Basic Engineering Study for Aung Sinkha Development Project Phase 1A

PIPELINE WALL THICKNESS, ROAD & WATER CROSSING, AND MATERIAL SELECTION REPORT

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

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PTTEP INTERNATIONAL LIMITED

Basic Engineering Study for Aung Sinkha Development Project Phase 1A

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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.

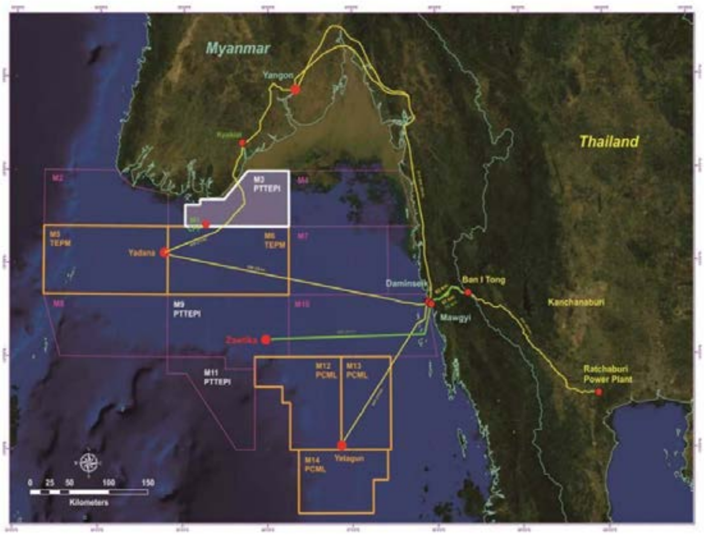

Figure 1-1: Block M3 – Aung Sinkha Field, Offshore Myanmar

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
- APL02 Onshore pipeline from APF to ACP

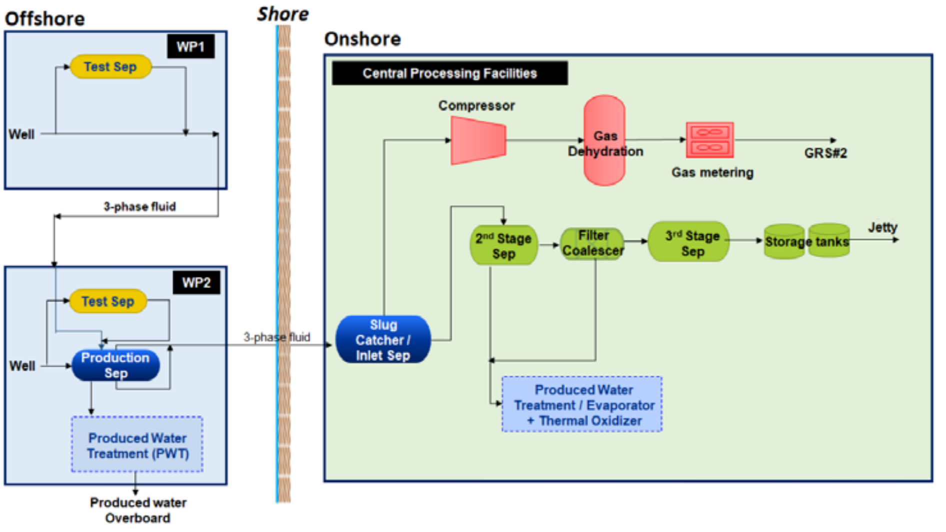

Figure 1-2: Field Block Flow Diagram

1.2 Purpose of Document

The purpose of this document is to calculate and verify the selected material grade and pipeline wall thicknesses for underground restrained and unrestrained sections and road and railroad crossing analyses of the 8.625” Condensate Pipeline (APL02) from APF to ACP 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
ACP	ASK Condensate Offloading and Personnel Transfer Facilities
APF	ASK Onshore Processing Facilities
API	American Petroleum Institute
ASK	Aung Sinkha Development Project
ASME	American Society of Mechanical Engineers
DOH	Department of Highways
DP	Design Pressure
FEED	Front End Engineering Design
GRS	Gas Receiving Station
HDD	Horizontal Directional Drilling
HFW	High Frequency Welding Pipe
LFP	Land Fall Point
LSAW	Longitudinally Submerged Arc Weld
MOGE	Myanmar Oil & Gas Enterprise
OD	Outside Diameter
OT	Operating Temperature
SMTS	Specified Minimum Tensile Strength
SMYS	Specified Minimum Yield Strength
WPA	Wellhead Platform
WT	Wall Thickness

2. SUMMARY AND CONCLUSIONS

2.1 Summary

Preliminary cost comparison of different material grades for line pipe based on calculated wall thicknesses was performed and can be tabulated in Table 2-1.

The material grade of API 5L X65 is the cheapest as shown in Table 2-1. Therefore, API 5L X65 is economically recommended and selected for onshore pipeline.

Table 2-1: Calculated Pipeline Wall Thickness with Material Costs

Pipeline Name	Class	Design Criteria Governing Case: Normal WT	API 5L X52	API 5L X60	API 5L X65
APL02	#150	Min. Selected WT (mm) (Note 1.)	9.53	6.35	6.35
		Unit Cost (USD/m)	100.47	67.31	66.64
		Approximate Length (km)	18		
		Pipeline Material Cost (USDx1000)	1,808	1,212	1,200
	#300	Min. Selected WT (mm) (Note 1.)	19.05	8.74	7.04
		Unit Cost (USD/m)	191.72	91.59	73.64
		Approximate Length (km)	18		
		Pipeline Material Cost (USDx1000)	3,451	1,649	1,326

Notes

1. The calculated wall thickness based on design pressure of 18.6 barg and 48.7 barg, and hydrotest pressure of 23.3 barg and 60.9 barg for class #150 and #300 respectively.

When compared in terms of different thicknesses and material coat, pipeline having wall thickness of 6.35 mm for maximum pressure of Class #150 and wall thickness of 7.04 mm for maximum pressure of Class #300 is difference only one schedule thickness which the pipeline can upgrade the service pressure in the future. Thus, the Class #300 was selected.

Pipeline wall thickness verification and road crossing analyses were performed for constant OD philosophy in accordance with design data in Section 3. and methodology in Section 3. Obtained results are in Section 5.

The calculated API 5L X65 linepipe wall thickness results in accordance with ASME B31.4 are summarized in Table 2-2.

Table 2-2: Wall Thickness Stress Calculation

Pipeline Name	Wall Thickness (mm)	Maximum Unity	Check
APL02	Normal Wall, 7.04	0.97	Pass
	Normal Wall (Hydrotest), 7.04	0.70	Pass
	Bend Mother Pipe, 7.04	0.54	Pass
	Bend Mother Pipe (Hydrotest), 7.04	0.31	Pass

Road crossing analyses were performed for open cut sections with no pavement and for bored sections with flexible pavement, conservatively. For open cut and bored sections for road crossing, cover depth of 2 m was considered.

The road crossing wall thickness verification results in accordance with API RP 1102 [7] are summarized in Table 2-3.

Table 2-3: Pipeline Crossing Wall Thickness Verifications

Pipeline Name	Crossing Type	Wall Thickness (mm)	Maximum Unity	Check
APL02	Open-Cut Road Crossing	7.04	0.41	Pass
	Boring Road Crossing	7.04	0.41	Pass

2.2 Conclusions

Based on the results obtained in this report, the following conclusions can be drawn:

- The material grade of API 5L X65 with class #300 condition is selected for the onshore pipelines.
- The proposed pipeline wall thickness as per ASME B31.4 for underground restrained and unrestrained sections of APL02 onshore pipeline is 7.04 mm .
- The maximum pipeline stresses in the open cut road crossing and bored road as per API RP 1102 [7] are within allowable limits. Therefore, the selected pipeline can be used for open cut road crossings, and no special provision for backfill material is required.

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	APL02
Service	-	Onshore Condensate Pipeline
Originating from	-	APF
Terminating at	-	ACP
Pipeline Size	mm (Inch)	219.1 (8.625)
Approximate Length	km	18
Pipeline Status	-	Buried
Design Life	Years	20
Corrosion Allowance	mm	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	APL02
Fluid	-	Condensate
Operating Pressure	barg	10.4
Design Pressure (DP)	barg	48.7
Hydrotest Pressure	barg	60.9
Operating Temperature (Min./ Max.)	°C	20.3/44.1
Design Temperature (Min./Max.)	°C	0/70
Max. Content Density	kg/m^3	723.3
Min. Content Density	kg/m^3	689.8

3.3 Material Data

Pipeline and coating material properties are presented in Table 3-3 [1][3].

Table 3-3: Pipeline and Coating Material Data [1][3]

Description	Unit	APL02
Pipeline OD	mm (Inch)	219.1 (8.625)
Line Pipe Material	-	API 5L X65
Manufacturing Process	-	SMLS or HFW
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 Vehicle Load Design Parameters

The vehicle load design parameters for pipeline crossing analysis can be summarized as follows:

Table 3-5: Vehicle Load Design Parameters

Parameter	Unit	Value
Maximum Single Axle Load	tonnes	10(Note1)
Maximum Tandem Axles Load	tonnes	16(Note1)
Contact Area of Wheel	m^2	0.093
Road Pavement Type	-	No Pavement for Open-cut Crossing Flexible Pavement for Boring Crossing
Cover Depth	m	2 (Open-cut Road Crossing) 2 (Bored Road Crossing)

Note:

1. Reference values from Myanmar's DOH have been shown in Appendix B.

3.6 Soil Data

Modulus of soil reaction and soil resilient modulus are based on recommended values from API RP 1102 [7]. Soft to medium clays and silts with high plasticities with soil unit weight of 18.9 kN/m^3 (1.93 ton/m^3) as per API RP 1102, Section 4.7.2.1 are considered, conservatively.

3.7 Peak Ground Velocities

PGVs at pipeline end used for calculation of maximum axial strain due to compression seismic wave are presented in Table 3-6.

Table 3-6: Peak Ground Acceleration and Velocities

Pipeline	Mercalli Scale Class	PGA (g)	PGV (cm/s)
APL02	VII	0.2	31

3.8 Assumption

In the pipeline wall thickness verifications performed in this report, the following assumptions are made:

- Minimum air temperature is used as installation temperature.
- Maximum surface water temperature is used as design temperature in case of hydrotest.
- According to Myanmar's maximum allowable vehicle weights as given in Appendix B, design loads as below are used.
  - For truck with 2 axles and maximum vehicle weight of 16 tonnes, design single axle load is assumed as 10 tonnes occurring at the rear wheels.
  - For truck with 3 axles and maximum vehicle weight of 21 tonnes, design tandem axles load is assumed as16 tonnes occurring at the rear wheels.

4. METHODOLOGY

4.1 Pipeline Wall Thickness Verification

The methodology for pipeline stresses calculation is in accordance with ASME B31.4 [4] for liquids pipeline can be summarized in the following sections.

4.1.1 Hoop Stress Criterion

For both restrained and unrestrained pipelines, the circumferential (hoop) stress due to internal pressure is calculated as per Section 402.3, ASME B31.4 [4] requirement.

$$S_H = \frac{P_i D}{2t} \tag{4.1}$$

Where

D = outside diameter of pipe, in. (mm)

P_i = internal design gage pressure, psi (bar)

S_H = circumferential (hoop) stress due to internal pressure, psi (MPa)

t = wall thickness of pipe, in. (mm)

The above equation may not be applicable for pipe D/t less than 20.

The nominal wall thickness (t_{nom}) shall be selected among standard ASME B36.10M [5] sizes such that:

$$t_{nom} \geq t + CA \tag{4.2}$$

Where

CA = Corrosion allowance, CA = 3 mm for APL02 line pipe.

$$t = \frac{P_i D}{2S} \tag{4.3}$$

Where

P_i = internal design gage pressure, psi (bar)

S = applicable allowable stress value, psi (MPa), as determined by the following equation: $S = F \times E \times S_y$

E = weld joint factor

F = design factor. The value of F used in this Code shall not be greater than 0.72.

Where indicated by service or location, users of this Code may elect to use a design factor, F, less than 0.72. In setting design factor, due consideration has been given to and allowance has been made for the underthickness tolerance and maximum allowable depth of imperfections provided for in the specifications approved by the Code.

S_y = specified minimum yield strength of the pipe, psi (MPa).

4.1.2 Longitudinal Stress Criterion

According to Section 402.6 of ASME B31.4 [4], longitudinal stress in restrained pipe is calculated as

$$S_L = S_E + vS_H + \frac{M}{Z} + F_a/A \tag{4.4}$$

And longitudinal stress for unrestrained pipeline is defined in the following equation [4]

$$S_L = \frac{P_i D}{40t} + \frac{iM}{Z} + \frac{F_a}{A} \tag{4.5}$$

Where

A = metal area of nominal pipe cross section, in.^{2} (mm^2)

F_a = axial force, such as weight on a riser, lb (N)

M = bending moment, in.-lb (N·m)

S_E = thermal expansion stress, psi (MPa)

S_H = circumferential (hoop) stress due to internal pressure, psi (MPa)

Z = section modulus of the pipe, in.^{3} (cm^3)

v = Poisson's ratio

D = outside diameter of pipe, in. (mm)

i = component stress intensification in plane of loading, limited by 0.75i $\geqslant$ 1.

For straight pipe, i = 1.0.

P_i = internal design gage pressure, psi (bar)

t = wall thickness of pipe, in. (mm)

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

4.1.3 Combined Stress Criterion

As per clause 402.7 of ASME B31.4 [4], in restrained pipe, the longitudinal and circumferential stresses are combined in accordance with the maximum shear stress theory as follows:

$$S_{eq} = 2\sqrt{[(S_L - S_H)/2]^2 + {S_t}^2} \quad (4.6)$$

Where

S_{eq} = equivalent combined stress

S_t = torsional stress, psi (MPa)

When S_t can be disregarded, the combined stress calculation can be reduced to the following [4]:

$$|S_L - S_H| \quad (4.7)$$

Stress values for steel pipe during operation shall not exceed the allowable values. The allowable values for pipeline system stresses of equivalent combined stress for restrained pipeline is defined in the following equation [4].

$$S_{eq} = 0.90 S_y \quad (4.8)$$

Where

S_y = specified minimum yield strength of pipe material, psi (MPa)

4.1.4 Bend Mother Pipe

Bend mother pipe wall thickness will be reduced due to wall thinning during hot induction bending process. The wall thinning depends on the manufacturing process but normally is less than 7% for 5D hot induction bend which shall be also included the effect of surface descaling [8].

4.1.5 Seismic Wave Propagation Effect

The following formula shall be used to obtain an upper-bound estimate of ground strain due to a propagating seismic wave with a constant shape. The maximum ground strain, ε_g, is given by [6][10]:

$$\varepsilon_g = \frac{V_{max}}{\alpha_{\varepsilon} \cdot c} \quad (4.9)$$

Where

V_{max} = the maximum horizontal ground velocity in the direction of wave propagation

c = the apparent propagation speed of the seismic wave (i.e., the component of wave speed parallel to the pipeline under consideration)

α_ε = ground strain coefficient corresponding to the most critical angle of incidence and type of seismic wave

= 1.0 for compression wave

An apparent propagation velocity of 2 km/sec shall be taken as a lower bound estimate to provide an upper bound estimate of ground strain.

Tension strain limit is 0.5% and compression strain limit of wave propagation is given by [6]:

$$\varepsilon_c = 0.75\left[0.50\left(\frac{t}{D'}\right) - 0.0025 + 3000\left(\frac{pD}{2Et}\right)^2\right] \quad (4.10)$$

When
$$D' = \frac{D}{1-\frac{3}{D}(D-D_{min})} \quad (4.11)$$

Where

E = modulus of elasticity of pipe

t = pipe wall thickness

4.2 Wall Thickness Verification of Pipelines Crossing Road and Railway

To ensure safe operation, the stresses affecting the uncased pipeline must be accounted for comprehensively, including both circumferential and longitudinal stresses. The analysis is to ensure that stresses in the pipeline road and railway crossings are within permissible limits according to the recommended design method for uncased road and railway crossings, API RP 1102, Steel Pipelines Crossing Railroads and Highways [7].

A carrier pipe with uncased crossing will be subjected to both internal load from pressurization and external loads from earth force (dead load) and road and railway traffic loads (live load). An impact factor should be applied to the live load. External loading on the carrier pipe will produce both circumferential and longitudinal stresses.

