

ANALYSIS IN A PIPELINE

FINAL YEAR PROJECT REPORT

Submitted by

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In partial fulfillment for the award of the degree of

MASTER OF TECHNOLOGY IN
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Vishnu S

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Vishnu S

30/04/15



CERTIFICATE

This is to certify that the thesis entitled, “**Analysis in a Pipeline**” being submitted by **Vishnu S** for the award of the degree of Master of Technology (Pipeline Engineering) of UPES Dehradun, is a record of bonafide research work carried out by him under our supervision and guidance. Mr. Vishnu S has worked for this semester on the above problem at the Department of Mechanical Engineering, University of Petroleum and Energy Studies, Dehradun and in **Saipem India Projects Pvt. Ltd.** this has reached the standard fulfilling the requirements and the regulation relating to the degree.

The contents of this thesis, in full or part, have not been submitted to any other university or institution for the award of any degree or diploma.

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ABSTRACT

The main aim of this master thesis is to carry out different analysis in a pipeline. Pipelines are designed for transporting oil & gas from one location to the other. If a Pipeline failure happens it will be catastrophic, nowadays pipeline safety is given importance in the designing stage itself. Therefore it is essential for good Pipeline design to perform different analysis considering the safety during operation. Different Analysis are done in mechanical, civil and process side respectively

This paper discusses about the mechanical analysis carried out in a pipeline. This report include Stress analysis, Pipeline expansion analysis, Stability analysis, Buckling analysis ,Crossing analysis, Seismic analysis of pipeline of different diameter.

Stress in a pipeline due to lowering, hydro testing and operational are found out and checked with standard API 1117.

Pipeline expansion analysis are done to found out the expansion length and virtual anchor length

Pipeline stability analysis are done to check the floatation of pipeline in marshy areas

Stress induced while crossing a river or rail are found out in crossing analysis

Seismic analysis had been specifically done assuming the pipeline to be coming under earth quake prone area. The maximum strain for various seismic loads has been calculated and checked against the allowable strain under operating conditions.

Contents

ACKNOWLEDGMENTS	3
DECLARATION	4
CERTIFICATE	5
ABSTRACT.....	6
NOMENCLATURE.....	10
List of Symbols	10
List of Figures	16
List of Tables	18
SAIPEM INDIA PROJECTS PVT LTD.....	19
CHAPTER 1	20
1 INTRODUCTION	21
1.1Background	21
1.1.1Design starting procedure	21
1.2 Objectives.....	25
1.3 Scope of Work.....	25
CHAPTER TWO	26
2 LITERATURE REVIEW	27
CHAPTER 3	29
3 THEORTICAL BACKGROUND.....	30
3.1 Carbon Steel Pipe.....	30
3.2 HDPE Pipe.....	32
3.3Classification of Loads.....	34
3.4 Modes of failure.....	35
3.5 Stress in pipe	37
3.5.1 Stress due to internal Pressure	37
3.5.2 Stress due to force and moments.....	38
3.6 Principal Stress	40
3.7 Theories of failure	40
3.8 Strain	41
3.9 Stress analysis	42
3.10 Seismic hazards	43

3.10.1 Permanent Ground Deformation.....	44
3.10.2 Buoyancy due to liquefaction	45
3.10.3 Faulting.....	45
3.10.4 Seismic Wave Propagation.....	46
3.11 Crossing analysis	46
CHAPTER 4	48
4 METHODOLOGY	49
4.1 Thickness calculation	49
4.1.1 WALL THICKNESS CALCULATIONS 30" MAINLINE	50
4.2 Stress analysis	51
4.2.1 Lowering In-Service Pipelines 30" X 14.3 mm Wall Thickness	54
4.2.2 Hydro test condition 30" X 14.3 mm Wall Thickness	56
4.2.3 Operating Condition 30" X 14.3 mm Wall Thickness	59
4.3 Pipe Expansion analysis.....	62
4.3.1 Pipe Expansion analysis for 30 X 14.3 Wall Thickness	63
4.4 Pipe Stability Analysis for crossings	65
4.4.1 Pipe Stability Analysis for 30"x14.3 Wall thickness	67
4.5 Crossing analysis	69
4.5.1 Rail Crossing	70
4.5.2 Highway Crossing	74
4.5.3 Rail crossing analysis for 30"x15.9 wall thickness	77
4.5.4 Highway crossing analysis for 30"x15.9 wall thickness	79
4.6 Seismic Analysis	81
4.6.1 Design Criteria for Permanent Ground Deformation (PGD)	85
4.6.2 Design Criteria for Buoyancy due to Liquefaction	86
4.6.3 Design Criteria for Fault Crossing.....	86
4.6.4 Design Criteria for Seismic Wave Propagation	87
4.6.5 Seismic Analysis for 30"x 15.9 wall thickness pipe	89
4.6.5.1 OPERATIONAL STRAIN.....	90
4.6.5.2 Calculation of Soil Resistance	90
4.6.5.3 Longitudinal PGD.....	92
4.6.5.4 Transverse PGD	92

ANALYSIS IN A PIPELINE

4.6.5.5 Buoyancy due to Liquefaction 93

4.6.5.6 Seismic Wave Propagation..... 94

4.6.5.7 Fault crossing 95

4.6.6. Measures to prevent pipeline failure under seismic activity..... 96

CHAPTER 5 101

RESULTS 102

1) Stress analysis 102

 Stress analysis for CS pipe..... 102

 Stress analysis for HDPE pipe..... 102

2) Pipeline Expansion analysis..... 102

3) Pipe Stability Analysis 102

4) Rail Crossing Analysis 103

5) Road Crossing Analysis..... 103

6) Seismic Analysis 103

CHAPTER 6 104

CONCLUSION..... 105

REFERENCES..... 106

Appendix A..... 107

 Lowering In-Service Pipelines 30" X 15.9 mm Wall Thickness 107

 Hydro test condition 30" X 15.9 mm Wall Thickness 109

 Operating condition 30" X 15.9 mm Wall Thickness 111

 Lowering In-Service HDPE Pipelines 30" 113

 Hydro test condition for 30" HDPE pipe 115

 Operating condition 30" HDPE pipe 117

Appendix B 120

 Pipe Expansion analysis for 24" X 14.3 Wall Thickness..... 120

Appendix C 123

 Pipe Stability Analysis for 24"x14.3 Wall thickness 123

Appendix D..... 126

 Seismic Analysis for 30"X 15.9 wall thickness pipe 126

NOMENCLATURE

List of Symbols

P	Pressure
D	Diameter of the pipe
T	Thickness of the pipe
N	Poisson ratio
E	Young's Modulus of Elasticity
α	Coefficient of thermal expansion
t_c	Thickness of the Coat
t_{cc}	Thickness of the Concrete
R_c	Radius of Curvature
SMYS	Specified Minimum Yield Strength
F	Design factor
ρ_{pipe}	Density of the pipe
ρ_{coat}	Density of the coat
$\rho_{concrete}$	Density of the concrete
$\rho_{content}$	Density of the content
ID	Inner diameter of the pipe
Δ	Mid –span deflection of the pipe
γ	Unit weight of the soil
H	Burial depth
T	Temperature derating Factor
F	Design Factor
E	Longitudinal Joint Factor
D_{coat}	Diameter of the pipe with coating

ANALYSIS IN A PIPELINE

D_{concrete}	Diameter of the pipe with concrete coating
CA	Corrosion Allowance
S_p	Longitudinal stress due to internal pressure
S_t	Longitudinal stress due to temperature change
S_c	Longitudinal flexure stress due to existing elastic curvature
S_e	Existing longitudinal stress in the pipe
S_b	Longitudinal stress in the pipe due to net downward weight of pipeline
S_s	Longitudinal stress in the pipe due to its elongation caused by the vertical deflection of pipe
W_{pipe}	Weight of the pipe
W_{coat}	Weight of the coating
W_{conc}	Weight of the concrete
W_{cont}	Weight of the content
W_{soil}	Weight of the soil
W_t	Total of the pipe
S	Section modulus
S_h	Hoop stress
S_{eq}	Equivalent stress in the supported zone
S_b	Allowable bending stress
L_t	Min. trench length
L_s	Allowable pipe span
T1	Temperature during installation

