DETAILED ENGINEERING ANALYSIS IN TRUNK PIPELINES

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Master of Technology

(Pipeline Engineering)

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ABSTRACT

Design is the first and foremost important part of any pipeline project. The design of pipelines is normally done in three stages, the conceptual design, preliminary engineering and detailed engineering. The detailed engineering phase is as the name suggests the development of the design to a point where the technical contribution for all purchases and construction can be defined in sufficient detail. The main objectives of detail engineering include the selection of wall thickness, confirmation of code requirements for strength and stability, confirmation of design or perform additional design after the basic engineering. The Detailed Engineering can be measured as one of the most important part of any cross-country pipeline project. But there are many actions which take place prior to detail engineering which play a vital role in getting to the detailed Engineering stage.

This project is concerned with the detailed engineering stage of a pipeline project in Dubai. It mainly emphases on the fundamentals of pipe wall thickness calculation and stress verification, highway & railroad crossing analysis, calculation for anchor force & its analysis, anti-buoyancy calculation of pipeline and review and confirmation of code requirements on various project specifications. It delivers a broad summary of the system approach of design for safe and efficient operation for entire life of pipeline system.

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INTRODUCTION

It is well recognized that the natural oil & gas resources in the worlds are gaining increasing importance as an energy source to help fuel world economic growth in the established and emerging economies alike. Pipelines have a distinct role in the development and production of oil and gas reserves as they provide the most reliable and most economical means of transportation compared to other options such as road transport, rail transport, etc. Add to this the growing need to provide major transportation infrastructure between producing regions and countries wishing to import product and future oil transmission systems, the requirement for new pipelines appears to be set for several years to come.

The design of these pipelines is therefore an important aspect to be considered in the oil and gas industry. L&T Gulf is one of the major companies in India which provide their services in design and detailed engineering of pipelines for various clients throughout the world. I got a chance to work on the live projects of the company. The project moves into the detailed design stage once the project bid is approved. During Detailed Design and Engineering, the FEED report is reviewed thoroughly and arising queries are resolved. Documents required for pipeline construction are prepared and sent to client for review and approval. If any changes are to be made, the documents are revised. In some situations, certain changes which have not been forecasted during FEED stage may be encountered. Such a situation may involve detailed discussions between the client and the contractors and may rise to the preparation of change orders. Even these factors have to be considered into account during Detailed Design and Engineering.

Stress analysis is the one of the important concept in the cross country pipelines. In this report, I mainly deal with the detailed engineering analysis in fundamentals of pipe wall thickness calculation and stress verification, highway & railroad crossing analysis, anchor force calculation, stability analysis through anti buoyancy calculation of pipeline. It provides a general overview of the system approach of design for safe and efficient operation for entire life of pipeline system.

LITERATURE REVIEW

API RP 1102, (Revised 2007), Steel Pipeline Crossings Railroads and Highways.

API stands for American Petroleum Institute. This standard gives key emphasis to the provisions of public safety. It covers the design, installation, inspection and testing required ensuring safe passages steel pipelines under railways and highways. The necessities of this practice are expressed to protect the system through which the pipeline, as well as provide adequate design for safe installation and operation of the pipeline. All the tables, figures and equation used for road crossing in my project are from this standard.

ASME B36.10, (Revised 2004), Welded and Seamless wrought steel pipe, American Society of Mechanical Engineers, New York.

ASME stands for American Society of Mechanical Engineers. This standard concentrates on the standardization of sizes of seamless and welded wrought steel pipe for large or small temperatures and pressures. This is used to determine the different thickness values possible for a given outside diameter. The initial thickness and the extra thickness added if necessary, all depends on the values in this standard.

Stress analysis methods for underground pipelines by Liang-Chuan Peng, Mechanical Engineer, AAA Technology & Specialities Co; Houston (Part 1 & Part 2).

In this paper Mr. Peng explains about the different kind of stresses which acting in a pipeline. Stress analysis in the above ground pipeline is quite different from that of underground pipeline. He also insists about the anchor force, virtual anchor length, lateral and longitudinal pipeline movement due to temperature & pressure effects.

API 1111, (Revised 2000), Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines.

From API 1111 the collapse pressure of pipe is verified and to ensure internal pressure is greater than the external collapse pressure.

E. W. McAllister, (2002), Pipeline rule of thumb handbook, Gulf Professional Publication.

From the pipeline rule of thumb, it is clearly explained the frictional force acting in a pipeline against the longitudinal movement of pipe and which is used to find virtual anchor length. A major factor in the stress analysis of buried pipelines is the movement that pipe undergoes in the presence of temperature and pressure differentials during its life.

Pipeline design basis & Contractual documents from L&T.

The different specifications and standards have been analyzed and the calculations are based on these specifications and standards. The result that has been calculated for this project is within the limits given by the standards.

Floating risk analysis of Submarine Pipelines by ZHANG Ya-jing & CHEN Han-bao, Tianjin Research Institute, China.

ZHANG Ya-jing & CHEN Han-bao insists that or a submarine pipeline systems, the different factors such as wave, tide and other hydrodynamic factors which affects the seabed and it simultaneously upsets the buoyancy of a pipeline systems.

ASME B31.4, (Revised 2012), Pipeline Transportation Systems for Liquid Hydrocarbons & Other Liquids.

To get an understanding of the codes & standards set for design of liquid pipelines. The wall thickness calculation and stress verifications are done from this standard. The different stresses and loads which affects in the operation of pipeline is stated here.

David A Willoughby, (2005), Horizontal Directional Drilling from McGraw-Hill.

David A Willoughby explains the different factors which affects the horizontal directional drilling & the different stages of Horizontal directional drilling process. HDD is a viable construction alternative that has become very competitive cost wise in areas where there is limited access and in high-traffic locations, where it eliminates most surface repairs.

PROJECT OBJECTIVES

Detailed Engineering may be considered as one of the most important part of any cross-country pipeline project. For the detailed engineering stage of a cross-country pipeline project there are number of process involves. In this project, I am concerned only about the fundamentals of pipe wall thickness calculation and stress verification, highway & railroad crossing analysis, anchor force and virtual anchor length calculation, stability analysis through anti buoyancy calculation of pipeline.

SCOPE OF THE PROJECT

This project focuses on the "Detailed engineering of Trunk Pipelines" which comprises of four chapters. These four chapters play an important role in detailed engineering stage of pipelines. For wall thickness calculation & stress verification, I have calculate the pipeline wall thickness from codes & standards, then the stress verification like pressure confinement criteria, longitudinal stress calculation, hydrotest pressure criteria, tensile load criteria and collapse pressure criteria. Second chapter states the detailed understanding about the crossing calculation, how it is carried out and to calculate the different type of load which acting in a pipeline when a road crossing exists. It also aims at understanding about the different external factors that are taken into consideration during crossing and the details about the deliverables needed for the calculation and how the client suggestions are taken into consideration in the actual calculation and how this varies the actual calculated values. For the anchor force calculation due to thermal expansion and due to pressure effect, opposing these forces is the frictional forces between pipe and soil is calculated & when a transition occurs in the pipeline from below ground to above ground and virtual anchor length is also calculated. For anti-buoyancy calculation, find the thickness of concrete coating needed to withstand the floatation occurs due to upward force. In anti-buoyancy systems, concrete coating is preferred due to its ability to provide mechanical protection to the pipeline systems.

DESCRIPTION OF SYMBOLS

PIPELINE WALLTHICKNESS CALCULATION AND STRESS VERIFICATION

t	=	Wall thickness of pipe, mm
P	=	Internal design pressure, kPa
D	=	Outside diameter of pipe, mm
CA	=	Corrosion allowance, mm
Es	=	Young’s modulus of steel, kPa
α	=	Coefficient of thermal expansion, mm/mm/°C
T_2	=	Design temperature, °C
T_1	=	Installation temperature, °C
ν	=	Poisson’s ratio for steel.
Fa	=	Axial Force, N
ρ_s	=	Soil density, kg/m^3
ρ_p	=	Pipe Density, kg/m^3
ρ_f	=	Fluid Density, kg/m^3
μ	=	Friction co efficient for Gravel, 0.6
H	=	Buried depth to the top of the pipe (shall be 1200mm)
T_2	=	Ambient temperature at °C (In hydrotest criteria)
Sp	=	Pulling stress, kPa
fs	=	Static friction coefficient.
L	=	Length of pipeline, mm
Wt	=	Weight per unit length, kg/m
A	=	Area of pipe, mm^2
Sb	=	Bending stress, kPa
r	=	Pipe Outside radius, mm (D/2)
Rr	=	Radius of curvature of the deflection curve, mm
Sab	=	Allowable stress of bending, kPa
Fo	=	Collapse factor = 0.7 for seamless pipe
P_{C2}	=	External collapse pressure, kPa
P_{C1}	=	Internal collapse pressure, kPa

