho_w\ g$	$W_{bmgeq}= 861.294$ N/m
Submerged weight	$W_{sub\_eq} =$	

$$\frac{[(Mst + Mcont + Mmar + MSWA)\ L + Mcc(L - 2Corrcutback) + Mcon\ (L - 2Concutback) + (Mfield1 + Mfield2)\ (corrcutback + conccutback)}{L}$$

$W_{sub\_eq} = 123.913$ N/m

Maximum submerged weight-water filled W_{sub_weq} =

$$\frac{[(Mst + Mw + Mmar + MSWA)\,L + Mcc(L - 2Corrcutback) + Mcon\,(L - 2Concutback) + (Mfield1 + Mfield2)\,(corrcutback + conccutback)}{L}$$

W_{sub_weq} = 827.347 N/m

DESIGN METHODS

Vertical stability in water

submerged weight $w_s = w_{sub\_eq}$ w_s = 123.913 N/m

buoyancy $b = w_{bmgeq}$ b= 861.294 N/m

submerged weight shall meet the following criterion

$$\gamma_W \cdot \frac{b}{w_s + b} = \frac{\gamma_W}{s_g} \le 1.00$$

Submerged weight check

$$w_{sub} := \begin{cases} \text{"PASS"} & \text{if } \gamma_W \cdot \dfrac{b}{w_s + b} \le 1.0 \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

$$\boxed{\mathbf{W_{sub} = \text{“PASS”}}}$$

Vertical stability on and in soil (check only for hydrotest condition)

Cross sectional area main pipe $A_{main} = \frac{\pi}{4} D_{oc}2$ A_{main}=0.086m^2

Maximum submerged specific weight – water filled $\gamma_{submax} = \frac{W_{sub\_weq}}{A_{main}}$ γ_{submax} = 9.656 kN.m^{-3}

Maximum submerged weight $W_{submax} = W_{sub\_weq}$ -

water filled $W_{submax} = 827.347$ N/m

Specific weight soil(including water) $\gamma_{soil\_wet} = \gamma_{soil}$

$\gamma_{soil\_wet} = 14.139$ kN.m^{-3}

VERTICAL SOIL REACTION AND PENETRATION

(ACCORDING TO DNV RP F105)

Bearing capacity factors

$$N_q := \exp(\pi \cdot \tan(\phi_s)) \cdot \tan\left(45\deg + \frac{\phi_s}{2}\right)^2$$ N_q=1

N_c = Л +2 $N_c = 5.142$

$$N_\gamma := 1.5(N_q - 1)\tan(\phi_s)$$ $N_\gamma = 0$

Diameter main pipe $D_v = D_{oc}$ $D_v = 0.33$m

Contact width for pipe-soil interaction

$$B(v) := \begin{cases} 2\sqrt{(D_v - v) \cdot v} & \text{if } v \le 0.5 \cdot D_v \\ D_v & \text{if } v > 0.5D_v \end{cases}$$

Bearing capacity – sand

$$R_{sand}(v) := \gamma_{soil} \cdot B(v) \cdot \left(N_q \cdot \max\left(v - \frac{D_v}{4}, 0m\right) + 0.5N_\gamma \cdot B(v)\right)$$

Vertical penetration – guess value $v = 0.0001D_v$ $v = 0.033$mm

$$\theta_v := 2\left(\operatorname{acos}\left(1 - \frac{2v}{D_v}\right)\right)$$

$$A_p(v_1) := \frac{1}{2}\cdot\left(\frac{D_v}{2}\right)^2(\theta_v - \sin(\theta_v))$$

$A_p(v_1) = 0.145\ mm^2$

Cross sectional area of penetrated part of pipe

$$A_p(v) := \begin{vmatrix} A_p(v_1) & \text{if } v \le 0.5 \cdot D_v \\ A_p(v_1) & \text{if } v > 0.5 D_v \end{vmatrix}$$

Bearing capacity – clay (constant shear strength)

$$R_{clay}(v) = N_c\ S_u\ B(v) + \gamma_{soil}\ A_p\ (v_1)$$

Bearing capacity

$$R_{vsoil}(v) := \begin{vmatrix} R_{sand}(v) & \text{if Soil = "Sand"} \\ R_{clay}(v) & \text{if Soil = "Clay"} \end{vmatrix}$$