4.2.1 Stress due to Earth Load

The stress at pipeline due to earth load is calculated by the following equation:

$$S_{He} = K_{He} \cdot B_e \cdot E_e \cdot \gamma \cdot D \tag{4.12}$$

Where

S_{He} = Circumferential stress from earth load

K_{He} = Stiffness factor for circumferential stress from earth load to be determined from Figure 3 of API RP 1102 [7]

B_e = Burial factor for earth load to be determined from Fig. 4 of API RP 1102 [7]

E_e = Excavation factor for earth load to be determined from Fig. 5 of API RP 1102 [7]

γ = Soil unit weight

D = Pipe outside diameter

4.2.2 Stress due to Live Load (Highway or Railway Cyclic Stress)

The stresses at pipeline due to highway live load are calculated by the following equations:

$$\Delta S_{Hh} = K_{Hh} \cdot G_{Hh} \cdot R \cdot L \cdot F_i \cdot w \tag{4.13}$$

$$\Delta S_{Lh} = K_{Lh} \cdot G_{Lh} \cdot R \cdot L \cdot F_i \cdot w \tag{4.14}$$

The stresses at pipeline due to railway live load are calculated by the following equations:

$$\Delta S_{Hr} = K_{Hr} \cdot G_{Hr} \cdot N_H \cdot F_i \cdot w \tag{4.15}$$

$$\Delta S_{Lr} = K_{Lr} \cdot G_{Lr} \cdot N_L \cdot F_i \cdot w \tag{4.16}$$

Where

ΔS_{Hh} = Cyclic circumferential stress due to highway vehicular load

ΔS_{Hr} = Cyclic circumferential stress due to railway vehicular load

ΔS_{LH} = Cyclic longitudinal stress due to highway vehicular load

ΔS_{Lr} = Cyclic longitudinal stress due to railway vehicular load

K_{Hh} = Highway stiffness factor for cyclic circumferential stress to be determined from Fig. 14 of API RP 1102 [7]

K_{Hr} = Railway stiffness factor for cyclic circumferential stress to be determined from Fig. 8 of API RP 1102 [7]

K_{Lh} = Highway stiffness factor for cyclic longitudinal stress to be determined from Fig. 16 of API RP 1102 [7]

K_{Lr} = Railway stiffness factor for cyclic longitudinal stress to be determined from Fig. 11 of API RP 1102 [7]

G_{Hh} = Highway geometry factor for cyclic circumferential stress to be determined from Fig. 15 of API RP 1102 [7]

G_{Hr} = Railway geometry factor for cyclic circumferential stress to be determined from Fig. 9 of API RP 1102 [7]

G_{Lh} = Highway geometry factor for cyclic longitudinal stress to be determined from Fig. 17 of API RP 1102 [7]

G_{Lr} = Railway geometry factor for cyclic longitudinal stress to be determined from Fig. 12 of API RP 1102 [7]

R = Highway pavement type factor to be determined from Table 2 of API RP 1102 [7]

L = Highway axle configuration factor to be determined from Table 2 of API RP 1102 [7]

N_H = Railroad track factor for cyclic circumferential stress from Fig. 10 of API RP 1102 [7]

N_L = Railroad track factor for cyclic longitudinal stress from Fig. 13 of API RP 1102 [7]

F_i = Impact factor to be determined from Fig. 7 of API RP 1102 [7]

w = Applied design surface pressure

4.2.3 Stress due to Internal Load

The stress at pipeline due to internal load is calculated by the following equation:

$$S_{Hi} = \frac{P \cdot (D - t_p)}{2 \cdot t_p} \quad (4.17)$$

Where

S_{Hi} = Circumferential stress due to internal pressure

P = Internal pressure

t_p = Pipeline wall thickness

4.2.4 Hoop Stress Criterion

Please refer to Section 4.1.1 for hoop stress criterion and

Table 4-1 below.

Table 4-1 : Design Factors [9]

Location	**Design Factor**
Onshore Pipeline (Open-Cut Road Crossings)	0.72
Onshore Pipeline (Bored Road Crossings)	0.72
Onshore Pipeline (Railway Crossings)	0.72

4.2.5 Combined Stress Criterion

Total effective stress must be less than the factored specified minimum yield strength, given by the following:

$$S_{eff} = \sqrt{\frac{1}{2}[(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2]} \leq F \cdot SMYS \qquad (4.18)$$

Where

S_1 = Maximum circumferential stress,

$S_{He} + \Delta S_{Hh} + S_{Hi}$ for highway

$S_{He} + \Delta S_{Hr} + S_{Hi}$ for railway

S_2 = Maximum longitudinal stress,

$\Delta S_{Lh} + E_s \alpha_T (T_2 - T_1) + v(S_{He} + S_{Hi})$ for highway

$\Delta S_{Lr} + E_s \alpha_T (T_2 - T_1) + v(S_{He} + S_{Hi})$ for railway

S_3 = Maximum radial stress, - *P*

F = Design Factor

E_s = Young’s modulus of steel

α_T = Coefficient of thermal expansion

v = Poisson’s ratio

4.2.6 Fatigue Criteria (Highway)

GIRTH WELD

The design check against girth weld fatigue is given by the following:

$$\Delta S_{Lh} \leq S_{FG} \cdot F \quad (4.19)$$

Where

S_{FG} = Fatigue endurance limit of girth weld, to be determined from Table 3, API RP 1102 [7]

LONGITUDINAL WELD

The design check against longitudinal weld fatigue is as follows:

$$\Delta S_{Hh} \leq S_{FL} \cdot F \quad (4.20)$$

Where

S_{FL} = Fatigue endurance limit of longitudinal weld, to be determined from Table 3, API RP 1102 [7]

4.2.7 Fatigue Criteria (Railway)

GIRTH WELD

The design check against girth weld fatigue is given by the following:

$$R_F \frac{\Delta S_{Lr}}{N_L} = S_{FG} \cdot F \quad (4.21)$$

Where

S_{FG} = Fatigue endurance limit of girth weld, to be determined from Table 3, API RP 1102 [7]

R_F = Longitudinal stress reduction factor for fatigue taken from Figure 18, API RP 1102 [7]: 1 if a girth weld is assumed to be located at a distance less than 5 ft (1.5 m) from the centerline of the track.

LONGITUDINAL WELD

The design check against longitudinal weld fatigue is as follows:

$$\frac{\Delta S_{Hr}}{N_H} = S_{FL} \cdot F \quad (4.22)$$

Where

S_{FL} = Fatigue endurance limit of longitudinal weld, to be determined from Table 3, API RP 1102 [7]

4.3 Load Cases for Pipeline Stress Analysis

The following combinations are used in the pipeline stress analysis.

Table 4-2 : Load Cases for Pipeline Wall Thickness Verification

Pipeline Name	Load Case	Pressure (barg)	Temperature (°C)	Minimum Bending Radius (m)(Note1)
APL02	1 (Expansion)	48.7	70	550D
	2 (Contraction)	48.7	0	550D
	3 (Hydrotest)	60.9	32.9(Note 2)	550D

Notes:
1. For pipeline wall thickness verification only.
2. In case of hydrotest, maximum surface water temperature is used for wall thickness verification.

Table 4-3 : Load Cases for Pipeline Crossing Verification

Pipeline Name	Load Case	Pressure (barg)	Temperature (°C)	Crossing Type
APL02	1 (Max OT)	48.7	44.1	1. Open-Cut Road Crossing 2. Boring Road Crossing
	2 (Min OT)	48.7	20.3	

5. RESULTS

5.1 Pipeline Material Grade Selection

The selection of pipeline material grade depends on several factors. The main requirements are weldable using conventional pipeline welding techniques and adequate fracture resistance to avoid ductile/brittle failure based on the minimum pipeline design temperature. The material options evaluated in this section are API 5L X52, X56, X60, X65, X70, and X80.

Controlled roll steels manufactured with SMYS of 360 MPa (X52), 415 MPa (X60), 450 MPa (X65) and 485 MPa (X70) have been used extensively for pipeline construction. C-Mn Steels with SMYS of 485 MPa (X70) and 555 MPa (X80) have been produced almost exclusively for non-sour service. The extra strength level is attained by using accelerated cooling, modifications to chemical composition and advanced controlled rolling technology, which all contribute to optimizing microstructure.

The high strengthening methods of increasing the level of alloying elements in X70 and higher grades, reduce the weldability of these steels and these grades are not very common in the region.

Among the remaining options, C-Mn steel with SMYS of 390 MPa (X56) is not a common proposed material for pipeline and needs special order, which may impose additional costs to the project. Hence, the best material choices are steels with SMYS of 360 MPa (X52), 415 MPa (X60) and 450 MPa (X65).

These three (3) materials grades are selected for further cost analysis in this report with SMYS of 360 MPa (X52), 415 MPa (X60) and 450 MPa (X65).

Detailed calculations for API 5L X52 and X60 are presented in Appendix E and detailed calculations for API 5L X65 are presented in Appendix C. Unit costs from a vendor are presented in Appendix F.

Table 5-1 : Calculated Pipeline WT with Material Unit Costs

Pipeline Name	Class	Design Criteria Governing Case: Normal WT	API 5L X52	API 5L X60	API 5L X65
APL02	#150	Min. Hoop Stress WT (mm)	3.79	3.69	3.63
		Min. Longitudinal Stress (Restrained) WT (mm)	3.77	3.48	3.39
		Min. Longitudinal Stress (Unrestrained) WT (mm)	4.25	3.83	3.69
		Min. Combined Stress WT (mm)	9.28	4.98	4.38
		Min. Selected WT (mm)	**9.53**	**6.35**(Note1)	**6.35**(Note1)
		Unit Cost (USD/m)	**100.47**	**67.31**	**66.64**
	#300	Min. Hoop Stress WT (mm)	5.06	4.79	4.65
		Min. Longitudinal Stress (Restrained) WT (mm)	5.02	4.25	4
		Min. Longitudinal Stress (Unrestrained) WT (mm)	6.26	5.17	4.79
		Min. Combined Stress WT (mm)	18.3	8.18	6.61
		Min. Selected WT (mm)	**19.05**	**8.74**	**7.04**
		Unit Cost (USD/m)	**191.72**	**91.59**	**73.64**

Note:
1. The minimum wall thickness of class #150 is 6.35 mm which selected from vacuum case.

5.2 Calculated Pipeline Wall Thickness Results

The results presented in this section are obtained by using the design data of Section 3, and methodology described in Section 1. The analyses were performed for proposed pipeline wall thicknesses were shown in Table 5-2. Detailed calculations are presented in Appendix C.

The 7% wall thinning was considered for 5D hot induction bend mother pipe.

Table 5-2 : Pipeline Stress Calculation

Pipeline Name	Wall Thickness (mm)	Criteria	Calculated Stress (MPa)	Allowable Stress (MPa)	Unity
APL02	Normal Wall 7.04	Hoop	132.04	324.00	0.41
		Longitudinal (Restrained)	284.23	405.00	0.70
		Longitudinal (Unrestrained)	254.20	337.50	0.75
		Combined	393.71	405.00	0.97
	Normal Wall (Hydrotest) 7.04	Hoop	94.76	324.00	0.29
		Longitudinal (Restrained)	193.36	405.00	0.48
		Longitudinal (Unrestrained)	235.56	337.50	0.70
		Combined	277.76	405.00	0.69
	Bend Mother Pipe 7.04	Hoop	150.27	324.00	0.46
		Longitudinal (Restrained)	101.51	405.00	0.25
		Longitudinal (Unrestrained)	75.13	337.50	0.22
		Combined	218.29	405.00	0.54
	Bend Mother Pipe (Hydrotest) 7.04	Hoop	101.85	324.00	0.31
		Longitudinal (Restrained)	7.30	405.00	0.02
		Longitudinal (Unrestrained)	50.92	337.50	0.15
		Combined	94.54	405.00	0.23

5.3 Pipeline Crossing Wall Thickness Verification Results

The results presented in this section are obtained by using the design data of Section 2, and methodology described in Section 0.

The analyses were performed for the following conditions:

- Road - Open cut Crossing at 2 m cover depth
- Road - Bored Crossing at 2 m cover depth

Load cases are based on design pressure and operating temperatures as per Section 4.3.

Pipeline crossing wall thickness verification results are shown in Table 5-3. Detailed calculations are presented in Appendix D.

Table 5-3 : Pipeline Crossing Wall Thickness Verification

Pipeline Name	Crossing Type	Wall Thickness (mm)	Criterion	Calculated Stress (MPa)	Allowable Stress (MPa)	Unity
APL02	Open-Cut Road Crossing	7.04 (Max. OT 44.1 °C)	Hoop	132.04	324.00	0.41
			Effective	145.33	405.00	0.36
			Girth Welds	9.31	59.57	0.16
			Longitudinal Welds	8.44	59.57	0.14
	Open-Cut Road Crossing	7.04 (Min. OT 20.3°C)	Hoop	132.04	324.00	0.41
			Effective	128.12	405.00	0.32
			Girth Welds	9.31	59.57	0.16
			Longitudinal Welds	8.44	59.57	0.14
	Boring Road Crossing	7.04 (Max. OT 44.1 °C)	Hoop	132.04	324.00	0.41
			Effective	145.01	405.00	0.36
			Girth Welds	8.47	59.57	0.14
			Longitudinal Welds	7.67	59.57	0.13
	Boring Road Crossing	7.04 (Min. OT 20.3°C)	Hoop	132.04	324.00	0.41
			Effective	127.54	405.00	0.31
			Girth Welds	8.47	59.57	0.14
			Longitudinal Welds	7.67	59.57	0.13

5.4 Maximum Allowable Tandem Load

The results presented in this section are obtained by using the governing case of Section 1.1, Detailed calculations are presented in Appendix G.

Table 5-4 : Maximum Allowable Tandem Load

Pipeline Name	Governing Case	Maximum Allowable Tandem Load (tonnes)
APL02	Open-Cut Road Crossing, WT 7.04 mm (Max. OT 44.1 °C)	72.6

5.5 Vacuum Drying Cases

The results in Appendix H show that total external pressure (1.4 barg) without internal pressure requires the minimum wall thickness is about 6 mm by using the governing case of Section 0. Therefore, the selected wall thicknesses are suitable for the vacuum drying case.

The total external pressure is the ambient pressure of 1.01325 barg plus the external earth pressure at depth 2 m of 0.378 barg.

5.6 Sensitivity Check for Open-Cut Road Crossings

The results presented in this section are obtained by using the governing case of Section 1.1. Detailed calculations are presented in Appendix I.

Deeper cover depth cases have higher stresses because the effect of earth load is more than the effect of vehicle load. Anyway, the results are almost identical in various cover depths.

Table 5-5 : Open-Cut Road Crossing with Various Cover Depths

Pipeline Name	Cover Depth (m)	Governing Case	Criterion	Calculated Stress (MPa)	Allowable Stress (MPa)	Unity
APL02	1.2	WT 7.04 mm (Max. OT 44.1°C)	Effective	145.61	405.00	0.36
			Girth Welds	7.21	59.57	0.12
			Longitudinal Welds	8.12	59.57	0.14
	2	WT 7.04 mm (Max. OT 44.1°C)	Effective	145.33	405.00	0.36
			Girth Welds	9.31	59.57	0.16
			Longitudinal Welds	8.44	59.57	0.14
	2.5	WT 7.04 mm (Max. OT 44.1°C)	Effective	144.48	405.00	0.36
			Girth Welds	8.25	59.57	0.14

Pipeline Name	Cover Depth (m)	Governing Case	Criterion	Calculated Stress (MPa)	Allowable Stress (MPa)	Unity
			Longitudinal Welds	6.93	59.57	0.12

5.7 Seismic Wave Propagation Effect

The results presented in this section are obtained by using the design data of Section 3, and methodology described in Section 4.1.5. Detailed calculations are presented in Appendix C.

Table 5-6 : Seismic Wave Propagation Effect

Pipeline Name	Case	Maximum Ground Strain (%)	Strain Limit (%)
APL02	Normal Wall 7.04 mm	0.016	0.5

6. REFERENCES

[1] Pipeline Basis of Design, Design Criteria, MM-ASK-1A-APL02-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] Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4

[5] Welded and Seamless Wrought Steel Pipe, ASME B36.10M

[6] Guidelines for the Design of Buried Steel Pipe, ASCE publication American Lifelines Ailliance

[7] Steel Pipelines Crossing Railroads and Highways, API RP 1102

[8] Project Particular Specification for Induction Bends for Pipeline (Onshore), MM-ASK-1A-GEN-PLR-SPE-0004

[9] Design and Construction of Onshore Pipeline and Rail, Road & Canal Crossings, 10008-STD-6-PLR-029

[10] Seismic Consideration for Onshore Pipelines in Seismic Hazardous Area, MM-ASK-1A-APL01-PLR-BOD-0002

APPENDIX A: BATTERY LIMITS FOR PIPELINES

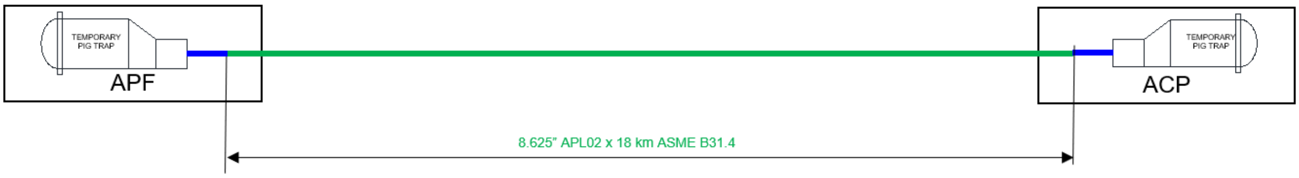

Figure A-1: Pipeline System Design Battery Limits

Note:

1. Scope of this document is APL02.

APPENDIX B: MYANMAR VEHICLE LOADS

		< 1/100 L Lamp	
6.	Min turning radius, max (m)	12	
7.	Elevation of speedometer (%)	-10 to +15	
8.	Exhaust Emission (Smoke)	< 50% Bosch unit	
9.	Depth of groove of tyre min (mm)	1 mm	

MOTOR VEHICLE REQUIREMENT ON AXLE LOAD, WEIGHT & DIMENSION

NO	SUB SUBJECT	STANDARD	REMARKS
1.	Axle load		
	Axle load maximum	10000 Kg	
2.	Vehicle weight		
	(a) Truck with 2 axles	16000 Kg	
	(b) Truck with 3 axles	21000 Kg	
	(c) Articulated Truck (max)	38000 Kg	
3.	Dimension		
	(a) Overall Length (max)	12.2 m	
	(b) Overall Width (max)	2.5 m	
	(c) Overall Height (max)		
	Normal vehicle	3.66 m	
	Container carrier	4.6 m	
4.	Rear overhang	60% of Wheelbase	

