Basic Engineering Study for
Aung Sinkha Development Project Phase 1A

PIPELINE BUOYANCY CONTROL AND ANCHORS SPACING CALCULATION REPORT

PTTEP

PTT Exploration and Production Public Company Limited
Aung Sinkha Development Project Phase 1A
Basic Engineering

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	MM-ASK-1A-APL01-PLR-RPT-0003	**REV** C1

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HOLD LIST

Hold No.	Description	Status
1	Non-liquified Soil Locations	Closed
2	Minimum Design Temperature	Closed

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1. INTRODUCTION

1.1 Project Overview

PTTEP International Limited (PTTEPI) intends to develop and produce hydrocarbon from the offshore Block M3 named Aung Sinkha (ASK) field. The project is under Production Sharing Contract (PSC) with Myanmar Oil & Gas Enterprise (MOGE) signed on 7th August 2004 while the PSC effective date was on 1st November 2004.

PTTEPI as an Operator had performed 2,842 line-km of 2D seismic, 619 km2 of 3D seismic, and drilled 11 Exploration and Appraisal wells. After successful exploration and appraisal drilling campaigns in 2015, PTTEPI completed the ASK Field Development Plan and submitted it to MOGE for approval. MOGE approved ASK Field Development Plan in April 2021.

The ASK field is located offshore in the Gulf of Moattama, Myanmar, as illustrated in Figure 1-1. The field is located approximately 70 km from Land Fall Point (LFP) at Daw Nyein village and 200 km south-west of Yangon with a water depth range of 15-25 meters.

The feed gas will be transported from two (2) offshore wellhead platforms through an offshore export pipeline to ASK Onshore Processing Facilities (APF) located in Daw Nyein village for processing. The sales gas after processing will be exported to the tie-in point at Gas Receiving Station no. 2 (GRS#2), of Domestic Gas to Power Pipeline Development Project, nearby the APF. The condensate will be kept in onshore storage tanks before loading, transporting/ offloading to customers. The design of the surface facilities will be based on a Contractual Daily Capacity (CDC) of 60 MMscfd with provision for future expansion to 100 MMscfd. The gas production is planned to start up by Q4 of 2025.

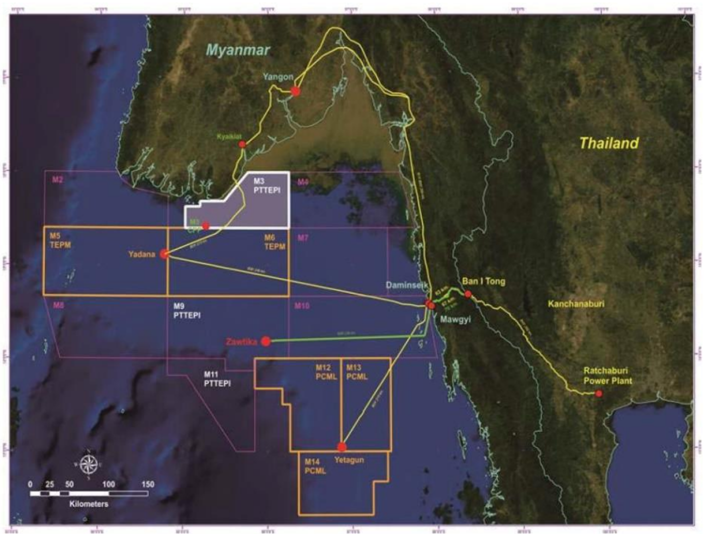


Figure 1-1: Block M3 – Aung Sinkha Field, Offshore Myanmar

The development of Phase 1A consists of the following facilities, as illustrated in Figure 1-2.

- 2 Wellhead Platforms (WPA-1 and WPA-2)
- 1 Intra-field pipeline which links between WPA-1 and WPA-2
- 1 Multiphase export pipeline to transport combined fluid of WPA-1 and WPA-2 to ASK Onshore Processing Facilities (APF)
- ASK Onshore Processing Facilities (APF)
- Onshore pipelines from APF to Gas Receiving Station#2 (GRS#2)
- Onshore infrastructure i.e. condensate offtake facilities, accommodation, Personal Material Transfer Facilities, telecommunication system, roads, etc.
- APL01 Onshore pipeline from landfall to APF

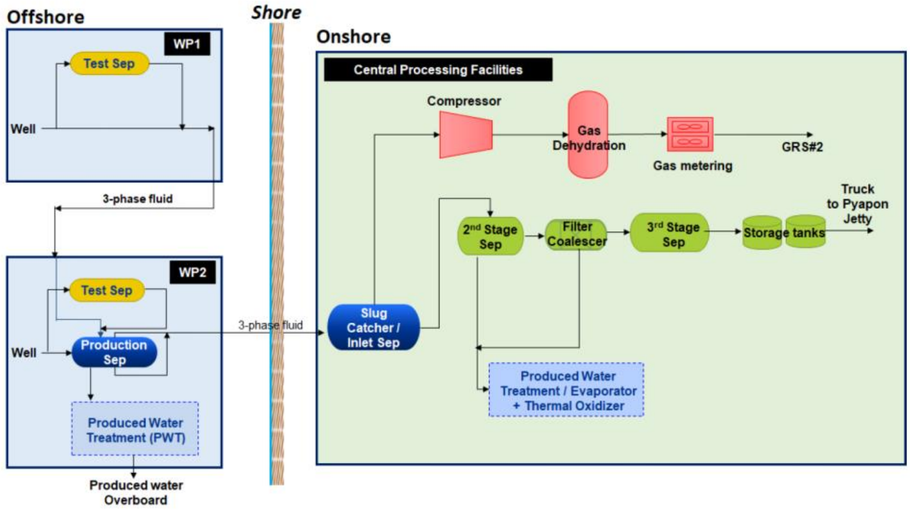


Figure 1-2: Field Block Flow Diagram

1.2 Purpose of Document

The purpose of this document is to perform the vertical stability analysis and buoyancy control design for underground restrained and unrestrained sections of the onshore pipelines in The Provision of Basic Engineering for Pipelines and Onshore Facilities for Aung Sinkha Development Project Phase 1A.

1.3 Definitions

The following definitions shall apply to this document:

COMPANY	PTTEP International Limited
PROJECT	Basic Engineering Study for Aung Sinkha Development Project Phase 1A

1.4 Abbreviation

3LPE	Three Layer Polyethylene
APF	ASK Onshore Processing Facilities
API	American Petroleum Institute
ASK	Aung Sinkha Development Project
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
DP	Design Pressure
FEED	Front End Engineering Design
GRS	Gas Receiving Station
LFP	Land Fall Point
LSAW	Longitudinally Submerged Arc Weld
OD	Outside Diameter
SMTS	Specified Minimum Tensile Strength
SMYS	Specified Minimum Yield Strength
WL	Water Level
WPA	Wellhead Platform
WT	Wall Thickness

2. SUMMARY AND CONCLUSIONS

2.1 Summary

This report presents the methodology and results of buoyancy control design. The calculation methodology for buoyancy control is based on “Guideline for the Design of Buried Steel Pipe” [5], as described in Section 4 of this report. Design data and assumptions are mainly based on the Basis of Design [1], and are presented in Section 3.

<u>Screw Anchoring</u>

For pipeline vertical stabilization, screw anchors with maximum spacings as below are required for pipeline sections installed by the open cut method.

- APL01; 44 m for fixed-fixed, 36 m for pinned-fixed

By using screw anchor pair with minimum hold down capacity of 40,000 lbf (177.9 kN), longitudinal and combined stresses in the pipeline are within the allowable limits of ASME B31.8 requirements.

Safety factor of ratio of total downward force to upward force is more than 1.2.

<u>Continuous Concrete Weight Coating</u>

For pipeline vertical stabilization, minimum thicknesses of 3,040 kg/m^3 continuous concrete weight coating as below are required for pipeline sections installed by the open cut method.

- APL01; 92 mm as minimum

Safety factor of ratio of total downward force to upward force is more than 1.2.

<u>Sand Bag Weight</u>

For pipeline vertical stabilization, minimum continuous sand bag unit weights per length as below are required for pipeline sections installed by the open cut method.

- APL01; 1,380 kg/m as minimum

Safety factor of ratio of total downward force to upward force is more than 1.2.

2.2 Conclusions

1. The recommended buoyancy control method is the screw anchoring as below reasons.
    - Normally, the continuous concrete weight coating is intentionally used for the mechanical protection. Moreover, the transportation weight is higher than the other methods. However, this method can be used for some specific area, such as wide waterway, watercourse, or pond crossing.
    - The continuous sand bag weight may be lost its weight when the bag is damaged. This will be uncertain for buoyancy control. However, this method can be used for some specific area, such as narrow waterway, watercourse, or pond crossing.
2. In order to cater for uncertainties and installation tolerances, it is recommended to limit screw anchor spacing as below.
    - APL01; 36 m

3. DESIGN DATA AND ASSUMPTIONS

3.1 Pipeline Design Data

Pipeline design data are presented in Table 3-1[1].

Table 3-1 : Pipeline Design Data [1]

Description	Unit	Value
Service	-	Onshore Gas Pipeline (Severe Sour Service)
Originating from	-	Daw Nyein Landfall
Terminating at	-	APF
Pipeline Size	mm (Inch)	508 (20)
Approximate Length	km	2.5
Pipeline Status	-	Buried
Design Life	Years	20
Corrosion Allowance	mm	5.6
Selected Pipeline Wall Thickness	mm	14.3
Anti-corrosion Coating	-	3LPE
Open-cut Anti-corrosion Thickness	mm	3.5
Boring/HDD Anti-corrosion Thickness	mm	4.5

3.2 Pipeline Operating Data

Pipeline operating data are presented in Table 3-2 [1].

Table 3-2 : Pipeline Operating Data [1]

Description	Unit	Value
Fluid	-	Multiphase
Operating Pressure [2]	barg	25
Design Pressure (DP)	barg	70
Hydrotest Pressure	barg	87.5
Operating Temperature (Min./ Max.) [2]	°C	22.7/33
Design Temperature (Min./Max.)	°C	-10/75
Max. Content Density	kg/m^3	34.59
Min. Content Density	kg/m^3	28.76

3.3 Material Data

Pipeline and coating material properties are presented in Table 3-3 [3].

Table 3-3 : Pipeline and Coating Material Data [3]

Description	Unit	Value
Pipeline OD	mm (Inch)	508 (20)
Line Pipe Material	-	API 5L X65 (Severe Sour Service)
Manufacturing Process	-	LSAW
Specified Minimum Yield Strength (SMYS)	MPa	450
Specified Minimum Tensile Strength (SMTS)	MPa	535
Poisson's Ratio	-	0.3
Steel Density	kg/m^3	7,850
Elastic Modulus	MPa	2.07×10^5
Coefficient of Linear Expansion	1/°C	1.17×10^{-5}
3LPE Density	kg/m^3	950
Field Joint Density	kg/m^3	127-222 1,025 (saturated)
Concrete Weight Coating Density	kg/m^3	3,040

3.4 Air Properties

Air properties are as given in Table 3-4 .

Table 3-4 : Air Properties

Parameter	Unit	Value
Temperature		
High	°C	38.3
Low	°C	23.3

3.5 Fluid Soil (Mud) Density

Fluidic soil (mud) density of 1,400 kg/m^3 is considered for buoyant force calculation [1].

3.6 Assumptions

In the buoyancy control design performed in this report, the following assumptions were made:

- Minimum air temperature will be used as installation temperature for pipe stress analysis in screw anchoring cases.
- For locations, where buoyancy control is required according to [1], buoyancy control design will be performed assuming water table level at the ground surface.
- Effective weight of soil above the pipe is not considered for conservatism.
- Fluid content inside the pipe is neglected.
- Only pipeline at end of operation is considered, conservatively.
- For area where number of screw anchors are more than 3, restrained section and fixed-fixed boundary condition are considered.
- For area where number of screw anchors are equal or less than 3, unrestrained section and pinned-fixed boundary condition are considered.
- Normal pipe wall thickness used in open cut section is considered, conservatively.