ANALYSIS IN A PIPELINE

T_2	Temperature during operation
μ	Coefficient of friction
A	Area of the pipe
$F_{ex(T)}$	Expansion Force due to Change in Temperature
$F_{ex(P)}$	Expansion Force due to pressure
F_{ex}	Expansion force
F_f	Friction force at soil pipe interface
L_a	Length of virtual anchor from point of entry
Δl_p	End expansion due to pressure effect
Δl_t	End expansion due to temperature effect
Δl_f	End expansion due to soil friction
Δl	Net pipeline end expansion
F_s	Factor of safety
A_t	Cross sectional area of pipe including the coatings
ρ_p	Submerged density of pipe
WDF	Weight of Displaced Fluid
WRB	Required buoyancy
S_{he}	Stress due to earth load
K_{he}	Stiffness factor for circumferential stress earth load
B_e	Burial factor for earth load
E_e	Excavation factor for earth load
ΔS_{Hh}	Cyclic circumferential stress due to highway
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
F_i	Impact factor
ΔS_{Lh}	Longitudinal circumferential stress due to highway
K_{Lh}	Highway stiffness factor for cyclic longitudinal stress
G_{Lh}	Highway geometry factor for cyclic longitudinal stress
ΔS_{Hr}	Cyclic circumferential stress due to rail
K_{Hr}	Rail stiffness factor for cyclic circumferential Stress
G_{Hh}	Rail geometry factor for cyclic circumferential Stress
F_i	Impact factor
ΔS_{Lh}	Longitudinal circumferential stress due to rail
K_{Lr}	Rail stiffness factor for cyclic longitudinal stress
G_{Lr}	Rail geometry factor for cyclic longitudinal stress
S1	Maximum circumferential stress
S2	Maximum longitudinal stress
S3	Maximum radial stress
n	Ramberg Oswood parameter
r	Ramberg oswood parameter
C	Coefficient of cohesion
Φ	Angle of friction

γ_{sat}	Saturated unit weight of soil
σ_y	Yield stress
ϵ_p	Strain due to pressure
ϵ_t	Strain due to change in temperature
ϵ_{ot}	Total operational strain
δ	Interface angle of friction between soil and pipe
K	Coefficient of soil pressure at rest
α	Adhesion Factor
tu	maximum axial soil force transmitted to the pipe
Pu	maximum transverse soil force that is transmitted to the Pipe per unit length
Nch	Horizontal bearing capacity factor for clay
Nqh	Horizontal bearing capacity factor for sandy soil
Ncv	Vertical uplift factor for clay
Nqv	Vertical uplift factor for sandy soil
Qu	maximum uplift soil resistance per unit length of pipe
Qd	maximum bearing resistant force of the soil upon unit length of the pipeline
δ^l	Expected amount of permanent ground movement Parallel to pipe axis
ϵ_a	Peak Axial Strain in Pipe
ϵ_b	Peak bending Strain in Pipe
W	Width of permanent ground deformation
Fb	Net upward force per unit length of pipeline

ANALYSIS IN A PIPELINE

V_g	Design wave propagation velocity
C	Velocity of seismic wave propagation
α_ε	Ground strain coefficient
δ_{fn}	Expected normal slip fault displacement
Ψ	Angle of dip of fault movement
β	Angle b/w pipeline & fault line
δ_{fax}	Displacement in axial direction
δ_{ftr}	Displacement in transverse direction

List of Figures

Figure 1: Flow Design Process	22
Figure 2: Design Analysis.....	23
Figure 3 Stress due to internal pressure.....	37
Figure 4 Longitudinal stress	37
Figure 5 Hoop Stress	38
Figure 6 Radial Stress	38
Figure 7 Stress due to forces.....	39
Figure 8 Stress due to moments	40
Figure 9 stress strain graph	42
Figure 10 Lowering of pipeline	43
Figure 11 Longitudinal PGD	44
Figure 12 Transverse PGD.....	45
Figure 13 Buoyancy due to liquefaction	45
Figure 14 Normal Fault	46
Figure 15 Strike slip.....	46
Figure 16 Road and rail crossing diagram.....	47
Figure 17 Stiffness factor due to earth load	71
Figure 18 Burial Factor for earth load.....	71
Figure 19 Excavation factor for earth load	71
Figure 20 Impact factor versus depth.....	72
Figure 21 Railroad stiffness factor for cyclic circumferential stress	72
Figure 22 Geometry factor versus diameter.....	73
Figure 23 Railroad track factor for cyclic circumferential stress	73
Figure 24 Rail road stiffness factor for cyclic longitudinal stress	73
Figure 25 railroad geometry factor for cyclic longitudinal stress.....	74
Figure 26 Highway stiffness factor for cyclic circumferential stress	75
Figure 27 Highway geometry factor for cyclic circumferential stress	75

ANALYSIS IN A PIPELINE

Figure 28 Highway Stiffness factor for longitudinal stress	76
Figure 29 Highway factor for cyclic longitudinal stress	76
Figure 30 BNFW model representing pipe soil interaction	84
Figure 31 Bearing capacity factor of soils of different soil friction values.....	85
Figure 32 trench design for strike slip fault	98
Figure 33 trench design for reversefault	99

List of Tables

Table 1 Properties of carbon steel.....	30
Table 2 Properties of HDPE pipe.....	33
Table 3 Rail and road crossing depth of trench	47
Table 4 Ramberg oswood parameter for buried pipeline.....	82
Table 5 Maximum allowable strain	82
Table 6 lateral bearing capacity of soil	84
Table 7 Importance Factor of different classes	85
Table 8 PGA for different seismic zone	88
Table 9 ratio of PGv/PGA.....	88

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Saipem is an international leader in Engineering, Procurement, Construction and Installation services to the oil & gas industry. It is present over 82 countries and in India it is named as Saipem India Projects (SIP) Ltd.

SIP's transformation into a full EPC hub is one of Saipem latest and major investments. Thus, its services now range from feasibility study to commissioning, operations and maintenance in the sectors of Onshore and Offshore Pipe laying, Cryogenic Tanks, Refining and Petrochemicals.

SIP covers the entire spectrum of upstream/downstream as well as onshore/offshore projects and all its teams are well-equipped to handle projects right from conceptual studies through detailed and field engineering. Its procurement services also encompass market scouting, cost estimation, request for quotation, technical and commercial evaluations, contracts negotiations, post-order management including inspection and expediting, shipment and customs clearance.

CHAPTER 1

1 INTRODUCTION

1.1 Background

Many factors must be considered in the design of long-distance pipelines. These include the volume of the oil /gas to be transmitted, Nature of oil/gas to be transmitted, the length of the pipeline, and type of terrain to be crossed, and maximum elevation of the route, diameter of the pipe. After a pumping station/ gas compression station is located and sized, the gathering system is designed. This involves the location of the wells, the ability of right of way, the amount of oil/gas to be handled, the distance to be transported, and the pressure difference between the field and the main transmission line. The wells are generally located in groups around a geological structure or within the defined limits of a pool or gas reservoir.

A successful design of a pipeline requires a team of well trained and experienced engineering and legal staff. Complex engineering studies are needed to decide on which is the best diameter, yield strength, and pumping horsepower required giving the optimum results for any particular pipeline transmission system. Analysis of these are done using Computer programs that enable high-pressure transmission networks to be dynamically simulated on a digital computer are used by gas pipeline operating companies and service companies. Several designs are usually made so that the economical one can be selected. The maximum capacity of a pipeline is limited by its initial parameters of construction. In general, the tendency is to use higher transmission pressures and strong materials of construction. For economic operation, it is important to preserve full pipeline utilization.

1.1.1 Design starting procedure

When a new pipeline is to be designed, there are no specified rules for the designer to follow. The problem can be solved in numerous ways. However most common procedure a designer follows are given below.

1. Make a written statement of the problem, as clearly as possible, and also for purpose for which the pipeline is to be designed.
2. Make selection of possible route which will give the desired output.

3. Determine the forces acting on and the energy transmitted by the each element being attached.
4. Select the best material suited for each element of the pipeline.
5. Determine the size of each Pipe, with a view to get desired delivery pressure & flow
6. Determine the allowable or design stress considering all the factors that affect the strength of the pipeline.
7. Make detail drawings of the pipeline with the complete specification for the materials and manufacturing.

So the design of a new pipeline may follow a tentative plan as shown by broken arrows, the designed plan is not a rigid one way process but there is a continuous feedback. After the general specifications of the pipeline have been set, the flow scheme is decided. This is followed by a force analysis. This force analysis at this stage would be rather incomplete for designs where dynamics is of importance, since volume of the liquid moving are not yet known. With this preliminary information, a tentative design of the forces is not known exactly.