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APPENDIX C: PIPELINE WALL THICKNESS CALCULATIONS

Technip Energies

Pipeline Engineering Department

ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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
3/6/2013	0	For Implementation	The spreadsheet was updated and validated by Soratus P.	SWN
1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Normal WT= 7.04 mm

A. Input Data

Design Pressure	$P_D := 48.7\ bar$	
Pipe Diameter	$D := 8.625\ in$	
Specified Minimum Yield Strength	$SMYS := 450\ MPa$	
Design Factor for Hoop Stress	$DF_D := 0.72$	
Longitudinal Joint Factor	$EF := 1$	(API Spec 5L SAWL)
Corrosion Allowance	$CA := 3\ mm$	
Selected Pipeline Wall Thickness	$t_{sel} := 7.04\ mm$	
Young's Modulus	$E := 207\ GPa$	
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$	
Minimum Air Temperature	$T_{amin} := 23.3\ °C$	
Maximum Design Temperature	$T_{dmax} := 70\ °C$	
Minimum Design Temperature	$T_{dmin} := 0\ °C$	
Radius of Curvature	$R := 550\ D$	
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$	
K Factor for Combined Stress	$k := 0.9$	
Maximum Horizontal Ground Velocity	$V_{max} := 31\ \frac{cm}{s}$	
Ground Strain Coefficient	$\alpha_\varepsilon := 1$	
Apparent Propagation Speed	$cc := 2\ \frac{km}{s}$	

B. Calculation

B-1 Hoop Stress

Hoop Stress

$$S_H(t,P) := \begin{cases} \dfrac{P\cdot(D-t)}{2\cdot t} & \text{if } \dfrac{D}{t} < 20 \\ \dfrac{P\cdot D}{2\cdot t} & \text{else} \end{cases}$$

Allowable Hoop Stress

$$S_{Hallow}(DF) := SMYS \cdot EF \cdot DF$$

Hoop Stress Checking

$$Check_H(t,P,DF) := \begin{cases} \text{"Pass"} & \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \text{"Fail"} & \text{else} \end{cases}$$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure in restrained pipeline

$$S_P(t,P) := 0.3 \cdot S_H(t,P)$$

Longitudinal Stress due to internal pressure in unrestrained pipeline

$$S_{PU}(t,P) := 0.5 \cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E \cdot \alpha \cdot (T_{amin} - T)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia

$$I(t) := \frac{\pi}{64} \cdot \left(D^4 - (D - 2\ t)^4\right)$$

Pipeline Sectional Elastic Modulus

$$Z(t) := \frac{2 \cdot I(t)}{D}$$

Bending Moment

$$M(t) := \frac{E \cdot I(t)}{R}$$

Longitudinal Stress due to bending moment

$$S_B(t) := \frac{M(t)}{Z(t)}$$

Net Longitudinal Stress in restrained pipeline

$$S_{L1}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) + S_B(t)$$

$$S_{L2}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline

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

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := (S_{PU}(t,P) + S_x) + S_B(t)$

$$S_{L4}(t,P) := (S_{PU}(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max(|S_{L3}(t,P)|, |S_{L4}(t,P)|)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Longitudinal Stress Checking

$$Check_L(t,P,T) := \begin{array}{l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

$$Check_{LU}(t,P) := \begin{array}{l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline $S_{com1}(t,P,T) := |S_{L1}(t,P,T) - S_H(t,P)|$

$$S_{com2}(t,P,T) := |S_{L2}(t,P,T) - S_H(t,P)|$$

Maximum Combined Stress $S_{com\_max}(t,P,T) := \max(|S_{com1}(t,P,T)|, |S_{com2}(t,P,T)|)$

Allowable Stress $S_{com\_allow} := k \cdot SMYS$

Combined Stress Checking

$$Check_C(t,P,T) := \begin{array}{l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

B-4 Min. Wall Thickness

Hoop Stress

$$t_{Hmin} := \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in restrained pipeline

$$t_{Lmin} := \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin})) \ge S_{Lallow} \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_{LUmax}(t - CA, P_D) \geq S_{LUallow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Combined Stress

$$t_{Cmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{com\_max}(t - CA, P_D, T_{dmax}), S_{com\_max}(t - CA, P_D, T_{dmin})\right) \geq S_{com\_allow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Min. Wall Thickness Checking

$$Check_{tmin} := \left\| \begin{array}{l} \text{if } \max(t_{Hmin}, t_{Lmin}, t_{LUmin}, t_{Cmin}) \leq t_{sel} \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right.$$

B-5 Seismic Wave Propagation Effect

Maximum Ground Strain

$$\varepsilon_g := \frac{V_{max}}{\alpha_\varepsilon \cdot cc} \qquad \varepsilon_g = 0.016\%$$

$$D_{min} := D - (0.0075 \cdot D) = 0.217\ m$$

$$D' := \frac{D}{1 - \left(\frac{3}{D} \cdot (D - D_{min})\right)} = 0.224\ m$$

$$\varepsilon_{com} := 0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right) = 0.01 \qquad \varepsilon_{com} = 0.968\%$$

Strain Limit

$$\varepsilon_c := min\left(0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right), 0.5\%\right) = 0.005 \qquad \varepsilon_c = 0.5\%$$

Strain Checking

$$Check_\varepsilon := \left\| \begin{array}{l} \text{if } \varepsilon_g \leq \varepsilon_c \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right. \qquad Check_\varepsilon = \text{“Pass”}$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress	$S_H\left(t_{sel}-CA, P_D\right)=132.041\ MPa$
Allowable Hoop Stress	$S_{Hallow}\left(DF_D\right)=324\ MPa$
Hoop Stress Checking	$Check_H\left(t_{sel}-CA, P_D, DF_D\right)=\text{"Pass"}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline	$S_{Lmax}\left(t_{sel}-CA, P_D, T_{dmax}\right)=261.672\ MPa$
	$S_{Lmax}\left(t_{sel}-CA, P_D, T_{dmin}\right)=284.225\ MPa$
Allowable Longitudinal Stress in restrained pipeline	$S_{Lallow}=405\ MPa$
Longitudinal Stress Checking in restrained pipeline	$Check_L\left(t_{sel}-CA, P_D, T_{dmax}\right)=\text{"Pass"}$
	$Check_L\left(t_{sel}-CA, P_D, T_{dmin}\right)=\text{"Pass"}$
Actual Net Longitudinal Stress in unrestrained pipeline	$S_{LUmax}\left(t_{sel}-CA, P_D\right)=254.203\ MPa$
Allowable Longitudinal Stress in unrestrained pipeline	$S_{LUallow}=337.5\ MPa$
Longitudinal Stress Checking in unrestrained pipeline	$Check_{LU}\left(t_{sel}-CA, P_D\right)=\text{"Pass"}$

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com\_max}\left(t_{sel}-CA, P_D, T_{dmax}\right)=393.714\ MPa$
	$S_{com\_max}\left(t_{sel}-CA, P_D, T_{dmin}\right)=224.181\ MPa$
Allowable Combined Stress	$S_{com\_allow}=405\ MPa$
Combined Stress Checking	$Check_C\left(t_{sel}-CA, P_D, T_{dmax}\right)=\text{"Pass"}$
	$Check_C\left(t_{sel}-CA, P_D, T_{dmin}\right)=\text{"Pass"}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 4.65\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 4\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 4.79\ mm$
Min. Combined Stress Wall Thickness	$t_{Cmin} = 6.61\ mm$
Selected Pipeline Wall Thickness	$t_{sel} = 7.04\ mm$
Min. Wall Thickness Checking	$Check_{tmin} = \text{“Pass”}$

Technip Energies
Pipeline Engineering Department

ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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

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1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Normal WT(Hydrotest)= 7.04 mm

A. Input Data

Hydrotest Pressure	$P_D := 60.9\ bar$
Pipe Diameter	$D := 8.625\ in$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Design Factor for Hoop Stress	$DF_D := 0.72$
Longitudinal Joint Factor	$EF := 1$ (API Spec 5L SAWL or ERW)
Corrosion Allowance	$CA := 0\ mm$
Selected Pipeline Wall Thickness	$t_{sel} := 7.04\ mm$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$
Minimum Air Temperature	$T_{amin} := 23.3\ °C$
Maximum Design Temperature	$T_{dmax} := 32.9\ °C$
Minimum Design Temperature	$T_{dmin} := 32.9\ °C$
Radius of Curvature	$R := 550\ D$
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$
K Factor for Combined Stress	$k := 0.9$
Maximum Horizontal Ground Velocity	$V_{max} := 31\ \frac{cm}{s}$
Ground Strain Coefficient	$\alpha_\varepsilon := 1$
Apparent Propagation Speed	$cc := 2\ \frac{km}{s}$

B. Calculation

B-1 Hoop Stress

Hoop Stress

$$S_H(t,P) := \begin{cases} \dfrac{P\cdot(D-t)}{2\cdot t} & \text{if } \dfrac{D}{t} < 20 \\ \dfrac{P\cdot D}{2\cdot t} & \text{else} \end{cases}$$

Allowable Hoop Stress

$$S_{Hallow}(DF) := SMYS\cdot EF\cdot DF$$

Hoop Stress Checking

$$Check_H(t,P,DF) := \begin{cases} \text{"Pass"} & \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \text{"Fail"} & \text{else} \end{cases}$$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure in restrained pipeline

$$S_P(t,P) := 0.3\cdot S_H(t,P)$$

Longitudinal Stress due to internal pressure in unrestrained pipeline

$$S_{PU}(t,P) := 0.5\cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E\cdot\alpha\cdot\left(T_{amin} - T\right)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia

$$I(t) := \frac{\pi}{64}\cdot\left(D^4 - (D-2\ t)^4\right)$$

Pipeline Sectional Elastic Modulus

$$Z(t) := \frac{2\cdot I(t)}{D}$$

Bending Moment

$$M(t) := \frac{E\cdot I(t)}{R}$$

Longitudinal Stress due to bending moment

$$S_B(t) := \frac{M(t)}{Z(t)}$$

Net Longitudinal Stress in restrained pipeline

$$S_{L1}(t,P,T) := \left(S_T(T) + S_P(t,P) + S_x\right) + S_B(t)$$

$$S_{L2}(t,P,T) := \left(S_T(T) + S_P(t,P) + S_x\right) - S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline

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

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := (S_{PU}(t,P) + S_x) + S_B(t)$

$$S_{L4}(t,P) := (S_{PU}(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max\left(\left|S_{L3}(t,P)\right|, \left|S_{L4}(t,P)\right|\right)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Combined Stress Checking

$$Check_L(t,P,T) := \begin{array}{|l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

$$Check_{LU}(t,P) := \begin{array}{|l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline $S_{com1}(t,P,T) := \left|S_{L1}(t,P,T) - S_H(t,P)\right|$

$$S_{com2}(t,P,T) := \left|S_{L2}(t,P,T) - S_H(t,P)\right|$$

Maximum Combined Stress $S_{com\_max}(t,P,T) := \max\left(\left|S_{com1}(t,P,T)\right|, \left|S_{com2}(t,P,T)\right|\right)$

Allowable Stress $S_{com\_allow} := k \cdot SMYS$

Combined Stress Checking $Check_C(t,P,T) := \begin{array}{|l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$

B-4 Min. Wall Thickness

Hoop Stress $t_{Hmin} := \begin{array}{|l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$

Longitudinal Stress in restrained pipeline

$$t_{Lmin} := \begin{array}{|l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin})\right) \ge S_{Lallow} \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_{LUmax}\left(t - CA, P_D\right) \geq S_{LUallow} \\ \quad \left\| \ t \leftarrow t + 0.01\ mm \right. \\ t \end{array} \right.$$

Combined Stress

$$t_{Cmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{com\_max}\left(t - CA, P_D, T_{dmax}\right), S_{com\_max}\left(t - CA, P_D, T_{dmin}\right)\right) \geq S_{com\_allow} \\ \quad \left\| \ t \leftarrow t + 0.01\ mm \right. \\ t \end{array} \right.$$

Min. Wall Thickness Checking

$$Check_{tmin} := \left\| \begin{array}{l} \text{if } \max\left(t_{Hmin}, t_{Lmin}, t_{LUmin}, t_{Cmin}\right) \leq t_{sel} \\ \quad \left\| \ \text{“Pass”} \right. \\ \text{else} \\ \quad \left\| \ \text{“Fail”} \right. \end{array} \right.$$

B-5 Seismic Wave Propagation Effect

Maximum Ground Strain

$$\varepsilon_g := \frac{V_{max}}{\alpha_\varepsilon \cdot cc} \qquad \varepsilon_g = 0.016\%$$

$$D_{min} := D - \left(0.0075 \cdot D\right) = 0.217\ m$$

$$D' := \frac{D}{1 - \left(\frac{3}{D} \cdot \left(D - D_{min}\right)\right)} = 0.224\ m$$

$$\varepsilon_{com} := 0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right) = 0.01 \qquad \varepsilon_{com} = 0.991\%$$

Strain Limit

$$\varepsilon_c := min\left(0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right), 0.5\%\right) = 0.005 \qquad \varepsilon_c = 0.5\%$$

Strain Checking

$$Check_\varepsilon := \left\| \begin{array}{l} \text{if } \varepsilon_g \leq \varepsilon_c \\ \quad \left\| \ \text{“Pass”} \right. \\ \text{else} \\ \quad \left\| \ \text{“Fail”} \right. \end{array} \right. \qquad Check_\varepsilon = \text{“Pass”}$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress	$S_H(t_{sel} - CA, P_D) = 94.756\ MPa$
Allowable Hoop Stress	$S_{Hallow}(DF_D) = 324\ MPa$
Hoop Stress Checking	$Check_H(t_{sel} - CA, P_D, DF_D) = \text{“Pass”}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline	$S_{Lmax}(t_{sel} - CA, P_D, T_{dmax}) = 193.358\ MPa$
	$S_{Lmax}(t_{sel} - CA, P_D, T_{dmin}) = 193.358\ MPa$
Allowable Longitudinal Stress in restrained pipeline	$S_{Lallow} = 405\ MPa$
Longitudinal Stress Checking in restrained pipeline	$Check_L(t_{sel} - CA, P_D, T_{dmax}) = \text{“Pass”}$
	$Check_L(t_{sel} - CA, P_D, T_{dmin}) = \text{“Pass”}$
Actual Net Longitudinal Stress in unrestrained pipeline	$S_{LUmax}(t_{sel} - CA, P_D) = 235.56\ MPa$
Allowable Longitudinal Stress in unrestrained pipeline	$S_{LUallow} = 337.5\ MPa$
Longitudinal Stress Checking in unrestrained pipeline	$Check_{LU}(t_{sel} - CA, P_D) = \text{“Pass”}$

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com\_max}(t_{sel} - CA, P_D, T_{dmax}) = 277.761\ MPa$
	$S_{com\_max}(t_{sel} - CA, P_D, T_{dmin}) = 277.761\ MPa$
Allowable Combined Stress	$S_{com\_allow} = 405\ MPa$
Combined Stress Checking	$Check_C(t_{sel} - CA, P_D, T_{dmax}) = \text{“Pass”}$
	$Check_C(t_{sel} - CA, P_D, T_{dmin}) = \text{“Pass”}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 2.06\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 0.84\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 2.24\ mm$
Min. Combined Stress Wall Thickness	$t_{Cmin} = 2.42\ mm$
Selected Pipeline Wall Thickness	$t_{sel} = 7.04\ mm$
Min. Wall Thickness Checking	$Check_{tmin} = \text{“Pass”}$

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Pipeline Engineering Department

ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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
3/6/2013	0	For Implementation	The spreadsheet was updated and validated by Soratus P.	SWN
1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Bend Mother Pipe WT = 7.04x0.93 = 6.55 mm

A. Input Data

Design Pressure	$P_D := 48.7\ bar$
Pipe Diameter	$D := 8.625\ in$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Design Factor for Hoop Stress	$DF_D := 0.72$
Longitudinal Joint Factor	$EF := 1$ (API Spec 5L SAWL or ERW)
Corrosion Allowance	$CA := 3\ mm$
Pipeline Remaining Wall Thickness after Wall Thinning	$t_{sel} := 6.55\ mm$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta °C}$
Minimum Air Temperature	$T_{amin} := 23.3\ °C$
Maximum Design Temperature	$T_{dmax} := 70\ °C$
Minimum Design Temperature	$T_{dmin} := 0\ °C$
Radius of Curvature	$R := \infty\ D$
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$
K Factor for Combined Stress	$k := 0.9$
Maximum Horizontal Ground Velocity	$V_{max} := 31\ \frac{cm}{s}$
Ground Strain Coefficient	$\alpha_\varepsilon := 1$
Apparent Propagation Speed	$cc := 2\ \frac{km}{s}$

B. Calculation

B-1 Hoop Stress

Hoop Stress

$$S_H(t,P) := \begin{cases} \text{if } \dfrac{D}{t} < 20 \\ \quad \dfrac{P \cdot (D-t)}{2 \cdot t} \\ \text{else} \\ \quad \dfrac{P \cdot D}{2 \cdot t} \end{cases}$$