4. METHODOLOGY

4.1 Vertical Soil Trench Pressure Acting on Top of Pipeline

Where the pipe is located below the water table and soil is not liquefied, the effect of soil grain buoyancy can be included in the earth load pressure. The following equation is used to determine vertical soil pressure acting on top of pipeline [5].

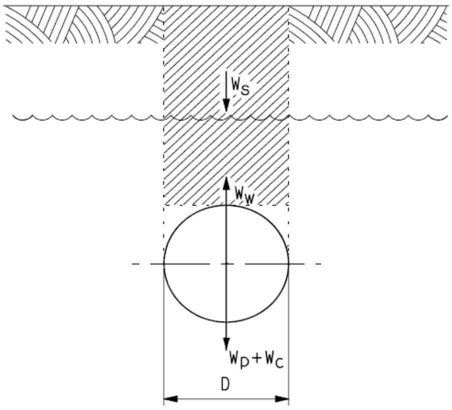


Figure 4-1: Resultant Buoyancy Load on Pipe

$$P_v = \gamma_w h_w + R_w \gamma_d C \qquad (4.1)$$

Where,

P_v = Vertical soil trench pressure acting on the top of pipe

C = Height of soil above pipe

R_w = Water buoyancy factor,

= $1 - 0.33(h_w/C)$

h_w = Distance between the top of the pipe and the ground water table (zero if the water table is below the top of the pipe and equal to C if the water level is above ground level)

γ_w = Unit weight of water

γ_d = Dry unit weight of soil

4.2 Safety Factor

Safety factor is the ratio of total downward force to upward force; safety factor can be defined in the following equation;

$$SF = \frac{W_P + W_C + W_S + \left(\frac{F_R}{L}\right) + W_{SB}}{W_W} \quad (4.2)$$

Where,

SF	=	Safety factor
F_R	=	Screw anchor resistance
L	=	Spacing between anchors
W_P	=	Weight of pipe per unit length of pipe
W_C	=	Weight of pipe contents per unit length of pipe
W_S	=	Scaled explosive weight per unit length of pipe, $(P_v - \gamma_w \cdot h_w) \cdot D$
W_w	=	Weight of displaced fluid per unit length of pipe
W_{SB}	=	Sand bag unit weight per length
D	=	Pipe outer diameter

Safety factor of 1.2 (minimum of 20% negative buoyancy) shall be used [1].

4.3 Stresses in Pipeline Between Screw Anchors

4.3.1 Hoop Stress Criterion

Hoop stress due to internal pressure shall be used as per Section 841.1.1, ASME B31.8 [6] requirements.

$$S_H = \frac{P \cdot D}{2 \cdot t} \text{ for } \frac{D}{t} \geq 30$$

$$S_H = \frac{P \cdot (D - t)}{2 \cdot t} \text{ for } \frac{D}{t} < 30 \quad (4.3)$$

Where,

S_H	=	Hoop stress
P	=	Internal design pressure

D = Pipe outer diameter

t = Pipeline wall thickness

4.3.2 Longitudinal Stress Criterion

Longitudinal stress for restrained pipeline is defined in the following equation [6].

$$S_L = S_P + S_T + S_X + S_B \quad (4.4)$$

Longitudinal stress for unrestrained pipeline is defined in the following equation [6].

$$S_L = S_P + S_X + S_B \quad (4.5)$$

Where,

S_L = Longitudinal stress

S_P = Longitudinal stress due to internal pressure,

$S_P = 0.3S_H$ for restrained pipeline

$S_P = 0.5S_H$ for unrestrained pipeline

S_T = Longitudinal stress due to thermal expansion, $S_T = E\alpha(T_1 - T_2)$

S_X = Longitudinal stress due to axial loading other than temperature and pressure (Consider to be 0)

S_B = Nominal bending stress in the pipeline

= $\pm \frac{F_b L^2}{12Z}$ for restrained pipe with fixed-fixed boundary condition

= $\pm \frac{F_b L^2}{8Z}$ for unrestrained pipe with pinned-fixed boundary condition

F_b = Net upward buoyancy force per unit length

L = Spacing between screw anchors

E = Pipe elastic modulus at ambient temperature

α = Pipe coefficient of thermal expansion

T_1 = Pipe temperature at the time of installation

T_2 = Warmest or coldest pipe design temperature

Z	=	Pipe section modulus, Z = $\frac{2I}{D}$
I	=	Pipe moment of inertia
S	=	Specified Minimum Yield Strength
T	=	Temperature Derating Factor

The maximum permitted values of $|S_L|$ for restrained pipe and unrestrained pipe are 0.9·S·T and 0.75·S·T, respectively.

4.3.3 Stress due to Saddle Load

There are local stresses in both longitudinal and circumferential directions due to the load from screw anchor saddle onto the pipe, which can be calculated using the following formula [5]:

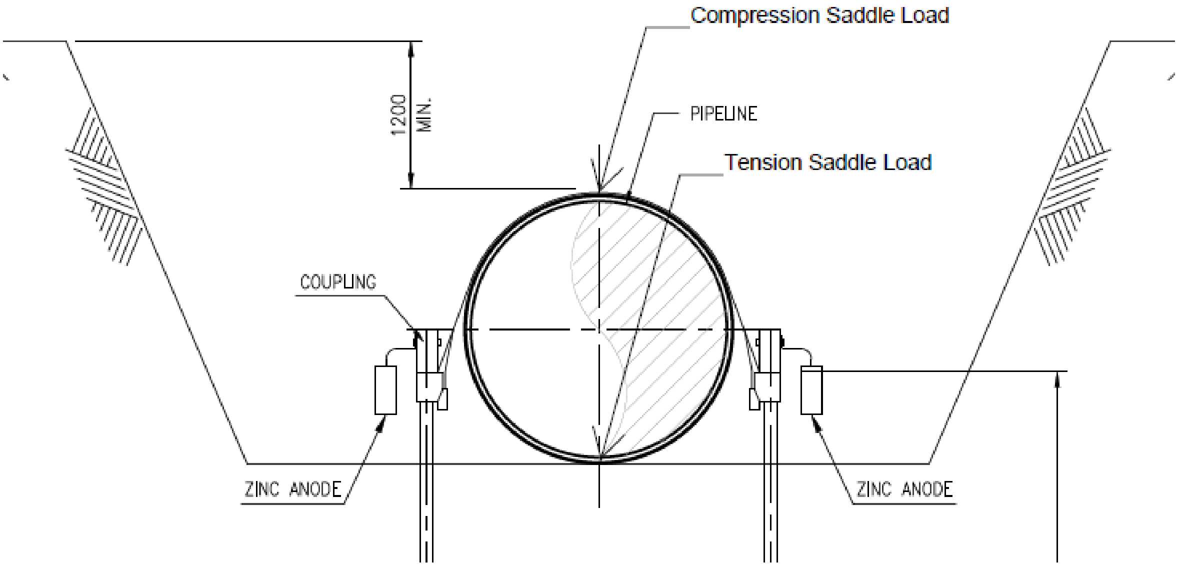


Figure 4-2: Saddle Load

$$S_S = k \cdot \frac{P}{t^2} \cdot \ln\left(\frac{R}{t}\right) \quad (4.6)$$

Where,

S_S	=	Maximum local stress due to saddle load
P	=	Total saddle reaction force (screw anchor resistance)
R	=	Pipe outer radius

t = Pipeline wall thickness

k = $0.02 - 0.00012 \cdot (\beta - 90°)$

β = Total angle in degrees subtended by arc of contact between pipe and saddle, 90 degrees is considered.

4.3.4 Combined Stress Criterion

To comply with Section 833.4, ASME B31.8 [6], stresses shall be combined to verify the following:

$$\sqrt{S_L^2 - S_L S_H + S_L^2} \leq kST \tag{4.7}$$

Where,

k = 0.9 for operation

4.4 Screw Anchor Spacing Criterion

4.4.1 Screw Anchor Capacity

Minimum hold down capacity of screw anchor pair is 40,000 lbf (177.9 kN) [1]. Screw anchor structural design shall be based on a safety factor of 2.0 [1].

For area where number of screw anchors are more than 3, fixed-fixed boundary condition is considered. Minimum required hold down load of screw anchor pair is calculated based on buoyancy force of given span.

$$F_l = F_b \cdot L \tag{4.8}$$

Where,

F_b = Net Upward Buoyancy Force per unit length

For area that number of screw anchors are equal or less than 3, pinned-fixed boundary condition is considered, conservatively.

The maximum force acting on one end of single span is calculated as below;

$$F_l = \frac{5F_b \cdot L}{8} \tag{4.9}$$

The minimum required hold down load per a pair of screw anchors for two spans is calculated by the following equation;

$$F_l = 2 \cdot \frac{5F_b \cdot L}{8} \tag{4.10}$$

4.4.2 Maximum Deflection

Maximum deflection of pipe can be determined based on distance between screw anchors [5].

For fixed-fixed boundary condition;

$$\delta_{max} \geq \frac{F_b \cdot L^4}{384 \cdot E \cdot I} \tag{4.11}$$

For pinned-fixed boundary condition;

$$\delta_{max} \geq \frac{F_b \cdot L^4}{185 \cdot E \cdot I} \tag{4.12}$$

Where,

δ_{max} = Maximum allowable deflection of pipe, 0.2 m

L = Spacing between screw anchors

E = Pipe modulus of elasticity

I = Pipe moment of inertia

F_b = Net upward buoyancy force per unit length, $W_w - [W_P + W_C + W_S]$

4.5 Continuous Concrete Weight Coating Criterion

The continuous concrete weight coating is considered to find the required concrete coating thickness to overcome the buoyant force from fluidic soil (mud). The safety factor in Section 4.2 neglecting screw anchor term shall be checked.

4.6 Continuous Sand Bag Weight Criterion

The continuous sand bag weight is considered to find the required unit weight/mass to overcome the buoyant force from fluidic soil (mud). The safety factor in Section 4.2 neglecting screw anchor term shall be checked.

4.7 Load Cases for Pipeline Stress Analysis in Screw Anchor Cases

The following load combinations are used in the pipeline stress analysis in screw anchor cases.

Table 4.1 : Load Cases

Pipeline Name	Load Case	Selected WT (mm)	Pressure (barg)	Temperature (°C)	Other Loads
APL01 (20” Pipeline)	1 (Expansion)	14.3	70	75	Bending moment due to buoyant force, and Load from Saddle
	2 (Contraction)	14.3	70	-10	

5. RESULTS

5.1 Non-liquified Top Soil

The soil below top of pipe will be considered as liquified soil but the soil above top of pipe will be considered as non-liquified soil, then this condition is needed to check the effect of the top soil weight.

By checking, top soil dry weight is sufficiently high against the buoyancy force when considering the cover depth of 1.2 m for open cut. Therefore, the buoyancy control method is not required.

The non-liquified soil locations and underground water table locations for indicated liquefied soil and saturated soil are extracted from Geotechnical Investigation Report [8] and presented in Table 5.1 and Table 5-2 respectively.

Table 5.1: Summary of Non-liquefaction Locations [8]

BH No. Location (KP)	FS	Result (FS < 1 Liquefied)
BH12-01-LF	0.39	Liquefied
BH12-02-LF	0.36	Liquefied
BH12-03-LF	0.39	Liquefied
BH30-16-ABV	0.51	Liquefied
BH30-05-APF	1.85	Non Liquefied

Table 5-2 : Summary of Underground Water Table [8]

BH No. Location (KP)	WL (m)	Result (WL ≤ 2m Saturated Soil)
BH3-03	0.2	Saturated Soil
BH3-01	0.4	Saturated Soil
BH3-01/1	0.3	Saturated Soil
BH3-02	0.2	Saturated Soil
BH3-02/1	0.1	Saturated Soil

5.2 Liquified Soil without Top Soil Weight Consideration

Screw Anchoring

Maximum spacing between screw anchors was determined based on the criteria presented in Section 4.4 of this report. Detailed Calculations are presented in Appendices B and C. Summary of the results is presented in the following tables.