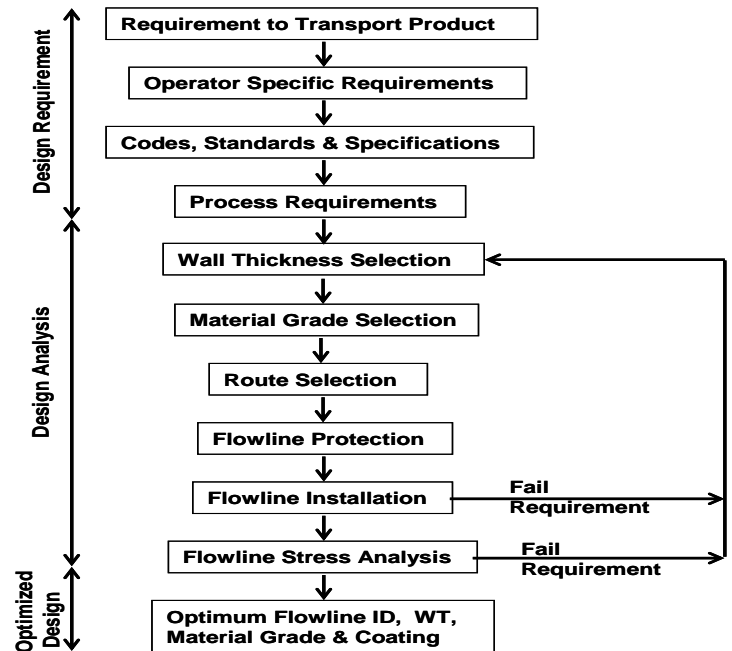
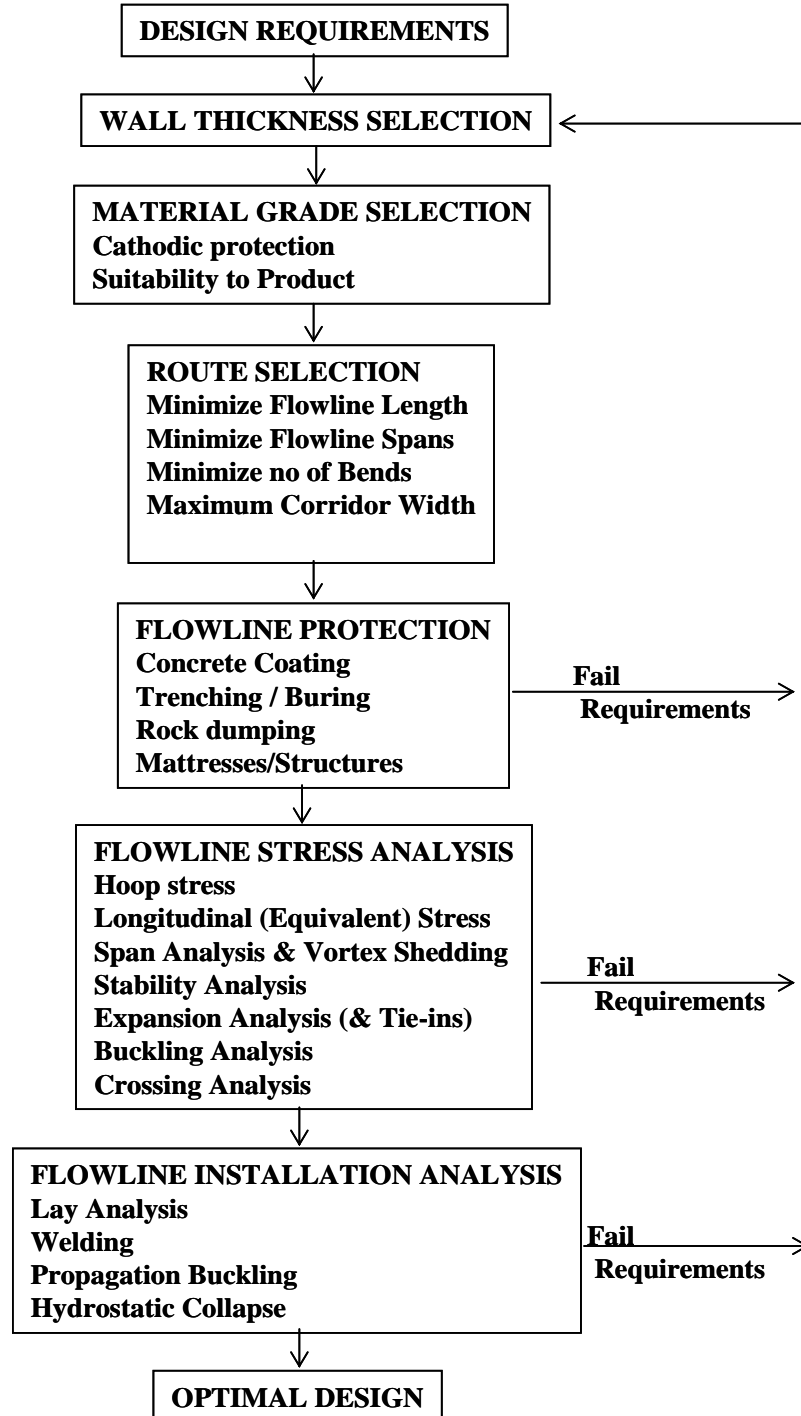


Figure 1: Flow Design Process

Each stage in the design should be addressed whether it is conceptual, preliminary or detailed design. However, the level of analysis will vary depending on the required output.

Figure 2: Design Analysis



The objectives of the detailed design should be developed such that:

- ❖ Pipeline wall thickness, grade, coating and length are specified so that pipeline can be fabricated.
- ❖ Route is determined such that alignment sheets can be compiled.
- ❖ Pipeline stress analysis is performed to verify that the pipeline is within allowable stresses at all stages of installation, testing and operation. The results will also include pipeline allowable spans, tie-in details (including expansion spool pieces), allowable testing pressures and other input into the design drawings and specifications.
- ❖ Pipeline installation analysis is performed to verify that stresses in the pipeline at all stages of installation are within allowable values. This analysis should specifically confirm if the proposed method of pipeline installation would not result in pipeline damage. The analysis will have input into the installation specifications.
- ❖ Analysis of global response;
 - Expansion, effective force and global buckling
 - Hydrodynamic response
 - Impact
- ❖ Analysis of local strength
 - Bursting, local buckling, ricketing
 - Corrosion defect and dents

Sizing Pipelines

The capacity of gas transmission of a pipeline is controlled mainly by its size. Complex equations have been developed for sizing natural gas pipelines in various flow conditions. The Weymouth equation, the Panhandle equation, and the Modified-Panhandle equation are used for relating the volume transmitted through a gas pipeline to the various factors involved, thus deciding the optimum pressure and pipe dimensions. From equations of this type, various combinations of pipe diameter and wall thickness for a desired rate of gas throughout can be calculated. An optimum balance is sought between pipe tonnage and pumping horsepower.

Corrosion Allowance

Extra wall thickness is added to account for corrosion when water is present in a fluid along with contaminants such as oxygen, hydrogen sulfide (H₂S), and carbon dioxide (CO₂). A review of standards, rules, and codes of practices (Hill and Warwick 1986) shows that wall allowance is only one of several methods available to prevent corrosion, and often the least recommended

1.2 Objectives

- ❖ To find out Stress developed in a pipeline for different diameters
- ❖ To carry out Pipeline expansion analysis in a pipeline for different diameters
- ❖ To check the floatation of pipeline in marshy areas
- ❖ Stress induced while crossing a river or rail are found out in crossing analysis
- ❖ Seismic analysis had been specifically done assuming the pipeline to be coming under earth quake prone area

1.3 Scope of Work

- ❖ Stress in a pipeline due to lowering, hydro testing and operational are found out and checked with standard API 1117.
- ❖ Stress developed in a pipeline for 30 inch and 24 inch pipeline has been found out
- ❖ Stress developed in HDPE pipe line is also calculated
- ❖ Pipeline expansion analysis are done to found out the expansion length and virtual anchor length
- ❖ Pipeline stability analysis are done to check the floatation of pipeline in marshy areas
- ❖ Stress induced while crossing a river or rail are found out in crossing analysis
- ❖ Seismic analysis had been specifically done assuming the pipeline to be coming under earth quake prone area like Permanent ground deformation, Faulting, Buoyancy due to liquefaction

CHAPTER TWO

2 LITERATURE REVIEW

- 1. Pipeline design and construction - A practical approach by M Mohitpur -**
Design calculations for pipelines in this project has been used with the help of this book. Chapter 7 of this book is mostly referred to get the idea about mechanical design of pipelines like the stress involved in pipeline during crossing ,pipeline expansion ,stability .Chapter 8 of this book is referred to get idea of the materials used in pipelines
- 2. ASME B 31.8-- 2002: Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids-** This book has been referred to get an understanding of the codes and standards set for the Design of Gas Pipelines.
- 3. ASME A 106-2004: Seamless Carbon Steel Pipe for High-Temperature Service-** This book has been referred to get an understanding of the carbon steel material its composition and types used in the industry.
- 4. Aquaflo HDPE pressure pipe systems,2009-**This document has been used to get an idea about HDPE pipelines and values of physical properties values used in the calculations are from this document
- 5. Pipe Stress Engineering by Liang-Chuan(L.C).PENG -2000-** This book has given an insight for understanding of the modes of failure in a pipe and type of stresses acting on a pipeline and the effect of stress acting in pipeline
- 6. API 5L:Specification for line pipe-**This standard has provided me with necessary guidelines followed for selecting a pipe diameter and wall thickness.
- 7. API 1102: Steel Pipelines Crossing Railroads and Highways.** This standard has provided me with necessary guidelines for finding out the stress induced in a pipeline during crossing of the Railroads and Highways and steps to be followed for calculating the total stress induced in a pipeline.
- 8. API 1117: Recommended Practice for Movement of In-service Pipeline-**
This standard has provided me with necessary guidelines for lowering of in-

service pipeline. Steps to be followed in lowering the pipelines and the stress calculations involved in lowering of pipelines

9. **IITK-GSDMA Guidelines for Seismic Design of Buried Pipelines, November 2007 edition-** This handbook has provided the information regarding Seismic activities like types of seismic activities its effects, how to mitigate these effects and calculate the strains induced in each seismic events
10. **Seismic Design of continuous pipeline by A.K.Arya, B Shingan, Ch. Vara Prasad.** This handbook has provided the information required regarding the ways to prevent pipeline failure under different seismic activity.
11. **ALA 2001 guidelines for the design of buried steel pipelines.** This book have given idea to design a pipeline in earthquake prone area as there is no specific standards for seismic analysis this guidelines was found very useful.