$R_{vsoil}\ (v) = 422.85\ kg/s^2$

Solve vertical penetration for vertical equilibrium

$$V = D_c/2 - (\ (D_c/2)^2 - (B/2)^2\ )^{1/2}$$

$$= (0.33/2) - [\ (0.33/2)^2 - (0.01292/2)^2\ ]^{1/2}$$

$$= 0.126\text{mm}$$

Vertical soil penetration requirement

Limited soil penetration sand or clay $Soil_{limit}$ = if ($v_p < 0.5\ D_v$, "PASS" , "FAIL")

$$\boxed{Soil_{limit} = \text{"PASS"}}$$

Vertical stability requirement- no sinking

Requirement

$$Stab_{vertical} := \begin{cases} \text{"PASS"} & \text{if } \gamma_{submax} < \gamma_{soil\_wet} \\ Soil_{limit} & \text{otherwise} \end{cases}$$

$$\boxed{Stab_{vertical} = \text{“PASS”}}$$

SHORT TERM WAVE CONDITIONS

$D_c = D_{mg}$; $ep = 0\%$; $eo = epD_c$; $\omega_p(T_p) = 2\pi/T_p$

$$\gamma(H_s, T_p) := \begin{cases} 5 & \text{if } \varphi \le 3.6 \\ e^{5.75-1.15\cdot\varphi} & \text{if } 3.6 < \varphi < 5 \\ 1 & \text{if } \varphi \ge 5 \end{cases}$$

Sigma(ω,T_p) = if ($\omega \le \omega_p(T_p)$, 0.07,0.09

$$\alpha_p(H_s, T_p) := \frac{5}{16} \cdot \frac{H_s^{\,2} \cdot \omega_p(T_p)^4}{g^2} \cdot \left(1 - 0.287 \cdot \ln\left(\gamma\left(H_s, T_p\right)\right)\right)$$

$$k(\omega) := \operatorname{root}\left(k \cdot h - \frac{\omega^2 \cdot h}{g} \cdot \coth(k \cdot h), k\right)$$

$$G(\omega) := \begin{cases} \dfrac{\omega \cdot \cosh\left[k(\omega) \cdot \left(D_c + e_o\right)\right]}{\sinh(k(\omega) \cdot h)} & \text{if } k(\omega) \cdot h < 100 \\ 0 & \text{otherwise} \end{cases}$$

$$S_{\eta\eta}(\omega, H_s, T_p) := \alpha_p(H_s, T_p) \cdot g^2 \cdot \omega^{-5} \cdot e^{\frac{-5}{4}\left(\frac{\omega}{\omega_p(T_p)}\right)^{-4}} \cdot \gamma(H_s, T_p)^{e^{-0.5 \cdot \left(\frac{\omega - \omega_p(T_p)}{\operatorname{sigma}(\omega, T_p) \cdot \omega_p(T_p)}\right)^2}}$$

$$S_{UU}(\omega, H_s, T_p) := G(\omega)^2 \cdot S_{\eta\eta}(\omega, H_s, T_p)$$

$$M0(Hs, T_p) := \int_{0s^{-1}}^{\infty \cdot s^{-1}} S_{UU}(\omega, H_s, T_p)\, d\omega$$

$$M2(Hs, Tp) := \int_{0s^{-1}}^{\infty \cdot s^{-1}} S_{UU}(\omega, H_s, T_p) \cdot \omega^2\, d\omega$$

$$U_s(H_s, Tp) := 2 \cdot \sqrt{M0(H_s, T_p)}$$

$\mathbf{U}_s(H_s,T_p) = 0.166$m/s

$$Tu(H_s, Tp) := 2 \cdot \pi \cdot \sqrt{\frac{M0(H_s, T_p)}{M2(H_s, T_p)}}$$

$T_u(H_s,T_p) = 5.836$ s

WAVE DIRECTIONALITY AND SPREADING REDUCTION FACTOR

$$k_w(s) := \sqrt{\frac{1}{\pi}} \cdot \frac{\Gamma\left(1 + \frac{s}{2}\right)}{\Gamma\left(\frac{1}{2} + \frac{s}{2}\right)}$$

$$w(\beta, s) := \begin{cases} k_w(s) \cdot \cos(\beta)^s & \text{if } |\beta| < \frac{\pi}{2} \\ 0 & \text{otherwise} \end{cases}$$