Table 5-3 : Screw Anchoring Buoyancy Control Calculation Results

Parameters		APL01		
		No. of Screw Anchors > 3		No. of Screw Anchors ≤ 3
		Load Case 1	Load Case 2	
Screw Anchor Spacing (m)		44	44	36
Force	Net Upward Force (N/m)	2,860	2,860	2,860
	Net Downward Force (N/m)	5,147	5,147	6,045
	Safety Factor	1.80	1.80	2.11
	Check (SF≥1.2)	Pass	Pass	Pass
Deflection	Calculated Deflection (mm)	194.7	194.7	181.1
	Allowable Deflection(mm)	200	200	200
	Check	Pass	Pass	Pass
Maximum Longitudinal Stress	Calculated Stress (MPa)	280.7	311.2	305.7
	Allowable Stress(MPa)	405	405	337.5
	Check	Pass	Pass	Pass
Maximum Combined Stress	Calculated Stress (MPa)	306.2	273.9	331.0 (Note 1)
	Allowable Stress(MPa)	405	405	405 (Note 1)
	Check	Pass	Pass	Not required
	Calculated Force(kN)	77.3	77.3	79.1

<table>
<tr><th colspan="2" rowspan="3">Parameters</th><th colspan="3">APL01</th></tr>
<tr><th colspan="2">No. of Screw Anchors > 3</th><th rowspan="2">No. of Screw Anchors ≤ 3</th></tr>
<tr><th>Load Case 1</th><th>Load Case 2</th></tr>
<tr><td rowspan="2">Screw Anchor Force</td><td>Allowable Force(kN)</td><td>177.9</td><td>177.9</td><td>177.9</td></tr>
<tr><td>Check</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
</table>

Note

1. For information

Continuous Concrete Weight Coating

Minimum continuous concrete weight coating thickness was determined based on the criterion presented in Section 4.5 of this report. The continuous concrete weight coating density of 3,040 kg/m3 is considered. Detailed Calculations are presented in Appendix D. Summary of the results is presented in the following tables.

Table 5-4 : Continuous Concrete Weight Coating Buoyancy Calculation Results

Pipeline Name	Min. Concrete Coating Thickness (mm)	Net Downward Force (N/m)	Net Upward Force (N/m)	Safety Factor	Check (SF≥1.2)
APL01	92	6,333	5,269	1.202	Pass

Continuous Sand Bag Weight

Minimum continuous sand bag unit weight and mass per length were determined based on the criterion presented in Section 4.6 of this report. Detailed Calculations are presented in Appendix E. Summary of the results is presented in the following tables.

Table 5-5 : Continuous Sand Bag Weight Buoyancy Calculation Results

Parameter	APL01
Minimum Sand Bag Unit Mass per Length (kg/m)	1,380
Sand Bag Volume (m^3/m)	0.816
Buoyancy Force per Length (kg/m)	1,142
Minimum Submerged Sand Bag Unit Mass per Length (kg/m)	238

Parameter	APL01
Sand Bag Unit Weight per Length (N/m)	2,336
Net Downward Force (N/m)	3,437
Net Upward Force (N/m)	2,860
Safety Factor	1.202
Check (SF≥1.2)	Pass

6. REFERENCES

[1] Pipeline Basis of Design, Design Criteria, MM-ASK-1A-APL01-PLR-BOD-0001

[2] Process Heat and Material Balance, MM-ASK-1A-APF-PRP-HMB-0001

[3] Specification for Line Pipe, API Spec 5L

[4] McGraw-Hill, Roark's Formula for Stress & Strain, Seventh Edition

[5] Guidelines for the Design of Buried Steel Pipe, ASCE

[6] Gas Transmission and Distribution Piping Systems, ASME B31.8

[7] Acceptance Criteria for Helical Foundation System and Devices, AC358, ICC Evaluation Service

[8] Geotechnical Investigation Report for Geotechnical Investigation (GTI) for Onshore Facilities of AUNG SINKHA Development Project by International Integrated Services Company Limited.

APPENDIX A: BATTERY LIMITS FOR PIPELINES

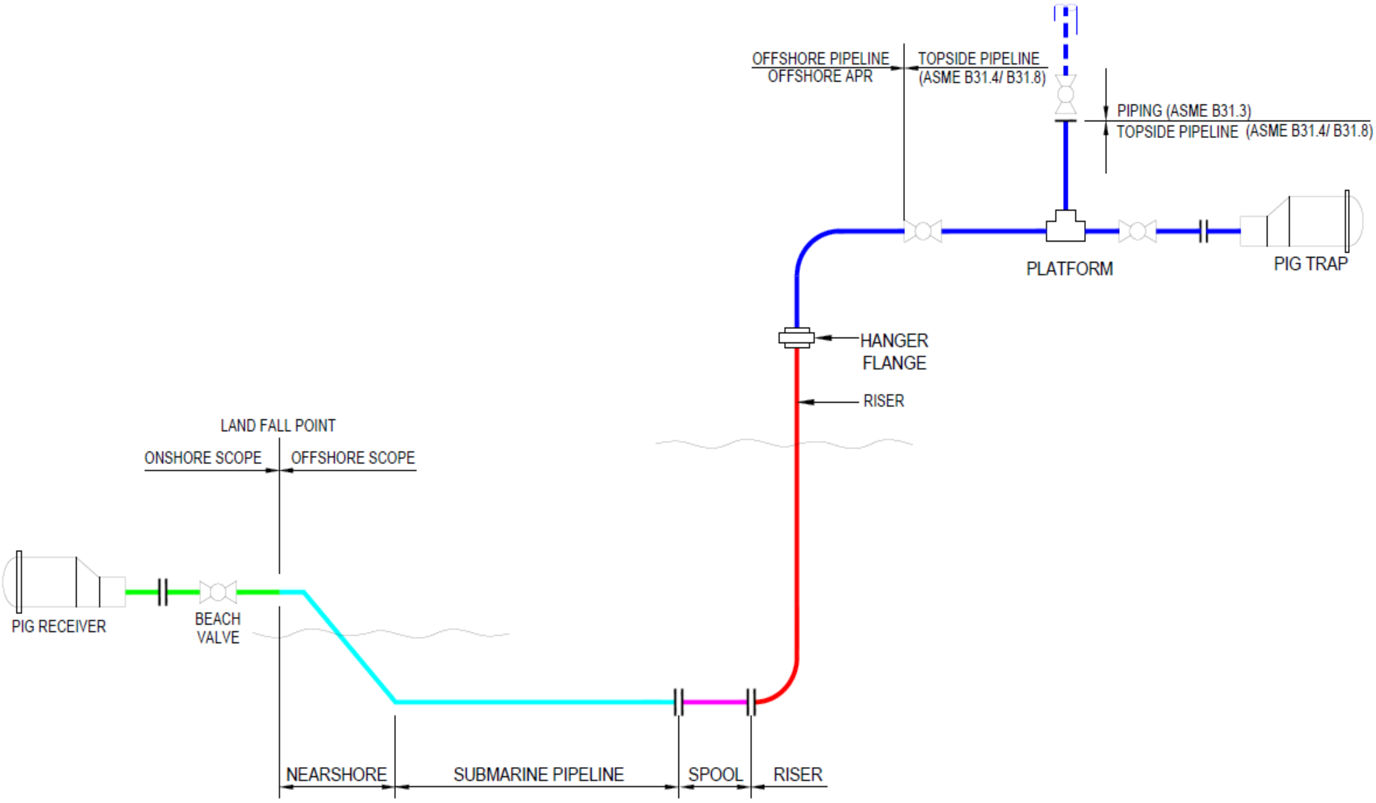


Figure A-1: Pipeline System Design Battery Limits

Note:

1. Scope of this document is APL01.

APPENDIX B: BUOYANCY CONTROL CALCULATION (NUMBER OF SCREW ANCHORS > 3)

Technip Energies

Pipeline Engineering Department

Buoyancy Control Calculation (Screw Anchor)

PROJECT : Basic Engineering Study for Aung Sinkha Development Project Phase 1A

PIPELINE NAME: APL01

Load Case 1: Temperature is 75 $°C$ - No. of Screw Anchor > 3

MAIN FEATURES

This spreadsheet performs the pipeline buoyancy control calculation for an onshore burial pipeline system. The following references are used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Gas Transmission and Distribution Piping Systems, ASME B31.8-2018)

/2/ American Lifelines Alliance and American Society of Civil (ASCE), Guidelines for the Design of Buried Steel Pipe, July 2001.

REFERENCE DOCUMENTATION

This spreadsheet was originally developed for application to specific project. It has been further enhanced and consolidated. A dedicated manual has been issued and should be read in conjunction with the use of this MATHCAD sheet.

REVISION HISTORY

Date	Rev.	Status	Comment	Author
20/8/17	0	For Implementation	The spreadsheet was updated by adding unrestrained pipe and installation torque calculation	TKI
18/2/13	1	For Implementation	The spreadsheet was updated and validation by Jakkrit K.	JKK
27/9/12	2	For Implementation	The spreadsheet was developed by Soratus P.	SWN
8/4/2021	3	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

A. Input Data

Pipeline Parameters

Condition Type	$HT := \text{"Hydrostatic Test"}$ $OB := \text{"Operation Beginning"}$ $OE := \text{"Operation End"}$
Condition Selection	$Condition := OE$
Boundary Type	$RP := \text{"Restrained Pipe"}$ $UP := \text{"Unrestrained Pipe"}$
Boundary Selection	$Boundary := RP$
Pipe Outside Diameter	$OD := 20\ in$
Pipe Wall Thickness	$WT := 14.3\ mm$
Internal Corrosion Allowance	$CA := 5.6\ mm$
Specified Minimum Yield Strength (S)	$S := 450\ MPa$
Steel Density	$\rho_{st} := 7850\ \frac{kg}{m^3}$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$

Design Parameters

Design Pressure	$P_d := 70\ bar$	
Maximum Allowable Operating Pressure	$MAOP := 25\ bar$	
Hydrotest Pressure	$P_h := 87.5$	(Location Class 2)
Design Temperature	$T_d := 75\ °C$	
Temperature Derating Factor	$T := 1$	($T < 121\ °C$)
Maximum Allowable Deflection in Pipe	$\delta_{max} := 200\ mm$	

Coating Parameters

External Corrosion Coating Density	$\rho_{cor} := 950\ \frac{kg}{m^3}$
External Corrosion Coating Thickness	$t_{cor} := 3.5\ mm$
Internal Corrosion Coating Density	$\rho_{in} := 0\ \frac{kg}{m^3}$

Internal Corrosion Coating Thickness $t_{inc} := 0\ mm$

Concrete Coating Density $\rho_{con} := 0\ \frac{kg}{m^3}$

Concrete Coating Thickness $t_{con} := 0\ mm$

Environment Parameters

Water Density $\rho_w := 1000\ \frac{kg}{m^3}$

Mud Density $\rho_m := 1400\ \frac{kg}{m^3}$

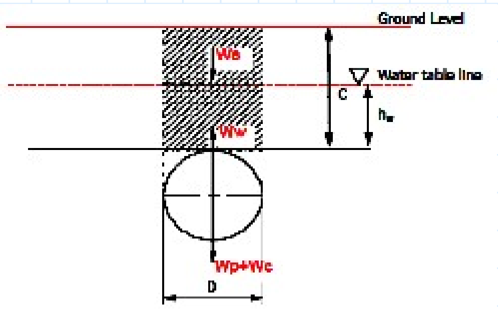
$W := \text{"Water"}$
$M := \text{"Mud"}$

Determined Buoyancy Force from $\rho := M$

Minimum Average Air Temperature $T_a := 23.3\ °C$

Mean Ground Temperature $T_g := 26\ °C$

Longitudinal Stress due to Other Axial Loading $S_x := 0\ Pa$



Height of Backfill above The Top of Pipeline $C := 1.2\ m$

Height of Water above The Top of Pipeline $h_w := C$

Consider Effective Soil Weight (SW) $SW := \text{"No"}$ (Yes or No)