CHAPTER 3

3 THEORETICAL BACKGROUND

3.1 Carbon Steel Pipe

Carbon Steel is the most widely used steel. In metallic pipes, carbon steel pipe is used 90% in industry. Carbon steel is the steel where the main alloying element is carbon and no minimum content is specified for other alloying elements including Cr, Ni, Mo, Ti, and Tungsten etc.

Carbon steel is generally four classes based on carbon content:

Mild and low carbon steel: Low carbon steel contains approx. 0.05-0.15% carbon and mild steel contains 0.16-0.29% carbon, therefore it is neither brittle nor ductile.

Medium carbon steels: carbon content in the range of 0.30 – 1.70% by weight can be successfully heat-treatment.

High carbon steel: Approximately 0.6-0.99% carbon content. Very strong, used for springs and high-strength wires.

Ultra-high carbon steel: Approximately 1.0-2.0% carbon content. Ultra-high Carbon Steel can be tempered to great hardness used for knives, axles or punches.

Table 1 Properties of carbon steel

Steel Type	Density 10^3 kgm^{-3}	Thermal conductivity $\text{Jm}^{-1}\text{K}^{-1} \text{ s}^{-1}$	Thermal expansion 10^{-6}K^{-1}	Young's modulus GNm^{-2}	Tensile strength MNm^{-2}	% elongation
Low carbon	7.86	50	11.7	210	350	30
Medium Carbon	7.85	48	11.3	210	600	20
High carbon	7.84	46	10.8	210	800	8

Carbon equivalent formulas is used to give a numeric value to a steel composition that would give an indication of the percentage of carbon present that would contribute to an equivalent level of hardenability for that steel.

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

CE Carbon Equivalent

C Carbon

Mn Manganese

Cr Chromium

V Vanadium

Ni Nickel

Cu Copper

The properties of Carbon steel can be enhanced by using the appropriate alloying elements. There are different alloying elements on steel like Magnesium, Silicon, Copper, Chromium, Molybdenum, Vanadium, Nickel, Aluminum, Boron, Titanium, Zirconium, Calcium, Lead Nitrogen, and Tungsten.

Carbon steel is available in virtually all product forms like pipes, tubes, plates, castings, fittings.

ASTM A 106/A 106M -Seamless Carbon Steel Pipe for High-Temperature Service is the common standard used for carbon steel pipeline

API 5L is the specification for line pipe

3.2 HDPE Pipe

High density polyethylene pipe has been used extensively around the world since the 1950's. Initially it was used for below 2 bar system. The unique properties of High density polyethylene pipe have offered an alternative to traditional material like steel and copper.

The common HDPE pipe used in industries are PE 80 and PE 100 material. HDPE pipes have excellent flow characteristics and properties such as impact resistance and resistance to abrasion, which have made HDPE pipe the obvious choice in the Mining and Industrial markets. Piping made from polyethylene is a cost effective solution for a broad range of piping applications in the municipal, industrial, marine, mining, landfill, duct and agricultural industries. It has been tested and proven effective for above ground, surface, buried slip-lined, floating and sub-surface marine applications.

High-density polyethylene pipe (HDPE) can carry potable water, wastewater, slurries, chemicals, hazardous wastes, and compressed gases. In fact, polyethylene pipe has a long and distinguished history of service in the gas, oil, mining and other industries. It has the lowest repair frequency per kilometer of pipe per year compared with all other pressure pipe materials used for urban gas distribution.

Polyethylene is a strong, extremely tough, very durable product which offers long service and trouble-free installation.

Characteristics of HDPE pipeline

- ❖ Resistance to weather degradation
- ❖ Highly corrosion resistant
- ❖ Ease of handling and installation, exceptional toughness
- ❖ Excellent abrasion resistance
- ❖ Manufactured to internationally accepted standards
- ❖ Service performance in excess of 50 years

Properties	Units	HDPE
Tensile strength at yield	MPa	26
Elongation at yield	%	10
Modulus of elasticity	MPa	900
Rockwell hardness	Shore	61
Dielectric strength	kV/mm	70
Density	kg/m ³	0.958×10^3
Co-efficient of linear expansion	K ⁻¹	16×10^{-5}
Thermal conductivity at 20°C	W/m/K	0.50
Specific heat	J/kg/K	2.3×10^3
Flammability	-	Flammable

Table 2 Properties of HDPE pipe

SABS 533, SABS ISO 4427 of 1996 is the standards for HDPE pipe

3.3 Classification of Loads

Primary Loads

These are typically steady or sustained types of loads such as internal fluid pressure, external pressure, gravitational forces acting on the pipe such as weight of pipe and fluid, forces due to relief or blow down pressure waves generated due to water hammer effects.

The last two loads are not necessarily sustained loads. All these loads occur because of forces created and acting on the pipe. In fact, primary loads have their origin in some force acting on the pipe causing tension, compression, torsion etc. leading to normal and shear stresses. A large load of this type often leads to plastic deformation. The deformation is limited only if the material shows strain hardening characteristics. If it has no strain hardening property or if the load is so excessive that the plastic instability sets in, the system would continue to deform till rupture. Primary loads are not self-limiting. It means that the stresses continue to exist as long as the load persists and deformation does not stop because the system has deformed into a no-stress condition but because strain hardening has come into play.

Secondary Loads

Just as the primary loads have their origin in some force, secondary loads are caused by displacement of some kind. For example, the pipe connected to a storage tank may be under load if the tank nozzle to which it is connected moves down due to tank settlement. Similarly, pipe connected to a vessel is pulled upwards because the vessel nozzle moves up due to vessel expansion; a pipe may experience expansion or contraction once it is subjected to temperatures higher or lower respectively as compared to temperature at which it was assembled.

The secondary loads are often cyclic but not always. For example load due to tank settlement is not cyclic. The load due to vessel nozzle movement during operation is cyclic because the displacement is withdrawn during shut-down and resurfaces again after fresh start-up. A pipe subjected to a cycle of hot and cold fluid similarly undergoes cyclic loads and deformation. Failure under such loads is often due to fatigue and not catastrophic in nature.

3.4 Modes of failure

A pipeline must be designed so that it works satisfactorily, without failure. The main purpose of the piping mechanical work is to prevent piping failure. Therefore, it is important to find out how the pipe fails. A pipeline may fail under the four modes given below

- 1 Strength-Yielding, rupture
- 2 Fatigue
- 3 Creep at high temperatures
- 4 Buckling-stability
- 5 Miscellaneous modes of failure

Failure by yielding, rupture

For brittle material, strict control of the stress and nature of loading is required. In places where mechanical or thermal shock loadings are anticipated, they cannot be used as this failure occurs unexpectedly & suddenly. This is due to

Its low energy absorbing capability, where even a slight impact or deformation translates to high stresses. The high stresses which are developed can only be relieved by yielding.

In case of ductile materials, as the load increases or when impact loading is done, the material is capable of absorbing excess energy by undergoing considerable plastic deformation and fails after going through fairly large amount of elongation. They elongate about 25% before failure.

There are some materials which becomes brittle due to temperature change. Most piping material lose their ductility as the temperature drops below a certain limit. Also there are few materials that become brittle at high temperatures due to metallurgical changes.

Fatigue Failure

The pipe can fail under a stress lower than the ultimate strength of the material if the stress is cyclic. Thermal or Mechanical fatigue is mostly common cause in high temperature cyclic piping systems

ANALYSIS IN A PIPELINE

Thermal fatigue is caused by frequent change in operating temperature. Mechanical fatigue is caused by pipe movement, vibration, restraints preventing free movements and other conditions.

In pipeline, the loading cycle applied is frequently only in thousands and mainly in startup, shut-down and regeneration cycle. This type of fatigue are called low cycle fatigue. In rotary equipment fatigue is normally High cycle fatigue

Due to cyclic loadings piping fails under a stress much lower than the ultimate strength of the material.