Allowable Hoop Stress

$$S_{Hallow}(DF) := SMYS \cdot EF \cdot DF$$

Hoop Stress Checking

$$Check_H(t,P,DF) := \begin{cases} \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{cases}$$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure in restrained pipeline

$$S_P(t,P) := 0.3 \cdot S_H(t,P)$$

Longitudinal Stress due to internal pressure in unrestrained pipeline

$$S_{PU}(t,P) := 0.5 \cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E \cdot \alpha \cdot (T_{amin} - T)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia

$$I(t) := \frac{\pi}{64} \cdot \left(D^4 - (D - 2\ t)^4\right)$$

Pipeline Sectional Elastic Modulus

$$Z(t) := \frac{2 \cdot I(t)}{D}$$

Bending Moment

$$M(t) := \frac{E \cdot I(t)}{R}$$

Longitudinal Stress due to bending moment

$$S_B(t) := \frac{M(t)}{Z(t)}$$

Net Longitudinal Stress in restrained pipeline

$$S_{L1}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) + S_B(t)$$

$$S_{L2}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline

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

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := (S_{PU}(t,P) + S_x) + S_B(t)$

$S_{L4}(t,P) := (S_{PU}(t,P) + S_x) - S_B(t)$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max(|S_{L3}(t,P)|, |S_{L4}(t,P)|)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Combined Stress Checking

$$Check_L(t,P,T) := \left\| \begin{array}{l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$$

$$Check_{LU}(t,P) := \left\| \begin{array}{l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline $S_{com1}(t,P,T) := |S_{L1}(t,P,T) - S_H(t,P)|$

$S_{com2}(t,P,T) := |S_{L2}(t,P,T) - S_H(t,P)|$

Maximum Combined Stress $S_{com\_max}(t,P,T) := \max(|S_{com1}(t,P,T)|, |S_{com2}(t,P,T)|)$

Allowable Stress $S_{com\_allow} := k \cdot SMYS$

Combined Stress Checking

$$Check_C(t,P,T) := \left\| \begin{array}{l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$$

B-4 Min. Wall Thickness

Hoop Stress

$$t_{Hmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Longitudinal Stress in restrained pipeline

$$t_{Lmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin})) \ge S_{Lallow} \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_{LUmax}(t - CA, P_D) \ge S_{LUallow} \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Combined Stress

$$t_{Cmin} := \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{com\_max}(t - CA, P_D, T_{dmax}), S_{com\_max}(t - CA, P_D, T_{dmin})\right) \ge S_{com\_allow} \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Min. Wall Thickness Checking

$$Check_{tmin} := \begin{array}{l} \text{if } \max(t_{Hmin}, t_{Lmin}, t_{LUmin}, t_{Cmin}) \le t_{sel} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

B-5 Seismic Wave Propagation Effect

Maximum Ground Strain

$$\varepsilon_g := \frac{V_{max}}{\alpha_\varepsilon \cdot cc} \qquad \varepsilon_g = 0.016\%$$

$$D_{min} := D - (0.0075 \cdot D) = 0.217\ m$$

$$D' := \frac{D}{1 - \left(\frac{3}{D} \cdot (D - D_{min})\right)} = 0.224\ m$$

$$\varepsilon_{com} := 0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right) = 0.009 \qquad \varepsilon_{com} = 0.892\%$$

Strain Limit

$$\varepsilon_c := min\left(0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right), 0.5\%\right) = 0.005 \qquad \varepsilon_c = 0.5\%$$

Strain Checking

$$Check_\varepsilon := \begin{array}{l} \text{if } \varepsilon_g \le \varepsilon_c \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array} \qquad Check_\varepsilon = \text{“Pass”}$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress $S_H(t_{sel} - CA, P_D) = 150.267\ MPa$

Allowable Hoop Stress $S_{Hallow}(DF_D) = 324\ MPa$

Hoop Stress Checking $Check_H(t_{sel} - CA, P_D, DF_D) = \text{“Pass”}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline $S_{Lmax}(t_{sel} - CA, P_D, T_{dmax}) = 68.023\ MPa$

$S_{Lmax}(t_{sel} - CA, P_D, T_{dmin}) = 101.51\ MPa$

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} = 405\ MPa$

Longitudinal Stress Checking in restrained pipeline $Check_L(t_{sel} - CA, P_D, T_{dmax}) = \text{“Pass”}$

$Check_L(t_{sel} - CA, P_D, T_{dmin}) = \text{“Pass”}$

Actual Net Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t_{sel} - CA, P_D) = 75.133\ MPa$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} = 337.5\ MPa$

Longitudinal Stress Checking in unrestrained pipeline $Check_{LU}(t_{sel} - CA, P_D) = \text{“Pass”}$

C-3 Combined Stress Checking

Actual Combined Stress $S_{com\_max}(t_{sel} - CA, P_D, T_{dmax}) = 218.29\ MPa$

$S_{com\_max}(t_{sel} - CA, P_D, T_{dmin}) = 48.757\ MPa$

Allowable Combined Stress $S_{com\_allow} = 405\ MPa$

Combined Stress Checking $Check_C(t_{sel} - CA, P_D, T_{dmax}) = \text{“Pass”}$

$Check_C(t_{sel} - CA, P_D, T_{dmin}) = \text{“Pass”}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 4.65\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 3.46\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 3.8\ mm$
Min. Combined Stress Wall Thickness	$t_{Cmin} = 4.28\ mm$
Pipeline Remaining Wall Thickness after Wall Thinning	$t_{sel} = 6.55\ mm$
Min. Wall Thickness Checking	$Check_{tmin} = \text{“Pass”}$

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ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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
3/6/2013	0	For Implementation	The spreadsheet was updated and validated by Soratus P.	SWN
1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Bend Mother WT(Hydrotest) = 7.04x0.93 = 6.55 mm

A. Input Data

Hydrotest Pressure	$P_D := 60.9\ bar$	
Pipe Diameter	$D := 8.625\ in$	
Specified Minimum Yield Strength	$SMYS := 450\ MPa$	
Design Factor for Hoop Stress	$DF_D := 0.72$	
Longitudinal Joint Factor	$EF := 1$	(API Spec 5L SAWL or ERW)
Corrosion Allowance	$CA := 0\ mm$	
Pipeline Remaining Wall Thickness after Wall Thinning	$t_{sel} := 6.55\ mm$	
Young's Modulus	$E := 207\ GPa$	
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$	
Minimum Air Temperature	$T_{amin} := 23.3\ °C$	
Maximum Design Temperature	$T_{dmax} := 32.9\ °C$	
Minimum Design Temperature	$T_{dmin} := 32.9\ °C$	
Radius of Curvature	$R := \infty\ D$	
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$	
K Factor for Combined Stress	$k := 0.9$	
Maximum Horizontal Ground Velocity	$V_{max} := 31\ \frac{cm}{s}$	
Ground Strain Coefficient	$\alpha_\varepsilon := 1$	
Apparent Propagation Speed	$cc := 2\ \frac{km}{s}$	

B. Calculation

B-1 Hoop Stress

Hoop Stress $S_H(t,P) := \frac{P \cdot D}{2 \cdot t}$

Allowable Hoop Stress $S_{Hallow}(DF) := SMYS \cdot EF \cdot DF$

Hoop Stress Checking $Check_H(t,P,DF) := \begin{Vmatrix} \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \quad \Vert \text{“Pass”} \\ \text{else} \\ \quad \Vert \text{“Fail”} \end{Vmatrix}$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure

$$S_P(t,P) := 0.3 \cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E \cdot \alpha \cdot (T_{amin} - T)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia $I(t) := \frac{\pi}{64} \cdot \left(D^4 - (D - 2\ t)^4\right)$

Pipeline Sectional Elastic Modulus $Z(t) := \frac{2 \cdot I(t)}{D}$

Bending Moment $M(t) := \frac{E \cdot I(t)}{R}$

Longitudinal Stress due to bending moment $S_B(t) := \frac{M(t)}{Z(t)}$

Net Longitudinal Stress in restrained pipeline $S_{L1}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) + S_B(t)$

$$S_{L2}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline $S_{Lmax}(t,P,T) := \max\left(\left|S_{L1}(t,P,T)\right|, \left|S_{L2}(t,P,T)\right|\right)$

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := \left(\frac{5}{3}\ S_P(t,P) + S_x\right) + S_B(t)$

$$S_{L4}(t,P) := \left(\frac{5}{3}\ S_P(t,P) + S_x\right) - S_B(t)$$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max\left(\left|S_{L3}(t,P)\right|, \left|S_{L4}(t,P)\right|\right)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Combined Stress Checking

$$Check_L(t,P,T) := \begin{array}{|l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array}$$

$$Check_{LU}(t,P) := \begin{array}{|l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array}$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline

$$S_{com1}(t,P,T) := |S_{L1}(t,P,T) - S_H(t,P)|$$

$$S_{com2}(t,P,T) := |S_{L2}(t,P,T) - S_H(t,P)|$$

Maximum Combined Stress

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

Allowable Stress

$$S_{com\_allow} := k \cdot SMYS$$

Combined Stress Checking

$$Check_C(t,P,T) := \begin{array}{|l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array}$$

B-4 Min. Wall Thickness

Hoop Stress

$$t_{Hmin} := \begin{array}{|l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress

$$t_{Lmin} := \begin{array}{|l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin}), S_{LUmax}(t - CA, P_D)\right) \ge S_{Lallow} \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \begin{array}{|l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_{LUmax}(t - CA, P_D) \ge S_{LUallow} \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Combined Stress

$$t_{Cmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{com\_max}\left(t - CA, P_D, T_{dmax}\right), S_{com\_max}\left(t - CA, P_D, T_{dmin}\right)\right) \ge S_{com\_allow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Min. Wall Thickness Checking

$$Check_{tmin} := \left\| \begin{array}{l} \text{if } \max\left(t_{Hmin}, t_{Lmin}, t_{Cmin}\right) \le t_{sel} \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right.$$

B-5 Seismic Wave Propagation Effect

Maximum Ground Strain

$$\varepsilon_g := \frac{V_{max}}{\alpha_\varepsilon \cdot cc} \qquad \varepsilon_g = 0.016\%$$

$$D_{min} := D - (0.0075 \cdot D) = 0.217\ m$$

$$D' := \frac{D}{1 - \left(\frac{3}{D} \cdot \left(D - D_{min}\right)\right)} = 0.224\ m$$

$$\varepsilon_{com} := 0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right) = 0.009 \qquad \varepsilon_{com} = 0.919\%$$

Strain Limit

$$\varepsilon_c := min\left(0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right), 0.5\%\right) = 0.005 \qquad \varepsilon_c = 0.5\%$$

Strain Checking

$$Check_\varepsilon := \left\| \begin{array}{l} \text{if } \varepsilon_g \le \varepsilon_c \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right. \qquad Check_\varepsilon = \text{“Pass”}$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress $S_H\left(t_{sel}-CA, P_D\right)=101.845\ MPa$

Allowable Hoop Stress $S_{Hallow}\left(DF_D\right)=324\ MPa$

Hoop Stress Checking $Check_H\left(t_{sel}-CA, P_D, DF_D\right)=\text{"Pass"}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline $S_{Lmax}\left(t_{sel}-CA, P_D, T_{dmax}\right)=7.303\ MPa$

$S_{Lmax}\left(t_{sel}-CA, P_D, T_{dmin}\right)=7.303\ MPa$

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow}=405\ MPa$

Longitudinal Stress Checking in restrained pipeline $Check_L\left(t_{sel}-CA, P_D, T_{dmax}\right)=\text{"Pass"}$

$Check_L\left(t_{sel}-CA, P_D, T_{dmin}\right)=\text{"Pass"}$

Actual Net Longitudinal Stress in unrestrained pipeline $S_{LUmax}\left(t_{sel}-CA, P_D\right)=50.922\ MPa$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow}=337.5\ MPa$

Longitudinal Stress Checking in unrestrained pipeline $Check_{LU}\left(t_{sel}-CA, P_D\right)=\text{"Pass"}$

C-3 Combined Stress Checking

Actual Combined Stress $S_{com\_max}\left(t_{sel}-CA, P_D, T_{dmax}\right)=94.542\ MPa$

$S_{com\_max}\left(t_{sel}-CA, P_D, T_{dmin}\right)=94.542\ MPa$

Allowable Combined Stress $S_{com\_allow}=405\ MPa$

Combined Stress Checking $Check_C\left(t_{sel}-CA, P_D, T_{dmax}\right)=\text{"Pass"}$

$Check_C\left(t_{sel}-CA, P_D, T_{dmin}\right)=\text{"Pass"}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 2.06\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 0.83\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 0.99\ mm$
Min. Combined Stress Wall Thickness	$t_{Cmin} = 1.23\ mm$
Pipeline Remaining Wall Thickness after Wall Thinning	$t_{sel} = 6.55\ mm$
Min. Wall Thickness Checking	$Check_{tmin} = \text{"Pass"}$

APPENDIX D: PIPELINE CROSSING WALL THICKNESS CALCULATIONS

Technip Energies
Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

/1/ Steel Pipelines Crossing Railroads and Highways, API RP 1102
/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	0	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Open-Cut Crossing, WT = 7.04 mm, Cover Depth of 2 m, Case: Max Operating Temp (44.1˚ C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$	
Operating Temperature	$T_{ope} := 44.1\ °C$	
Installation Temperature	$T_{ins} := 23.3\ °C$	
Design Factor	$F_d := 0.72$	
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$	
Longitudinal Joint Factor	$E_w := 1$	(API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$	

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$	
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$	
Corrosion Allowance	$CA := 3\ mm$	
Specified Minimum Yield Strength	$SMYS := 450\ MPa$	
Poisson's Ratio	$\upsilon := 0.3$	
Young Modulus	$E_s := 207\ GPa$	20
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \dfrac{1}{\Delta °C}$	
Corrosion Depth	$T_{corr} := 100\%$	
Anti Corrosion Coating Thickness	$t_{corr} := 3.5\ mm$	
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$	
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$	

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 2\ m$	
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"	
Pavement Selection	$Pavement := NP$	
Bored Diameter of Crossing	$B_d := D + 0\ in$	(Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \frac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 39.24\ kN$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.3$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} 1.5 & \text{if } H_b \le 5\ ft \\ -\left(\dfrac{\frac{H_b}{ft} - 56}{34}\right) & \text{if } 5\ ft < H_b \le 22\ ft \\ 1 & \text{else} \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{"Single Axle"} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \wedge Pavement = NP \\ \text{"Tandem Axles"} & \text{else} \end{cases}$$

Applied Design Surface Pressure
(/1/, Equation 2)

$$w := \begin{cases} \dfrac{P_s}{A_w} & \text{if } axle = \text{"Single Axle"} \\ \dfrac{P_t}{A_w} & \text{else} \end{cases}$$

Highway Pavement Type Factor

(/1/, Table 2)

$$R_{f1} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \wedge axle = \text{“Tandem Axles”} \\ 1.2 & \text{if } Pavement = NP \wedge axle = \text{“Single Axle”} \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_{f2} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_f := \begin{cases} R_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ R_{f2} & \text{else} \end{cases}$$

Highway Axle Configuration Factor

(/1/, Table 2)

$$L_{f1} := \begin{cases} 1 & \text{if } axle = \text{“Tandem Axles”} \\ 0.75 & \text{if } Pavement = FP \wedge axle = \text{“Single Axle”} \\ 0.8 & \text{if } Pavement = NP \wedge axle = \text{“Single Axle”} \\ 0.9 & \text{if } Pavement = RP \wedge axle = \text{“Single Axle”} \end{cases}$$

$$L_{f2} := \begin{cases} 1 & \text{if } axle = \text{“Tandem Axles”} \\ 0.65 & \text{if } axle = \text{“Single Axle”} \end{cases}$$

$$L_f := \begin{cases} L_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ L_{f2} & \text{else} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress
(/1/, Figure 14)

$K_{Hh} := 12.5$

Highway Geometry Factor for Cyclic Circumferential Stress
(/1/, Figure 15)

$G_{Hh} := 1$

Highway Stiffness Factor for Cycle Longitudinal Stress
(/1/, Figure 16)

$K_{Lh} := 11.50$

Highway Geometry Factor for Cyclic Longitudinal Stress
(/1/, Figure 17)

$G_{Lh} := 1.2$

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld
(/1/, Table 3)

$S_{FL} := 12000\ psi$ (X65 SAWL or ERW)

Fatigue Endurance Limit of Girth Weld
(/1/, Table 3)

$S_{FG} := 12000\ psi$

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress

$$S_{Hi\_Barlow} := \frac{P_d \cdot D}{2\ t}$$

Allowable Stress

$$S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$$

Barlow Stress Checking

$$CHECK_1 := \begin{array}{l} \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-2 Effective Stress

Circumferential Stress due to Earth Load
(/1/, Section 4.7.2.1, Eq.1)

$$S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$$

Cyclic Circumferential Stress
(/1/, Section 4.7.2.2.4.1, Eq.5)

$$\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$$

Cyclic Longitudinal Stress
(/1/, Section 4.7.2.2.4.2, Eq.6)

$$\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$$

Circumferential Stress due to Internal Pressure
(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D - t)}{2\ t}$$

Maximum Circumferential Stress
(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress
(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot (T_{ope} - T_{ins}) + \upsilon \cdot (S_{He} + S_{Hi})$$

Maximum Radial Stress
(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress
(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 \right)}$$

Allowable Stress for Principal Stress
(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking
(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{|l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld
(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking
(/1/, Equation 17)

$$CHECK_3 := \begin{array}{|l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld
(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking
(/1/, Equation 20)

$$CHECK_4 := \begin{array}{|l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress $S_{Hi\_Barlow} = 132.041\ MPa$