PIPELINE CROSSINGS IN RAIL ROADS & HIGHWAYS

K_{he}	=	Stiffness factor for circumferential stress from earth load.
Be	=	Burial factor for circumferential stress from earth load.
Ee	=	Excavation factor for circumferential stress from earth load.
γ	=	Unit weight of soil, kN/m3.
E	=	Longitudinal Joint Factor
H	=	Depth Cover, m
B_d	=	Bored diameter, mm
E’	=	Modulus of Soil Reaction, Mpa
E_r	=	Resilient Modulus, Mpa
P	=	Design Wheel load, KN
α	=	Coefficient of Thermal Expansion, mm/mm/^{0}C
D	=	External diameter of pipe, mm
S_{he}	=	Stress due to earth load, kPa
K_{Hh}	=	Highway stiffness factor for cyclic circumferential stress.
G_{Hh}	=	Highway geometry factor for cyclic circumferential stress.
R	=	Highway pavement type factor.
L	=	Highway axle configuration factor.
Fi	=	Impact factor.
w	=	Applied design surface pressure, kPa
K_{Lh}	=	Highway stiffness factor for cyclic longitudinal stress.
G_{Lh}	=	Highway geometry factor for cyclic longitudinal stress.
F	=	Design factor.
T	=	Temperature derating factor.
S_{eff}	=	Total effective stress, kPa.
S_1	=	Maximum circumferential stress, kPa
S_2	=	Maximum longitudinal stress, kPa
S_3	=	Maximum radial stress, kPa
α_T	=	Coefficient of thermal expansion of steel, mm/mm/^{0}C
T_1	=	Installation Temperature,^{0}C

T_2	=	Design Temperature, ^0C
ΔS_{Lh}	=	Cyclic longitudinal stress from highway vehicular load, kPa.
S_{FG}	=	Fatigue endurance limit of girth weld, kPa.
ΔS_{Hh}	=	Cyclic circumferential stress from Highway vehicular load, kPa.
S_{FL}	=	Fatigue endurance limit of longitudinal weld, kPa.

ANCHOR FORCE & VIRTUAL ANCHOR LENGTH IN PIPELINES

P_h	=	Hydrostatic test pressure, kPa
P	=	Design pressure, kPa
D_0	=	Nominal outside diameter, mm
t_{nom}	=	Wall thickness of pipe, mm
t_c	=	Corroded thickness of pipe, mm
α	=	Linear coefficient of thermal expansion, mm/mm/^0C
E	=	Modulus of elasticity, kPa
T_1	=	Installation temperature, ^0C
T_2	=	Design temperature, ^0C
Ap	=	Cross-sectional area of pipe, mm^2
ρ_s	=	Density of soil, kg/m^3
ρ_p	=	Density of pipe, kg/m^3
ρ_f	=	Density of fluid, kg/m^3
μ	=	Friction coefficient of gravel
F_A	=	Anchor force, N
La	=	Virtual anchor length, m
H	=	Depth of burial, mm
W_L	=	Weight of the pipe along the virtual anchor length, N/m
F_F	=	Frictional force, N/m
W_F	=	Weight of the fluid inside the pipe, N/m

ANTIBUOYOANCY IN PIPELINE SYSTEMS

D_0	=	Outer diameter of pipe, mm
t_{FBE}	=	Thickness of external FBE coating, mm
Di	=	Inner diameter of pipe, mm
D_{FBE}	=	Diameter with external FBE coating, mm
ρ_S	=	Density of steel, kg/m^3
ρ_{FBE}	=	Density of external FBE coating, kg/m^3
ρ_C	=	Density of concrete coating, kg/m^3
ρ_W	=	Density of water, kg/m^3
L	=	Length of pipe, m
L_C	=	Length of concrete cut back in one length of pipe, m
F_S	=	Factor of safety
L_{FBE}	=	Length of FBE coating cut back in one length of pipe, m
W_1	=	Weight of steel pipe, N
W_2	=	Weight of external FBE coating, N
W_3	=	Weight of concrete, N
Wb	=	Buoyancy of pipe, N
t_{CC}	=	Thickness of concrete coating calculated, mm
t_{CCS}	=	Thickness of concrete coating selected, mm
D_{OD}	=	Overall diameter of pipe, mm

CHAPTER 1.0: PIPELINE WALL THICKNESS CALCULATION AND STRESS VERIFICATION

1.1 OVERVIEW

This chapter outlines the calculation and validation of pipeline wall thickness against pressure confinement, hydrotest pressure, tensile load, collapse pressure, longitudinal stress against line pipe thickness specified in bid document for the design of treated water disposal well pipelines which handles the treated water from Dubai to Abu Dhabi which is located in UAE.

1.2 FACTORS THAT AFFECTS WALL THICKNESS

When the inside diameter of pipe is finalized, the thickness of pipe wall should be intended. Many elements which affect the pipe wall are

1) The maximum allowable operating pressure and the operational pressure.

2) The maximum allowable operating temperature and the operational temperature.

3) Liquid properties.

4) Velocity of fluid.

5) Material of pipeline and its grade

6) Design factor

1.3 THEORETICAL DEVELOPMENT

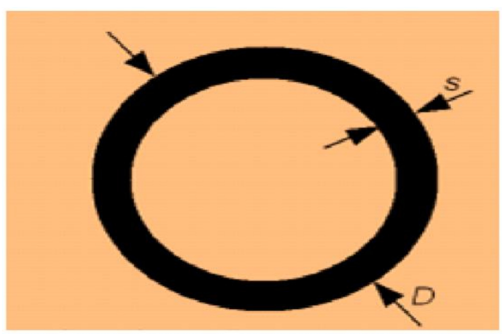

Figure Source: enggtoolbox.com

Figure 1 : Wall thickness representation

Where,

D - Outside diameter of the pipeline

S - Wall thickness of pipeline

Pipeline designs mainly alarmed with the choice of suitable wall thickness and check in coincidence with the hydrostatic criteria, tensile load criteria and collapse pressure criteria. In design of pipelines we can say that pipeline wall thickness calculation is the most fundamental task. But in this task has many technical aspects linked to different design scenarios, primary design loads applicable to the containment of the inside pressure is as follows:

- The differential pressure loads
- Longitudinal functional loads
- External impact loads

Currently in pipeline we do design calculation in terms of hoop stress and longitudinal stress, and then we find equivalent stress and compare with the safe stress. Actually this practice has been proven safe, except the external load which acts in the system.

Considering the specific design and effective quality and operational control achieved by modern industry, it has been understood that there is a necessity to rationalize the pipeline wall thickness sizing for safe and economical design.

1.4 WALL THICKNESS DESIGNATIONS & SELECTIONS

A pipe is mainly classified into different standard like double extra strong, extra strong, standard and has been used from many decades. Normally standards and schedule number are use together to form a suitable designation. Wall thickness selection mainly depends upon the internal pressure with which it can withstand. It is mentioned in the ASME B 31 codes and other similar codes.

1.5 PROCEDURE FOR WALL THICKNESS CALCULATION AND STRESS VERIFICATION

The methodology adopted for pipeline wall thickness verification is as follow:

- Wall thickness calculation as per ASME B31.4

Wall thickness verification with respect to following:-

- Pressure Confinement Criteria
- Hydrotest pressure Criteria
- Tensile Load Criteria

- Collapse Pressure Criteria

1.5.1 Pressure Confinement Criteria

As per ASME B31.4, wall thickness for a straight pipe under internal pressure is given by the following expression:

$$t_n = \frac{P.D}{2.S} + CA$$

Allowable stress, S, is defined in ASME B 31.4

$$S = f \times E \times SMYS$$

SMYS the Specified Minimum Yield Strength of the pipe material in kPa and f the design factor, Pipeline wall thickness is calculated with consideration of design factor as 0.72 as per ASME B 31.4.

Equivalent Stress

Hoop Stress

Hoop Stress (S_h) = $\frac{P \times D}{2 \times (t - CA)}$ (Ref ASME B 31.4)

Longitudinal Stress

Longitudinal stress (S_L) = $Es \times \propto \times (T_2 - T_1) - v \times S_h - \frac{F_a}{A}$

The axial soil resistance Fa =$\mu D[(2 \times \rho_s \times H) + (\pi \times \rho_p \times t) + (\pi \times \rho_f)(\frac{D}{4})]$

Formula for axial force is from CAESAR II Basic Model based on Stress Analysis Methods for Underground Pipelines, L.C. Peng, published in 1978 in Pipeline Industry"

Equivalent Stress

Equivalent stress (Seq) = |Longitudinal stress (SL) - Hoop stress (Sh)|

Von Mises stresses are commonly used by designers to check if their design will withstand a given load condition, Von Mises Combined Stress (Seq) = $\sqrt{(S_h^2 + S_L^2 - S_L \times S_h)}$

As per ASME B31.4, the maximum of the Equivalent stress shall not exceed the 90% of SMYS of line pipe material in order to ensure for safe design.

Equivalent stress (Seq) $\leq$ 0.9 x SMYS

1.5.2 Hydrotest Pressure Criteria

Hoop Stress

Hoop Stress (Sh) = $\frac{P \times D}{2 \times (t - CA)}$

Longitudinal Stress

Longitudinal stress (SL) = $Es \times \propto \times \ (T_2 - T_1) - v \times S_h - \frac{F_a}{A}$

Equivalent Stress

Equivalent stress (Seq) = $\left| \text{Longitudinal stress (SL) - Hoop stress (Sh)} \right|$

Von Mises stresses are commonly used by designers to check if their design will withstand a given load condition, Von Mises Combined Stress (Seq) = $\sqrt{(S_h^2 + S_L^2 - S_L \times S_h)}$

Equivalent stress (Seq) $\leq$ 0.9 x SMYS

1.5.3 Tensile Load Criteria

Pulling Stress

Pulling stress (Sp) = $\frac{f_S \times L \times Wt}{A}$

Pulling Stress can be equated to the load per unit area or the force (F) applied per cross-sectional area (A) perpendicular to the force.