Wave energy spreading function

$$R_D(\theta_w) := \begin{array}{|l} RD \leftarrow 0 \\ \text{for } s \in 2, 3 .. 8 \\ \quad \begin{array}{|l} rd \leftarrow \sqrt{\displaystyle\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} w(\beta, s) \sin(\theta_w - \beta)^2 \, d\beta} \\ RD \leftarrow rd \ \text{ if } \ rd > RD \end{array} \end{array}$$

$R_d(\Theta_w) = 0.949$

$U_s = U_s(H_s,T_p)\, R_d(\Theta_w)$ $\qquad$ $U_s = 0.157\text{m/s}$

$T_u = T_u(H_s,T_p)$ $\qquad$ $T_u = 5.836$ s

$\gamma = \gamma(H_s,T_p)$ $\qquad$ $\gamma = 1$

$T_n = (h/g)1/2$ $\qquad$ $T_n = 1.195\text{s}$

The ratio between design oscillation velocity period and the average zero up crossing period

$$k_T = \frac{T'}{T_u} = \begin{array}{|l} k_t - 5\cdot(k_t - 1)\cdot\dfrac{T_n}{T_u} \ \text{ if } \ \dfrac{T_n}{T_u} \le 0.2 \\ 1 \ \text{ if } \ \dfrac{T_n}{T_u} > 0.2 \end{array}$$

$$k_t := \begin{array}{|l} 1.25 \ \text{ if } \ \gamma = 1.0 \\ 1.21 \ \text{ if } \ \gamma = 3.3 \\ 1.17 \ \text{ if } \ \gamma = 5.0 \\ 1.25 - \left[(\gamma - 1)\cdot\dfrac{1.25 - 1.21}{3.3 - 1.0}\right] \ \text{ if } \ 1.0 < \gamma < 3.3 \\ 1.21 - \left[(\gamma - 3.3)\cdot\dfrac{1.21 - 1.17}{5.0 - 3.3}\right] \ \text{ if } \ 3.3 < \gamma < 5.0 \end{array}$$

$k_t = 1.25$

$$T' := \begin{cases} T_u \cdot \left[k_t - 5 \cdot (k_t - 1) \cdot \dfrac{T_n}{T_u}\right] & \text{if } \dfrac{T_n}{T_u} \le 0.2 \\ T_u & \text{if } \dfrac{T_n}{T_u} > 0.2 \end{cases}$$

T’ = 5.836 s

Number of oscillation in the design bottom velocity spectrum

ح = Tstorm/ Tu

= 1.851 x 103

The ratio between the design single oscillation velocity amplitude and the design spectral velocity amplitude for ح oscillation is:

$$k_u = \frac{U'}{U_s} = \frac{1}{2} \cdot \left(\sqrt{2 \cdot \ln(\tau)} + \frac{0.5772}{\sqrt{2 \cdot \ln(\tau)}} \right)$$

$$U' := \frac{U_s}{2} \cdot \left(\sqrt{2 \cdot \ln(\tau)} + \frac{0.5772}{\sqrt{2 \cdot \ln(\tau)}} \right)$$

U’ = 0.317 m/s

DETERMINATION OF CURRENT SPEED VELOCITY VALUES

Average current velocity, Vc

$$V_c := \frac{1}{\ln\left(\dfrac{z_r}{z_o} + 1\right)} \left[\left(1 + \frac{z_o}{D_{oc}}\right) \ln\left(\frac{D_{oc}}{z_o} + 1\right) - 1 \right] \cdot V_r \cdot \sin(\theta_c)$$

Steady current velocity associated with single design oscillation:

$V_c = 0.298$ m/s

Steady current velocity associated with single design oscillation: $V' = V_c$

Steady to oscillatory velocity ratio of the design spectrum and the significant keulegan-carpenter number