Allowable Stress $S_{allow\_Barlow} = 324\ MPa$

Barlow Stress Checking $CHECK_1 = \text{"Pass"}$

D-2 Effective Combined Stress Checking

Effective Combined Stress $S_{eff} = 145.332\ MPa$

Allowable Stress for Principal Stress $S_{allow\_Principle} = 405\ MPa$

Effective Combined Stress Checking $CHECK_2 = \text{"Pass"}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress $\Delta S_{Lh} = 9.313\ MPa$

Design Fatigue Endurance Limit of Girth Weld $DS_{FG} = 59.571\ MPa$

Girth Weld Fatigue Checking $CHECK_3 = \text{"Pass"}$

Cyclic Circumferential Stress $\Delta S_{Hh} = 8.436\ MPa$

Design Fatigue Endurance Limit of Longitudinal Weld $DS_{FL} = 59.571\ MPa$

Longitudinal Weld Fatigue Checking $CHECK_4 = \text{"Pass"}$

Technip Energies

Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

/1/ Steel Pipelines Crossing Railroads and Highways, API RP 1102
/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	0	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Open-Cut Crossing, WT = 7.04 mm, Cover Depth of 2 m, Case: Min Operating Temp (20.3˚ C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$
Operating Temperature	$T_{ope} := 20.3\ °C$
Installation Temperature	$T_{ins} := 23.3\ °C$
Design Factor	$F_d := 0.72$
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$
Longitudinal Joint Factor	$E_w := 1$ (API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$
Corrosion Allowance	$CA := 3\ mm$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Poisson's Ratio	$\upsilon := 0.3$
Young Modulus	$E_s := 207\ GPa$
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \frac{1}{\Delta °C}$
Corrosion Depth	$T_{corr} := 100\%$
Anti Corrosion Coating Thickness	$t_{corr} := 3.5\ mm$
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 2\ m$
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"
Pavement Selection	$Pavement := NP$
Bored Diameter of Crossing	$B_d := D + 0\ in$ (Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \frac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 39.24\ kN$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.3$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} \text{if } H_b \le 5\ ft \\ \quad 1.5 \\ \text{if } 5\ ft < H_b \le 22\ ft \\ \quad -\left(\dfrac{\dfrac{H_b}{ft} - 56}{34}\right) \\ \text{else} \\ \quad 1 \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \wedge Pavement = NP \\ \quad \text{“Single Axle”} \\ \text{else} \\ \quad \text{“Tandem Axles”} \end{cases}$$

Applied Design Surface Pressure
(/1/, Equation 2)

$$w := \begin{cases} \text{if } axle = \text{“Single Axle”} \\ \quad \dfrac{P_s}{A_w} \\ \text{else} \\ \quad \dfrac{P_t}{A_w} \end{cases}$$

Highway Pavement Type Factor

(/1/, Table 2)

$$R_{f1} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \wedge axle = \text{“Tandem Axles”} \\ 1.2 & \text{if } Pavement = NP \wedge axle = \text{“Single Axle”} \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_{f2} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_f := \begin{cases} R_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ R_{f2} & \text{else} \end{cases}$$

Highway Axle Configuration Factor

(/1/, Table 2)

$$L_{f1} := \begin{cases} 1 & \text{if } axle = \text{“Tandem Axles”} \\ 0.75 & \text{if } Pavement = FP \wedge axle = \text{“Single Axle”} \\ 0.8 & \text{if } Pavement = NP \wedge axle = \text{“Single Axle”} \\ 0.9 & \text{if } Pavement = RP \wedge axle = \text{“Single Axle”} \end{cases}$$

$$L_{f2} := \begin{cases} 1 & \text{if } axle = \text{“Tandem Axles”} \\ 0.65 & \text{if } axle = \text{“Single Axle”} \end{cases}$$

$$L_f := \begin{cases} L_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ L_{f2} & \text{else} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress
(/1/, Figure 14)

$K_{Hh} := 12.5$

Highway Geometry Factor for Cyclic Circumferential Stress
(/1/, Figure 15)

$G_{Hh} := 1$

Highway Stiffness Factor for Cycle Longitudinal Stress
(/1/, Figure 16)

$K_{Lh} := 11.50$

Highway Geometry Factor for Cyclic Longitudinal Stress
(/1/, Figure 17)

$G_{Lh} := 1.2$

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld
(/1/, Table 3)

$S_{FL} := 12000\ psi$ (X65 SAWL or ERW)

Fatigue Endurance Limit of Girth Weld
(/1/, Table 3)

$S_{FG} := 12000\ psi$

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress

$$S_{Hi\_Barlow} := \frac{P_d \cdot D}{2\ t}$$

Allowable Stress

$$S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$$

Barlow Stress Checking

$$CHECK_1 := \left\| \begin{array}{l} \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$$

C-2 Effective Stress

Circumferential Stress due to Earth Load
(/1/, Section 4.7.2.1, Eq.1)

$$S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$$

Cyclic Circumferential Stress
(/1/, Section 4.7.2.2.4.1, Eq.5)

$$\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$$

Cyclic Longitudinal Stress
(/1/, Section 4.7.2.2.4.2, Eq.6)

$$\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$$

Circumferential Stress due to Internal Pressure
(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D - t)}{2\ t}$$

Maximum Circumferential Stress
(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress
(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot (T_{ope} - T_{ins}) + \upsilon \cdot (S_{He} + S_{Hi})$$

Maximum Radial Stress
(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress
(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 \right)}$$

Allowable Stress for Principal Stress
(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking
(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{|l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld
(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking
(/1/, Equation 17)

$$CHECK_3 := \begin{array}{|l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld
(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking
(/1/, Equation 20)

$$CHECK_4 := \begin{array}{|l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress $S_{Hi\_Barlow} = 132.041\ MPa$

Allowable Stress $S_{allow\_Barlow} = 324\ MPa$

Barlow Stress Checking $CHECK_1 = \text{“Pass”}$

D-2 Effective Combined Stress Checking

Effective Combined Stress $S_{eff} = 128.122\ MPa$

Allowable Stress for Principal Stress $S_{allow\_Principle} = 405\ MPa$

Effective Combined Stress Checking $CHECK_2 = \text{“Pass”}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress $\Delta S_{Lh} = 9.313\ MPa$

Design Fatigue Endurance Limit of Girth Weld $DS_{FG} = 59.571\ MPa$

Girth Weld Fatigue Checking $CHECK_3 = \text{“Pass”}$

Cyclic Circumferential Stress $\Delta S_{Hh} = 8.436\ MPa$

Design Fatigue Endurance Limit of Longitudinal Weld $DS_{FL} = 59.571\ MPa$

Longitudinal Weld Fatigue Checking $CHECK_4 = \text{“Pass”}$

Technip Energies
Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

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/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	0	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Boring Crossing, WT = 7.04 mm, Cover Depth of 2 m, Case: Max Operating Temp (44.1˚ C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$	
Operating Temperature	$T_{ope} := 44.1\ °C$	
Installation Temperature	$T_{ins} := 23.3\ °C$	
Design Factor	$F_d := 0.72$	
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$	
Longitudinal Joint Factor	$E_w := 1$	(API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$	

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$
Corrosion Allowance	$CA := 3\ mm$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Poisson's Ratio	$\upsilon := 0.3$
Young Modulus	$E_s := 207\ GPa$
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \frac{1}{\Delta °C}$
Corrosion Depth	$T_{corr} := 100\%$
Anti Corrosion Coating Thickness	$t_{corr} := 4.5\ mm$
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 2\ m$	
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"	
Pavement Selection	$Pavement := FP$	
Bored Diameter of Crossing	$B_d := D + 2\ in$	(Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \dfrac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 39.24\ kN$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.3$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} 1.5 & \text{if } H_b \le 5\ ft \\ -\left(\dfrac{\dfrac{H_b}{ft} - 56}{34}\right) & \text{if } 5\ ft < H_b \le 22\ ft \\ 1 & \text{else} \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{"Single Axle"} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \wedge Pavement = NP \\ \text{"Tandem Axles"} & \text{else} \end{cases}$$

Applied Design Surface Pressure

(/1/, Equation 2)

$$w := \begin{cases} \dfrac{P_s}{A_w} & \text{if } axle = \text{"Single Axle"} \\ \dfrac{P_t}{A_w} & \text{else} \end{cases}$$

Highway Pavement Type Factor

(/1/, Table 2)

$$R_{f1} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \land axle = \text{"Tandem Axles"} \\ 1.2 & \text{if } Pavement = NP \land axle = \text{"Single Axle"} \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_{f2} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_f := \begin{cases} R_{f1} & \text{if } H_b < 1.2\ m \land D \le 12.75\ in \\ R_{f2} & \text{else} \end{cases}$$

Highway Axle Configuration Factor

(/1/, Table 2)

$$L_{f1} := \begin{cases} 1 & \text{if } axle = \text{"Tandem Axles"} \\ 0.75 & \text{if } Pavement = FP \land axle = \text{"Single Axle"} \\ 0.8 & \text{if } Pavement = NP \land axle = \text{"Single Axle"} \\ 0.9 & \text{if } Pavement = RP \land axle = \text{"Single Axle"} \end{cases}$$

$$L_{f2} := \begin{cases} 1 & \text{if } axle = \text{"Tandem Axles"} \\ 0.65 & \text{if } axle = \text{"Single Axle"} \end{cases}$$

$$L_f := \begin{cases} L_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ L_{f2} & \text{else} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress
(/1/, Figure 14)

$K_{Hh} := 12.5$

Highway Geometry Factor for Cyclic Circumferential Stress
(/1/, Figure 15)

$G_{Hh} := 1$

Highway Stiffness Factor for Cycle Longitudinal Stress
(/1/, Figure 16)

$K_{Lh} := 11.50$

Highway Geometry Factor for Cyclic Longitudinal Stress
(/1/, Figure 17)

$G_{Lh} := 1.2$

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld
(/1/, Table 3)

$S_{FL} := 12000\ psi$ (X65 SAWL or ERW)

Fatigue Endurance Limit of Girth Weld
(/1/, Table 3)

$S_{FG} := 12000\ psi$

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress

$$S_{Hi\_Barlow} := \frac{P_d \cdot D}{2\ t}$$

Allowable Stress

$$S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$$

Barlow Stress Checking

$$CHECK_1 := \begin{cases} \text{"Pass"} & \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \text{"Fail"} & \text{else} \end{cases}$$

C-2 Effective Stress

Circumferential Stress due to Earth Load
(/1/, Section 4.7.2.1, Eq.1)

$$S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$$

Cyclic Circumferential Stress
(/1/, Section 4.7.2.2.4.1, Eq.5)

$$\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$$

Cyclic Longitudinal Stress
(/1/, Section 4.7.2.2.4.2, Eq.6)

$$\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$$

Circumferential Stress due to Internal Pressure
(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D - t)}{2\ t}$$

Maximum Circumferential Stress
(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress
(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot (T_{ope} - T_{ins}) + \upsilon \cdot (S_{He} + S_{Hi})$$

Maximum Radial Stress
(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress
(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 \right)}$$

Allowable Stress for Principal Stress
(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking
(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld
(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking
(/1/, Equation 17)

$$CHECK_3 := \begin{array}{l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld
(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking
(/1/, Equation 20)

$$CHECK_4 := \begin{array}{l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress	$S_{Hi\_Barlow} = 132.041\ MPa$
Allowable Stress	$S_{allow\_Barlow} = 324\ MPa$
Barlow Stress Checking	$CHECK_1 = \text{“Pass”}$

D-2 Effective Combined Stress Checking

Effective Combined Stress	$S_{eff} = 145.006\ MPa$
Allowable Stress for Principal Stress	$S_{allow\_Principle} = 405\ MPa$
Effective Combined Stress Checking	$CHECK_2 = \text{“Pass”}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress	$\Delta S_{Lh} = 8.467\ MPa$
Design Fatigue Endurance Limit of Girth Weld	$DS_{FG} = 59.571\ MPa$
Girth Weld Fatigue Checking	$CHECK_3 = \text{“Pass”}$

Cyclic Circumferential Stress	$\Delta S_{Hh} = 7.669\ MPa$
Design Fatigue Endurance Limit of Longitudinal Weld	$DS_{FL} = 59.571\ MPa$
Longitudinal Weld Fatigue Checking	$CHECK_4 = \text{“Pass”}$

Technip Energies
Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

/1/ Steel Pipelines Crossing Railroads and Highways, API RP 1102
/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	0	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Boring Crossing, WT = 7.04 mm, Cover Depth of 2 m, Case: Min Operating Temp (20.3˚ C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$	
Operating Temperature	$T_{ope} := 20.3\ °C$	
Installation Temperature	$T_{ins} := 23.3\ °C$	
Design Factor	$F_d := 0.72$	
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$	
Longitudinal Joint Factor	$E_w := 1$	(API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$	

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$	
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$	
Corrosion Allowance	$CA := 3\ mm$	
Specified Minimum Yield Strength	$SMYS := 450\ MPa$	
Poisson's Ratio	$\upsilon := 0.3$	
Young Modulus	$E_s := 207\ GPa$	
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \frac{1}{\Delta °C}$	
Corrosion Depth	$T_{corr} := 100\%$	
Anti Corrosion Coating Thickness	$t_{corr} := 4.5\ mm$	
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$	
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$	

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 2\ m$	
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"	
Pavement Selection	$Pavement := FP$	
Bored Diameter of Crossing	$B_d := D + 2\ in$	(Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \frac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 39.24\ kN$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.3$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} \text{if } H_b \le 5\ ft \\ \quad 1.5 \\ \text{if } 5\ ft < H_b \le 22\ ft \\ \quad -\left(\dfrac{\dfrac{H_b}{ft} - 56}{34}\right) \\ \text{else} \\ \quad 1 \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \wedge Pavement = NP \\ \quad \text{"Single Axle"} \\ \text{else} \\ \quad \text{"Tandem Axles"} \end{cases}$$

Applied Design Surface Pressure

(/1/, Equation 2)

$$w := \begin{cases} \text{if } axle = \text{“Single Axle”} \\ \quad \dfrac{P_s}{A_w} \\ \text{else} \\ \quad \dfrac{P_t}{A_w} \end{cases}$$

Highway Pavement Type Factor

(/1/, Table 2)

$$R_{f1} := \begin{cases} \text{if } Pavement = FP \\ \quad 1 \\ \text{if } Pavement = NP \land axle = \text{“Tandem Axles”} \\ \quad 1.1 \\ \text{if } Pavement = NP \land axle = \text{“Single Axle”} \\ \quad 1.2 \\ \text{if } Pavement = RP \\ \quad 0.9 \end{cases}$$

$$R_{f2} := \begin{cases} \text{if } Pavement = FP \\ \quad 1 \\ \text{if } Pavement = NP \\ \quad 1.1 \\ \text{if } Pavement = RP \\ \quad 0.9 \end{cases}$$

$$R_f := \begin{cases} \text{if } H_b < 1.2\ m \land D \le 12.75\ in \\ \quad R_{f1} \\ \text{else} \\ \quad R_{f2} \end{cases}$$

Highway Axle Configuration Factor

(/1/, Table 2)

$$L_{f1} := \begin{cases} \text{if } axle = \text{“Tandem Axles”} \\ \quad 1 \\ \text{if } Pavement = FP \land axle = \text{“Single Axle”} \\ \quad 0.75 \\ \text{if } Pavement = NP \land axle = \text{“Single Axle”} \\ \quad 0.8 \\ \text{if } Pavement = RP \land axle = \text{“Single Axle”} \\ \quad 0.9 \end{cases}$$

$$L_{f2} := \begin{cases} \text{if } axle = \text{“Tandem Axles”} \\ \quad 1 \\ \text{if } axle = \text{“Single Axle”} \\ \quad 0.65 \end{cases}$$

$$L_f := \begin{cases} L_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ L_{f2} & \text{else} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress (/1/, Figure 14) — $K_{Hh} := 12.5$

Highway Geometry Factor for Cyclic Circumferential Stress (/1/, Figure 15) — $G_{Hh} := 1$

Highway Stiffness Factor for Cycle Longitudinal Stress (/1/, Figure 16) — $K_{Lh} := 11.50$

Highway Geometry Factor for Cyclic Longitudinal Stress (/1/, Figure 17) — $G_{Lh} := 1.2$

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld (/1/, Table 3) — $S_{FL} := 12000\ psi$ (X65 SAWL or ERW)

Fatigue Endurance Limit of Girth Weld (/1/, Table 3) — $S_{FG} := 12000\ psi$

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress — $S_{Hi\_Barlow} := \dfrac{P_d \cdot D}{2\ t}$

Allowable Stress — $S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$

Barlow Stress Checking — $CHECK_1 := \begin{cases} \text{"Pass"} & \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \text{"Fail"} & \text{else} \end{cases}$

C-2 Effective Stress

Circumferential Stress due to Earth Load (/1/, Section 4.7.2.1, Eq.1) — $S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$

Cyclic Circumferential Stress (/1/, Section 4.7.2.2.4.1, Eq.5) — $\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$

Cyclic Longitudinal Stress (/1/, Section 4.7.2.2.4.2, Eq.6) — $\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$

Circumferential Stress due to Internal Pressure
(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D - t)}{2\ t}$$