Creep Failure

At high temperature environment, pipe continue to deform under sustain i.e. weight and pressure loading. The pipe may fail after a certain period even if the stress is much lower than the ultimate strength of the material. This time dependent progressive deformation and consequent failure is called creep. They only occur at high temperatures

Stability Failure

Stability failure is mainly caused by the compressive stress. This failure mode is prone to thin walled shells and pipes. Also in thick pipes this failure mode may occur, but only when subjected to external pressure like deep water

Miscellaneous mode of failure

There are other mode of failure like corrosion, erosion & Hydrogen cracking

Corrosion affects the pipe in two areas, Firstly there is reduction in wall thickness and then there is stress intensification of the corroded pits. These corroded pits can greatly reduce the fatigue strength

Rubbing of the fluid against pipe wall erodes pipe wall to some extent. Most of the two phase flow causes erosion. Turbulence, low PH and low oxygen content are some of the parameters that favours erosion of carbon steel pipes

Excessive deflections or sagging caused in the piping system leading to fluid trapping

3.5 Stress in pipe

A pipe experiences two main types of stresses. The first type of stress comes from the pressure, either internal or external. The second category of stress comes from the forces and moments generated by weight, thermal expansion, wind, and earthquake

3.5.1 Stress due to internal Pressure

When a pipe is pressurized, its inside surface is exposed to the same pressure in all directions. The pressure force is acting in the normal direction of the surface.

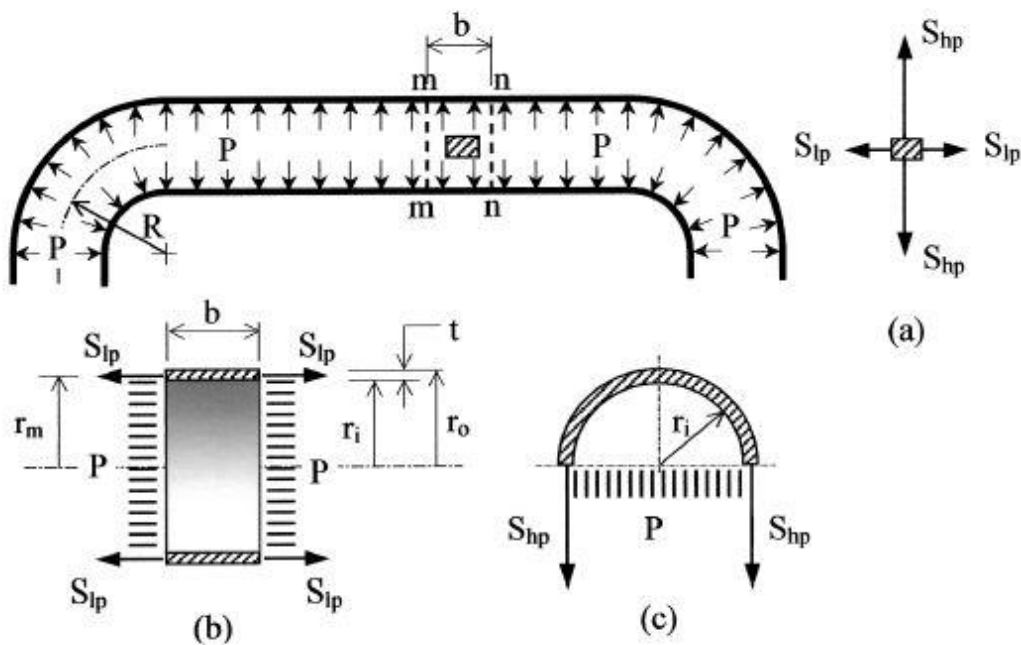


Figure 3 Stress due to internal pressure

Longitudinal Stress

Stress in the axial direction of the pipe is called longitudinal stress

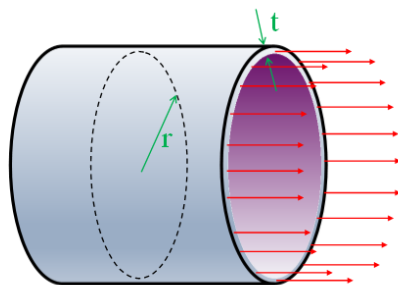


Figure 4 Longitudinal stress

$$Slp = \frac{PD}{4t}$$

Circumferential Stress

Stress in the circumferential direction of the pipe is called circumferential or Hoop stress

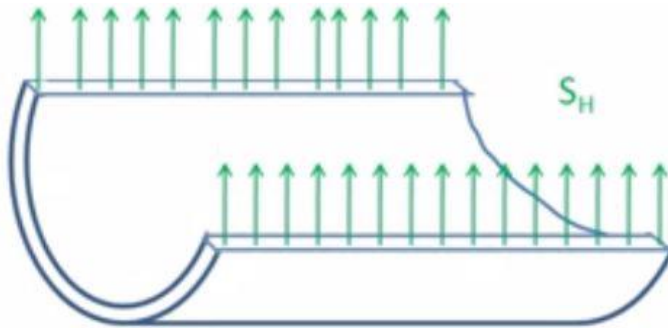


Figure 5 Hoop Stress

$$SHp = \frac{PD}{2t}$$

Radial Stress

Stress towards or away from the central axis of the pipe is called radial stress. The radial stress of a pipe is equal to the gauge pressure on the inside and zero on the outer side. It acts parallel to the pipe radius

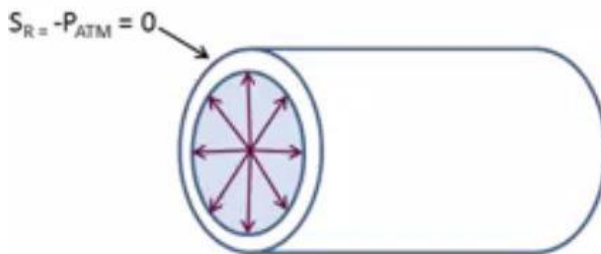


Figure 6 Radial Stress

The circumferential stress and longitudinal stress are much larger than the radial stress for thin walled pressure vessel so its normal neglected

3.5.2 Stress due to force and moments

Besides the internal pressure that generates stress other loadings can also produce internal forces and moments that generate significant stress in the pipe. These internal forces and moments acting at a given pipe cross-section are the result

of thermal expansion, weight, wind, earthquake, and other internal and external loads applied to the piping system.

Stress due to forces

In a piping component, forces can be divided into two categories: shear force, F_s , which acts in a direction perpendicular to the pipe axis; and axial force, F_a , which acts in the axial direction of the pipe. With coordinate axes selected as the shear force comprises two forces, F_y and F_z , each of which produces a shear stress at the pipe cross-section. The stress is not uniform, and is greatest at the diametrical centerline perpendicular to the force.

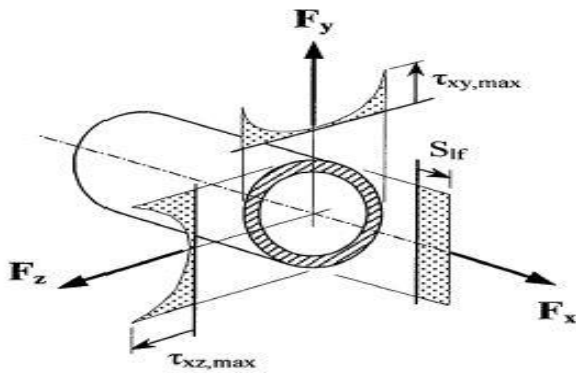


Figure 7 Stress due to forces

The two shear forces are first combined into a resultant shear force as F_s . The stress is then calculated using this resultant force. For the axial force, $F_a = F_x$, the stress is either pure tension or compression, depending on the sign of the force. The axial stress generated is uniform across the cross-section. Therefore, at a given cross-section of the pipe we have the stresses due to forces

$$F_s = \sqrt{F_y^2 + F_z^2}$$

$$\tau = \frac{F_s}{A} \quad \sigma_x = \frac{F_a}{A}$$

Stress due to moments

Moment loads are also divided into two categories: bending moment and torsion moment. The bending moment is further divided into two components, M_y and M_z , around the conveniently selected y-axis and z-axis, respectively. Each

bending moment creates a linear distribution of stress with the highest stress occurring at the outer surface farthest from the bending axis and is equal to

$$S_{by} = \frac{M_y}{z} \quad S_{bz} = \frac{M_z}{y}$$

$$S_b = \sqrt{S_{by}^2 + S_{bz}^2}$$

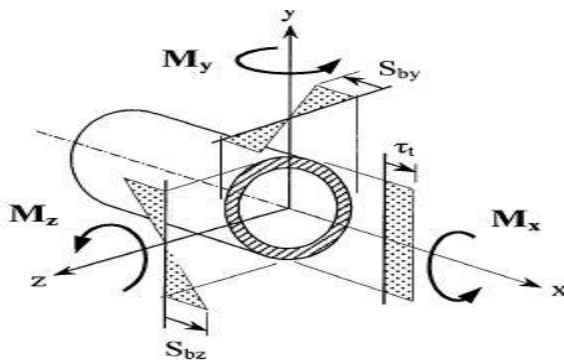


Figure 8 Stress due to moments

The stress created by the torsion moment, $M_t = M_x$, is shear stress that is linearly distributed in the diametrical direction with the maximum at the outer surface. The shear stress, however, is uniformly distributed along the circumferential direction.

The magnitude of the highest shear stress is calculated by

$$\tau_t = \frac{M_t}{2Z}$$

3.6 Principal Stress

These maximum and minimum normal stresses, which are perpendicular to each other, are called principal stresses. Principal stresses are the basic stresses used in evaluating the damaging effect on the material. The planes on which these principal stresses act upon are called principal planes. There are no shear stresses in principal planes.