Soil Parameters

Unit Weight of Wet Soil $\gamma_{wet} := 0\ \frac{kN}{m^3}$

Moisture Content of Wet Soil $w := 0\%$

Screw Anchor Parameters

Minimum Hold on Capacity (ultimate) $Q_a := 177.929\ kN$

Span Length of Screw Anchor $L_s := 44\ m$

Minimum Angle Subtended by arc of Contact between Pipe and Saddle (Degree) $\beta := 90$

Empirical Installation torque coefficient $K_T := 10 \cdot ft^{-1}$

Factor of Safety

Requirement for Negative Buoyancy Force $W_R := 0\ \frac{kg}{m}$ (0 if assigned the SF_b)

Safety Factor for Buoyancy Force $SF_b := 1.2$ (0 if assigned the W_R)

B. Calculation

B-1 Parameter Calculation

Internal Pressure

$$P_i := \begin{array}{l} \text{if } Condition = \text{“Hydrostatic Test”} \\ \quad P_h \\ \text{else} \\ \quad P_d \end{array}$$

Temperature Changed

$$\Delta T := \begin{array}{l} \text{if } Condition = \text{“Hydrostatic Test”} \\ \quad T_g - T_a \\ \text{else} \\ \quad T_d - T_a \end{array}$$

Fluid Displacement Density

$$\rho_b := \begin{array}{l} \text{if } \rho = \text{“Water”} \\ \quad \rho_w \\ \text{else} \\ \quad \rho_m \end{array}$$

Corroded Pipe Wall Thickness

$$WT := \begin{array}{l} \text{if } Condition = \text{“Operation End”} \\ \quad WT - CA \\ \text{else} \\ \quad WT \end{array}$$

Internal Corrosion Coating Thickness

$$t_{in} := \begin{array}{l} \text{if } Condition = \text{“Operation End”} \\ \quad 0\ mm \\ \text{else} \\ \quad t_{inc} \end{array}$$

Internal Corrosion Coating Inner Diameter $ID_{in} := OD - 2\ WT - 2\ t_{in}$

Pipeline Internal Diameter $ID := OD - 2\ WT$

Outside Coating Diameter $D_{cor} := OD + 2\ t_{cor}$

Total Outside Pipe Diameter $D := D_{cor} + 2\ t_{con}$

Pipeline Moment of Inertia $I := \frac{\pi}{64} \left(OD^4 - ID^4\right)$

Pipeline Sectional Elastic Modulus $Z := \frac{2\ I}{OD}$

Content Weight

$$W_c := \begin{cases} \text{if } Condition = \text{"Hydrostatic Test"} \\ \quad \dfrac{\rho_w \cdot \pi \cdot ID_{in}^{\ 2} \cdot g}{4} \\ \text{else} \\ \quad 0 \ \dfrac{N}{m} \end{cases}$$

Internal Liner Weight

$$W_{in} := \rho_{in} \cdot g \cdot \frac{\pi}{4} \cdot \left(ID^2 - ID_{in}^{\ 2}\right)$$

Pipeline Weight (Steel Weight)

$$W_{st} := \rho_{st} \cdot g \cdot \frac{\pi}{4} \cdot \left(OD^2 - ID^2\right)$$

External Corrosion Coating Weight

$$W_{cor} := \rho_{cor} \cdot g \cdot \frac{\pi}{4} \cdot \left(D_{cor}^{\ 2} - OD^2\right)$$

Concrete Coating Weight

$$W_{con} := \rho_{con} \cdot g \cdot \frac{\pi}{4} \cdot \left(D^2 - D_{cor}^{\ 2}\right)$$

Weight of Pipe per Unit Length

$$W_p := W_c + W_{in} + W_{st} + W_{cor} + W_{con}$$

Unit Weight of Water

$$\gamma_w := \rho_w \cdot g$$

Unit Weight of Displacement Fluid

$$\gamma_b := \rho_b \cdot g$$

Unit Weight of dry soil

$$\gamma_d := \frac{\gamma_{wet}}{1 + w}$$

Effective Unit Weight

$$\gamma_{eff} := \gamma_{wet} - \gamma_w$$

Weight of fluid displaced by pipe per unit length

$$W_b := \gamma_b \cdot \frac{\pi}{4} \cdot D^2$$

Water Buoyancy Factor

$$R_w := 1 - 0.33 \left(\frac{h_w}{C}\right)$$

Earth Pressure Acting to Top of Pipeline

$$P_v := \gamma_w \cdot h_w + R_w \cdot \gamma_d \cdot C$$

Effective Weight of Soil above Pipe

$$W_s := \begin{cases} \text{if } SW = \text{"Yes"} \\ \quad \left(P_v - \gamma_w \cdot h_w\right) \cdot D \\ \text{else} \\ \quad 0 \ \dfrac{N}{m} \end{cases}$$

Net Upward Force due to Buoyancy per unit length

$$F_b := \left(W_b + W_R \cdot g\right) - \left(W_p + W_s\right)$$

Bending Moment

$$M := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad \dfrac{1}{12} \cdot F_b \cdot L_s^{\ 2} \\ \text{else} \\ \quad \dfrac{1}{8} \cdot F_b \cdot L_s^{\ 2} \end{cases}$$

B-2 Buoyancy Safety Factor

Safety Factor

$$SF := \frac{W_p + W_s + \dfrac{Q_a}{L_s}}{W_b}$$

Safety Factor Checking

$$Check_{SFB} := \begin{cases} \text{if } SF > SF_b \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{cases}$$

B-3 Stress Calculation

Stress due to Saddle Load

$$S_S := (0.02 - 0.00012 \cdot (\beta - 90)) \cdot \frac{Q_a}{WT^2} \cdot \ln\left(\frac{OD}{2\ WT}\right)$$

Hoop Stress
1: Bottom of Pipe
2: Top of Pipe

$$S_{H1} := \begin{cases} \text{if } \frac{OD}{WT} \ge 30 \\ \quad \frac{P_i \cdot OD}{2\ WT} \\ \text{else} \\ \quad \frac{P_i \cdot (OD - WT)}{2\ WT} \end{cases} \qquad S_{H2} := \begin{cases} \text{if } \frac{OD}{WT} \ge 30 \\ \quad \frac{P_i \cdot OD}{2\ WT} - S_S \\ \text{else} \\ \quad \frac{P_i \cdot (OD - WT)}{2\ WT} - S_S \end{cases}$$

Longitudinal Stress

Longitudinal Stress due to Internal Pressure

$$S_{p1} := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.3 \cdot S_{H1} \\ \text{else} \\ \quad 0.5 \cdot S_{H1} \end{cases} \qquad S_{p2} := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.3 \cdot S_{H2} \\ \text{else} \\ \quad 0.5 \cdot S_{H2} \end{cases}$$

Longitudinal Stress due to Thermal Expansion

$$S_T := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad -E \cdot \alpha \cdot \Delta T \\ \text{else} \\ \quad 0\ MPa \end{cases}$$

Longitudinal Stress due to Bending Moment

$$S_B := \frac{M}{Z}$$

Net Longitudinal Stress in Pipeline

$$S_{L1} := S_{p1} + S_T + S_x + (S_B)$$

$$S_{L2} := S_{p2} + S_T + S_x - S_B$$

Maximum Longitudinal Stress

$$S_{Lmax} := \max\left(\left|S_{L1}\right|, \left|S_{L2}\right|\right)$$

Allowable Longitudinal Stress

$$S_{Lallow} := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.9 \cdot S \cdot T \\ \text{else} \\ \quad 0.75 \cdot S \cdot T \end{cases}$$

Longitudinal Stress Checking

$$Check_L := \begin{cases} \text{if } S_{Lmax} \le S_{Lallow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{cases}$$

Combined Stress

Combined Stress for Restrained Pipeline

$$S_{com1} := \sqrt{S_{L1}^2 - S_{L1} \cdot S_{H1} + S_{H1}^2}$$

$$S_{com2} := \sqrt{S_{L2}^2 - S_{L2} \cdot S_{H2} + S_{H2}^2}$$

Maximum Combined Stress

$$S_{com\_max} := \max\left(\left|S_{com1}\right|, \left|S_{com2}\right|\right)$$

Allowable Combined Stress

$$S_{com\_allow} := \begin{cases} \text{if } Boundary = \text{“Restrained Pipe”} \wedge Condition = \text{“Hydrostatic Test”} \\ \quad 1.0 \cdot S \cdot T \\ \text{else} \\ \quad 0.9 \cdot S \cdot T \end{cases}$$

Combined Stress Checking

$$Check_{com} := \begin{cases} \text{if } Boundary = \text{“Unrestrained Pipe”} \\ \quad \text{“Not Required”} \\ \text{else if } Boundary = \text{“Restrained Pipe”} \wedge S_{com\_max} \le S_{com\_allow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{cases}$$

Deflection

Maximum Deflection in Pipeline

$$\delta_{ac} := \begin{cases} \text{if } Boundary = \text{“Restrained Pipe”} \\ \quad \dfrac{F_b \cdot L_s^4}{384 \cdot E \cdot I} \\ \text{else} \\ \quad \dfrac{F_b \cdot L_s^4}{185 \cdot E \cdot I} \end{cases}$$

Deflection Checking

$$Check_{de} := \begin{cases} \text{if } \delta_{ac} \le \delta_{max} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{cases}$$

Force

Anchor Force

$$F_1 := \begin{cases} \text{if } Boundary = \text{“Restrained Pipe”} \\ \quad F_b \cdot L_s \\ \text{else} \\ \quad 2 \cdot \dfrac{5 \cdot F_b \cdot L_s}{8} \end{cases}$$

Anchor Force Checking

$$Check_{af} := \begin{cases} \text{if } F_1 \le Q_a \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{cases}$$

Installation Torque

$$T_{min} := \frac{Q_a}{2 \cdot K_T}$$

C. Summary of Results

C-1 Safety Factor for Buoyancy Control Checking

Safety Factor for Buoyancy Control	$SF=1.8$	
Safety Factor for Buoyancy Control Checking	$Check_{SFB}=\text{“Pass”}$	(SF > 1.2)

C-2 Net Longitudinal Stress Checking

Actual Longitudinal Stress	$S_{L1}=105.346\ MPa$	$S_{L2}=-280.739\ MPa$
Maximum Longitudinal Stress	$S_{Lmax}=280.739\ MPa$	
Allowable Longitudinal Stress	$S_{Lallow}=405\ MPa$	
Longitudinal Stress Checking	$Check_L=\text{“Pass”}$	

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com1}=177.016\ MPa$	$S_{com2}=306.181\ MPa$
Maximum Combined Stress	$S_{com\_max}=306.181\ MPa$	
Allowable Combined Stress	$S_{com\_allow}=405\ MPa$	
Longitudinal Combined Checking	$Check_{com}=\text{“Pass”}$	

C-4 Deflection Checking

Maximum Deflection	$\delta_{ac}=194.749\ mm$
Allowable Deflection	$\delta_{max}=200\ mm$
Deflection Checking	$Check_{de}=\text{“Pass”}$

C-5 Anchor Force Checking

Upward Force due to Buoyancy per unit length	$F_b=1.757\ \frac{kN}{m}$
Maximum Anchor Force	$F_1=77.306\ kN$
Allowable Anchor Force	$Q_a=177.929\ kN$
Net Downward Force	$W_p+W_s+\frac{Q_a}{L_s}=5.147\ \frac{kN}{m}$
Net Upward Force	$W_b=2.86\ \frac{kN}{m}$
Screw Installation Torque	$T_{min}=2.712\ kN \cdot m$
Anchor Force Checking	$Check_{af}=\text{“Pass”}$

Technip Energies
Pipeline Engineering Department

Buoyancy Control Calculation (Screw Anchor)

PROJECT : Basic Engineering Study for Aung Sinkha Development Project Phase 1A

PIPELINE NAME: APL01

Load Case 2: Temperature is -10 ℃ - No. of Screw Anchor > 3

MAIN FEATURES

This spreadsheet performs the pipeline buoyancy control calculation for an onshore burial pipeline system. The following references are used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Gas Transmission and Distribution Piping Systems, ASME B31.8-2018)

/2/ American Lifelines Alliance and American Society of Civil (ASCE), Guidelines for the Design of Buried Steel Pipe, July 2001.