Maximum Circumferential Stress
(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress
(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot (T_{ope} - T_{ins}) + \upsilon \cdot (S_{He} + S_{Hi})$$

Maximum Radial Stress
(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress
(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 \right)}$$

Allowable Stress for Principal Stress
(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking
(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld
(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking
(/1/, Equation 17)

$$CHECK_3 := \begin{array}{l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld
(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking
(/1/, Equation 20)

$$CHECK_4 := \begin{array}{l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress	$S_{Hi\_Barlow} = 132.041\ MPa$
Allowable Stress	$S_{allow\_Barlow} = 324\ MPa$
Barlow Stress Checking	$CHECK_1 = \text{“Pass”}$

D-2 Effective Combined Stress Checking

Effective Combined Stress	$S_{eff} = 127.54\ MPa$
Allowable Stress for Principal Stress	$S_{allow\_Principle} = 405\ MPa$
Effective Combined Stress Checking	$CHECK_2 = \text{“Pass”}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress	$\Delta S_{Lh} = 8.467\ MPa$
Design Fatigue Endurance Limit of Girth Weld	$DS_{FG} = 59.571\ MPa$
Girth Weld Fatigue Checking	$CHECK_3 = \text{“Pass”}$
Cyclic Circumferential Stress	$\Delta S_{Hh} = 7.669\ MPa$
Design Fatigue Endurance Limit of Longitudinal Weld	$DS_{FL} = 59.571\ MPa$
Longitudinal Weld Fatigue Checking	$CHECK_4 = \text{“Pass”}$

APPENDIX E: PIPELINE WALL THICKNESS CALCULATIONS FOR API 5L X52 AND X60 MATERIAL GRADES

Technip Energies

Pipeline Engineering Department

ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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
3/6/2013	0	For Implementation	The spreadsheet was updated and validated by Soratus P.	SWN
1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Normal WT= 8.74 mm

A. Input Data

Design Pressure	$P_D := 48.7\ bar$
Pipe Diameter	$D := 8.625\ in$
Specified Minimum Yield Strength	$SMYS := 415\ MPa$
Design Factor for Hoop Stress	$DF_D := 0.72$
Longitudinal Joint Factor	$EF := 1$ (API Spec 5L SAWL)
Corrosion Allowance	$CA := 3\ mm$
Selected Pipeline Wall Thickness	$t_{sel} := 8.74\ mm$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta °C}$
Minimum Air Temperature	$T_{amin} := 23.3\ °C$
Maximum Design Temperature	$T_{dmax} := 70\ °C$
Minimum Design Temperature	$T_{dmin} := 0\ °C$
Radius of Curvature	$R := 550\ D$
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$
K Factor for Combined Stress	$k := 0.9$
Maximum Horizontal Ground Velocity	$V_{max} := 31\ \frac{cm}{s}$
Ground Strain Coefficient	$\alpha_\varepsilon := 1$
Apparent Propagation Speed	$cc := 2\ \frac{km}{s}$

B. Calculation

B-1 Hoop Stress

Hoop Stress

$$S_H(t,P) := \begin{cases} \dfrac{P\cdot(D-t)}{2\cdot t} & \text{if } \dfrac{D}{t} < 20 \\ \dfrac{P\cdot D}{2\cdot t} & \text{else} \end{cases}$$

Allowable Hoop Stress

$$S_{Hallow}(DF) := SMYS\cdot EF\cdot DF$$

Hoop Stress Checking

$$Check_H(t,P,DF) := \begin{cases} \text{“Pass”} & \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \text{“Fail”} & \text{else} \end{cases}$$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure in restrained pipeline

$$S_P(t,P) := 0.3\cdot S_H(t,P)$$

Longitudinal Stress due to internal pressure in unrestrained pipeline

$$S_{PU}(t,P) := 0.5\cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E\cdot\alpha\cdot(T_{amin}-T)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia

$$I(t) := \frac{\pi}{64}\cdot\left(D^4-(D-2\ t)^4\right)$$

Pipeline Sectional Elastic Modulus

$$Z(t) := \frac{2\cdot I(t)}{D}$$

Bending Moment

$$M(t) := \frac{E\cdot I(t)}{R}$$

Longitudinal Stress due to bending moment

$$S_B(t) := \frac{M(t)}{Z(t)}$$

Net Longitudinal Stress in restrained pipeline

$$S_{L1}(t,P,T) := (S_T(T)+S_P(t,P)+S_x)+S_B(t)$$

$$S_{L2}(t,P,T) := (S_T(T)+S_P(t,P)+S_x)-S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline

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

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := (S_{PU}(t,P) + S_x) + S_B(t)$

$$S_{L4}(t,P) := (S_{PU}(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max(|S_{L3}(t,P)|, |S_{L4}(t,P)|)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Longitudinal Stress Checking

$$Check_L(t,P,T) := \left\| \begin{array}{l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$$

$$Check_{LU}(t,P) := \left\| \begin{array}{l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline $S_{com1}(t,P,T) := |S_{L1}(t,P,T) - S_H(t,P)|$

$$S_{com2}(t,P,T) := |S_{L2}(t,P,T) - S_H(t,P)|$$

Maximum Combined Stress $S_{com\_max}(t,P,T) := \max(|S_{com1}(t,P,T)|, |S_{com2}(t,P,T)|)$

Allowable Stress $S_{com\_allow} := k \cdot SMYS$

Combined Stress Checking $Check_C(t,P,T) := \left\| \begin{array}{l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \| \text{“Pass”} \\ \text{else} \\ \quad \| \text{“Fail”} \end{array} \right.$

B-4 Min. Wall Thickness

Hoop Stress

$$t_{Hmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Longitudinal Stress in restrained pipeline

$$t_{Lmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin})) \ge S_{Lallow} \\ \quad \| t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_{LUmax}(t - CA, P_D) \ge S_{LUallow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Combined Stress

$$t_{Cmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{com\_max}(t - CA, P_D, T_{dmax}), S_{com\_max}(t - CA, P_D, T_{dmin})\right) \ge S_{com\_allow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Min. Wall Thickness Checking

$$Check_{tmin} := \left\| \begin{array}{l} \text{if } \max\left(t_{Hmin}, t_{Lmin}, t_{LUmin}, t_{Cmin}\right) \le t_{sel} \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right.$$

B-5 Seismic Wave Propagation Effect

Maximum Ground Strain

$$\varepsilon_g := \frac{V_{max}}{\alpha_\varepsilon \cdot cc} \qquad \varepsilon_g = 0.016\%$$

$$D_{min} := D - (0.0075 \cdot D) = 0.217\ m$$

$$D' := \frac{D}{1 - \left(\frac{3}{D} \cdot (D - D_{min})\right)} = 0.224\ m$$

$$\varepsilon_{com} := 0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right) = 0.012 \qquad \varepsilon_{com} = 1.238\%$$

Strain Limit

$$\varepsilon_c := min\left(0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right), 0.5\%\right) = 0.005 \qquad \varepsilon_c = 0.5\%$$

Strain Checking

$$Check_\varepsilon := \left\| \begin{array}{l} \text{if } \varepsilon_g \le \varepsilon_c \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right. \qquad Check_\varepsilon = \text{“Pass”}$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress $S_H\left(t_{sel}-CA, P_D\right)=92.935\ MPa$

Allowable Hoop Stress $S_{Hallow}\left(DF_D\right)=298.8\ MPa$

Hoop Stress Checking $Check_H\left(t_{sel}-CA, P_D, DF_D\right)=\text{“Pass”}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline $S_{Lmax}\left(t_{sel}-CA, P_D, T_{dmax}\right)=273.404\ MPa$

$S_{Lmax}\left(t_{sel}-CA, P_D, T_{dmin}\right)=272.493\ MPa$

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow}=373.5\ MPa$

Longitudinal Stress Checking in restrained pipeline $Check_L\left(t_{sel}-CA, P_D, T_{dmax}\right)=\text{“Pass”}$

$Check_L\left(t_{sel}-CA, P_D, T_{dmin}\right)=\text{“Pass”}$

Actual Net Longitudinal Stress in unrestrained pipeline $S_{LUmax}\left(t_{sel}-CA, P_D\right)=234.649\ MPa$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow}=311.25\ MPa$

Longitudinal Stress Checking in unrestrained pipeline $Check_{LU}\left(t_{sel}-CA, P_D\right)=\text{“Pass”}$

C-3 Combined Stress Checking

Actual Combined Stress $S_{com\_max}\left(t_{sel}-CA, P_D, T_{dmax}\right)=366.339\ MPa$

$S_{com\_max}\left(t_{sel}-CA, P_D, T_{dmin}\right)=196.806\ MPa$

Allowable Combined Stress $S_{com\_allow}=373.5\ MPa$

Combined Stress Checking $Check_C\left(t_{sel}-CA, P_D, T_{dmax}\right)=\text{“Pass”}$

$Check_C\left(t_{sel}-CA, P_D, T_{dmin}\right)=\text{“Pass”}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 4.79\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 4.25\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 5.17\ mm$
Min. Combined Stress Wall Thickness	$t_{Cmin} = 8.18\ mm$
Selected Pipeline Wall Thickness	$t_{sel} = 8.74\ mm$
Min. Wall Thickness Checking	$Check_{tmin} = \text{“Pass”}$

Technip Energies
Pipeline Engineering Department

ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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
3/6/2013	0	For Implementation	The spreadsheet was updated and validated by Soratus P.	SWN
1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Normal WT= 19.05 mm

A. Input Data

Design Pressure	$P_D := 48.7\ bar$
Pipe Diameter	$D := 8.625\ in$
Specified Minimum Yield Strength	$SMYS := 360\ MPa$
Design Factor for Hoop Stress	$DF_D := 0.72$
Longitudinal Joint Factor	$EF := 1$ (API Spec 5L SAWL)
Temperature Derating Factor	$TF := 1$
Corrosion Allowance	$CA := 3\ mm$
Selected Pipeline Wall Thickness	$t_{sel} := 19.05\ mm$
Young's Modulus	$E := 207\ GPa$
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$
Minimum Air Temperature	$T_{amin} := 23.3\ °C$
Maximum Design Temperature	$T_{dmax} := 70\ °C$
Minimum Design Temperature	$T_{dmin} := 0\ °C$
Radius of Curvature	$R := 550\ D$
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$
K Factor for Combined Stress	$k := 0.9$
Maximum Horizontal Ground Velocity	$V_{max} := 31\ \frac{cm}{s}$
Ground Strain Coefficient	$\alpha_\varepsilon := 1$
Apparent Propagation Speed	$cc := 2\ \frac{km}{s}$

B. Calculation

B-1 Hoop Stress

Hoop Stress
$$S_H(t,P) := \begin{cases} \dfrac{P\cdot(D-t)}{2\cdot t} & \text{if } \dfrac{D}{t} < 20 \\ \dfrac{P\cdot D}{2\cdot t} & \text{else} \end{cases}$$

Allowable Hoop Stress
$$S_{Hallow}(DF) := SMYS \cdot EF \cdot DF$$

Hoop Stress Checking
$$Check_H(t,P,DF) := \begin{cases} \text{“Pass”} & \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \text{“Fail”} & \text{else} \end{cases}$$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure in restrained pipeline

$$S_P(t,P) := 0.3 \cdot S_H(t,P)$$

Longitudinal Stress due to internal pressure in unrestrained pipeline

$$S_{PU}(t,P) := 0.5 \cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E \cdot \alpha \cdot (T_{amin} - T)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia
$$I(t) := \frac{\pi}{64} \cdot \left(D^4 - (D - 2\ t)^4\right)$$

Pipeline Sectional Elastic Modulus
$$Z(t) := \frac{2 \cdot I(t)}{D}$$

Bending Moment
$$M(t) := \frac{E \cdot I(t)}{R}$$

Longitudinal Stress due to bending moment
$$S_B(t) := \frac{M(t)}{Z(t)}$$

Net Longitudinal Stress in restrained pipeline
$$S_{L1}(t,P,T) := \left(S_T(T) + S_P(t,P) + S_x\right) + S_B(t)$$

$$S_{L2}(t,P,T) := \left(S_T(T) + S_P(t,P) + S_x\right) - S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline
$$S_{Lmax}(t,P,T) := \max\left(\left|S_{L1}(t,P,T)\right|, \left|S_{L2}(t,P,T)\right|\right)$$

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := (S_{PU}(t,P) + S_x) + S_B(t)$

$S_{L4}(t,P) := (S_{PU}(t,P) + S_x) - S_B(t)$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max(|S_{L3}(t,P)|, |S_{L4}(t,P)|)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Longitudinal Stress Checking

$$Check_L(t,P,T) := \begin{array}{l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

$$Check_{LU}(t,P) := \begin{array}{l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline $S_{com1}(t,P,T) := |S_{L1}(t,P,T) - S_H(t,P)|$

$S_{com2}(t,P,T) := |S_{L2}(t,P,T) - S_H(t,P)|$

Maximum Combined Stress $S_{com\_max}(t,P,T) := \max(|S_{com1}(t,P,T)|, |S_{com2}(t,P,T)|)$

Allowable Stress $S_{com\_allow} := k \cdot SMYS$

Combined Stress Checking $Check_C(t,P,T) := \begin{array}{l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$

B-4 Min. Wall Thickness

Hoop Stress

$$t_{Hmin} := \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in restrained pipeline

$$t_{Lmin} := \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin})) \ge S_{Lallow} \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } S_{LUmax}(t - CA, P_D) \geq S_{LUallow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Combined Stress

$$t_{Cmin} := \left\| \begin{array}{l} t \leftarrow CA + 0.01\ mm \\ \text{while } \max\left(S_{com\_max}(t - CA, P_D, T_{dmax}), S_{com\_max}(t - CA, P_D, T_{dmin})\right) \geq S_{com\_allow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Min. Wall Thickness Checking

$$Check_{tmin} := \left\| \begin{array}{l} \text{if } \max(t_{Hmin}, t_{Lmin}, t_{LUmin}, t_{Cmin}) \leq t_{sel} \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right.$$

B-5 Seismic Wave Propagation Effect

Maximum Ground Strain

$$\varepsilon_g := \frac{V_{max}}{\alpha_\varepsilon \cdot cc} \qquad \varepsilon_g = 0.016\%$$

$$D_{min} := D - (0.0075 \cdot D) = 0.217\ m$$

$$D' := \frac{D}{1 - \left(\frac{3}{D} \cdot (D - D_{min})\right)} = 0.224\ m$$

$$\varepsilon_{com} := 0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right) = 0.029 \qquad \varepsilon_{com} = 2.943\%$$

Strain Limit

$$\varepsilon_c := min\left(0.75 \cdot \left(0.50 \cdot \left(\frac{t_{sel}}{D'}\right)\right) - 0.0025 + \left(3000 \cdot \left(\frac{P_D \cdot D}{2\ E \cdot t_{sel}}\right)^2\right), 0.5\%\right) = 0.005 \qquad \varepsilon_c = 0.5\%$$

Strain Checking

$$Check_\varepsilon := \left\| \begin{array}{l} \text{if } \varepsilon_g \leq \varepsilon_c \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right. \qquad Check_\varepsilon = \text{“Pass”}$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress	$S_H(t_{sel}-CA, P_D) = 30.802\ MPa$
Allowable Hoop Stress	$S_{Hallow}(DF_D) = 259.2\ MPa$
Hoop Stress Checking	$Check_H(t_{sel}-CA, P_D, DF_D) = \text{“Pass”}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline	$S_{Lmax}(t_{sel}-CA, P_D, T_{dmax}) = 292.044\ MPa$
	$S_{Lmax}(t_{sel}-CA, P_D, T_{dmin}) = 253.853\ MPa$
Allowable Longitudinal Stress in restrained pipeline	$S_{Lallow} = 324\ MPa$
Longitudinal Stress Checking in restrained pipeline	$Check_L(t_{sel}-CA, P_D, T_{dmax}) = \text{“Pass”}$
	$Check_L(t_{sel}-CA, P_D, T_{dmin}) = \text{“Pass”}$
Actual Net Longitudinal Stress in unrestrained pipeline	$S_{LUmax}(t_{sel}-CA, P_D) = 203.583\ MPa$
Allowable Longitudinal Stress in unrestrained pipeline	$S_{LUallow} = 270\ MPa$
Longitudinal Stress Checking in unrestrained pipeline	$Check_{LU}(t_{sel}-CA, P_D) = \text{“Pass”}$

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com\_max}(t_{sel}-CA, P_D, T_{dmax}) = 322.846\ MPa$
	$S_{com\_max}(t_{sel}-CA, P_D, T_{dmin}) = 223.051\ MPa$
Allowable Combined Stress	$S_{com\_allow} = 324\ MPa$
Combined Stress Checking	$Check_C(t_{sel}-CA, P_D, T_{dmax}) = \text{“Pass”}$
	$Check_C(t_{sel}-CA, P_D, T_{dmin}) = \text{“Pass”}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 5.06\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 5.02\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 6.26\ mm$

Min. Combined Stress Wall Thickness $t_{Cmin} = 18.3\ mm$

Selected Pipeline Wall Thickness $t_{sel} = 19.05\ mm$

Min. Wall Thickness Checking $Check_{tmin} = \text{“Pass”}$

APPENDIX F: VENDOR'S UNIT COSTS FOR LINEPIPES

Re: ASK miniFEED - Line Pipe Budgetary

Xia Jun <xia.jun@misteel.com.sg>
To Adikarn Tongsa-ad; Jakkrit Kraikitikan
Cc Chaiwit Junyanuntajit; Thitirat Sorasitmontri; MITA. Thailand

Tue 12/27

Follow up. Start by Wednesday, January 4, 2023. Due by Wednesday, January 4, 2023.