Bending Stress

Strain = $\frac{r}{R_r}$

Where r is Pipe Outside radius, Rr is the radius of curvature of the deflection curve.

Therefore, Stress = Strain x Elastic modulus

Bending stress (Sb) = $E_S \times \frac{r}{R_r}$

Where,

Radius of curvature of deflection, Rr = $E_s \times \frac{r}{S_{ab}}$

Where,

Sab = 0.9×SMYS-Seq

Combined Longitudinal Stress

Pulling stress + Bending stress $\leq$ 0.9 × SMYS

1.5.4 Collapse Pressure Criteria

In the Collapse pressure criteria, calculate the internal collapse pressure from yield pressure at collapse and elastic collapse pressure of pipe. External collapse pressure should be calculated from external pressure at maximum water depth. By comparing both internal collapse pressure and external collapse pressure we should ensure that the internal collapse pressure should be greater than that of external collapse pressure.

Yield Pressure at Collapse

Yield pressure at collapse (Py) = $2 \times SMYS \times \frac{t}{D}$ (Ref. API 1111)

Elastic Collapse Pressure

Elastic collapse pressure (Pe) = $2 \times E_S \times \frac{(\frac{t}{D})^{\wedge}3}{(1-v^2)}$

Collapse Pressure of Pipe

Collapse pressure of pipe (P_{C1}) = $\frac{P_y \times P_e}{\sqrt{P_y^2 + P_e^2}}$

TABLE 1: CALCULATIONS FOR PIPE WALL THICKNESS & STRESS VERIFICATION

Sl.No	Parameter's Used	Symbol	Value	Units	Formula used
PRESSURE CONFINEMENT CRITERIA					
1	Design Pressure	P	13900.00	kPa	
2	Nominal Outside Diameter	D	168.3	mm	
3	Grade	API 5L GR B			
4	SMYS	SMYS	241000	kPa	
5	Design factor	F	0.72		
6	Wall Thickness	T	6.74	mm	P×D/(2×S×F)
7	Corrosion Allowance	CA	3.2	mm	
8	Minimum req. wall thickness	tnom	9.9	mm	t+CA
9	**Wall Thickness Provided Accor 36.10**	**t'**	**10.97**	**mm**	
EQUIVALENT STRESS CHECK IN PRESSURE CONFINEMENT CRITERIA					
1	Hoop stress	Sh	150538.61	kPa	P×D/(2×(t'-CA))
2	Young's modulus for steel	Es	198569000	kPa	
3	Co efficient of Thermal Expansion	A	0.0000117	mm/mm/°C	
4	Installation Temperature	T1	17	°C	
5	Design Temperature	T2	60	°C	
6	Poisson's Ratio for Steel	N	0.3		
7	Burried depth to the top of the pipe	H	1200	mm	
8	Soil density	Ps	1718.49	kg/ m3	
9	Pipe Density	Pp	7850	kg/ m3	
10	Fluid Density	Pf	1170.68	kg/ m3	
11	Friction co efficient for Gravel	µ	0.6		
12	Axial force	Fa	4.51	N/mm	µD [(2 ρs H) + (π ρp t) + (π ρf) (D/4)]
13	Nominal pipe cross section area	A	5419.36	mm2	
14	Fa/A		0.83	kPa	
15	Longitudinal Stress	SL	54739.31	kPa	Es×α×(T2-T1)-ν×Sh-Fa/A
16	Equivalent stress	Seq	95799.30	kPa	SL- Sh
17	Von Misses formula	Seq	131976.84	kPa	SQRT(Sh^2+SL^2-SL×Sh)
18	Ratio of Equivalent stress and SMYS		0.548		Seq/SMYS
19	**Safe Stress**		**TRUE**		**Seq<0.9×SMYS**

HYDROTEST PRESSURE CRITERIA					
1	Hydro test Pressure	Ph	17375.00	kPa	1.25×P
2	Nominal Outside Diameter	D	168.3	mm	
3	Grade		API 5L GR B		
4	SMYS	SMYS	241000	kPa	
5	Design factor for Hydrostatic test	F	0.9		
6	Wall Thickness	T	6.74	mm	P×D/(2×S×F)
7	Corrosion Allowance	CA	3.2	mm	
8	Minimum req. wall thickness	tnomh	9.94	mm	
9	**Wall Thickness Provided**	**t'**	**10.97**	**mm**	
STRESS CHECK IN HYDROTEST PRESSURE CRITERIA					
1	Hoop stress	Sh	188173.3	kPa	P×D/(2×(t'-CA))
2	Young's modulus for steel	Es	198569000	kPa	
3	Co efficient of Thermal Expansion	A	0.0000117	mm/m/°C	
4	Installation Temperature	T1	17	°C	
5	Temperature at GC-30	T2	55	°C	
6	Poisson's Ratio for Steel	N	0.3		
7	Longitudinal Stress	SL	31830.98	kPa	Es×α×(T2-T1)-ν×Sh-Fa/A
8	Equivalent stress	Seq	156342.29	kPa	SL-Sh
8.1	Von Misses formula	Seq	174449.56	kPa	SQRT(Sh^2+SL^2-SL×Sh)
9	Ratio of Equivalent stress and SMYS		0.724		Seq/SMYS
10	**Safe Stress**		**TRUE**		**Seq<0.9×SMYS**
TENSILE LOAD CRITERIA					
1	Young's modulus	Es	198569000	kPa	
2	Pipe Outside radius	R	84.15	mm	D/2
3	Allowable stress of bending	Sab	84923.16	kPa	0.9×SMYS-Seq
4	Radius of curvature	Rr	196761.17	mm	Es×r/Sb
5	Length of pipeline	L	12000	mm	
6	Area of pipe	A	6341544	mm²	π×D×L
7	Inside diameter	Di	146.3600	mm	D-(2×t)
8	Density of Steel	ρ_S	7850	kg/m3	
9	Density of water	ρ_{water}	1025	kg/m3	
10	Weight per unit length	Wt.	59.78	kg/m	Weight of the pipe+ Weight of water
11	Static friction co-efficient	Fs	0.7		
12	Pulling stress	Sp	0.000777	kPa	(Fs×L×Wt)/A
13	Bending stress	Sb	84923.16	kPa	(Es×r/Rr)
14	**Combined longitudinal stress**	**Sc**	**TRUE**		**Sp+Sb<0.9*SMYS**

COLLAPSE CRITERIA					
1	Young's Modulus for steel	Es	198569000	kPa	
2	Nominal Outside Diameter	D	168.3	mm	
3	Specified Minimum Yield Strength of Pipe	SMYS	241000	kPa	
4	Density of Water	ρ_{water}	1025	kg/m^3	
5	Maximum Water Depth Considered	d_{max}	25000	mm	
6	Selected Pipeline Wall Thickness	t_{select}	10.97	mm	
7	Acceleration due to Gravity	G	9.81	m/s^2	
8	External Pressure at Maximum Water Depth	P_o	2465.30	kPa	$\rho_{water} \times d_{max} \times g$
9	Collapse Factor	f_0	0.7		
10	P_{C2}	$(P_o-P_i)/f_0$	3521.85	kPa	
11	Yield Pressure at collapse	P_Y	7394767.5	kPa	2×SMYS×/(t/D) (API 1111)
12	Elastic Collapse Pressure	P_e	120855.8	kPa	$2 \times Es \times ((t/D)^3/(1-\nu^2))$
13	Collapse Pressure of Pipe	P_{C1}	120839.68	kPa	$Py \times Pe/(Py^2+Pe^2)^{½}$
14	Pressure Check	$P_{C1}>P_{C2}$	TRUE		
15	**Wall Thickness Provided**	**t'collapse**	**10.97**	**mm**	

CHAPTER 2.0: PIPELINE CROSSINGS IN RAIL ROADS & HIGHWAYS

2.1 OVERVIEW

The major objective is to get a thorough understanding about the crossing calculation, how it is carried out. The project also aims at understanding about the different external factors that are taken into consideration during crossing and the details about the deliverables needed for the calculation and how the client suggestions are taken into consideration in the actual calculation and how this varies the actual calculated values.

2.2 THEORETICAL DEVELOPMENT

Crossing pipes is done to rivers, railways and roads. While crossing we should take into consideration various loads that act on the pipeline and also the type of crossing method to be used which depends on the location of crossing and the intensity of population in that area. All pipeline crossings is carried out in accordance with API 1102 for road and railways, and for river crossing we add extra loads that come into consideration and calculated using the same principle in 1102. The need for API pipe cover is decided by the type of crossing method made or according to the request of the company to which the crossing is planned or is based on government policies.