REFERENCE DOCUMENTATION

This spreadsheet was originally developed for application to specific project. It has been further enhanced and consolidated. A dedicated manual has been issued and should be read in conjunction with the use of this MATHCAD sheet.

REVISION HISTORY

Date	Rev.	Status	Comment	Author
20/8/17	0	For Implementation	The spreadsheet was updated by adding unrestrained pipe and installation torque calculation	TKI
18/2/13	1	For Implementation	The spreadsheet was updated and validation by Jakkrit K.	JKK
27/9/12	2	For Implementation	The spreadsheet was developed by Soratus P.	SWN
8/4/2021	3	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

A. Input Data

Pipeline Parameters

Condition Type	$HT :=$ "Hydrostatic Test" $OB :=$ "Operation Beginning" $OE :=$ "Operation End"
Condition Selection	$Condition := OE$
Boundary Type	$RP :=$ "Restrained Pipe" $UP :=$ "Unrestrained Pipe"
Boundary Selection	$Boundary := RP$
Pipe Outside Diameter	$OD := 20\ in$
Pipe Wall Thickness	$WT := 14.3\ mm$
Internal Corrosion Allowance	$CA := 5.6\ mm$
Specified Minimum Yield Strength (S)	$S := 450\ MPa$
Steel Density	$\rho_{st} := 7850\ \frac{kg}{m^3}$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$

Design Parameters

Design Pressure	$P_d := 70\ bar$	
Maximum Allowable Operating Pressure	$MAOP := 25\ bar$	
Hydrotest Pressure	$P_h := 87.5$	(Location Class 2)
Design Temperature	$T_d := -10\ °C$	
Temperature Derating Factor	$T := 1$	(T < 121 $°C$)
Maximum Allowable Deflection in Pipe	$\delta_{max} := 200\ mm$	

Coating Parameters

External Corrosion Coating Density	$\rho_{cor} := 950\ \frac{kg}{m^3}$
External Corrosion Coating Thickness	$t_{cor} := 3.5\ mm$
Internal Corrosion Coating Density	$\rho_{in} := 0\ \frac{kg}{m^3}$

Internal Corrosion Coating Thickness $t_{inc} := 0\ mm$

Concrete Coating Density $\rho_{con} := 0\ \frac{kg}{m^3}$

Concrete Coating Thickness $t_{con} := 0\ mm$

Environment Parameters

Water Density $\rho_w := 1000\ \frac{kg}{m^3}$

Mud Density $\rho_m := 1400\ \frac{kg}{m^3}$

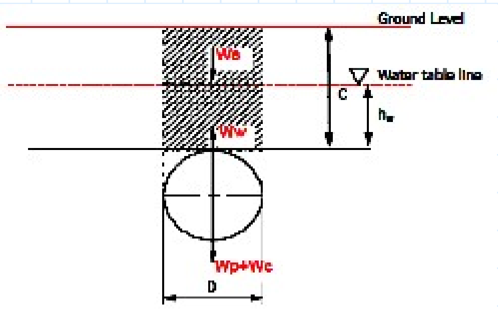
$W := \text{“Water”}$
$M := \text{“Mud”}$

Determined Buoyancy Force from $\rho := M$

Minimum Average Air Temperature $T_a := 23.3\ °C$

Mean Ground Temperature $T_g := 26\ °C$

Longitudinal Stress due to Other Axial Loading $S_x := 0\ Pa$



Height of Backfill above The Top of Pipeline $C := 1.2\ m$

Height of Water above The Top of Pipeline $h_w := C$

Consider Effective Soil Weight (SW) $SW := \text{“No”}$ (Yes or No)

Soil Parameters

Unit Weight of Wet Soil $\gamma_{wet} := 0\ \frac{kN}{m^3}$

Moisture Content of Wet Soil $w := 0\%$

Screw Anchor Parameters

Minimum Hold on Capacity (ultimate) $Q_a := 177.929\ kN$

Span Length of Screw Anchor $L_s := 44\ m$

Minimum Angle Subtended by arc of Contact between Pipe and Saddle (Degree) $\beta := 90$

Empirical Installation torque coefficient $K_T := 10 \cdot ft^{-1}$

Factor of Safety

Requirement for Negative Buoyancy Force $W_R := 0\ \frac{kg}{m}$ (0 if assigned the SF_b)

Safety Factor for Buoyancy Force $SF_b := 1.2$ (0 if assigned the W_R)

B. Calculation

B-1 Parameter Calculation

Internal Pressure

$$P_i := \begin{cases} \text{if } Condition = \text{“Hydrostatic Test”} \\ \quad P_h \\ \text{else} \\ \quad P_d \end{cases}$$

Temperature Changed

$$\Delta T := \begin{cases} \text{if } Condition = \text{“Hydrostatic Test”} \\ \quad T_g - T_a \\ \text{else} \\ \quad T_d - T_a \end{cases}$$

Fluid Displacement Density

$$\rho_b := \begin{cases} \text{if } \rho = \text{“Water”} \\ \quad \rho_w \\ \text{else} \\ \quad \rho_m \end{cases}$$

Corroded Pipe Wall Thickness

$$WT := \begin{cases} \text{if } Condition = \text{“Operation End”} \\ \quad WT - CA \\ \text{else} \\ \quad WT \end{cases}$$

Internal Corrosion Coating Thickness

$$t_{in} := \begin{cases} \text{if } Condition = \text{“Operation End”} \\ \quad 0\ mm \\ \text{else} \\ \quad t_{inc} \end{cases}$$

Internal Corrosion Coating Inner Diameter $ID_{in} := OD - 2\ WT - 2\ t_{in}$

Pipeline Internal Diameter $ID := OD - 2\ WT$

Outside Coating Diameter $D_{cor} := OD + 2\ t_{cor}$

Total Outside Pipe Diameter $D := D_{cor} + 2\ t_{con}$

Pipeline Moment of Inertia $I := \frac{\pi}{64}\left(OD^4 - ID^4\right)$

Pipeline Sectional Elastic Modulus $Z := \frac{2\ I}{OD}$

Content Weight

$$W_c := \begin{cases} \frac{\rho_w \cdot \pi \cdot ID_{in}^{\ 2} \cdot g}{4} & \text{if } Condition = \text{"Hydrostatic Test"} \\ 0\ \frac{N}{m} & \text{else} \end{cases}$$

Internal Liner Weight

$$W_{in} := \rho_{in} \cdot g \cdot \frac{\pi}{4} \cdot \left(ID^2 - ID_{in}^{\ 2}\right)$$

Pipeline Weight (Steel Weight)

$$W_{st} := \rho_{st} \cdot g \cdot \frac{\pi}{4} \cdot \left(OD^2 - ID^2\right)$$

External Corrosion Coating Weight

$$W_{cor} := \rho_{cor} \cdot g \cdot \frac{\pi}{4} \cdot \left(D_{cor}^{\ 2} - OD^2\right)$$

Concrete Coating Weight

$$W_{con} := \rho_{con} \cdot g \cdot \frac{\pi}{4} \cdot \left(D^2 - D_{cor}^{\ 2}\right)$$

Weight of Pipe per Unit Length

$$W_p := W_c + W_{in} + W_{st} + W_{cor} + W_{con}$$

Unit Weight of Water

$$\gamma_w := \rho_w \cdot g$$

Unit Weight of Displacement Fluid

$$\gamma_b := \rho_b \cdot g$$

Unit Weight of dry soil

$$\gamma_d := \frac{\gamma_{wet}}{1 + w}$$

Effective Unit Weight

$$\gamma_{eff} := \gamma_{wet} - \gamma_w$$

Weight of fluid displaced by pipe per unit length

$$W_b := \gamma_b \cdot \frac{\pi}{4} \cdot D^2$$

Water Buoyancy Factor

$$R_w := 1 - 0.33 \left(\frac{h_w}{C}\right)$$

Earth Pressure Acting to Top of Pipeline

$$P_v := \gamma_w \cdot h_w + R_w \cdot \gamma_d \cdot C$$

Effective Weight of Soil above Pipe

$$W_s := \begin{cases} \left(P_v - \gamma_w \cdot h_w\right) \cdot D & \text{if } SW = \text{"Yes"} \\ 0\ \frac{N}{m} & \text{else} \end{cases}$$

Net Upward Force due to Buoyancy per unit length

$$F_b := \left(W_b + W_R \cdot g\right) - \left(W_p + W_s\right)$$

Bending Moment

$$M := \begin{cases} \frac{1}{12} \cdot F_b \cdot L_s^{\ 2} & \text{if } Boundary = \text{"Restrained Pipe"} \\ \frac{1}{8} \cdot F_b \cdot L_s^{\ 2} & \text{else} \end{cases}$$

B-2 Buoyancy Safety Factor

Safety Factor

$$SF := \frac{W_p + W_s + \frac{Q_a}{L_s}}{W_b}$$

Safety Factor Checking

$$Check_{SFB} := \begin{cases} \text{if } SF > SF_b \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{cases}$$

B-3 Stress Calculation

Stress due to Saddle Load

$$S_S := \left(0.02 - 0.00012 \cdot (\beta - 90)\right) \cdot \frac{Q_a}{WT^2} \cdot \ln\left(\frac{OD}{2\ WT}\right)$$

Hoop Stress
1: Bottom of Pipe
2: Top of Pipe

$$S_{H1} := \begin{cases} \text{if } \frac{OD}{WT} \ge 30 \\ \quad \frac{P_i \cdot OD}{2\ WT} \\ \text{else} \\ \quad \frac{P_i \cdot (OD - WT)}{2\ WT} \end{cases} \qquad S_{H2} := \begin{cases} \text{if } \frac{OD}{WT} \ge 30 \\ \quad \frac{P_i \cdot OD}{2\ WT} - S_S \\ \text{else} \\ \quad \frac{P_i \cdot (OD - WT)}{2\ WT} - S_S \end{cases}$$

Longitudinal Stress

Longitudinal Stress due to Internal Pressure

$$S_{p1} := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.3 \cdot S_{H1} \\ \text{else} \\ \quad 0.5 \cdot S_{H1} \end{cases} \qquad S_{p2} := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.3 \cdot S_{H2} \\ \text{else} \\ \quad 0.5 \cdot S_{H2} \end{cases}$$

Longitudinal Stress due to Thermal Expansion

$$S_T := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad -E \cdot \alpha \cdot \Delta T \\ \text{else} \\ \quad 0\ MPa \end{cases}$$

Longitudinal Stress due to Bending Moment

$$S_B := \frac{M}{Z}$$

Net Longitudinal Stress in Pipeline

$$S_{L1} := S_{p1} + S_T + S_x + (S_B)$$

$$S_{L2} := S_{p2} + S_T + S_x - S_B$$

Maximum Longitudinal Stress

$$S_{Lmax} := \max\left(\left|S_{L1}\right|, \left|S_{L2}\right|\right)$$

Allowable Longitudinal Stress

$$S_{Lallow} := \begin{cases} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.9 \cdot S \cdot T \\ \text{else} \\ \quad 0.75 \cdot S \cdot T \end{cases}$$

Longitudinal Stress Checking

$$Check_L := \begin{cases} \text{if } S_{Lmax} \le S_{Lallow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{cases}$$

Combined Stress

Combined Stress for Restrained Pipeline

$$S_{com1} := \sqrt{S_{L1}^2 - S_{L1} \cdot S_{H1} + S_{H1}^2}$$

$$S_{com2} := \sqrt{S_{L2}^2 - S_{L2} \cdot S_{H2} + S_{H2}^2}$$

Maximum Combined Stress

$$S_{com\_max} := \max\left(\left|S_{com1}\right|, \left|S_{com2}\right|\right)$$