From: Adikarn Tongsa-ad <adikarn.b@mitt.co.th>
Sent: Monday, December 26, 2022 18:17
To: Jakkrit Kraikitikan <jakkrit.kraikitikan@technipenergies.com>
Cc: Chaiwit Junyanuntajit <chaiwit.junyanuntajit@technipenergies.com>; Thitirat Sorasitmontri <thitirat.sorasitmontri@technipenergies.com>; MITA. Thailand <MITA.Thailand@misteel.com.sg>
Subject: RE: ASK miniFEED - Line Pipe Budgetary

Dear Khun Jakkrit,

This is year end. Our Singapore office is already closed, and Japan Office will be closed soon.
Could you please allow us to reply after new year.

For quick budgetary prices, SMLS pipe is 2,000 USD/Mton. Price gap for each grade is 20 USD/Mton.

Regards,
Adikarn T.
Tel: +66 2617 7633-6
Mobile: +668 1552 3397

APPENDIX G: MAXIMUM ALLOWABLE TANDEM LOAD CALCULATIONS

Technip Energies

Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

/1/ Steel Pipelines Crossing Railroads and Highways, API RP 1102
/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	1	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Open-Cut Crossing, WT = 7.04 mm, Cover Depth of 2 m, Case: Max Operating Temp (44.1˚ C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$	
Operating Temperature	$T_{ope} := 44.1\ °C$	
Installation Temperature	$T_{ins} := 23.3\ °C$	
Design Factor	$F_d := 0.72$	
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$	
Longitudinal Joint Factor	$E_w := 1$	(API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$	

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$
Corrosion Allowance	$CA := 3\ mm$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Poisson's Ratio	$\upsilon := 0.3$
Young Modulus	$E_s := 207\ GPa$
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \dfrac{1}{\Delta °C}$
Corrosion Depth	$T_{corr} := 100\%$
Anti Corrosion Coating Thickness	$t_{corr} := 3.5\ mm$
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 2\ m$	
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"	
Pavement Selection	$Pavement := NP$	
Bored Diameter of Crossing	$B_d := D + 0\ in$	(Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \dfrac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 178\ kN$

$P_{allow} := \dfrac{P_t}{g} = 18.151\ tonne$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.3$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} 1.5 & \text{if } H_b \le 5\ ft \\ -\left(\dfrac{\dfrac{H_b}{ft} - 56}{34}\right) & \text{if } 5\ ft < H_b \le 22\ ft \\ 1 & \text{else} \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{"Single Axle"} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \wedge Pavement = NP \\ \text{"Tandem Axles"} & \text{else} \end{cases}$$

Applied Design Surface Pressure

(/1/, Equation 2)

$$w := \begin{cases} \dfrac{P_s}{A_w} & \text{if } axle = \text{"Single Axle"} \\ \dfrac{P_t}{A_w} & \text{else} \end{cases}$$

Highway Pavement Type Factor

(/1/, Table 2)

$$R_{f1} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \land axle = \text{"Tandem Axles"} \\ 1.2 & \text{if } Pavement = NP \land axle = \text{"Single Axle"} \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_{f2} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_f := \begin{cases} R_{f1} & \text{if } H_b < 1.2\ m \land D \le 12.75\ in \\ R_{f2} & \text{else} \end{cases}$$

Highway Axle Configuration Factor

(/1/, Table 2)

$$L_{f1} := \begin{cases} 1 & \text{if } axle = \text{"Tandem Axles"} \\ 0.75 & \text{if } Pavement = FP \land axle = \text{"Single Axle"} \\ 0.8 & \text{if } Pavement = NP \land axle = \text{"Single Axle"} \\ 0.9 & \text{if } Pavement = RP \land axle = \text{"Single Axle"} \end{cases}$$

$$L_{f2} := \begin{cases} 1 & \text{if } axle = \text{"Tandem Axles"} \\ 0.65 & \text{if } axle = \text{"Single Axle"} \end{cases}$$

$$L_f := \begin{cases} \text{if } H_b < 1.2\ m \land D \le 12.75\ in \\ \quad L_{f1} \\ \text{else} \\ \quad L_{f2} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress (/1/, Figure 14) $K_{Hh} := 12.5$

Highway Geometry Factor for Cyclic Circumferential Stress (/1/, Figure 15) $G_{Hh} := 1$

Highway Stiffness Factor for Cycle Longitudinal Stress (/1/, Figure 16) $K_{Lh} := 11.50$

Highway Geometry Factor for Cyclic Longitudinal Stress (/1/, Figure 17) $G_{Lh} := 1.2$

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld (/1/, Table 3) $S_{FL} := 12000\ psi$ (X65 SAWL or ERW)

Fatigue Endurance Limit of Girth Weld (/1/, Table 3) $S_{FG} := 12000\ psi$

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress $S_{Hi\_Barlow} := \dfrac{P_d \cdot D}{2\ t}$

Allowable Stress $S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$

Barlow Stress Checking

$$CHECK_1 := \begin{cases} \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \quad \text{"Pass"} \\ \text{else} \\ \quad \text{"Fail"} \end{cases}$$

C-2 Effective Stress

Circumferential Stress due to Earth Load (/1/, Section 4.7.2.1, Eq.1) $S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$

Cyclic Circumferential Stress (/1/, Section 4.7.2.2.4.1, Eq.5) $\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$

Cyclic Longitudinal Stress (/1/, Section 4.7.2.2.4.2, Eq.6) $\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$

Circumferential Stress due to Internal Pressure
(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D-t)}{2\ t}$$

Maximum Circumferential Stress
(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress
(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot \left(T_{ope} - T_{ins}\right) + \upsilon \cdot \left(S_{He} + S_{Hi}\right)$$

Maximum Radial Stress
(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress
(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left(\left(S_1 - S_2\right)^2 + \left(S_2 - S_3\right)^2 + \left(S_3 - S_1\right)^2\right)}$$

Allowable Stress for Principal Stress
(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking
(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{|l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld
(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking
(/1/, Equation 17)

$$CHECK_3 := \begin{array}{|l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld
(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking
(/1/, Equation 20)

$$CHECK_4 := \begin{array}{|l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress $S_{Hi\_Barlow} = 132.041\ MPa$

Allowable Stress $S_{allow\_Barlow} = 324\ MPa$

Barlow Stress Checking $CHECK_1 = \text{“Pass”}$

D-2 Effective Combined Stress Checking

Effective Combined Stress $S_{eff} = 161.847\ MPa$

Allowable Stress for Principal Stress $S_{allow\_Principle} = 405\ MPa$

Effective Combined Stress Checking $CHECK_2 = \text{“Pass”}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress $\Delta S_{Lh} = 42.247\ MPa$

Design Fatigue Endurance Limit of Girth Weld $DS_{FG} = 59.571\ MPa$

Girth Weld Fatigue Checking $CHECK_3 = \text{“Pass”}$

Cyclic Circumferential Stress $\Delta S_{Hh} = 38.267\ MPa$

Design Fatigue Endurance Limit of Longitudinal Weld $DS_{FL} = 59.571\ MPa$

Longitudinal Weld Fatigue Checking $CHECK_4 = \text{“Pass”}$

D-4 Maximum Tandem Load

Design Wheel Load for Tandem Axle $P_t = 178\ kN$

Design Wheel Weight $P_{allow} := \frac{P_t}{g} = 18.151\ tonne$

Maximum Allowable Tandem Load $W_{allow} := 4 \cdot P_{allow}$

$W_{allow} = 72.604\ tonne$

APPENDIX H: VACUUM DRYING CASE CALCULATIONS

Technip Energies

Pipeline Engineering Department

ONSHORE PIPELINE WALL THICKNESS VERIFICATION

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

PIPELINE NAME: APL02

MAIN FEATURES

This spreadsheet performs the pipeline wall thickness verification. The following reference is used in this calculation sheet.

/1/ American Society of Mechanical Engineers, Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

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
3/6/2013	0	For Implementation	The spreadsheet was updated and validated by Soratus P.	SWN
1/2/2014	1	For Implementation	The spreadsheet was updated and validated by Thamonwan K.	TKI
8/4/2021	2	For Implementation	The spreedsheet was converted to MathCAD Prime by Wut T.	WUT

Pipeline Case: Normal WT= 7.04 mm, Vacuum Drying Case

A. Input Data

Design Pressure	$P_D := 1.4\ bar$	Vacuum Drying Cases
Pipe Diameter	$D := 8.625\ in$	
Specified Minimum Yield Strength	$SMYS := 450\ MPa$	
Design Factor for Hoop Stress	$DF_D := 0.72$	
Longitudinal Joint Factor	$EF := 1$	(API Spec 5L SAWL or ERW)
Temperature Derating Factor	$TF := 1$	
Corrosion Allowance	$CA := 3\ mm$	
Selected Pipeline Wall Thickness	$t_{sel} := 7.04\ mm$	
Young's Modulus	$E := 207\ GPa$	
Coefficient of Thermal Expansion	$\alpha := 11.7 \cdot 10^{-6} \cdot \frac{1}{\Delta°C}$	
Minimum Air Temperature	$T_{amin} := 23.3\ °C$	
Maximum Design Temperature	$T_{dmax} := 70\ °C$	
Minimum Design Temperature	$T_{dmin} := 0\ °C$	
Radius of Curvature	$R := 550\ D$	
Longitudinal Stress due to Other Axial Loading	$S_x := 0\ Pa$	
K Factor for Combined Stress	$k := 0.9$	

B. Calculation

B-1 Hoop Stress

Hoop Stress
$$S_H(t,P) := \begin{cases} \text{if } \dfrac{D}{t} < 20 \\ \quad \dfrac{P \cdot (D-t)}{2 \cdot t} \\ \text{else} \\ \quad \dfrac{P \cdot D}{2 \cdot t} \end{cases}$$

Allowable Hoop Stress
$$S_{Hallow}(DF) := SMYS \cdot EF \cdot DF$$

Hoop Stress Checking
$$Check_H(t,P,DF) := \begin{cases} \text{if } S_H(t,P) \le S_{Hallow}(DF) \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{cases}$$

B-2 Longitudinal Stress

Longitudinal Stress due to internal pressure in restrained pipeline

$$S_P(t,P) := -0.3 \cdot S_H(t,P)$$

Longitudinal Stress due to internal pressure in unrestrained pipeline

$$S_{PU}(t,P) := -0.5 \cdot S_H(t,P)$$

Longitudinal Stress due to thermal expansion in restrained pipeline

$$S_T(T) := E \cdot \alpha \cdot (T_{amin} - T)$$

Longitudinal Stress due to bending moment

Pipeline Moment of Inertia
$$I(t) := \frac{\pi}{64} \cdot \left(D^4 - (D - 2\,t)^4\right)$$

Pipeline Sectional Elastic Modulus
$$Z(t) := \frac{2 \cdot I(t)}{D}$$

Bending Moment
$$M(t) := \frac{E \cdot I(t)}{R}$$

Longitudinal Stress due to bending moment
$$S_B(t) := \frac{M(t)}{Z(t)}$$

Net Longitudinal Stress in restrained pipeline
$$S_{L1}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) + S_B(t)$$

$$S_{L2}(t,P,T) := (S_T(T) + S_P(t,P) + S_x) - S_B(t)$$

Maximum Longitudinal Stress in restrained pipeline
$$S_{Lmax}(t,P,T) := \max\left(\left|S_{L1}(t,P,T)\right|, \left|S_{L2}(t,P,T)\right|\right)$$

Allowable Longitudinal Stress in restrained pipeline $S_{Lallow} := 0.9 \cdot SMYS$

Net Longitudinal Stress in unrestrained pipeline $S_{L3}(t,P) := (S_{PU}(t,P) + S_x) + S_B(t)$

$S_{L4}(t,P) := (S_{PU}(t,P) + S_x) - S_B(t)$

Maximum Longitudinal Stress in unrestrained pipeline $S_{LUmax}(t,P) := \max\left(\left|S_{L3}(t,P)\right|, \left|S_{L4}(t,P)\right|\right)$

Allowable Longitudinal Stress in unrestrained pipeline $S_{LUallow} := 0.75 \cdot SMYS$

Combined Stress Checking

$$Check_L(t,P,T) := \begin{array}{|l} \text{if } S_{Lmax}(t,P,T) \le S_{Lallow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

$$Check_{LU}(t,P) := \begin{array}{|l} \text{if } S_{LUmax}(t,P) \le S_{LUallow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

B-3 Combined Stress

Combined Stress for Restrained Pipeline $S_{com1}(t,P,T) := \left|S_{L1}(t,P,T) - S_H(t,P)\right|$

$S_{com2}(t,P,T) := \left|S_{L2}(t,P,T) - S_H(t,P)\right|$

Maximum Combined Stress $S_{com\_max}(t,P,T) := \max\left(\left|S_{com1}(t,P,T)\right|, \left|S_{com2}(t,P,T)\right|\right)$

Allowable Stress $S_{com\_allow} := k \cdot SMYS$

Combined Stress Checking

$$Check_C(t,P,T) := \begin{array}{|l} \text{if } S_{com\_max}(t,P,T) \le S_{com\_allow} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

B-4 Min. Wall Thickness

Hoop Stress

$$t_{Hmin} := \begin{array}{|l} t \leftarrow 6.01\ mm \\ \text{while } S_H(t - CA, P_D) \ge S_{Hallow}(DF_D) \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in restrained pipeline

$$t_{Lmin} := \begin{array}{|l} t \leftarrow 6.01\ mm \\ \text{while } \max\left(S_{Lmax}(t - CA, P_D, T_{dmax}), S_{Lmax}(t - CA, P_D, T_{dmin})\right) \ge S_{Lallow} \\ \quad t \leftarrow t + 0.01\ mm \\ t \end{array}$$

Longitudinal Stress in unrestrained pipeline

$$t_{LUmin} := \left\| \begin{array}{l} t \leftarrow 6.01\ mm \\ \text{while } S_{LUmax}(t - CA, P_D) \geq S_{LUallow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Combined Stress

$$t_{Cmin} := \left\| \begin{array}{l} t \leftarrow 6.01\ mm \\ \text{while } \max\left(S_{com\_max}(t - CA, P_D, T_{dmax}), S_{com\_max}(t - CA, P_D, T_{dmin})\right) \geq S_{com\_allow} \\ \quad \| \ t \leftarrow t + 0.01\ mm \\ t \end{array} \right.$$

Min. Wall Thickness Checking

$$Check_{tmin} := \left\| \begin{array}{l} \text{if } \max\left(t_{Hmin}, t_{Lmin}, t_{LUmin}, t_{Cmin}\right) \leq t_{sel} \\ \quad \| \ \text{“Pass”} \\ \text{else} \\ \quad \| \ \text{“Fail”} \end{array} \right.$$

C. Summary of Results

C-1 Hoop Stress Checking

Actual Hoop Stress	$S_H(t_{sel}-CA, P_D) = 3.796\ MPa$
Allowable Hoop Stress	$S_{Hallow}(DF_D) = 324\ MPa$
Hoop Stress Checking	$Check_H(t_{sel}-CA, P_D, DF_D) = \text{“Pass”}$

C-2 Net Longitudinal Stress Checking

Actual Net Longitudinal Stress in restrained pipeline	$S_{Lmax}(t_{sel}-CA, P_D, T_{dmax}) = 302.423\ MPa$
	$S_{Lmax}(t_{sel}-CA, P_D, T_{dmin}) = 243.473\ MPa$
Allowable Longitudinal Stress in restrained pipeline	$S_{Lallow} = 405\ MPa$
Longitudinal Stress Checking in restrained pipeline	$Check_L(t_{sel}-CA, P_D, T_{dmax}) = \text{“Pass”}$
	$Check_L(t_{sel}-CA, P_D, T_{dmin}) = \text{“Pass”}$
Actual Net Longitudinal Stress in unrestrained pipeline	$S_{LUmax}(t_{sel}-CA, P_D) = 190.08\ MPa$
Allowable Longitudinal Stress in unrestrained pipeline	$S_{LUallow} = 337.5\ MPa$
Longitudinal Stress Checking in unrestrained pipeline	$Check_{LU}(t_{sel}-CA, P_D) = \text{“Pass”}$

C-3 Combined Stress Checking

Actual Combined Stress	$S_{com\_max}(t_{sel}-CA, P_D, T_{dmax}) = 306.219\ MPa$
	$S_{com\_max}(t_{sel}-CA, P_D, T_{dmin}) = 239.677\ MPa$
Allowable Combined Stress	$S_{com\_allow} = 405\ MPa$
Combined Stress Checking	$Check_C(t_{sel}-CA, P_D, T_{dmax}) = \text{“Pass”}$
	$Check_C(t_{sel}-CA, P_D, T_{dmin}) = \text{“Pass”}$

C-4 Min. Wall Thickness Checking

Min. Hoop Stress Wall Thickness	$t_{Hmin} = 6.01\ mm$
Min. Longitudinal Stress Wall Thickness in restrained pipeline	$t_{Lmin} = 6.01\ mm$
Min. Longitudinal Stress Wall Thickness in unrestrained pipeline	$t_{LUmin} = 6.01\ mm$
Min. Combined Stress Wall Thickness	$t_{Cmin} = 6.01\ mm$
Selected Pipeline Wall Thickness	$t_{sel} = 7.04\ mm$
Min. Wall Thickness Checking	$Check_{tmin} = \text{"Pass"}$