Steady to oscillatory velocity ratio for design spectrum

$M = V_c/U_s$ $M = 1.892$

Significant keulegan-carpenter number

$K_s = (U_s\ T_u)/D_{oc}$ $K_s = 2.781$

Stady to oscillatory velocity ratio for single design oscillation

$M' = V' / U'$ $M' = 0.94$

Significant keulegan-carpenter number for single design oscillation

$K'_s = (U'\ T')/D_{oc}$ $K'_s = 5.6$

Determination of load coefficients

Peak load coefficients Cy and Cz are taken from table 3.1 and 3.2

Horizontal load coefficient $C_y = 2.227$

Vertical load coefficient $C_z = 1.269$

PENETRATION DEPTH

Penetration due to movement (assumed) Zpm = 0.5% Doc

Penetration due to pipe laying (assumed) Zpl = 5% Doc

Zero lift force is assumed Fz = 0 kN/m

$$K_{clay} := \frac{S_u \cdot D_{oc}}{w_s - F_z}$$

$K_{clay} = 33.186$

$$K_{sand} := \frac{\gamma'_s \cdot D_{oc}{}^2}{w_s - F_z}$$

$K_{sand} = 0$

$$G_c := \frac{S_u}{D_{oc} \cdot \gamma_s}$$

$G_c = 2.356$

$$z_{pi} := \begin{cases} \left[0.0071 \cdot \left(\frac{G_c{}^{0.3}}{K_{clay}}\right)^{3.2} + 0.062 \cdot \left(\frac{G_c{}^{0.3}}{K_{clay}}\right)^{0.7}\right] \cdot D_{oc} & \text{if Soil = "Clay"} \\ 0.037 \cdot K_{sand}{}^{-0.67} \cdot D_{oc} & \text{if Soil = "Sand"} \end{cases}$$

Z_{pi} = 2.112 x 10-3 m

Total penetration $Z_p = Z_{pm} + Z_{pl} + Z_{pi}$

=5.288 x 10-3 m

Load reduction due to pipe soil interaction

Load reduction due to permeable sea bed $r_{perm\_z} = 0.7$

No reduction factor due to y direction which make the value equal to 1

$r_{perm\_y} = 1.0$

Load reduction due to penetration:

$$r_{pen\_y} := \max\left(1.0 - 1.4 \cdot \frac{z_p}{D_{oc}}, 0.3\right)$$

= 0.914

$$r_{pen\_z} := \max\left[1.0 - 1.3\left(\frac{z_p}{D_{oc}} - 0.1\right), 0.0\right]$$

$= 1.05$

Load reduction due to trenching :

$$r_{tr\_y} := \begin{cases} 1.0 - 0.18\cdot(\theta_t - 5)^{0.25}\cdot\left(\frac{z_t}{D_{oc}}\right)^{0.42} & \text{if } 5 \le \theta_t \le 45 \\ 1.0 & \text{otherwise} \end{cases}$$

$$r_{tr\_z} := \begin{cases} 1.0 - 0.14\cdot(\theta_t - 5)^{0.43}\cdot\left(\frac{z_t}{D_{oc}}\right)^{0.46} & \text{if } 5 \le \theta_t \le 45 \\ 1.0 & \text{otherwise} \end{cases}$$

$r_{tr\_y} = r_{tr\_z} = 1$

Total load reduction

$r_{tot\_y} = r_{perm\_y}\, r_{pen\_y}\, r_{tr\_y}$ $\quad$ $r_{tot\_y} = 0.914$

$r_{tot\_z} = r_{perm\_z}\, r_{pen\_z}\, r_{tr\_z}$ $\quad$ $r_{tot\_z} = 1.05$

Absolute lateral static stability method

Peak vertical hydrodynamic (lift) load

$$F'_z := r_{tot\_z}\cdot\frac{1}{2}\rho_w\cdot D_{oc}\cdot C'_z\cdot(U' + V')^2$$

$F'_z = 0.08535$ kN/m

Peak vertical hydrodynamic (drag and inertia) load

$$F'_y := r_{tot\_y}\cdot\frac{1}{2}\rho_w\cdot D_{oc}\cdot C'_y\cdot(U' + V')^2$$

$F'_y = 0.13$ kN/m

SOIL RESISTANCE:

Passive resistance

$F_c = W_s\text{-}F_z$ $\qquad\qquad$ $F_c = 123.913$ N/m

$$F_R := \begin{cases} \begin{cases} F_c \cdot \left(5.0 \cdot k_s - 0.15 \cdot k_s^{\,2}\right) \cdot \left(\dfrac{z_p}{D_{oc}}\right)^{1.25} & \text{if } k_s \le 26.7 \\ F_c \cdot k_s \cdot \left(\dfrac{z_p}{D_{oc}}\right)^{1.25} & \text{if } k_s > 26.7 \end{cases} & \text{if Soil} = \text{"Sand"} \\ F_c \cdot 4.1 \cdot \dfrac{k_c}{G_c^{\,0.39}} \cdot \left(\dfrac{z_p}{D_{oc}}\right)^{1.31} & \text{if Soil} = \text{"Clay"} \end{cases}$$

F_R = 123.913 x 4.1 (33.186/2.356 0.39) (0.0202/0.3303)1.31

= 312.023 N/m

DESIGN CRITERION:

A pipeline can be considered to satisfy the absolute static stability requirement if:

$$\gamma_{sc} \cdot \frac{F'_y + \mu \cdot F'_z}{\mu \cdot w_s + F_R} \le 1.0$$

$$1.0 \frac{130+0.2 \times 85}{0.2 \times 123.913+312.023} = 0.436 \le 1.0$$

$$\gamma_{sc} \cdot \frac{F'_z}{w_s} \le 1.0$$

$$1.0 \text{ x } \frac{85}{123.913} = 0.686 \leq 1.0$$

Safety factors $\gamma_{sc} = 1.0$

Absolute static stability check:

$$\text{Absolute\_Static\_Stability\_Req} := \begin{cases} \text{"PASS"} & \text{if } \left(\gamma_{sc} \cdot \frac{F'_y + \mu \cdot F'_z}{\mu \cdot w_s + F_R} \leq 1.0\right) \wedge \left(\gamma_{sc} \cdot \frac{F'_z}{w_s} \leq 1.0\right) \\ \text{"FAIL"} & \text{otherwise} \end{cases}$$

Absolute_static_stability_requirement = "PASS"

SUMMARY

Submerged weight check **W_{sub} = "PASS"**

Vertical soil penetration requirement **$Soil_{limit}$ = "PASS"**

Vertical stability requirement – No sinking **$Stab_{vertical}$ = "PASS"**

Absolute static stability requirement

Absolute_static_stability_Req = "PASS"

The details need to be changed in input values for other conditions are

Condition = Hydrotest

Content density = 1025 kg/m^3

Condition = Operation

Corrosion allowance t_{cc} = 1.6 mm

Marine growth t_{mg} = 25.4mm

Contents density ρ_{cmax}= 860 kg/m3

Concrete water absorption SWA = 3 %

Location class = 1

Return period

H_s = 3m

T_p= 8 sec

V_r = 0.385 m/s

Z_{pm} = 0.5%

Z_{pp} = 7 %

γ_{sc} = 1.138

γ_w = 1.1

FOR 5M DEPTH

Condition = Installation

h = 5m

$\Theta_t = 14^o$

Z_t = 2.4m

V_r = 0.311 m/s

$\Theta_w = 60^o$

Condition = Operation

H_s = 3m

V_r = 0.332

$\Theta_t = 14^o$

$\Theta_w = 60^o$

T_p = 8sec

h = 5m

Z_t = 2.4m

FOR 1.4M DEPTH CONDITIONS

Condition =Installation

$\Theta_t = 14^o$

$Z_t = 2.4m$

$V_r = 0.259$ m/s

$\Theta_w = 60^o$

Condition = Operation

$H_s = 3m$

$V_r = 0.277m/s$

$Z_t = 2.4m$

T_p =8 sec

$\Theta_w = 60^o$

$\Theta_t = 14^o$

RESULT

KP Sections	Position of Pipe	Min WD	Installation	Hydrotest	Operation	Selected CWC
KP0-KP17	Exposed	14m	0mm	0mm	40mm	40mm
KP17-KP19.7	Exposed	13m	0mm	0mm	50mm	50mm
KP19.7-LFP	Post-Trench	5m	49mm	0mm	0mm	50mm
	Pre-Trench	1.4m	50mm	0mm	0mm	