Types of Crossings

The road, railway crossings can be classified into

- **Cased crossings**
- **Uncased crossings**

2.2.1 Cased Crossings

Cased crossings are essentially a pipe within a pipe and utilize centralizers for maintaining an equal axial distance between the carrier pipe and the casing. Cased crossings can range about approximately 20 to more than 300 feet long. The carrier pipe is inside the cased pipe and many factors must be taken into consideration while using a cased crossing.

The different factors should consider while selecting a casing are,

Minimum diameter

The inside diameter of the casing pipe must be large enough to facilitate the installation of the carrier pipe, to provide an adequate insulation for maintenance of Cathodic protection and to prevent transmission of external loads from the casing pipe to the carrier pipe. The protection pipe must be at least two nominal pipe sizes larger than the carrier pipe.

Installations

Carrier pipe installed in a casing should be clear holding of the casing pipe through well-designed supports, insulation, or other devices, and installed so that no external load will be forwarded to the pipeline. This can also be achieved by forming a coating layer of ring and outer shell, or by a concrete casing. Manufactured insulation which is used, they should be spaced accurately and securely fastened to the carrier pipe.

Casing seal

The casing must be fixed with end seals at both ends to decrease the interruption of water. It is recognized that a water-tight seal may not constantly be possible under field conditions, and in some circumstances water infiltration should be anticipated. The seal must be formed with a flexible material which will inhibit the formation of a channel through the casing.

Insulator

Insulators electrically insulate the carrier pipe and casing pipe by providing a circular cover that prevents direct contact between both. The insulator must be designed to endorse minimum bearing pressure between the career coating and the insulator.

Inspection and testing

Supervision and inspection must be provided during construction of the crossing. Before installation, the section of carrier pipe used at the crossing should be visually inspected for defects. All girth welds shall be inspected by radiographic or other non-destructive methods. After a cased pipe installed, a test must be conducted to determine that the carrier pipe is electrically isolated from the casing pipe.

Figure Source: Farwestcorrosion.com

Figure 2 : Cased pipeline

2.2.2 Uncased Crossings

Uncased crossings are used mainly when horizontal directional drilling is used and when the company policy allows using uncased crossing.

2.2.3 Crossing methods

Crossings can be mainly classified into three types according to the procedure.

- **Open cut crossing method**
- **Horizontal thrust boring**
- **Horizontal directional drilling**

Open cut crossings

This method is used in road and river crossings, in roads basically trenching is carried out cutting open the road and lay then pipeline and then we backfill it and this can be used in roads where the traffic is very less.

Horizontal thrust boring

Thrust boring is a drilling method used for installing pipe & casing is also installed under a surface where the danger of hole collapse while installing larger diameters of pipe has been identified. The thrust boring can be done in an economical way and almost in variety of ground condition.

In this method the auger is placed inside the pipe. A rectangular hole space is dig on either side to accommodate the auger boring machines/equipment's. Pipes consist of augers which connect end to end and the leading edge is connected to a cutting head and the end is connected to an auger machine which pushes the whole system. The important point should be checked here that the alignment of track system. If it is not proper, may cause difficulty to adjust later. The auger is attached with the boring machine and a casing is attached to the system by welding and boring process starts. The dig has the length of around 11.5 m to adjust both auger and the line pipe.

Figure Source: http://rebar.ecn.purdue.edu/Trenchless

Figure 3 : Horizontal thrust boring

The banding is used to prevent the edge of the pipe from damage. Thrust boring not works best in above underground water region. If the water is found, care should take to remove the water as prior to boring. The main drawback of this type of crossing method is that it can be used only for straight line crossing; no angle can be made in this type of crossing so it cannot be used for areas which need an angle boring for that kind of crossing directional drilling is used.

Horizontal directional drilling

HDD is a trenchless construction method and will not create disturbances to top of the surface. HDD is used in the construction of Petroleum pipelines (Steel or plastic), and other types of pipelines where conventional open trench construction is not possible. HDD technology is used in many situations which includes the following,

- Lake crossings
- Wetland crossings
- Canal and watercourse crossings
- Valley crossings
- Sensitive wildlife habitat
- Road and railway crossings

HDD installation involves four main steps:

1. Pre-site planning
2. Drilling a pilot hole
3. Expanding the pilot hole by reaming
4. Pull back of pre-fabricated pipe

Pre-Site Planning

A determination is made whether a HDD is technically feasible and geotechnical study of the existing geological data and conduct field surveys to assess the conditions of the soil and characteristics likely to be encountered. If an HDD is determined to be feasible, a drill path is designed to meet the necessities of the crossing and suitable drill entrance and leaving locations are selected.

Drilling the Pilot Hole

An HDD drill rig and supporting equipment's is set-up at the drill entry location determined during the pre-site planning phase, a pilot hole is drilled along the predetermined drill path. The readings are to be taken from the probe which is placed near to the drill bit to find the position from the entry region through the monitoring from the surface. Drilling fluid is injected under pressure ahead of the drill bit to transport drill cuttings to the surface, clean buildup on the drill bit, cool the drill bit, reduce the friction between the drill bits and bore wall, and stabilize the bore hole. A transmitter is attached to the drill bit to locate the drill bit system.

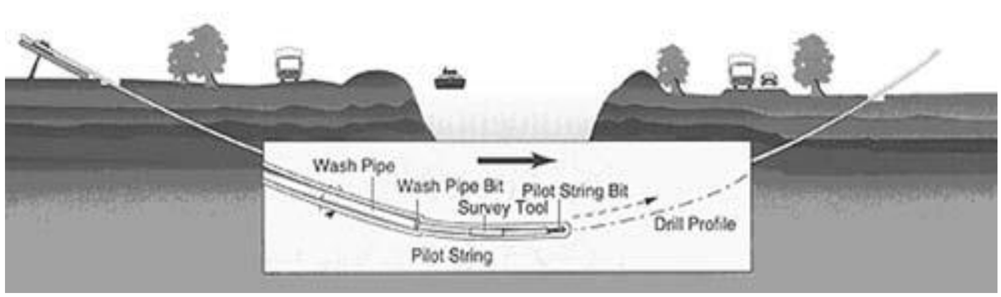

Figure Source: Horizontal Directional drilling by David A Willoughby from McGraw-Hill

Figure 4 : Drilling the Pilot Hole

Reaming of the Pilot Hole

The drill bit is replaced with a back reamer. The drill string is dragged back through the bore hole and the back reamer increases the width of the drill hole. The reamer may be pulled from the pipe side of the HDD crossing, in some cases the bored diameter is not sufficient. During such situation we can conduct different reaming stages. Sometimes if the pipeline diameter is less the reaming stage is not required.

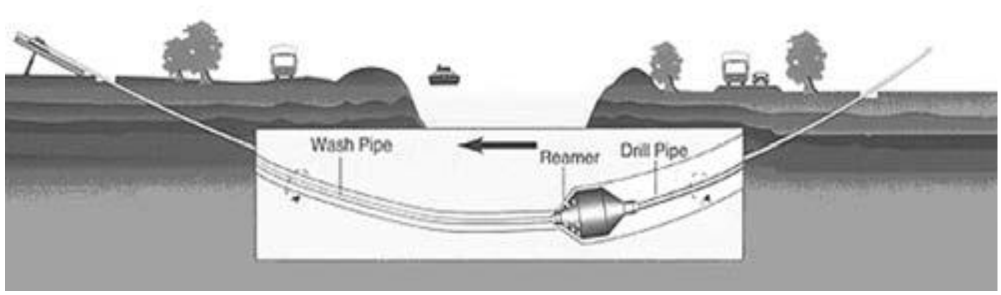

Figure Source: Horizontal Directional drilling by David A Willoughby from McGraw-Hill

Figure 5 : Reaming of the Pilot Hole

Pipe String Pull back

Pipe is welded into a pipe string or drag section, which is longer than that of the hole at the entry region. The pipe is typically coated with a corrosion and abrasion resistant covering, and is commonly hydrostatically pretested to ensure pipeline integrity. The pipe string is pulled up to the exit hole region since the system comes till at the exist region. The coating of the pipeline should be visually inspected and ensure that there is no defects. An internal inspection of the pipe string is performed to identify any damage done to the pipeline during the pull back.

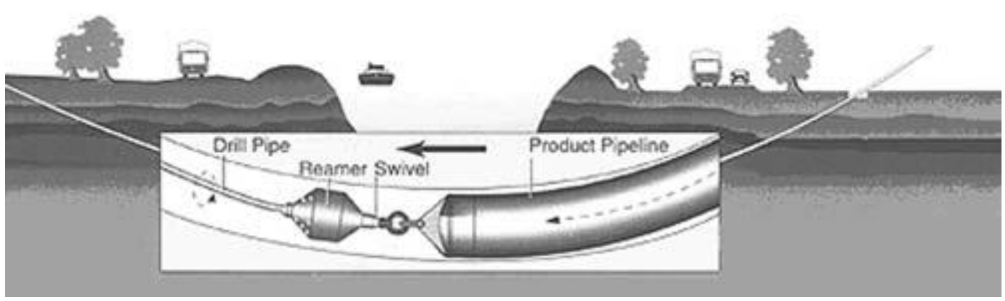

Figure Source: Horizontal Directional drilling by David A Willoughby from McGraw-Hill

Figure 6 : Pipe String Pull back

2.2.4 Loads in crossings

According to API 1102 (road crossings under rails and highways), there are mainly three types of load which acts in a pipeline subjects to crossing. In the standard there is an additional impact factor is added to the live load to ensure safety. Other type of load like temperature expansion due to season change, nearby blasting's, local instability, shrinking and swelling soils. Loads are classified into

- External load
- Live load
- Internal load

External Load

The earth load can considered as per API 1102 is mainly the soil which is deposited at the top of the pipe. The earth load like the weight of the soil of a particular are can be calculated with reference to many standards and procedures.