3.7 Theories of failure

There are several different theories of failure that have been proposed and used. These theories include:

Maximum stress theory: predicts that the material will yield when the absolute magnitude of any of the principal stresses reaches the yield strength of the material;

Maximum strain theory: predicts that the material will yield when the maximum strain reaches the yield point strain

Maximum shear theory: predicts that the material will yield when the maximum shear stress in the material reaches the maximum shear stress at the yield point in the tension test

Maximum energy theory: predicts that the material will yield when the strain energy per unit volume in the material reaches the strain energy per unit volume at yielding in the simple tension test

Maximum distortion energy theory: predicts that the material will yield when the distortion energy per unit volume in the material reaches the distortion energy per unit volume at yielding in simple tension test.

The maximum stress theory fits very well with brittle materials such as concrete and non-ductile cast iron. For the ductile materials that are prevalent in piping, both the maximum shear theory and the maximum distortion energy theory agree very well with the experiments. The maximum distortion energy theory is slightly more accurate, but the maximum shear theory is simpler and easier to apply.

ASME has adopted the maximum shear failure theory in its piping and pressure vessel codes.

3.8 Strain

Normal strain defined as the deformation per unit length of a member under axial loading

$$\varepsilon = \frac{\Delta l}{L}$$

Thermal strain is the changes in temperature produce expansion or compression, which causes strain.

$$\varepsilon_t = \alpha \Delta T$$

Stress strain Curve

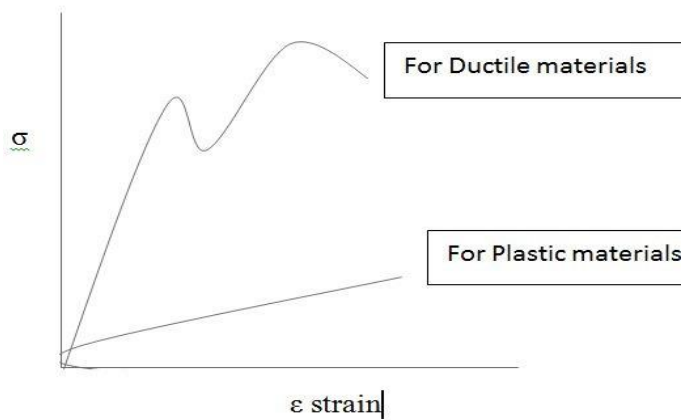


Figure 9 stress strain graph

3.9 Stress analysis

Pipelines are the most delicate components used for transporting oil and gas. They are the busiest entities. They are subjected to almost all kinds of loads, intentional or unintentional. It is very important to take note of all potential loads that a piping system would encounter during operation as well as during other stages in the life cycle of a process plant. Ignoring any such load while designing, erecting, hydro-testing, start-up shut-down, normal operation, maintenance etc. can lead to inadequate design and engineering of piping system. The system may fail on the first occurrence of this overlooked load. Failure of a pipeline may trigger a Domino effect and cause a major disaster

Pipe stress analysis is the analysis of the stress in the pipe. The process of determining, associating & analyzing the route ,supports and loads in pipe is called stress analysis and this can be achieved by general layout designs, rule of thumb, nomographs , charts, various related soft wares.

Proper blend of knowledge, codes and tools the requirements to meet the very objectives of pipeline design is met.

ANALYSIS IN A PIPELINE

Earlier before the advent of computers and advanced computing software, pipe stress analysis was handled by very specialized engineers based on subject knowledge & code guidelines, it normally took a specialist to use a calculator and work out the formulae results to analyze the flexibility of moderately complex piping system to absorb the thermal expansion of pipe

With the rapid advancement of computer technology and software calculations became easier and faster. The task of stress engineers has been shifted from stress calculation to stress engineering.

Stresses generated during Lowering

When the top soil is eroded or the line need to be relocated .it is necessary to lower the pipe. Stress generated during lowering is to be calculated and checked with acceptable limit

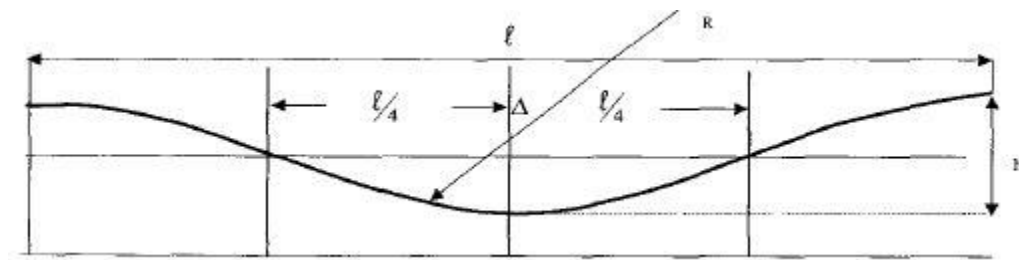


Figure 10 Lowering of pipeline

Stresses generated during Hydro test

Stress that will generate when pipeline works in hydro test pressure is calculated and check whether it is within acceptable limit

Stresses generated during Operation

Stress that will generate when pipeline works in operating pressure is calculated check whether it is within acceptable limit.

3.10 Seismic hazards

Seismic hazards which affect the pipeline are classified into four

1) Permanent ground deformation related to soil failures:

- a. Longitudinal permanent ground deformation
 - b. Transverse permanent ground deformation
 - c. Landslide
- 2) Buoyancy due to liquefaction
 - 3) Permanent ground deformation related to faulting. (Abrupt PGD)
 - 4) Seismic wave propagation

3.10.1 Permanent Ground Deformation

Permanent ground deformation refers to the unrecoverable soil displacement due to liquefaction-induced lateral spreading. Lateral spreading is activity which occurs in a gently sloping ground when the soil deposit liquefies due to seismic shaking. The soil loses its shear strength during liquefaction, which in turn results in lateral movement of liquefied soil and any overlying soil layer.

Longitudinal Permanent Ground Deformation

If a pipeline crossing permanent ground deformation zone in the direction of ground movement it is called longitudinal permanent ground deformation

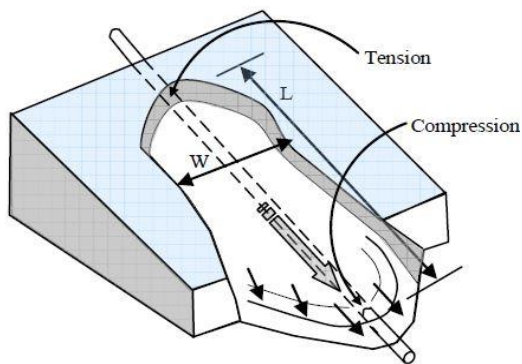


Figure 11 Longitudinal PGD

Transverse Permanent Ground deformation

If a pipeline crossing permanent ground deformation zone in the direction perpendicular of ground movement it is called transverse permanent ground deformation

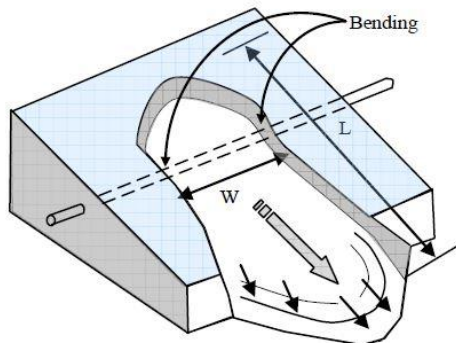


Figure 12 Transverse PGD

3.10.2 Buoyancy due to liquefaction

When liquefaction of soil occurs around the pipeline, buoyant forces are exerted on pipeline and must be resisted by suitable anchoring device.

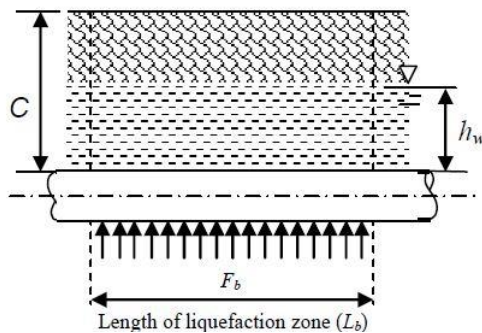


Figure 13 Buoyancy due to liquefaction

3.10.3 Faulting

Fault movement is the seismic activity related to the tearing of the ground surface by differential movement across the fault line

A fault is a crack or zone of crack between two blocks of rock. Faults allow the blocks to move relative to each other. This movement may be due to sudden displacement or may be due to gradual accumulation. The sudden fault movement is mostly associated with the seismic event, whereas the gradual displacement is mainly associated with the plate movement.

Faults may be classified according to the direction of motion as normal slip, strike slip, or reverse slip faults.

Normal slip are formed due to tensile stress

Strike slip are formed due to shear stress

Reverse slip are formed due to compressive stress

The normal or reverse fault occurs in combination with the strike slip fault. This kind of faulting is referred to as oblique fault. This is formed due to the combination of stresses acting both vertically and horizontally.