Allowable Combined Stress

$$S_{com\_allow} := \begin{cases} 1.0 \cdot S \cdot T & \text{if } Boundary = \text{"Restrained Pipe"} \land Condition = \text{"Hydrostatic Test"} \\ 0.9 \cdot S \cdot T & \text{else} \end{cases}$$

Combined Stress Checking

$$Check_{com} := \begin{cases} \text{"Not Required"} & \text{if } Boundary = \text{"Unrestrained Pipe"} \\ \text{"Pass"} & \text{else if } Boundary = \text{"Restrained Pipe"} \land S_{com\_max} \le S_{com\_allow} \\ \text{"Fail"} & \text{else} \end{cases}$$

Deflection

Maximum Deflection in Pipeline

$$\delta_{ac} := \begin{cases} \dfrac{F_b \cdot L_s^4}{384 \cdot E \cdot I} & \text{if } Boundary = \text{"Restrained Pipe"} \\ \dfrac{F_b \cdot L_s^4}{185 \cdot E \cdot I} & \text{else} \end{cases}$$

Deflection Checking

$$Check_{de} := \begin{cases} \text{"Pass"} & \text{if } \delta_{ac} \le \delta_{max} \\ \text{"Fail"} & \text{else} \end{cases}$$

Force

Anchor Force

$$F_1 := \begin{cases} F_b \cdot L_s & \text{if } Boundary = \text{"Restrained Pipe"} \\ 2 \cdot \dfrac{5 \cdot F_b \cdot L_s}{8} & \text{else} \end{cases}$$

Anchor Force Checking

$$Check_{af} := \begin{cases} \text{"Pass"} & \text{if } F_1 \le Q_a \\ \text{"Fail"} & \text{else} \end{cases}$$

Installation Torque

$$T_{min} := \frac{Q_a}{2 \cdot K_T}$$

TEN TECHNIP ENERGIES

C. Summary of Results

C-1 Safety Factor for Buoyancy Control Checking

Safety Factor for Buoyancy Control	$SF = 1.8$	
Safety Factor for Buoyancy Control Checking	$Check_{SFB} = \text{"Pass"}$	(SF > 1.2)

C-2 Net Longitudinal Stress Checking

Actual Longitudinal Stress	$S_{L1} = 311.208\ MPa$	$S_{L2} = -74.877\ MPa$
Maximum Longitudinal Stress	$S_{Lmax} = 311.208\ MPa$	
Allowable Longitudinal Stress	$S_{Lallow} = 405\ MPa$	
Longitudinal Stress Checking	$Check_L = \text{"Pass"}$	

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com1} = 273.89\ MPa$	$S_{com2} = 105.467\ MPa$
Maximum Combined Stress	$S_{com\_max} = 273.89\ MPa$	
Allowable Combined Stress	$S_{com\_allow} = 405\ MPa$	
Longitudinal Combined Checking	$Check_{com} = \text{"Pass"}$	

C-4 Deflection Checking

Maximum Deflection	$\delta_{ac} = 194.749\ mm$
Allowable Deflection	$\delta_{max} = 200\ mm$
Deflection Checking	$Check_{de} = \text{"Pass"}$

C-5 Anchor Force Checking

Upward Force due to Buoyancy per unit length	$F_b = 1.757\ \frac{kN}{m}$
Maximum Anchor Force	$F_1 = 77.306\ kN$
Allowable Anchor Force	$Q_a = 177.929\ kN$
Net Downward Force	$W_p + W_s + \frac{Q_a}{L_s} = 5.147\ \frac{kN}{m}$
Net Upward Force	$W_b = 2.86\ \frac{kN}{m}$
Screw Installation Torque	$T_{min} = 2.712\ kN \cdot m$
Anchor Force Checking	$Check_{af} = \text{"Pass"}$

APPENDIX C BUOYANCY CONTROL CALCULATION (NUMBER OF SCREW ANCHORS ≤ 3)

Technip Energies

Pipeline Engineering Department

Buoyancy Control Calculation (Screw Anchor)

PROJECT : Basic Engineering Study for Aung Sinkha Development Project Phase 1A

PIPELINE NAME: APL01

No. of Screw Anchor ≤ 3

MAIN FEATURES

This spreadsheet performs the pipeline buoyancy control calculation for an onshore burial pipeline system. The following references are used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Gas Transmission and Distribution Piping Systems, ASME B31.8-2018)

/2/ American Lifelines Alliance and American Society of Civil (ASCE), Guidelines for the Design of Buried Steel Pipe, July 2001.

REFERENCE DOCUMENTATION

This spreadsheet was originally developed for application to specific project. It has been further enhanced and consolidated. A dedicated manual has been issued and should be read in conjunction with the use of this MATHCAD sheet.

REVISION HISTORY

Date	Rev.	Status	Comment	Author
20/8/17	0	For Implementation	The spreadsheet was updated by adding unrestrained pipe and installation torque calculation	TKI
18/2/13	1	For Implementation	The spreadsheet was updated and validation by Jakkrit K.	JKK
27/9/12	2	For Implementation	The spreadsheet was developed by Soratus P.	SWN
8/4/2021	3	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

A. Input Data

Pipeline Parameters

Condition Type	$HT := \text{"Hydrostatic Test"}$ $OB := \text{"Operation Beginning"}$ $OE := \text{"Operation End"}$
Condition Selection	$Condition := OE$
Boundary Type	$RP := \text{"Restrained Pipe"}$ $UP := \text{"Unrestrained Pipe"}$
Boundary Selection	$Boundary := UP$
Pipe Outside Diameter	$OD := 20\ in$
Pipe Wall Thickness	$WT := 14.3\ mm$
Internal Corrosion Allowance	$CA := 5.6\ mm$
Specified Minimum Yield Strength (S)	$S := 450\ MPa$
Steel Density	$\rho_{st} := 7850\ \frac{kg}{m^3}$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$

Design Parameters

Design Pressure	$P_d := 70\ bar$	
Maximum Allowable Operating Pressure	$MAOP := 25\ bar$	
Hydrotest Pressure	$P_h := 1.25 \cdot MAOP$	(Location Class 2)
Design Temperature	$T_d := 75\ °C$	
Temperature Derating Factor	$T := 1$	($T < 121\ °C$)
Maximum Allowable Deflection in Pipe	$\delta_{max} := 200\ mm$	

Coating Parameters

External Corrosion Coating Density	$\rho_{cor} := 950\ \frac{kg}{m^3}$
External Corrosion Coating Thickness	$t_{cor} := 3.5\ mm$
Internal Corrosion Coating Density	$\rho_{in} := 0\ \frac{kg}{m^3}$

Internal Corrosion Coating Thickness $t_{inc} := 0\ mm$

Concrete Coating Density $\rho_{con} := 0\ \frac{kg}{m^3}$

Concrete Coating Thickness $t_{con} := 0\ mm$

Environment Parameters

Water Density $\rho_w := 1000\ \frac{kg}{m^3}$

Mud Density $\rho_m := 1400\ \frac{kg}{m^3}$

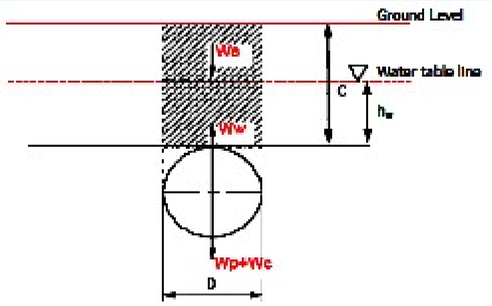
$W := \text{"Water"}$
$M := \text{"Mud"}$

Determined Buoyancy Force from $\rho := M$

Minimum Average Air Temperature $T_a := 23.3\ °C$

Mean Ground Temperature $T_g := 26\ °C$

Longitudinal Stress due to Other Axial Loading $S_x := 0\ Pa$



Height of Backfill above The Top of Pipeline $C := 1.2\ m$

Height of Water above The Top of Pipeline $h_w := C$

Consider Effective Soil Weight (SW) $SW := \text{"No"}$ (Yes or No)

Soil Parameters

Unit Weight of Wet Soil $\gamma_{wet} := 0\ \frac{kN}{m^3}$

Moisture Content of Wet Soil $w := 0\%$

Screw Anchor Parameters

Minimum Hold on Capacity (ultimate) $Q_a := 177.929\ kN$

Span Length of Screw Anchor $L_s := 36\ m$

Minimum Angle Subtended by arc of Contact between Pipe and Saddle (Degree) $\beta := 90$

Empirical Installation torque coefficient $K_T := 10 \cdot ft^{-1}$

Factor of Safety

Requirement for Negative Buoyancy Force $W_R := 0\ \frac{kg}{m}$ (0 if assigned the SF_b)

Safety Factor for Buoyancy Force $SF_b := 1.2$ (0 if assigned the W_R)

B. Calculation

B-1 Parameter Calculation

Internal Pressure

$$P_i := \begin{cases} P_h & \text{if } Condition = \text{"Hydrostatic Test"} \\ P_d & \text{else} \end{cases}$$

Temperature Changed

$$\Delta T := \begin{cases} T_g - T_a & \text{if } Condition = \text{"Hydrostatic Test"} \\ T_d - T_a & \text{else} \end{cases}$$

Fluid Displacement Density

$$\rho_b := \begin{cases} \rho_w & \text{if } \rho = \text{"Water"} \\ \rho_m & \text{else} \end{cases}$$

Corroded Pipe Wall Thickness

$$WT := \begin{cases} WT - CA & \text{if } Condition = \text{"Operation End"} \\ WT & \text{else} \end{cases}$$

Internal Corrosion Coating Thickness

$$t_{in} := \begin{cases} 0\ mm & \text{if } Condition = \text{"Operation End"} \\ t_{inc} & \text{else} \end{cases}$$

Internal Corrosion Coating Inner Diameter $ID_{in} := OD - 2\ WT - 2\ t_{in}$

Pipeline Internal Diameter $ID := OD - 2\ WT$

Outside Coating Diameter $D_{cor} := OD + 2\ t_{cor}$

Total Outside Pipe Diameter $D := D_{cor} + 2\ t_{con}$

Pipeline Moment of Inertia $I := \frac{\pi}{64} \left(OD^4 - ID^4 \right)$

Pipeline Sectional Elastic Modulus $Z := \frac{2\ I}{OD}$

Content Weight

$$W_c := \begin{cases} \dfrac{\rho_w \cdot \pi \cdot ID_{in}^{\ 2} \cdot g}{4} & \text{if } Condition = \text{“Hydrostatic Test”} \\ 0 \ \dfrac{N}{m} & \text{else} \end{cases}$$

Internal Liner Weight

$$W_{in} := \rho_{in} \cdot g \cdot \frac{\pi}{4} \cdot \left(ID^2 - ID_{in}^{\ 2}\right)$$

Pipeline Weight (Steel Weight)

$$W_{st} := \rho_{st} \cdot g \cdot \frac{\pi}{4} \cdot \left(OD^2 - ID^2\right)$$

External Corrosion Coating Weight

$$W_{cor} := \rho_{cor} \cdot g \cdot \frac{\pi}{4} \cdot \left(D_{cor}^{\ 2} - OD^2\right)$$

Concrete Coating Weight

$$W_{con} := \rho_{con} \cdot g \cdot \frac{\pi}{4} \cdot \left(D^2 - D_{cor}^{\ 2}\right)$$