Live Load

For pipelines live load can occur in railways and in highways, for railways the load of the train or any rolling stock is taken as the live load and in case of highways the truck and other vehicle load is taken as live load. Live load cannot be determined accurately so a factor of safety is always added to it. Impact factor is also added to it while calculation to account for any impact load.

Internal Load

Internal load of the pipeline is the internal pressure of the pipeline. In many cases maximum allowable operation pressure (MAOP) is taken for calculation of internal load in view of extra safety.

2.2.5 Stresses

In pipeline road crossings the different stresses acting in pipeline are circumferential stresses and longitudinal stress. Circumferential stress can also be called as hoop stress. The hoop stress which acts circumferentially in both direction. This determines the rate of internal pressure with which the pipeline can withstand. Longitudinal stress can also be called as axial stress which acts along the length of the body, which may tend to change in the length.

2.2.6 Cathodic protection at crossing

Cathodic guard at crossing should be taken into important consideration as there is a chance of decrease in the effectiveness of cathodic protection. So the carrier pipe and casing should be properly isolated in case there is a casing pipe provided or in case there is no casing care should be taken while lowering of the pipeline to avoid any type of failure to the coating. In case of crossing with cased pipe care should be taken and a full proof isolation should be provided. The insulation can be given by filling the casing with a corrosion inhibitor, inert gas. Check the pipeline for coating defects and give necessary coating to carrier pipe if there is any defect for the coating.

The main reason for corrosion in cased pipeline will be the presence of any moisture or air between the casing pipe and the carrier pipe and also if there is any contact between the casing and the carrier pipe. The insulators isolate the carrier pipe from casing pipe by providing a circular enclosure that prevents the direct contact between the two. Casing spacers are also used for isolation.

2.2.7 Carrier pipe & Casing pipe

The pipeline wall thickness selected for the crossings is to be checked for compliance with the Barlow stress, total effective stress and fatigue criteria defined in API RP 1102, showing wall thickness is sufficient for pipeline at each crossing location.

In case casing pipe is required following shall be taken care.

The casing pipe should be free of internal obstructions, should be as straight as practicable, and should have uniform bedding for the entire length of the crossing. The casing pipe should be joined completely to ensure a continuous casing from end to end. Care shall be taken to isolate the pipeline crossing installation from aerial electrical wire and shall be suitably insulated from underground conduits carrying electrical wires.

2.3 CALCULATION PROCEDURE FOR ROAD CROSSINGS

Stresses Due to External Loads

External loads on uncasing pipe will produce both circumferential and longitudinal stresses.

2.3.1 Stresses Due to Earth Load

The circumferential stress at the pipeline invert caused by earth load,

S_{He} is determined as follows:

$$S_{He} = K_{He} \times B_e \times E_e \times \gamma \times D \quad \text{(API 1102)}$$

2.3.2 Stresses Due to Live Load

Surface live load

The external live load (w) is the vehicular load applied at the surface of the crossing.

Impact factor

Impact factor (Fi) is a function of the depth of burial (H) of the carrier pipeline at the crossing. The live load is increased by an impact factor. The impact factor is 1.5 for highways.

Cyclic stresses for road crossing

a. The Cyclic Circumferential Stress (ΔSHh) due to vehicular load may be calculated as follows.

$$\Delta S_{Hh} = K_{Hh} \times G_{Hh} \times R \times L \times F_i \times w$$

b.The Cyclic Longitudinal Stress (ΔSLh) due to vehicular load may be calculated as follows.

$$\Delta S_{Lh} = K_{Lh} \times G_{Lh} \times R \times L \times F_i \times w$$

2.3.3 Stresses Due to Internal Load

The circumferential stress due to internal pressure (SHi) may be calculated as follows.

$$S_{Hi} = P(D - t_w)/2t_w$$

2.3.4 Limits of Calculated Stresses

The stresses calculated above may not exceed certain allowable values. The allowable stresses for controlling yielding and fatigue in the pipeline are described in the following subsections.

A. Check for Allowable Stresses

Two checks for the allowable stress are required as follows:

a) $S_{Hi}(Barlow) \leq F \times E \times T \times SMYS$

$S_{Hi}(Barlow) = (P \times D)/(2 \times T_w)$

b) $S_{eff} \leq SMYS \times F$

Also $S_{eff} = \sqrt{0.5[(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2]}$

$S_1 = S_{He} + \Delta S_H + S_{Hi}$

$S_2 = \Delta S_L - E_s \alpha_T (T_2 - T_1) + v_s (S_{He} + S_{Hi})$, $S_3 = -P = -MAOP$

B. Check for Fatigue

The check for fatigue is accomplished by comparing a stress component normal to a weld in the pipeline against an allowable value of this stress, referred to as a fatigue endurance limit.

C. Girth Weld

The design check is accomplished by assuring that the live load cyclic longitudinal stress is less than the factored fatigue endurance limit. The design check is mentioned as follows.

$\Delta S_{Lh} \leq S_{FG} \times F$

D. Longitudinal Weld

The design check is accomplished by assuring that the live load cyclic circumferential stress is less than the factored fatigue endurance limit. The design check is mentioned as follows.

$\Delta S_{Hh} \leq S_{FL} \times F$

TABLE 2: STRESS CALCULATION FOR PIPELINE ROAD CROSSINGS

Sl.No	Parameter's Used	Symbol	Value	Units	Formula used
A	**Pipe and Operational Characteristics:**				
1	Outside Diameter of Pipe	D	168.3	mm	
2	Design Pressure	p	13,900	kPa	
3	Steel Grade	API 5L Gr B			
4	Specified Minimum Yield Strength	SMYS	241000	kPa	
5	Design Factor	F	0.72	-	
6	Longitudinal Joint Factor	E	1.00	-	
7	Wall Thickness	t_w	10.97	mm	
8	Depth Cover	H	1.20	m	
9	Bored Diameter	B_d	219.10	mm	
10	Soil Type	loose to medium dense sands and gravels			
11	Modulus of Soil Reaction	E'	3.10	Mpa	
12	Resilient Modulus	E_r	69	Mpa	API 1102, Table A-2
13	Unit soil weight	γ	20	kN/m^3	
14	Design Wheel Load	P	112.09	KN	
15	Pavement Type	Flexible pavement			
16	Young's Modulus	E_s	198569000	kPa	
17	Poisson's Ratio	v	0.30		
18	Co efficient of Thermal Expansion	α	0.0000117	mm/mm/°C	
19	Installation Temperature	T1	17	°C	

Sl.No	Parameter's Used	Symbol	Value	Units	Formula used
20	Max. Operating Temperature	T2	55	°C	
B	**Circumferential Stress Due to Earth Load**				
1	Wall Thickness/ Pipe Diameter	t_w/D	0.065		t_w/D
2	Stiffness Factor For Circumferential Stress from earth load	K_{He}	280		Ref. fig. 3, API 1102
3	Depth/ Bored Diameter	H/B_d	5.48		
4	Burial Factor for Circumferential Stress from Earth Load	B_e	1.13		Ref. fig. 4, API 1102
5	Bored Diameter/Pipe Diameter	B_d/ D	1.302		
6	Excavation Factor for Circumferential Stress from Earth Load	E_e	1.4		Ref. fig. 5, API 1102
7	Circumferential Stress due to Earth Load	S_{He}	1,491	kPa	KHe X Be X Ee X γ X D
C	**Cyclic Stresses**				
	A) Cyclic Circumferential Stresses				
1	Impact Factor	Fi	1.5		Ref. fig. 7, API 1102 for highway with depth of cover 1.2 m
2	Stiffness Factor for Cyclic Circumferential Stresses	K_{Hh}	3.50		Ref. fig. 14, API 1102
3	Geometry Factor for Cyclic Circumferential stress from Highway Vehicular Load	G_{Hh}	1.45		Ref. fig. 15, API 1102
4	Highway Pavement Factor,	R	1.00		API 1102, Table 2 with Flexible pavement
5	Highway Axle Configuration Factor	L	1.00		API 1102, Table 2 with Flexible pavement
6	Applied Design Surface Pressure	w	1,207	kPa	w=P/Ap Ap taken as 144 in^2
7	Cyclic Circumferential Stress	ΔS_{Hh}	9,185	kPa	ΔSHh=KHh X GHh X R X L X Fi X w
	B) Cyclic Longitudinal Stress				
1	Stiffness Factor for Cyclic Longitudinal Stresses	K_{Lh}	5.5		Ref. fig. 16, API 1102