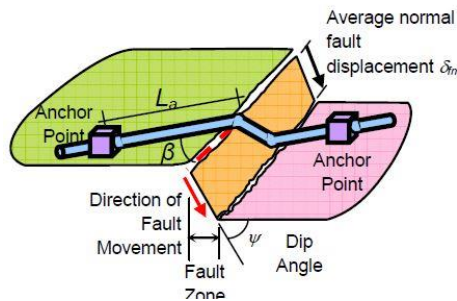


Figure 14 Normal Fault

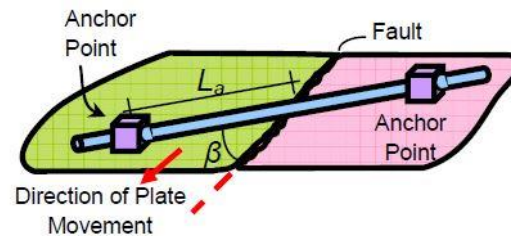


Figure 15 Strike slip

3.10.4 Seismic Wave Propagation

When earthquake occurs, seismic waves are propagated from the epicenter and they manifest themselves as strong ground shaking. Ground motions are composed of two types of waves- body waves and surface waves. Body waves weaken with distance rapidly as compared to the surface waves. The above ground structures are more susceptible to the seismic wave hazards than the underground structures. However, pipelines buried at a very shallow depth may get damaged due to the ground shaking.

3.11 Crossing analysis

Crossing analysis is done to provide adequate design for safe installation and operation of the pipeline beneath rail and roads. Pipe under railroads should be installed with a minimum of cover, to the base of the rail.

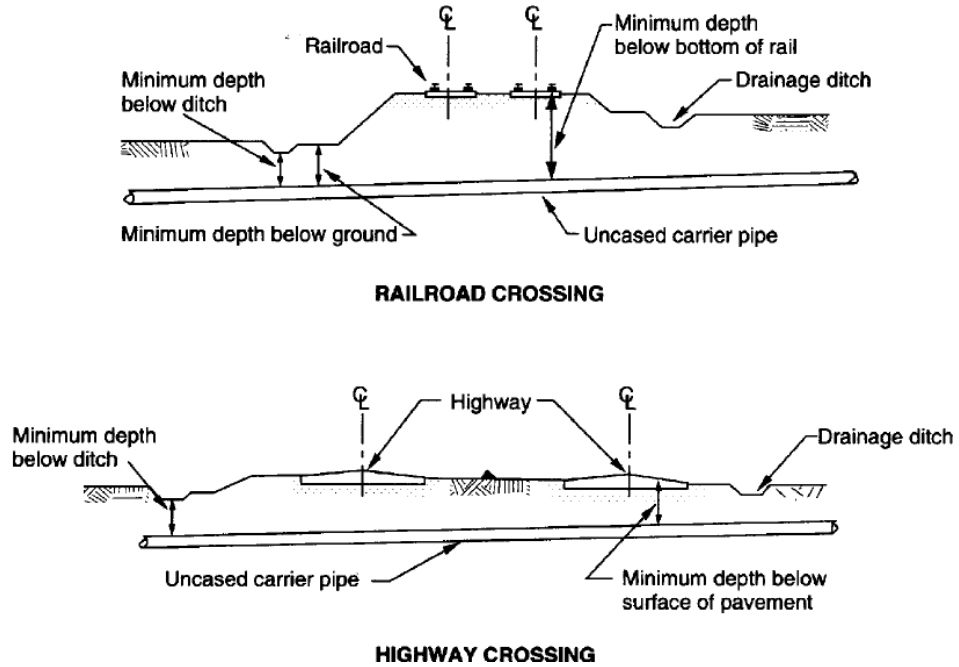


Figure 16 Road and rail crossing diagram

Table 3 Rail and road crossing depth of trench

Location	Minimum Cover for rail crossing(M)	Minimum cover for road crossing(M)
Under track structure proper	1.8	1.2
Under all other surfaces within the right-of-way or from the bottom of ditches	.9	.9
For pipelines transporting HVL, from the bottom of ditches	1.2	1.2

CHAPTER 4

4 METHODOLOGY

4.1 Thickness calculation

The wall thickness of pipe is selected based on the thickness required for the internal pressure and allowances. Hoop stress is used for wall thickness calculation and the pipeline is supported sufficiently such that longitudinal stress is within the limits of the required Code

Calculation of wall thickness for a straight pipe is the first step toward the pressure design of all the components.

Pressure thickness is selected in five steps

- 1) From the design pressure, the minimum required thickness is calculated
- 2) The net thickness is then added with allowances such as corrosion and erosion
- 3) The final step is to select a commercially available nominal from the codes that is next higher to the net thickness calculated
- 4) Check selected wall thickness for hydro test condition.
- 5) Check for handling practice, that is, pipeline handling is difficult for D/t larger than 50; welding of wall thickness less than 0.3 in (7.6 mm) requires special provisions

The nominal wall thickness for a given design pressure shall be determined as per ASME B31.8.

$$t = \frac{PD}{2SEFT} + CA$$

D = Nominal outside diameter of pipe

E = Longitudinal joint factor

F = Design factor

P = Design Pressure

S = Specified minimum yield strength of line pipe material

T = Temperature derating factor

CA = Corrosion allowance (Nil)

4.1.1 WALL THICKNESS CALCULATIONS 30" MAINLINE

Basic Data

Symbols	Nomenclature	value	Units
P	pressure	9.8	Mpa
D	diameter	762	mm
μ	poission ratio	0.3	
E	young's modulus	2.07E+05	MPa
T1	installation temperature	20	°C
T2	operating temperature	60	°C
S	SMYS	485	Mpa
CA	Corrosion allowance	0	
E	joint factor	1	
T	factor	1	
F	design factor	0.6	
F	design factor for crossing	0.5	
F	design factor for valve location	0.5	

- a) Minimum wall thickness required for the design-internal pressure.

$$t = \frac{PD}{2SEFT} + CA$$

Thickness t = 12.83092784 mm

Checking with standard API 5l

Closest Higher Wall Thickness t = 14.3

- b) At mainline block valve location / terminal pigging station

Thickness t = 15.39711 mm

Checking with standard API 5L

Closest Higher Wall Thickness $t = 15.9$

c) At public road crossings without casing

Thickness $t = 15.39711$ mm

Checking with standard API 5L

Closest Higher Wall Thickness $t = 15.9$

4.2 Stress analysis

The longitudinal stresses have been calculated for the pipelines during operation considering the following:

- Longitudinal stress due to internal design pressure.
- Longitudinal stress due to difference in temperature.
- Longitudinal stress due to flexure stress due to elastic curvature.
- Longitudinal stress due to bending result of free spanning.
- Longitudinal stress due to elongation result of deflection.

Longitudinal stress

The total longitudinal stress SL , in the pipe will be calculated by the following formula.

$$SL = SE + SB + SS$$

Total longitudinal stress, SL calculated by above formula shall not exceed SMYS.

Where,

1) SE - Existing longitudinal stress in the pipe, in psi

Total existing longitudinal stress shall be computed considering pressure, temperature and bending effects.

$SE = SP + SN + SC$ (For restrained lines)

$SE = SP + SC$ (For unrestrained lines)

Where,

ANALYSIS IN A PIPELINE

a) SP is the longitudinal stress due to internal pressure.

The longitudinal stress, (SP) in the pipe due to internal pressure shall be calculated by the following equation:

$$SP = \frac{PDv}{2t} \quad \text{- For restrained section}$$

$$SP = 0.5 PD / 2t \quad \text{- For unrestrained section}$$

Where

P - Pressure

D - Outside diameter of the pipe

v - Poisson's ratio for steel = 0.3

t - Nominal wall thickness of the pipe

b) Longitudinal stress due to temperature change.

The longitudinal stresses in the pipe due to a change in the temperature will be calculated with following equation.

$$SN = E\alpha (T2 - T1) \quad \text{- For restrained section}$$

E - Modulus of elasticity of steel, in psi.

α - Linear co-efficient of thermal expansion of steel, mm/mm per °F

T1 - Temperature of the pipe at the time of installation, °C

T2 - Max. & Min. temperature at the time of operation, °C

c) Longitudinal flexure stress due to existing elastic curvature, SC

$$SC = ED / 2R$$

R = Radius of curvature of pipeline, in mm.

2) SB - Longitudinal stress in the pipe due to net downward weight of pipeline including coating and content caused by vertical deflection of pipe

$$SB = WrLI^2 / 12S$$

Wr - Net weight of pipeline with coating and content, N/m

LI - Minimum trench length required to reach mid-span, m

S - Elastic section modulus of the pipe, m³.