Weight of Pipe per Unit Length

$$W_p := W_c + W_{in} + W_{st} + W_{cor} + W_{con}$$

Unit Weight of Water

$$\gamma_w := \rho_w \cdot g$$

Unit Weight of Displacement Fluid

$$\gamma_b := \rho_b \cdot g$$

Unit Weight of dry soil

$$\gamma_d := \frac{\gamma_{wet}}{1 + w}$$

Effective Unit Weight

$$\gamma_{eff} := \gamma_{wet} - \gamma_w$$

Weight of fluid displaced by pipe per unit length

$$W_b := \gamma_b \cdot \frac{\pi}{4} \cdot D^2$$

Water Buoyancy Factor

$$R_w := 1 - 0.33 \left(\frac{h_w}{C}\right)$$

Earth Pressure Acting to Top of Pipeline

$$P_v := \gamma_w \cdot h_w + R_w \cdot \gamma_d \cdot C$$

Effective Weight of Soil above Pipe

$$W_s := \begin{cases} \left(P_v - \gamma_w \cdot h_w\right) \cdot D & \text{if } SW = \text{“Yes”} \\ 0 \ \dfrac{N}{m} & \text{else} \end{cases}$$

Net Upward Force due to Buoyancy per unit length

$$F_b := \left(W_b + W_R \cdot g\right) - \left(W_p + W_s\right)$$

Bending Moment

$$M := \begin{cases} \dfrac{1}{12} \cdot F_b \cdot L_s^{\ 2} & \text{if } Boundary = \text{“Restrained Pipe”} \\ \dfrac{1}{8} \cdot F_b \cdot L_s^{\ 2} & \text{else} \end{cases}$$

B-2 Buoyancy Safety Factor

Safety Factor

$$SF := \frac{W_p + W_s + \dfrac{Q_a}{L_s}}{W_b}$$

Safety Factor Checking

$$Check_{SFB} := \begin{array}{l} \text{if } SF > SF_b \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

B-3 Stress Calculation

Stress due to Saddle Load

$$S_S := (0.02 - 0.00012 \cdot (\beta - 90)) \cdot \frac{Q_a}{WT^2} \cdot \ln\left(\frac{OD}{2\ WT}\right)$$

Hoop Stress
1: Bottom of Pipe
2: Top of Pipe

$$S_{H1} := \begin{array}{l} \text{if } \frac{OD}{WT} \geq 30 \\ \quad \frac{P_i \cdot OD}{2\ WT} \\ \text{else} \\ \quad \frac{P_i \cdot (OD - WT)}{2\ WT} \end{array} \qquad S_{H2} := \begin{array}{l} \text{if } \frac{OD}{WT} \geq 30 \\ \quad \frac{P_i \cdot OD}{2\ WT} - S_S \\ \text{else} \\ \quad \frac{P_i \cdot (OD - WT)}{2\ WT} - S_S \end{array}$$

Longitudinal Stress

Longitudinal Stress due to Internal Pressure

$$S_{p1} := \begin{array}{l} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.3 \cdot S_{H1} \\ \text{else} \\ \quad 0.5 \cdot S_{H1} \end{array} \qquad S_{p2} := \begin{array}{l} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.3 \cdot S_{H2} \\ \text{else} \\ \quad 0.5 \cdot S_{H2} \end{array}$$

Longitudinal Stress due to Thermal Expansion

$$S_T := \begin{array}{l} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad -E \cdot \alpha \cdot \Delta T \\ \text{else} \\ \quad 0\ MPa \end{array}$$

Longitudinal Stress due to Bending Moment

$$S_B := \frac{M}{Z}$$

Net Longitudinal Stress in Pipeline

$$S_{L1} := S_{p1} + S_T + S_x + (S_B)$$

$$S_{L2} := S_{p2} + S_T + S_x - (S_B + S_S)$$

Maximum Longitudinal Stress

$$S_{Lmax} := \max\left(\left|S_{L1}\right|, \left|S_{L2}\right|\right)$$

Allowable Longitudinal Stress

$$S_{Lallow} := \begin{array}{l} \text{if } Boundary = \text{"Restrained Pipe"} \\ \quad 0.9 \cdot S \cdot T \\ \text{else} \\ \quad 0.75 \cdot S \cdot T \end{array}$$

Longitudinal Stress Checking

$$Check_L := \begin{array}{l} \text{if } S_{Lmax} \leq S_{Lallow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

Combined Stress

Combined Stress for Restrained Pipeline

$$S_{com1} := \sqrt{S_{L1}^2 - S_{L1} \cdot S_{H1} + S_{H1}^2}$$

$$S_{com2} := \sqrt{S_{L2}^2 - S_{L2} \cdot S_{H2} + S_{H2}^2}$$

Maximum Combined Stress

$$S_{com\_max} := \max\left(\left|S_{com1}\right|, \left|S_{com2}\right|\right)$$

Allowable Combined Stress

$$S_{com\_allow} := \begin{cases} 1.0 \cdot S \cdot T & \text{if } Boundary = \text{"Restrained Pipe"} \wedge Condition = \text{"Hydrostatic Test"} \\ 0.9 \cdot S \cdot T & \text{else} \end{cases}$$

Combined Stress Checking

$$Check_{com} := \begin{cases} \text{"Not Required"} & \text{if } Boundary = \text{"Unrestrained Pipe"} \\ \text{"Pass"} & \text{else if } Boundary = \text{"Restrained Pipe"} \wedge S_{com\_max} \le S_{com\_allow} \\ \text{"Fail"} & \text{else} \end{cases}$$

Deflection

Maximum Deflection in Pipeline

$$\delta_{ac} := \begin{cases} \dfrac{F_b \cdot L_s^4}{384 \cdot E \cdot I} & \text{if } Boundary = \text{"Restrained Pipe"} \\ \dfrac{F_b \cdot L_s^4}{185 \cdot E \cdot I} & \text{else} \end{cases}$$

Deflection Checking

$$Check_{de} := \begin{cases} \text{"Pass"} & \text{if } \delta_{ac} \le \delta_{max} \\ \text{"Fail"} & \text{else} \end{cases}$$

Force

Anchor Force

$$F_1 := \begin{cases} F_b \cdot L_s & \text{if } Boundary = \text{"Restrained Pipe"} \\ 2 \cdot \dfrac{5 \cdot F_b \cdot L_s}{8} & \text{else} \end{cases}$$

Anchor Force Checking

$$Check_{af} := \begin{cases} \text{"Pass"} & \text{if } F_1 \le Q_a \\ \text{"Fail"} & \text{else} \end{cases}$$

Installation Torque

$$T_{min} := \frac{Q_a}{2 \cdot K_T}$$

C. Summary of Results

C-1 Safety Factor for Buoyancy Control Checking

Safety Factor for Buoyancy Control	$SF = 2.114$	
Safety Factor for Buoyancy Control Checking	$Check_{SFB} = \text{“Pass”}$	(SF > 1.2)

C-2 Net Longitudinal Stress Checking

Actual Longitudinal Stress	$S_{L1} = 272.131\ MPa$	$S_{L2} = -305.708\ MPa$
Maximum Longitudinal Stress	$S_{Lmax} = 305.708\ MPa$	
Allowable Longitudinal Stress	$S_{Lallow} = 337.5\ MPa$	
Longitudinal Stress Checking	$Check_L = \text{“Pass”}$	

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com1} = 245.371\ MPa$	$S_{com2} = 330.956\ MPa$
Maximum Combined Stress	$S_{com\_max} = 330.956\ MPa$	
Allowable Combined Stress	$S_{com\_allow} = 405\ MPa$	
Longitudinal Combined Checking	$Check_{com} = \text{“Not Required”}$	

C-4 Deflection Checking

Maximum Deflection	$\delta_{ac} = 181.148\ mm$
Allowable Deflection	$\delta_{max} = 200\ mm$
Deflection Checking	$Check_{de} = \text{“Pass”}$

C-5 Anchor Force Checking

Upward Force due to Buoyancy per unit length	$F_b = 1.757\ \frac{kN}{m}$
Maximum Anchor Force	$F_1 = 79.063\ kN$
Allowable Anchor Force	$Q_a = 177.929\ kN$
Net Downward Force	$W_p + W_s + \frac{Q_a}{L_s} = 6.045\ \frac{kN}{m}$
Net Upward Force	$W_b = 2.86\ \frac{kN}{m}$
Screw Installation Torque	$T_{min} = 2.712\ kN \cdot m$
Anchor Force Checking	$Check_{af} = \text{“Pass”}$

APPENDIX D: BUOYANCY CONTROL CALCULATION (CONTINUOUS CONCRETE WEIGHT COATING)

Technip Energies

Pipeline Engineering Department

Buoyancy Control Calculation (Concrete Weight Coating)

PROJECT : Basic Engineering Study for Aung Sinkha Development Project Phase 1A

PIPELINE NAME: APL01

Case: Location Class 2

MAIN FEATURES

This spreadsheet performs the pipeline buoyancy control calculation for an onshore burial pipeline system. The following reference is used in this calculation sheet.

/1/ American Lifelines Alliance and American Society of Civil (ASCE), Guidelines for the Design of Buried Steel Pipe, July 2001.

REFERENCE DOCUMENTATION

This spreadsheet was originally developed for application to specific project. It has been further enhanced and consolidated. A dedicated manual has been issued and should be read in conjunction with the use of this MATHCAD sheet.

REVISION HISTORY

Date	Rev.	Status	Comment	Author
18/2/2013	0	For Implementation	The spreadsheet was updated and validation by Jakkrit K.	JKK
8/4/2021	1	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

A. Input Data

Pipeline Parameters

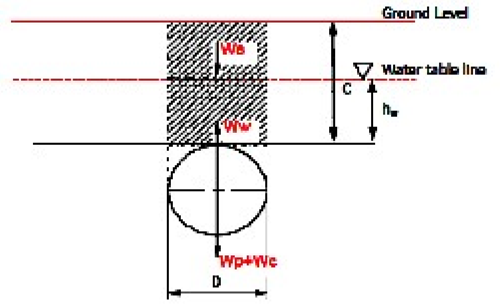
Condition Type	$HT := \text{"Hydrostatic Test"}$ $OB := \text{"Operation Beginning"}$ $OE := \text{"Operation End"}$
Condition Selection	$Condition := OE$
Pipe Outside Diameter	$OD := 20\ in$
Pipe Wall Thickness	$WT := 14.3\ mm$
Internal Corrosion Allowance	$CA := 5.6\ mm$
Steel Density	$\rho_{st} := 7850\ \frac{kg}{m^3}$

Coating Parameters

External Corrosion Coating Density	$\rho_{cor} := 950\ \frac{kg}{m^3}$
External Corrosion Coating Thickness	$t_{cor} := 3.5\ mm$
Internal Corrosion Coating Density	$\rho_{in} := 0\ \frac{kg}{m^3}$
Internal Corrosion Coating Thickness	$t_{inc} := 0\ mm$
Concrete Coating Density	$\rho_{con} := 3040\ \frac{kg}{m^3}$
Concrete Coating Thickness	$t_{con} := 92\ mm$

Environment Parameters

Water Density	$\rho_w := 1000\ \frac{kg}{m^3}$
Mud Density	$\rho_m := 1400\ \frac{kg}{m^3}$
	$W := \text{"Water"}$ $M := \text{"Mud"}$
Determined Buoyancy Force from	$\rho := M$



Height of Backfill above The Top of Pipeline $C := 1.2\ m$

Height of Water above The Top of Pipeline $h_w := C$

Consider Effective Soil Weight (SW) $SW := \text{“No”}$ (Yes or No)

Soil Parameters

Unit Weight of Wet Soil $\gamma_{wet} := 0\ \frac{kN}{m^3}$

Moisture Content of Wet Soil $w := 0\%$

Factor of Safety

Requirement for Negative Buoyancy Force $W_R := 0\ \frac{kg}{m}$ (0 if assigned the SF_b)

Safety Factor for Buoyancy Force $SF_b := 1.2$ (0 if assigned the W_R)

B. Calculation

B-1 Parameter Calculation

Fluid Displacement Density

$$\rho_b := \begin{cases} \text{if } \rho = \text{"Water"} \\ \quad \rho_w \\ \text{else} \\ \quad \rho_m \end{cases}$$

Corroded Pipe Wall Thickness

$$WT := \begin{cases} \text{if } Condition = \text{"Operation End"} \\ \quad WT - CA \\ \text{else} \\ \quad WT \end{cases}$$