Sl.No	Parameter's Used	Symbol	Value	Units	Formula used
2	Geometry Factor for Cyclic Circumferential Stress from Highway Vehicular Load	G_{Lh}	1.6		Ref. fig. 17, API 1102
3	Cyclic Longitudinal Stress	ΔS_{Lh}	15,927	kPa	$\Delta S_{Lh} = K_{Lh}$ X G_{Lh} X R X L X F_i X w
D	**Circumferential Stress due to Internal Pressurization**				
1	Circumferential Stress due to Internal Pressurization	S_{Hi}	99,676	kPa	S_{Hi} = P X (D – Tw) / (2 X Tw)
			CHECK I		
E	**Allowable Barlow Stress**				
1	Allowable Stress		1,73,748	kPa	F X E XSMYS
2	Barlow	S_h (Barlow)	1,06,626	kPa	S_H = P X D / (2 X Tw)
3	Allowable Stress ≥ Barlow Stress		**SAFE**		S_{hi} < F X E X T X SMYS
			CHECK II		
F	**Principal Stresses S_1,S_2 & S_3**				
1	Circumferential	S_1	1,10,352	kPa	$S_1 = S_{He}+\Delta S_{Hh}+S_{Hi}$
2	Longitudinal	S_2	-42,007	kPa	$S_2 = \Delta S_{Lh}$ – [E_s X α_t X(T_2- T_1)] +[v ($S_{He} + S_{Hi}$)]
3	Radial	S_3	-13,900	kPa	S_3 = -P
4	Effective Stress	S_{eff}	1,40,431	kPa	$S_{eff} = (1/2[(S_1 -S_2)^2+ (S_2 -S_3)^2 +(S_3 - S_1)^2])^{½}$
5	SMYS X Fa :	kPa	1,73,520	kPa	SMYS X Fa
6	S_{eff} ≤ SMYS X 0.72		**SAFE**		
			CHECK III		
G	**Fatigue Test :Girth Weld**				
1	Fatique Endurance Limit	S_{FG}	82,737	kPa	Ref. table 3 of API RP 1102
2	Cyclic Longitudinal Stress	ΔS_{Lh}	15,927	kPa	
3	Factored Fatique Endurance Limit	kPa	59,571	kPa	S_{FG} X F
4	S_{FG} X F ≥ ΔS_{Lh}		**SAFE**		
H	**Fatigue Test :Longitudinal Welds :**				
1	Fatique Endurance Limit	S_{FL}	82,737	kPa	Ref. table 3 of API RP 1102
2	Cyclic Circumferential Stress	ΔS_{Hh}	9,185	kPa	
3	Factored Fatique endurance limit		59,571	kPa	S_{FL} X F
4	S_{FL} X F ≥ ΔS_{Hh}		**SAFE**		

CHAPTER 3.0: ANCHOR FORCE AND VIRTUAL ANCHOR LENGTH IN PIPELINE

3.1 OVERVIEW

Materials get expand when it became heated at a particular temperature and it get contract when there is a change in temperature and the same is applicable in the case of pressure also. This is a basic theory which is applicable to pipes also. This chapter includes the basics of stresses and anchor force which caused due to thermal expansion. In every pipeline project anchor force is calculated by client's requirement. From the calculation if it's find required we suggest anchor block for the area where anchor force acts.

3.2 THEORETICAL DEVELOPMENT

Investigating an underground pipeline is quite different than to analyze an above ground pipeline. There are some problems which involved due to some certain characteristics in pipeline. The different elements that are analyzed which are anchorage force, movement of pipe, lateral soil force, pipe to soil interaction. The allowable stress in the pipeline is higher than that of plant piping. The other unique characteristics of pipeline are its high yield strength, although a pipeline operating beyond the yield strength may not create structural integrity problem but it may cause some deformations. It is more economical when a gas pipeline transports gas with low temperature. Hence the stress involved is gas pipeline is less than that of oil pipeline. Based on the nature and duration of external loads, pipeline stresses are classified into different types. They are primary stresses and secondary stresses. The primary stresses are mainly the internal pressure, external pressure, live and dead loads. Primary stresses are not self-limiting. The secondary stresses are developed by self-constraint of the structure. The temperature differential, earthquake motions are included in the secondary stress. The allowable stress criteria should be verified as per codes and standards.

Based on the application of loads, pipeline can be classified into

- **3.2.1 Restrained pipeline**
- **3.2.2 Unrestrained pipeline**

In normal situations the buried pipelines are considered as restrained. Stress calculations are necessary when there is a significant temperature change or a deviation is found from straight line. Safe operation is assumed in buried pipeline since it covered with soil from all sides .At the end of the pipeline, due to the change in temperature and pressure difference a longitudinal movement may occur in the pipelines. Soil cover in that particular area may unable to prevent that movement. The length of pipeline which is subject to longitudinal movement may be several distance and at end of the pipeline should be anchored. Restrained above ground pipelines should be anchored and hence we can stop the longitudinal movement. While designing, consideration should be given to beam bending stress and its elastic instability due to compressive force which occurs longitudinally. The supports should prevent the lateral buckling which occurs in the pipeline.

In the case of unrestrained pipelines, pipelines shall be designed to have enough flexibility to control contraction and enlargement from producing stress in pipeline material. When pipe is unrestrained, it is not beyond the virtual anchor length and so can experience longitudinal or transverse displacements and the stress should be analyzed and checked.

3.2.3 Expansion & Flexibility

The main task of the stress analysis is the flexibility analysis. Codes & standards of pipelines are classified into two types, restrained and the unrestrained pipelines. A pipeline which is underground or above ground can be fully restrained or unstrained. The moving portion is same as that of the unrestrained pipeline in the codes. As shown in the figure the pipeline which is located in the above ground pipeline, the axial movement is controlled by using anchors and guides but in the case of the below ground pipelines the movement is controlled by soil friction.

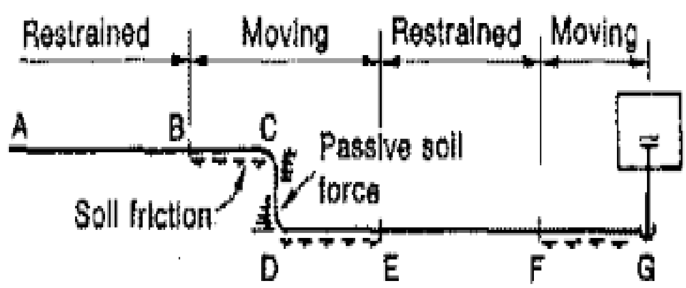

Figure Source: Stress analysis methods for underground pipelines by Liang-Chuan Peng

Figure 7: Restrained & Unrestrained pipelines

3.2.4 Anchor force

In the cross-country pipelines there is a transition may occur from below ground to above ground, in this areas stresses and deflections may occur. The deflection and stresses should be analyzed carefully and check for the anchor block requirement to control the movement of pipeline; else it may cause a problem to the pipeline supports and other areas.

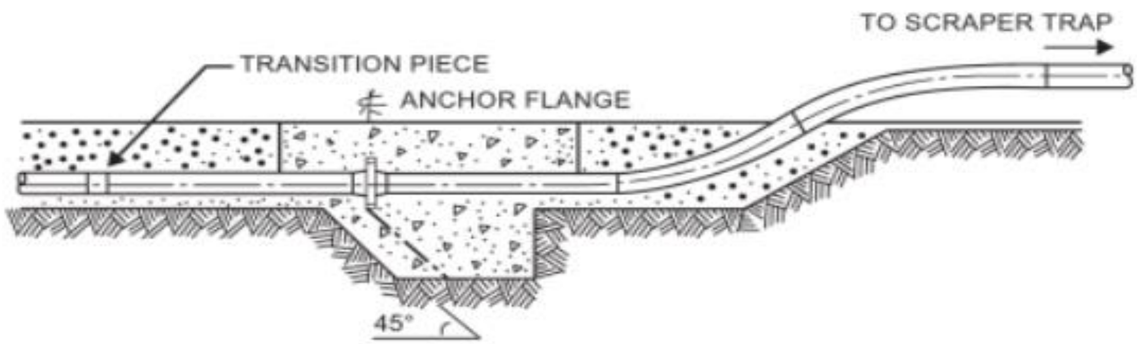

Figure Source: Pipeline Rule of Thumb Handbook (5th Ed.), E. W. McAllister

Figure 8: Anchor force representation

There are four constraints are there in anchor force analysis

1) Force calculation due to both temperature and pressure change with respect to pipe to soil friction

2) Virtual anchor length

3) Anchor flange according to our requirement

4) Anchor block calculation.

In buried pipelines the interaction between pipes to soil is clearly checked. Any pipe movement should be measured and ensure whether there is a proper downward force acting to control pipe movement. If the weight of soil is not sufficient to withstand the movement of the pipeline, should go for the design of anchor, guides should be carried out. The anchor force can be defined as the sum of expansion force due to temperature change and expansion force due to pressure.