APPENDIX I: SENSITIVITY CHECK FOR OPEN-CUT ROAD CROSSINGS

Technip Energies
Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

/1/ Steel Pipelines Crossing Railroads and Highways, API RP 1102
/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	0	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Open-Cut Crossing, WT = 7.04 mm, Cover Depth of 1.2 m, Case: Max Operating Temp (44.1° C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$
Operating Temperature	$T_{ope} := 44.1\ °C$
Installation Temperature	$T_{ins} := 23.3\ °C$
Design Factor	$F_d := 0.72$
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$
Longitudinal Joint Factor	$E_w := 1$ (API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$
Corrosion Allowance	$CA := 3\ mm$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Poisson's Ratio	$\upsilon := 0.3$
Young Modulus	$E_s := 207\ GPa$
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \frac{1}{\Delta °C}$
Corrosion Depth	$T_{corr} := 100\%$
Anti Corrosion Coating Thickness	$t_{corr} := 3.5\ mm$
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 1.2\ m$
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"
Pavement Selection	$Pavement := NP$
Bored Diameter of Crossing	$B_d := D + 0\ in$ (Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \frac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 39.24\ kN$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.15$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} 1.5 & \text{if } H_b \le 5\ ft \\ 1.5 - \left(\dfrac{\dfrac{H_b}{ft} - 56}{34}\right) & \text{if } 5\ ft < H_b \le 22\ ft \\ 1 & \text{else} \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{"Single Axle"} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \wedge Pavement = NP \\ \text{"Tandem Axles"} & \text{else} \end{cases}$$

TEN TECHNIP ENERGIES

Applied Design Surface Pressure
(/1/, Equation 2)

$$w := \begin{cases} \dfrac{P_s}{A_w} & \text{if } axle = \text{"Single Axle"} \\ \dfrac{P_t}{A_w} & \text{else} \end{cases}$$

Highway Pavement Type Factor
(/1/, Table 2)

$$R_{f1} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \land axle = \text{"Tandem Axles"} \\ 1.2 & \text{if } Pavement = NP \land axle = \text{"Single Axle"} \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_{f2} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_f := \begin{cases} R_{f1} & \text{if } H_b < 1.2\ m \land D \le 12.75\ in \\ R_{f2} & \text{else} \end{cases}$$

Highway Axle Configuration Factor
(/1/, Table 2)

$$L_{f1} := \begin{cases} 1 & \text{if } axle = \text{"Tandem Axles"} \\ 0.75 & \text{if } Pavement = FP \land axle = \text{"Single Axle"} \\ 0.8 & \text{if } Pavement = NP \land axle = \text{"Single Axle"} \\ 0.9 & \text{if } Pavement = RP \land axle = \text{"Single Axle"} \end{cases}$$

$$L_{f2} := \begin{cases} 1 & \text{if } axle = \text{"Tandem Axles"} \\ 0.65 & \text{if } axle = \text{"Single Axle"} \end{cases}$$

TEN TECHNIP ENERGIES

$$L_f := \begin{cases} L_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ L_{f2} & \text{else} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress $K_{Hh} := 12.5$

(/1/, Figure 14)

Highway Geometry Factor for Cyclic Circumferential Stress $G_{Hh} := 1.4$

(/1/, Figure 15)

Highway Stiffness Factor for Cycle Longitudinal Stress $K_{Lh} := 11.50$

(/1/, Figure 16)

Highway Geometry Factor for Cyclic Longitudinal Stress $G_{Lh} := 1.35$

(/1/, Figure 17)

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld $S_{FL} := 12000\ psi$ (X65 SAWL or ERW)

(/1/, Table 3)

Fatigue Endurance Limit of Girth Weld $S_{FG} := 12000\ psi$

(/1/, Table 3)

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress $S_{Hi\_Barlow} := \dfrac{P_d \cdot D}{2\ t}$

Allowable Stress $S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$

Barlow Stress Checking

$$CHECK_1 := \begin{cases} \text{"Pass"} & \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \text{"Fail"} & \text{else} \end{cases}$$

C-2 Effective Stress

Circumferential Stress due to Earth Load $S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$

(/1/, Section 4.7.2.1, Eq.1)

Cyclic Circumferential Stress $\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$

(/1/, Section 4.7.2.2.4.1, Eq.5)

Cyclic Longitudinal Stress $\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$

(/1/, Section 4.7.2.2.4.2, Eq.6)

Circumferential Stress due to Internal Pressure

(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D - t)}{2\ t}$$

Maximum Circumferential Stress

(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress

(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot (T_{ope} - T_{ins}) + \upsilon \cdot (S_{He} + S_{Hi})$$

Maximum Radial Stress

(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress

(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 \right)}$$

Allowable Stress for Principal Stress

(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking

(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld

(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking

(/1/, Equation 17)

$$CHECK_3 := \begin{array}{l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld

(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking

(/1/, Equation 20)

$$CHECK_4 := \begin{array}{l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress $S_{Hi\_Barlow} = 132.041\ MPa$

Allowable Stress $S_{allow\_Barlow} = 324\ MPa$

Barlow Stress Checking $CHECK_1 = \text{“Pass”}$

D-2 Effective Combined Stress Checking

Effective Combined Stress $S_{eff} = 145.609\ MPa$

Allowable Stress for Principal Stress $S_{allow\_Principle} = 405\ MPa$

Effective Combined Stress Checking $CHECK_2 = \text{“Pass”}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress $\Delta S_{Lh} = 7.206\ MPa$

Design Fatigue Endurance Limit of Girth Weld $DS_{FG} = 59.571\ MPa$

Girth Weld Fatigue Checking $CHECK_3 = \text{“Pass”}$

Cyclic Circumferential Stress $\Delta S_{Hh} = 8.122\ MPa$

Design Fatigue Endurance Limit of Longitudinal Weld $DS_{FL} = 59.571\ MPa$

Longitudinal Weld Fatigue Checking $CHECK_4 = \text{“Pass”}$

Technip Energies
Pipeline Engineering Department

ROAD CROSSING CALCULATION

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

PIPELINE NAME: APL02

MAIN FEATURES

The objective of this spreadsheet is to check whether uncased pipeline properties are able to resist the applied external load due to earth, live load and internal pressure load. This calculation is performed based on API RP 1102, Steel Pipelines Crossing Railroads and Highways. All the referred data in this calculation are taken from API RP 1102.

The following references are used in this calculation sheet.

/1/ Steel Pipelines Crossing Railroads and Highways, API RP 1102
/2/ Pipeline Transportation Systems for Liquids and Slurries, ASME B31.4-2019.

The main outputs are calculated stresses and also compared with allowable limits.

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
6-Jul-14	0	For Implementation	Initial issue of the spreadsheet by Soratus P.	Soratus P.
8-Apr-21	0	For Implementation	The spreadsheet was converted to MathCAD Prime by Wut T.	Wut T.

Pipeline Case: Open-Cut Crossing, WT = 7.04 mm, Cover Depth of 2.5 m, Case: Max Operating Temp (44.1° C)

A. Input Parameters

A-1 Design and Operating Parameters

Design Pressure	$P_d := 48.7\ bar$	
Operating Temperature	$T_{ope} := 44.1\ °C$	
Installation Temperature	$T_{ins} := 23.3\ °C$	
Design Factor	$F_d := 0.72$	
Equivalent Stress Factor (Von Mises)	$F_e := 0.9$	
Longitudinal Joint Factor	$E_w := 1$	(API Spec 5L SAWL or ERW)
Temperature Derating Factor	$T_{df} := 1$	

A-2 Pipeline Mechanical Properties

Pipe Outside Diameter	$D := 8.625\ in$
Pipeline Selected Wall Thickness	$T_W := 7.04\ mm$
Corrosion Allowance	$CA := 3\ mm$
Specified Minimum Yield Strength	$SMYS := 450\ MPa$
Poisson's Ratio	$\upsilon := 0.3$
Young Modulus	$E_s := 207\ GPa$
Thermal Expansion Coefficient	$\alpha_T := 1.17 \cdot 10^{-5} \cdot \frac{1}{\Delta°C}$
Corrosion Depth	$T_{corr} := 100\%$
Anti Corrosion Coating Thickness	$t_{corr} := 3.5\ mm$
Remaining Pipeline Wall Thickness	$t := T_W - T_{corr} \cdot CA$
Total Pipe Outside Diameter	$D_t := D + 2 \cdot t_{corr}$

A-3 Installation and Site Characteristics

Burial Depth to the top of pipe @ road	$H_b := 2.5\ m$	
Pavement Type	$FP :=$ "Flexible Pavement" $NP :=$ "No Pavement" $RP :=$ "Rigid Pavement"	
Pavement Selection	$Pavement := NP$	
Bored Diameter of Crossing	$B_d := D + 0\ in$	(Boring plus 2 in, Open cut plus 0 in)

Modulus of Soil Reaction
(/1/, Table A-1)

$E_1 := 1.4\ MPa$

Resilient Modulus of Soil
(/1/, Table A-2)

$E_r := 34\ MPa$

Unit Weight of Soil

$\gamma_{soil} := 18.9\ \frac{kN}{m^3}$

Design Wheel Load for Single Axle

$P_s := 49.05\ kN$

Design Wheel Load for Tandem Axle

$P_t := 39.24\ kN$

Contact Area of Wheel

$A_w := 0.093\ m^2$

B. Input Factors from API RP 1102

B-1 Circumferential Stress due to Earth Load

Stiffness factor for circumferential stress from earth load
(/1/, Figure 3)

$K_{He} := 950$

Burial factor for earth load
(/1/, Figure 4)

$B_e := 1.35$

Excavation factor for circumferential stress from earth load
(/1/, Figure 5)

$E_e := 0.83$

B-2 Impact Factor and Applied Design Surface Pressure

Impact Factor for Highways
(/1/, Figure 7)

$$F_i := \begin{cases} \text{if } H_b \le 5\ ft \\ \quad 1.5 \\ \text{if } 5\ ft < H_b \le 22\ ft \\ \quad -\left(\dfrac{\dfrac{H_b}{ft} - 56}{34}\right) \\ \text{else} \\ \quad 1 \end{cases}$$

Critical Axle Configuration
(/1/, Table 1)

$$axle := \begin{cases} \text{if } H_b < 1.2\ m \land D \le 12.75\ in \land Pavement = NP \\ \quad \text{“Single Axle”} \\ \text{else} \\ \quad \text{“Tandem Axles”} \end{cases}$$

Applied Design Surface Pressure

(/1/, Equation 2)

$$w := \begin{cases} \dfrac{P_s}{A_w} & \text{if } axle = \text{“Single Axle”} \\ \dfrac{P_t}{A_w} & \text{else} \end{cases}$$

Highway Pavement Type Factor

(/1/, Table 2)

$$R_{f1} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \land axle = \text{“Tandem Axles”} \\ 1.2 & \text{if } Pavement = NP \land axle = \text{“Single Axle”} \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_{f2} := \begin{cases} 1 & \text{if } Pavement = FP \\ 1.1 & \text{if } Pavement = NP \\ 0.9 & \text{if } Pavement = RP \end{cases}$$

$$R_f := \begin{cases} R_{f1} & \text{if } H_b < 1.2\ m \land D \le 12.75\ in \\ R_{f2} & \text{else} \end{cases}$$

Highway Axle Configuration Factor

(/1/, Table 2)

$$L_{f1} := \begin{cases} 1 & \text{if } axle = \text{“Tandem Axles”} \\ 0.75 & \text{if } Pavement = FP \land axle = \text{“Single Axle”} \\ 0.8 & \text{if } Pavement = NP \land axle = \text{“Single Axle”} \\ 0.9 & \text{if } Pavement = RP \land axle = \text{“Single Axle”} \end{cases}$$

$$L_{f2} := \begin{cases} 1 & \text{if } axle = \text{“Tandem Axles”} \\ 0.65 & \text{if } axle = \text{“Single Axle”} \end{cases}$$

$$L_f := \begin{cases} L_{f1} & \text{if } H_b < 1.2\ m \wedge D \le 12.75\ in \\ L_{f2} & \text{else} \end{cases}$$

B-3 Highway Stiffness and Geometry Factors

Highway Stiffness Factor for Cycle Circumferential Stress $K_{Hh} := 12.5$
(/1/, Figure 14)

Highway Geometry Factor for Cyclic Circumferential Stress $G_{Hh} := 0.85$
(/1/, Figure 15)

Highway Stiffness Factor for Cycle Longitudinal Stress $K_{Lh} := 11.50$
(/1/, Figure 16)

Highway Geometry Factor for Cyclic Longitudinal Stress $G_{Lh} := 1.1$
(/1/, Figure 17)

B-4 Fatigue Endurance Limits

Fatigue Endurance Limit of Longitudinal Weld $S_{FL} := 12000\ psi$ (X65 SAWL or ERW)
(/1/, Table 3)

Fatigue Endurance Limit of Girth Weld $S_{FG} := 12000\ psi$
(/1/, Table 3)

C. Stress Calculation

C-1 Barlow Stress

Barlow Stress $S_{Hi\_Barlow} := \frac{P_d \cdot D}{2\ t}$

Allowable Stress $S_{allow\_Barlow} := SMYS \cdot F_d \cdot E_w \cdot T_{df}$

Barlow Stress Checking

$$CHECK_1 := \begin{cases} \text{“Pass”} & \text{if } S_{Hi\_Barlow} \le S_{allow\_Barlow} \\ \text{“Fail”} & \text{else} \end{cases}$$

C-2 Effective Stress

Circumferential Stress due to Earth Load $S_{He} := K_{He} \cdot B_e \cdot E_e \cdot \gamma_{soil} \cdot D_t$
(/1/, Section 4.7.2.1, Eq.1)

Cyclic Circumferential Stress $\Delta S_{Hh} := K_{Hh} \cdot G_{Hh} \cdot R_f \cdot L_f \cdot F_i \cdot w$
(/1/, Section 4.7.2.2.4.1, Eq.5)

Cyclic Longitudinal Stress $\Delta S_{Lh} := K_{Lh} \cdot G_{Lh} \cdot R_f \cdot L_f \cdot F_i \cdot w$
(/1/, Section 4.7.2.2.4.2, Eq.6)

Circumferential Stress due to Internal Pressure
(/1/, Section 4.7.3, Eq.7)

$$S_{Hi} := \frac{P_d \cdot (D - t)}{2\ t}$$

Maximum Circumferential Stress
(/1/, Section 4.8.1.2, Eq.9)

$$S_1 := S_{He} + \Delta S_{Hh} + S_{Hi}$$

Maximum Longitudinal Stress
(/1/, Section 4.8.1.2, Eq.10)

$$S_2 := \Delta S_{Lh} - E_s \cdot \alpha_T \cdot (T_{ope} - T_{ins}) + \upsilon \cdot (S_{He} + S_{Hi})$$

Maximum Radial Stress
(/1/, Section 4.8.1.2, Eq.11)

$$S_3 := -P_d$$

Effective Combined Stress
(/1/, Section 4.8.1.3, Eq.12)

$$S_{eff} := \sqrt{0.5 \cdot \left((S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2 \right)}$$

Allowable Stress for Principal Stress
(/1/, Section 4.8.1.3, Eq.13)

$$S_{allow\_Principle} := SMYS \cdot F_e$$

Effective Stress Checking
(/1/, Section 4.8.1.3, Eq.13)

$$CHECK_2 := \begin{array}{l} \text{if } S_{eff} \le S_{allow\_Principle} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

C-3 Fatigue

Design Fatigue Endurance Limit of Girth Weld
(/1/, Equation 17)

$$DS_{FG} := S_{FG} \cdot F_d$$

Girth Weld Fatigue Checking
(/1/, Equation 17)

$$CHECK_3 := \begin{array}{l} \text{if } \Delta S_{Lh} \le DS_{FG} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

Design Fatigue Endurance Limit of Longitudinal Weld
(/1/, Equation 20)

$$DS_{FL} := S_{FL} \cdot F_d$$

Longitudinal Weld Fatigue Checking
(/1/, Equation 20)

$$CHECK_4 := \begin{array}{l} \text{if } \Delta S_{Hh} \le DS_{FL} \\ \quad \text{“Pass”} \\ \text{else} \\ \quad \text{“Fail”} \end{array}$$

D. Summary of Results

D-1 Barlow Stress Checking

Barlow Stress $S_{Hi\_Barlow} = 132.041\ MPa$

Allowable Stress $S_{allow\_Barlow} = 324\ MPa$

Barlow Stress Checking $CHECK_1 = \text{“Pass”}$

D-2 Effective Combined Stress Checking

Effective Combined Stress $S_{eff} = 144.483\ MPa$

Allowable Stress for Principal Stress $S_{allow\_Principle} = 405\ MPa$

Effective Combined Stress Checking $CHECK_2 = \text{“Pass”}$

D-3 Fatigue Checking

Cyclic Longitudinal Stress $\Delta S_{Lh} = 8.254\ MPa$

Design Fatigue Endurance Limit of Girth Weld $DS_{FG} = 59.571\ MPa$

Girth Weld Fatigue Checking $CHECK_3 = \text{“Pass”}$

Cyclic Circumferential Stress $\Delta S_{Hh} = 6.933\ MPa$

Design Fatigue Endurance Limit of Longitudinal Weld $DS_{FL} = 59.571\ MPa$

Longitudinal Weld Fatigue Checking $CHECK_4 = \text{“Pass”}$