Internal Corrosion Coating Thickness

$$t_{in} := \begin{cases} \text{if } Condition = \text{"Operation End"} \\ \quad 0\ mm \\ \text{else} \\ \quad t_{inc} \end{cases}$$

Internal Corrosion Coating Inner Diameter $ID_{in} := OD - 2\ WT - 2\ t_{in}$

Pipeline Internal Diameter $ID := OD - 2\ WT$

Outside Coating Diameter $D_{cor} := OD + 2\ t_{cor}$

Total Outside Pipe Diameter $D := D_{cor} + 2\ t_{con}$

Pipeline Moment of Inertia $I := \frac{\pi}{64}\left(OD^4 - ID^4\right)$

Pipeline Sectional Elastic Modulus $Z := \frac{2\ I}{OD}$

Content Weight

$$W_c := \begin{cases} \text{if } Condition = \text{"Hydrostatic Test"} \\ \quad \frac{\rho_w \cdot \pi \cdot ID_{in}^{\ 2} \cdot g}{4} \\ \text{else} \\ \quad 0\ \frac{N}{m} \end{cases}$$

Internal Liner Weight $W_{in} := \rho_{in} \cdot g \cdot \frac{\pi}{4} \cdot \left(ID^2 - ID_{in}^{\ 2}\right)$

Pipeline Weight (Steel Weight) $W_{st} := \rho_{st} \cdot g \cdot \frac{\pi}{4} \cdot \left(OD^2 - ID^2\right)$

External Corrosion Coating Weight $W_{cor} := \rho_{cor} \cdot g \cdot \frac{\pi}{4} \cdot \left(D_{cor}^{\ 2} - OD^2\right)$

Concrete Coating Weight $W_{con} := \rho_{con} \cdot g \cdot \frac{\pi}{4} \cdot \left(D^2 - D_{cor}^{\ 2}\right)$

Weight of Pipe per Unit Length $W_p := W_c + W_{in} + W_{st} + W_{cor} + W_{con}$

Unit Weight of Water $\gamma_w := \rho_w \cdot g$

Unit Weight of Displacement Fluid $\gamma_b := \rho_b \cdot g$

Unit Weight of dry soil $\gamma_d := \frac{\gamma_{wet}}{1+w}$

Effective Unit Weight $\gamma_{eff} := \gamma_{wet} - \gamma_w$

Weight of fluid displaced by pipe per unit length $W_b := \gamma_b \cdot \frac{\pi}{4} \cdot D^2$

Water Buoyancy Factor $R_w := 1 - 0.33 \left(\frac{h_w}{C}\right)$

Earth Pressure Acting to Top of Pipeline $P_v := \gamma_w \cdot h_w + R_w \cdot \gamma_d \cdot C$

Effective Weight of Soil above Pipe

$$W_s := \begin{cases} \text{if } SW = \text{"Yes"} \\ \quad (P_v - \gamma_w \cdot h_w) \cdot D \\ \text{else} \\ \quad 0 \, \frac{N}{m} \end{cases}$$

Net Upward Force due to Buoyancy per unit length $F_b := (W_b + W_R \cdot g) - (W_p + W_s)$

B-2 Buoyancy Safety Factor

Safety Factor $SF := \frac{W_p + W_s}{W_b}$

Safety Factor Checking

$$Check_{SFB} := \begin{cases} \text{if } SF > SF_b \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{cases}$$

TEN TECHNIP ENERGIES

C. Summary of Results

C-1 Safety Factor for Buoyancy Control Checking

Safety Factor for Buoyancy Control	$SF = 1.202$	
Safety Factor for Buoyancy Control Checking	$Check_{SFB} = \text{“Pass”}$	(SF > 1.2)
Net Downward Force	$W_p + W_s = 6.333 \; \frac{kN}{m}$	
Net Upward Force	$W_b = 5.269 \; \frac{kN}{m}$	

APPENDIX E: BUOYANCY CONTROL CALCULATION (CONTINUOUS SAND BAG WEIGHT)

Technip Energies
Pipeline Engineering Department

Buoyancy Control Calculation (Continuous Sand Bag Weight)

PROJECT : Basic Engineering Study for Aung Sinkha Development Project Phase 1A

PIPELINE NAME: APL01

Case: Location Class 2

MAIN FEATURES

This spreadsheet performs the pipeline buoyancy control calculation for an onshore burial pipeline system. The following reference is used in this calculation sheet.

/1/ American Lifelines Alliance and American Society of Civil (ASCE), Guidelines for the Design of Buried Steel Pipe, July 2001.

REFERENCE DOCUMENTATION

This spreadsheet was originally developed for application to specific project. It has been further enhanced and consolidated. A dedicated manual has been issued and should be read in conjunction with the use of this MATHCAD sheet.

REVISION HISTORY

Date	Rev.	Status	Comment	Author
18/2/2013	0	For Implementation	The spreadsheet was updated and validation by Jakkrit K.	JKK
8/4/2021	1	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

A. Input Data

Pipeline Parameters

Condition Type: $HT := \text{"Hydrostatic Test"}$
$OB := \text{"Operation Beginning"}$
$OE := \text{"Operation End"}$

Condition Selection: $Condition := OE$

Pipe Outside Diameter: $OD := 20\ in$

Pipe Wall Thickness: $WT := 14.3\ mm$

Internal Corrosion Allowance: $CA := 5.6\ mm$

Steel Density: $\rho_{st} := 7850\ \frac{kg}{m^3}$

Coating Parameters

External Corrosion Coating Density: $\rho_{cor} := 950\ \frac{kg}{m^3}$

External Corrosion Coating Thickness: $t_{cor} := 3.5\ mm$

Internal Corrosion Coating Density: $\rho_{in} := 0\ \frac{kg}{m^3}$

Internal Corrosion Coating Thickness: $t_{inc} := 0\ mm$

Concrete Coating Density: $\rho_{con} := 0\ \frac{kg}{m^3}$

Concrete Coating Thickness: $t_{con} := 0\ mm$

Sand Bag Unit Mass per Length: $m_{sb} := 238\ \frac{kg}{m}$

Sand Bag Unit Weight per Length: $W_{sb} := m_{sb} \cdot g$ $\quad W_{sb} = 2.334\ \frac{kN}{m}$

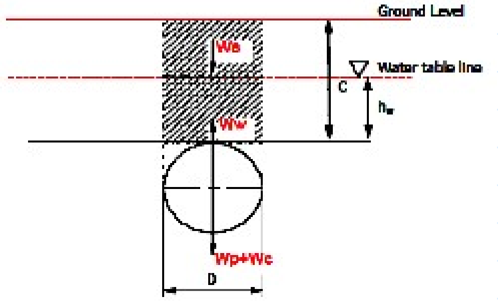
Environment Parameters

Water Density: $\rho_w := 1000\ \frac{kg}{m^3}$

Mud Density: $\rho_m := 1400\ \frac{kg}{m^3}$

$W := \text{"Water"}$
$M := \text{"Mud"}$

Determined Buoyancy Force from $\rho := M$



Height of Backfill above The Top of Pipeline $C := 1.2\ m$

Height of Water above The Top of Pipeline $h_w := C$

Consider Effective Soil Weight (SW) $SW := \text{"No"}$ (Yes or No)

Soil Parameters

Unit Weight of Wet Soil $\gamma_{wet} := 0\ \frac{kN}{m^3}$

Moisture Content of Wet Soil $w := 0\%$

Factor of Safety

Requirement for Negative Buoyancy Force $W_R := 0\ \frac{kg}{m}$ (0 if assigned the SF_b)

Safety Factor for Buoyancy Force $SF_b := 1.2$ (0 if assigned the W_R)

B. Calculation

B-1 Parameter Calculation

Fluid Displacement Density

$$\rho_b := \begin{cases} \text{if } \rho = \text{“Water”} \\ \quad \rho_w \\ \text{else} \\ \quad \rho_m \end{cases}$$

Corroded Pipe Wall Thickness

$$WT := \begin{cases} \text{if } Condition = \text{“Operation End”} \\ \quad WT - CA \\ \text{else} \\ \quad WT \end{cases}$$

Internal Corrosion Coating Thickness

$$t_{in} := \begin{cases} \text{if } Condition = \text{“Operation End”} \\ \quad 0\ mm \\ \text{else} \\ \quad t_{inc} \end{cases}$$

Internal Corrosion Coating Inner Diameter $\quad ID_{in} := OD - 2\ WT - 2\ t_{in}$

Pipeline Internal Diameter $\quad ID := OD - 2\ WT$

Outside Coating Diameter $\quad D_{cor} := OD + 2\ t_{cor}$

Total Outside Pipe Diameter $\quad D := D_{cor} + 2\ t_{con}$

Pipeline Moment of Inertia $\quad I := \frac{\pi}{64}\left(OD^4 - ID^4\right)$

Pipeline Sectional Elastic Modulus $\quad Z := \frac{2\ I}{OD}$

Content Weight

$$W_c := \begin{cases} \text{if } Condition = \text{“Hydrostatic Test”} \\ \quad \frac{\rho_w \cdot \pi \cdot {ID_{in}}^2 \cdot g}{4} \\ \text{else} \\ \quad 0\ \frac{N}{m} \end{cases}$$

Internal Liner Weight $\quad W_{in} := \rho_{in} \cdot g \cdot \frac{\pi}{4} \cdot \left(ID^2 - {ID_{in}}^2\right)$

Pipeline Weight (Steel Weight) $\quad W_{st} := \rho_{st} \cdot g \cdot \frac{\pi}{4} \cdot \left(OD^2 - ID^2\right)$

External Corrosion Coating Weight $\quad W_{cor} := \rho_{cor} \cdot g \cdot \frac{\pi}{4} \cdot \left({D_{cor}}^2 - OD^2\right)$

Concrete Coating Weight $\quad W_{con} := \rho_{con} \cdot g \cdot \frac{\pi}{4} \cdot \left(D^2 - {D_{cor}}^2\right)$

Weight of Pipe per Unit Length $W_p := W_c + W_{in} + W_{st} + W_{cor} + W_{con}$

Unit Weight of Water $\gamma_w := \rho_w \cdot g$

Unit Weight of Displacement Fluid $\gamma_b := \rho_b \cdot g$

Unit Weight of dry soil $\gamma_d := \dfrac{\gamma_{wet}}{1+w}$

Effective Unit Weight $\gamma_{eff} := \gamma_{wet} - \gamma_w$

Weight of fluid displaced by pipe per unit length $W_b := \gamma_b \cdot \dfrac{\pi}{4} \cdot D^2$

Water Buoyancy Factor $R_w := 1 - 0.33 \left(\dfrac{h_w}{C}\right)$

Earth Pressure Acting to Top of Pipeline $P_v := \gamma_w \cdot h_w + R_w \cdot \gamma_d \cdot C$

Effective Weight of Soil above Pipe

$$W_s := \begin{cases} \text{if } SW = \text{“Yes”} \\ \quad \left(P_v - \gamma_w \cdot h_w\right) \cdot D \\ \text{else} \\ \quad 0 \ \dfrac{N}{m} \end{cases}$$

Net Upward Force due to Buoyancy per unit length $F_b := \left(W_b + W_R \cdot g\right) - \left(W_p + W_s + W_{sb}\right)$

B-2 Buoyancy Safety Factor

Safety Factor $SF := \dfrac{W_p + W_s + W_{sb}}{W_b}$

Safety Factor Checking

$$Check_{SFB} := \begin{cases} \text{if } SF > SF_b \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{cases}$$

C. Summary of Results

C-1 Safety Factor for Buoyancy Control Checking

Safety Factor for Buoyancy Control $SF = 1.202$

Safety Factor for Buoyancy Control Checking $Check_{SFB} = \text{“Pass”}$ (SF > 1.2)

Net Downward Force $W_p + W_s + W_{sb} = 3.437\ \frac{kN}{m}$

Net Upward Force $W_b = 2.86\ \frac{kN}{m}$