Expansion force due to temperature change $F_{ex(t)} = (E \times A \times \alpha \times \Delta T)$**…………………… (A)**

Expansion force due to pressure

Hoop stress (Sh) = $\frac{PD}{2.T}$

Axial Stress (Sa) = $\frac{PD}{4.T}$

Expansion due to axial stress (ΔL_1) = $\frac{L}{E}Sa \quad (E = \frac{stress}{strain} = \frac{S_a}{\Delta L} \times L)$

Contraction due to hoop stress (ΔL_2) = $\frac{L}{E} \times v \times s_h \left(v = \frac{lateral}{longitudinal} = \frac{\Delta L2}{\Delta L1}\right)$

Total pressure expansion (ΔL) = $(\Delta L_1 - \Delta L_2)$

$$= \frac{L}{E}[Sa - (v.sh)] \qquad \frac{sh}{2} = Sa$$

$$= \frac{L}{E}\left[\frac{Sh}{2} - (v.sh)\right]$$

$$\Delta L = \left[\frac{L.Sh}{E}\right] \times (0.5 - v)$$

Pressure expansion force (F) $= E \times A \times \frac{\Delta L}{L} \quad \left[E = \frac{Stress}{strain} = \frac{F}{A} \times \frac{L}{\Delta L}\right]$

Substituting the value of ΔL

$$\mathbf{F} = (\boldsymbol{A} \times \boldsymbol{S_h} \times (\mathbf{0.5} - \boldsymbol{v})) \text{.................................. } \mathbf{(B)}$$

Adding (A) and (B) gives

Anchor Force, $\mathbf{F_{EX}} = (\boldsymbol{E} \times \boldsymbol{A} \times \boldsymbol{\alpha} \times \Delta \boldsymbol{T}) + (\boldsymbol{A} \times \boldsymbol{S_h} \times (\mathbf{0.5} - \boldsymbol{v}))$

3.2.5 Virtual anchor length

Virtual anchor lengths are generally assumed to be located at a distance where the equivalent forces to stop the thermal expansion and the pressure is equal to the friction provided by the soil.

This is the length obtained by taking the equivalent pressure and thermal expansion force, dividing by the friction of pipe to soil.

Weight of pipe along the length = $A \times \rho_P \times L_a$

Weight of the fluid in pipe = $\left[\pi \frac{D_I 2}{4}\right] \times \rho_F \times La$

Total weight of the pipe (Wp) = $A \times \rho_P \times L_a + \left[\pi \frac{D2}{4}\right] \times \rho_F \times La$

According to Pipeline thump rule by E.W.McAllister

Frictional force (F_F) = $\boldsymbol{\mu.\left[(2 \times \rho_s \times D \times H \times L_a) + W_p\right]}$

Equating this equation with the anchor force give the anchor length L_a

$$\boldsymbol{(E \times A \times \alpha \times \Delta T) + (A \times S_h \times (0.5 - v)) = \mu.\left[(2 \times \rho_s \times D \times H \times L_a) + W_p\right.}$$

Virtual anchor length, $\mathbf{La} = \dfrac{\mathbf{(E \times A \times \alpha \times \Delta T) + (A \times Sh \times (0.5 - v))}}{\mu\left\{\left((\boldsymbol{2 \times \rho_s \times D \times H}) + \left(\boldsymbol{A \times \rho_p}\right) + \left[\left(\boldsymbol{\frac{\pi D^2}{4}}\right) \boldsymbol{\times \rho_f}\right]\right)\right\}}$

3.2.6 Anchor flange

Anchor flange is used to control the longitudinal movement of the pipeline due to the thermal expansion, due the force created when change in pressure or due to external load. The common method is that anchor flange is to be attached with an anchor block to prevent the longitudinal movement by transferring the force to anchor block. However there is some other method to control longitudinal movement without the use of anchor flange.

3.2.7 Anchor block

Anchor block is placed at the situation where above ground movement of pipe is higher than a certain limit. Concrete block or anchor block are placed there to control the longitudinal movement. The longitudinal force which occurred in the pipeline is controlled by friction force between ground and anchor block. Anchor block are usually rectangular in structure.

TABLE 3: CALCULATION FOR ANCHOR FORCE & VIRTUAL ANCHOR LENGTH

SL No	Parameter's Used	Symbol	OPERATING CASE	CORRODED CASE	HYDROTEST CASE	SI UNITS	Formula used
A	**Input Data**						
1	Design Pressure	P	13900	13900	13900	kPa	
2	Hydrostatic Test Pressure	Ph	17375	17375	17375	kPa	1.25×P
3	Nominal Outside Diameter	D_o	168.3	168.3	168.3	mm	
4	Wall thickness of pipe	t_{nom}	10.97	10.97	10.97	mm	
5	Corrosion allowance	CA	3.2	3.2	3.2	mm	
6	Corroded thickness of pipe	tc	7.77	7.77	7.77	mm	tnom-CA
7	Linear coefficient of thermal expansion	α	0.0000117	0.0000117	0.0000117	mm/mm/ °C	
8	Modulus of elasticity	E	198569000	198569000	198569000	kPa	
9	Installation temperature	T_1	17	17	17	°C	
10	Design Temperature	T_2	60	60	50	°C	
11	Change in temperature	ΔT	43	43	33	°C	ΔT=T2-T1
12	Poisson's ratio	v	0.3	0.3	0.3	-	
13	Safety factor	S.F	1.1	1.1	1.1	-	
B	**Anchor Force Calculation**						
1	Internal diameter	D_i	146.36	152.76	146.36	mm	Di = Do-2×t
2	Cross-sectional area of pipe	A_P	5419.36	3916.58	5419.36	mm^2	Ap = π×(Do-tc)×t
3	Force at anchor	F_A	656962.85	509185.74	559949.39	N	F_A =[((P×Do / 2×t)×(0.5 - v))+(E×α×ΔT)]×Ap

4	Force at anchor	F_A	**656.96**	**509.19**	**559.95**	KN	
5	Force at anchor considering 10% Safety factor	F'_A	**722.66**	**560.10**	**615.94**	KN	$F'_A = F_A \times S.F$
C	**Input data**						
1	Burried depth to the top of the pipe	H	1200	1200	1200	mm	Ref. ASME B31.4-2012, Table 434.6-1
2	Soil density	ρ_s	1718.49	1718.49	1718.49	kg/ m^3	
3	Pipe Density	ρ_p	7850	7850	7850	kg/ m^3	
4	Fluid Density	ρ_f	1170.68	1170.68	1170.68	kg/ m^3	
5	Friction co efficient for Gravel	μ	0.6	0.6	0.6		
D	**Friction Force at soil/Pipe Interface**						
1	Weight of the pipe along its length	W_L	417.33 La	301.60 La	417.33 La	N/m	$A \times \rho p \times La \times 9.81$
2	Weight of the fluid inside the pipe	W_F	193.11 La	210.37 La	193.11 La	N/m	$(3.14 \times (D_i^2/4)) \times \rho f \times La \times 9.81$
3	Total Weight of the pipe	Wp	610.45 La	511.98 La	610.45 La	N/m	$W_L + W_F$
4	Frictional Force	Ff	4085.66 La	4085.66 La	4085.66La	N/m	$\mu((2 \times \rho s \times D \times H \times La) + Wp) \times 9.81$
Now equating the anchor force with frictional force to find the virtual anchor length							
5	Virtual Anchor Length	La	160.79	124.62	137.05	m	Fa/Ff

CHAPTER 4.0: ANTI-BUOYANCY IN PIPELINE AND ITS CALCULATIONS

4.1 OVERVIEW

Practically almost all the pipelines has to cross aquatic environments such as lakes, rivers etc. There are some cases also when pipeline are passes through semi-aquatic environments like marches etc. If the pipelines are not buried, there are some probabilities to lift towards the surface. This can be eliminated by anti-buoyancy methods.

4.2 THEORETICAL DEVELOPMENT

The buoyancy in the pipeline should be prevented otherwise it may cause buckling or even rupture risks. There is a method to control the buoyancy by increasing the wall thickness of the pipeline. If we increase the thickness, it causes high cost of line pipe and hence it is not economical.

To avoid floatation, there are three methods are used by pipeline companies.

- Aerial crossings
- Under crossings
- Buoyancy control systems

4.2.1 Aerial crossings

In the aerial crossing the pipeline is installed over the lake, rivers. This could be carried out by putting the pipeline through existing bridges or to install a separate bridge for the pipelines over the lake, rivers etc. The benefit of this technique is the reduction of disturbances from the wet surroundings. Meanwhile if it is open to the environment it may cause damage with the weather factors like floods, UV degradation etc.

4.2.2 Under crossings

In the under crossing pipeline is installed under the river, lakes etc. This can be done by using HDD (Horizontal directional drilling) method. By using HDD method it will not make troubles to the top surface while installing the pipeline. But in marshy areas it may be difficult to install the pipelines.

4.2.3 Buoyancy control systems

The purpose of these systems is that, it will resolve the above mentioned problem and create downward force which act counter to the floatation effect and hence pipe tends to stay in the design position. The benefit of this process is that it can carry out with more economical and the pipeline installation in the marshy land is comparatively easy while relating with HDD. In the buoyancy control system some gives mechanical protection to the pipeline.

The types of buoyancy control system are

- Concrete Weight Coatings
- Aggregate Envelope Systems
- Steel Screw anchor

Concrete weight coating

Concrete weight coatings have been industrialized forty years ago to supply negative buoyancy to the system. Concrete coatings offer mechanical protection to the systems and act as an anti-corrosion coating during the pipeline construction process. It requires at least 28 days solidity strength is in the 45-50 Mpa range. Drying of concrete coating can be done in different ways, concrete coating wrapped in a perforated polyethylene which avoids concrete break up into chips.

Concrete weight coating offers highly flexibility to both pipeline designers and contractors, concrete coating delivers good stability to the system. The important factor that taken care is that both plant concrete coating and site coatings are expensive in view of certain aspects. In the case of plant coating once concrete is done, it is difficult to transfer that pipe to remote site location. Concrete coating in site will take long time and it may delay the pipeline construction process.

Figure Source: http://wiki.iploca.com/display/rtswiki

Figure 9: Concrete weight coating

Aggregate Envelope coating

Aggregate envelope coating system developed in the year of 1990 to avoid the buoyancy issues in pipelines systems. It arise with fewer time due to the less cost to control the buoyancy process. This system made up of non-woven geotextile and some other materials which are then filled with sand. The main advantage for this is that transportation cost is also less, installation is also simple. It can also be used in semi-aquatic environments like marshy areas. Extra care should be given while handling the bags and the efficiency of these systems is depending upon the quality of installation process in the field, which cannot be guaranteed.

Figure Source: http://wiki.iploca.com/display/rtswiki

Figure 10: Aggregate Envelope coating

Steel screw anchor

Screw anchors are actually a steel shaft with helices that are screwed into the soil. Anchors are placed on the either side of the pipeline with a saddle, which limits the rising effort of the pipeline. There are some factors which should consider while selecting steel screw anchor system.

- Pipe characteristics should be identified
- The arrangement of the screw anchor is calculated in compliance with soil strength, anchor strength, allowable pipe stress etc.

Figure Source: http://wiki.iploca.com/display/rtswiki

Figure 11: Steel screw anchor

4.2.4 Strategies for choosing buoyancy control system

1) Client will assess the different buoyancy control system and will select the system which is more economical. The purchase cost as well as the installation cost which includes the total cost of the system.

2) Client is concerned to choose a floatation control system which creates minimum environmental impact.

3) Some floatation control system cannot be used due to the limited access of right of way.

4) In case of buoyancy control system the client may choose the system which try to maintain the negative buoyancy for entire life of the system, and prefer if any additional features like mechanical protection etc.

Let us consider a pipeline which controls the buoyancy by using concrete casing method.

The Pipeline concrete coating thickness required to satisfy the negative buoyancy criteria have been calculated by the following method.

1. Calculation of Overall Diameter

Weight of steel pipe + Weight of FBE coating + Weight of concrete	=	Buoyancy of pipe × Factor of Safety
$(W_{1+}W_2+W_3)$	=	$W_b \times$ FOS
$W_{1:}$ Weight of Steel pipe (N)	=	$\pi/4 \times (D_o^2 - D_i^2) \times \rho_s \times 9.81 \times L / 10^6$
$W_{2:}$ Weight of FBE Coating pipe (N)	=	$\pi/4 \times (D^2_{FBE} - D_O^2) \times \rho_{FBE} \times 9.81 \times (L-2L_{FBE})/10^6$
$W_{3:}$ Weight of Concrete Coating (N)	=	$\pi/4 \times (D^2_{OD} - D^2_{FBE}) \times \rho_C \times 9.81 \times (L-2L_C)/10^6$
$W_{b:}$ Buoyancy of pipe (N)	=	$\pi/4 \times D^2_{OD} \times \rho_W \times 9.81 \times L / 10^6$

D_{OD}: Overall diameter of pipe with concrete coating

2. Calculation of Concrete Coating Thickness

$t_{CC} = (D_{OD}-D_{FBE})/2$

TABLE 4: CALCULATION OF ANTI-BUOYANCY IN PIPELINE BY CONCRETE CASING METHOD

A	PIPE AND OPERATIONAL CHARACTERISTICS:	SYMBOL	UNITS	QUANTITY	FORMULA
1	Outer Diameter Of pipe	D_0	mm	406.4	
2	Wall thickness of pipe	t	mm	9.53	
3	Thickness of external FBE coating	t_{FBE}	mm	0.4	
4	Inner Diameter of pipe	D_i	mm	387.34	$D_0 - 2\,t$
5	Diameter with external FBE coating	D_{FBE}	mm	407.2	$D_0 + 2\,t_{FBE}$
6	Density of steel	ρ_S	kg/m³	7850	
7	Density of external FBE coating	ρ_{FBE}	kg/m³	1400	
8	Density of Concrete coating	ρ_C	kg/m³	3043	
9	Density of water	ρ_W	kg/m³	1000	
10	Length of pipe	L	m	12	
11	Length of concrete cutback in one length of pipe	L_C	m	0.3	
12	Factor of safety	F_S		1.1	
13	Length of FBE coating cutback in one length of pipe	L_{FBE}	m	0.065	

B	WEIGHT CALCULATIONS	SYMBOL	UNITS	QUANTITY	FORMULA
1	Weight of steel pipe	W_1	N	10980.22	$\pi/4 \times (D_0^2 - D_i^2) \times \rho_s \times 9.81 \times L/10^6$
2	Weight of external FBE coating	W_2	N	83.34	$\pi/4 \times (D_{FBE}^2 - D_0^2) \times \rho_{FBE} \times 9.81 \times (L-2L_{FBE})/10^6$
3	Weight of concrete	W_3	N	$0.27D^2_{OD}$ - 44318.11	$\pi/4 \times (D_{0D}^2 - D_{FBE}^2) \times \rho_C \times 9.81 \times (L - 2L_C)/10^6$
4	Buoyancy of pipe.	W_b	N	$0.09D^2_{OD}$	$\pi/4 \times D_{0D}^2 \times \rho_w \times 9.81 \times L/10^6$
C	**CONDITION FOR ANTI-BUOYANCY**	**SYMBOL**	**UNITS**	**QUANTITY**	**FORMULA**
1	Wt. of steel pipe + Wt. of FBE coating + Wt. of concrete		N	$0.27D^2_{OD}$ - 33254.56	$W_1 + W_2 + W_3$
2	Buoyancy of pipe * Factor of Safety		N	0.1017 D^2_{OD}	$W_b \times F_s$
D	**RESULTS**	**SYMBOL**	**UNITS**	**QUANTITY**	**FORMULA**
1	Overall Diameter of Pipe	D_{OD}	mm	448.15	By Equating C1 & C2
2	Thickness of concrete coating calculated	t_{CC}	mm	20.48	$(D_{OD} - D_{FBE})/2$
3	Thickness of concrete coating selected	t_{CCS}	mm	25	

CHAPTER 5: RESULTS AND DISCUSSIONS

For wall thickness calculation and stress verification, by choosing a pipe wall thickness of 10.97 mm as per ASME codes we have found that it is safe design criteria. Stress verification is done with respect to hydrotest pressure criteria, tensile load criteria, collapse criteria etc.

For road crossing calculations, the thickness was found to be sufficient to withstand the loads. The design check is carried out and thickness provided is found to be satisfying all three design check conditions and so there is no need to add any extra thickness to the pipeline unless recommended by the client according to their policies. Understanding about the different external factors that are taken into consideration during crossing is also done.

For anchor force and virtual anchor length, calculation of virtual anchor length is done based on anchor force. Further analysis should be conducted here to validate the above ground pipe movement through Ceaser II and appropriate decision to be made. By analyzing the above ground movement of pipe, we would come to know that whether the anchor block is required or not.

For pipeline anti-buoyancy system, optimal buoyancy control system is selected from various researches. From client requirement, here we choose concrete coating system to avoid the floatation. Discussion is done for the challenges of concrete coating system if it is coated in plant or at the site. From calculations, the concrete thickness is to be 20.48mm. But from the safety point of view and client’s recommendation we choose 25mm as the thickness of concrete coating.

CHAPTER 6: CONCLUSION

The details which I have stated here is a part of an ongoing project. For wall thickness calculation & stress verification as per client requirement we followed ASME B 36.10 and took 10.97 mm as wall thickness. It has been found that the stress verification is satisfied and is within the criteria limit. By having a safety factor, we can find a more economical wall thickness if the client requires. For road crossing analysis, a suitable cover depth, pipe grade and wall thickness should be considered for a safe crossing. From the soil investigation and analyzing the risk of crossings, a suitable boring method is chosen and simultaneously checked to find out the different stress and loads which are acceptable and within the safety limit. Sometimes as per client requirement we choose higher grade pipe with the concern of higher loads in crossings. For anchor force and virtual anchor length, I have found virtual anchor length from manual calculation. For more investigation the virtual anchor length should be thoroughly inspected through Caeser II software and should find the above ground movement of pipe is within the acceptable limit, which is provided by the Client. For anti-buoyancy calculation, from my research I found the most efficient buoyancy control system is concrete casing method except that the concrete coating is a time consuming task. But when I compared with the other buoyancy control systems the main advantage which I have found in concrete coating system is that, it can provide mechanical protection to the pipeline systems from external damages.

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