ANALYSIS IN A PIPELINE

3) S_s - Longitudinal stress in the pipe due to its elongation caused by the vertical deflection of pipe, in psi.

$$S_s = 2.67E \left(\frac{\Delta}{L} \right)^2$$

Where

Δ - mid –span deflection of the pipe, in feet (considered max. 1/8")

L - Min. trench length required to reach the mid-span of the pipe (D), in feet

Trench length will be calculated by the following empirical equation

$$L = \sqrt{\frac{((3.87 \times 10^7 \times D \times \Delta) + (7.74 \times 10^7 \times \Delta^2))}{((F_d \times SMYS) - S_e)}}$$

D - Diameter of the pipe in feet

FD - Design factor

$SMYS$ - in PSI

SE - Existing longitudinal stress in psi

4. Combined and Equivalent Stress Checks.

According to OISD 141 – The total of the following shall not exceed the SMYS of the pipe material.

- a) The combined stress due to expansion
- b) The longitudinal pressure stress
- c) The longitudinal bending stress due to weight and external loads.

In addition to the above, a) shall be less than 0.72 of SMYS and the sum of (b) and (c) shall not exceed 75% of SMYS.

Further the equivalent stress computed considering the hoop and longitudinal stress shall not exceed 90% of SMYS. The equivalent stress calculations shall be based on maximum shear stress theory.

The maximum combined and equivalent stresses shall be evaluated considering the signs of bending stresses.

All the above longitudinal stresses are carried out considering different cases of the pipeline parameters such as different thickness and diameters

4.2.1 Lowering In-Service Pipelines 30" X 14.3 mm Wall Thickness

Basic Data

Symbols	Nomenclature	values	Units	Values	Units
p	pressure	9.8	Mpa		
D	diameter	762	mm	24.9936	feet
t	thickness	14.3	mm		
v	poisson ratio	0.3			
E	young's modulus	2.07E+05	Mpa		
α	coefficient of thermal expansion	1.17E-05	per degc		
T1	installation temp	20	$^{\circ}$ c		
T2	operational temp	60	$^{\circ}$ c		
tc	thickness coat	3.2	mm		
tcc	thickness concrete	0	mm		
Rc	radius of curvature	1600000	mm		
SMYS		485	mpa	70343.28	psi
F	design factor	0.9			
ρ pipe	density pipe	7850	kg/m ³		
Δ	mid –span deflection of the pipe, in feet	5.45	m		
ρ coat	Density of the coat	900	kg/m ³		
ρ cc	Density of the concrete	2400	kg/m ³		

pcontent	Density of the content	56.47	kg/m ³		
id	inner diameter	733.4	mm	23.95056	Feet
D w	Diameter with coating	765.2	mm	25.09856	Feet
γ	unit soil weight	1800	kg/m ³		
H	burial depth	1	m		

$$S_p = PD_v / 2t$$

$$S_p = 78.33146853 \text{ MPA}$$

$$S_n = E\alpha (T_2 - T_1)$$

$$S_n = 96.876 \text{ Mpa}$$

$$S_c = ED/2R$$

$$S_c = 49.291875 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = S_p + S_n + S_c$$

$$SE_1 = S_p + S_n - S_c$$

$$SE_1 = 125.9155 \text{ MPA}$$

$$SE_2 = SE + S_n + S_c$$

$$SE_2 = 224.499 \text{ MPA}$$

$$L_t = \sqrt{\frac{((3.87 \times 10^7 \times D \times \Delta) + (7.74 \times 10^7 \times \Delta^2))}{((F_d \times SMYS) - S_e)}}$$

$$L_t = 304.6443 \text{ feet}$$

$$L_t = 92.855 \text{ m}$$

$$S_s = 2.67E \left(\frac{\Delta}{L} \right)^2$$

$$S_s = 176.8839 \text{ Mpa}$$

Allowable longitudinal stress for bending, Sb

$$S_{b1} = FD * SMYS - SE_1 - S_s$$

$$S_{b1} = 133.7004 \text{ MPA}$$

$$S_{b2} = FD * SMYS - SE_2 - S_s$$

ANALYSIS IN A PIPELINE

$$S_{b2} = 35.1167248 \text{ Mpa}$$

Allowable longitudinal stress for bending, S_b is taken minimum of S_{b1} and S_{b2}

Total longitudinal stress, SL_1

$$SL_1 = SE_1 + SS + S_{b1}$$

$$SL_1 = 436.5 \text{ Mpa}$$

Total longitudinal stress, SL_2

$$SL_2 = SE_2 + SS + S_{b2}$$

$$SL_2 = 436.5 \text{ Mpa}$$

Total longitudinal stress should be less than SMYS

$$\text{Here } SL = 436.50 < \text{SMYS of } 485 \text{ Mpa}$$

Hence ok

Support spacing requirement while lowering in to the trench

$$L_s = \sqrt{\frac{0.0286 S_b (D^4 - d^4)}{D^3 - 0.8724 d^2 D}}$$

Where D – Outer diameter of the pipeline

d - Inner diameter of the pipeline

$$L_s = 51.88934086 \text{ feet}$$

4.2.2 Hydro test condition 30" X 14.3 mm Wall Thickness

Basic Data

P	pressure	14.7	Mpa		
D	diameter	762	mm	24.9936	feet
t	thickness	14.3	mm		
μ	poisson ratio	0.3			
E	young's modulus	2.07E+05	Mpa		
α	coefficient of thermal expansion	1.17E-05	per deg		
T1	installation temp	20	$^{\circ}\text{C}$		
T2	operational temp	60	$^{\circ}\text{C}$		

tc	thickness coat	3.2	mm		
tcc	thickness concrete	0	mm		
Rc	radius of curvature	1600000	mm		
SMYS		485	mpa	70343.28	psi
F	design factor	0.9			
ρpipe	Density of the pipe	7850	kg/m ³		
ρcoat	Density of the coat	900	kg/m ³		
ρcc	Density of the concrete	2400	kg/m ³		
ρcontent	Density of the content	1000	kg/m ³		
id	inner diameter	733.4	mm		
D w	dia with coat	768.4	mm		
γ	unit soil wt	1800	kg/m ³		
H	bury depth	1	m		

Longitudinal tensile stress in pipe due to internal pressure, Sp

$$S_p = PD_v / 2t$$

$$S_p = 117.4972 \text{ Mpa}$$

Longitudinal compressive stress due to temperature change

$$S_n = E\alpha (T_2 - T_1)$$

$$S_n = 96.876 \text{ Mpa}$$

Longitudinal flexure stress due to existing elastic curvature

$$S_c = ED/2R$$

$$S_c = 49.291875 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = S_p + S_n + S_c$$

$$SE_1 = S_p + S_n - S_c$$

$$SE_1 = 28.6707 \text{ Mpa}$$

ANALYSIS IN A PIPELINE

$$SE2 = SE + S_n + S_c$$

$$SE2 = 69.91308 \text{ Mpa}$$

$$SL = \text{Maximum of SE1 or SE2 which should be less than SMYS}$$

Hence ok

Allowable bending stress considering $S_b = 0.75 \text{ SMYS} - S_p + \text{or} - S_c$

$$S_b = 196.9609 \text{ Mpa}$$

Finding weight of the pipe, coat, content and soil

$$W_{\text{pipe}} = \frac{\pi(D^2 - ID^2)\rho_{\text{pipe}}g}{4 \times 10^6}$$

$$W_{\text{pipe}} = 2585.423 \text{ N/m}$$

$$W_{\text{coat}} = \frac{\pi(D_{\text{coat}}^2 - D^2)\rho_{\text{coat}}g}{4 \times 10^6}$$

$$W_{\text{coat}} = 67.8837 \text{ N/m}$$

$$W_{\text{cont}} = \frac{\pi ID^2 \rho_{\text{cont}}g}{4 \times 10^6}$$

$$W_{\text{cont}} = 4142.099006 \text{ N/m}$$

$$W_{\text{soil}} = \gamma_b(D + 2t_c + 2t_{cc})9.81/1000$$

$$W_{\text{soil}} = 13568.4072 \text{ N/m}$$

$$W_{\text{tot}} = \text{Total load per meter}$$

$$W_{\text{tot}} = W_{\text{pipe}} + W_{\text{coat}} + W_{\text{content}} + W_{\text{soil}}$$

$$W_{\text{tot}} = 20363.81373 \text{ N/m}$$

Section modulus, S

$$S = \pi[D^4 - (D-2t)^4] / [32 * D * 10^9]$$

$$S = 0.006160156 \text{ m}$$

Allowable pipeline span, L

$$L = \sqrt{\frac{12 * S * S_B}{W_r}}$$

$$L = 26.739 \text{ m}$$

Hoop Stress, SH

$$SH = (P * D / (2 * t))$$

ANALYSIS IN A PIPELINE

$$S_h = 391.6573427 \text{ Mpa}$$

Using Von moises equation, $Seq = \sqrt{S_H^2 + S_L^2 - S_H * S_L}$

$$Seq1 = \sqrt{S_H^2 + S_{E1}^2 - S_H * S_{E1}}$$

$$Seq1 = 406.7512272 \text{ Mpa}$$

$$Seq2 = \sqrt{S_H^2 + S_{E2}^2 - S_H * S_{E2}}$$

$$Seq2 = 361.8029052 \text{ Mpa}$$

Seq1 and Seq2 is less than the smys

Hence ok

4.2.3 Operating Condition 30" X 14.3 mm Wall Thickness

Basic Data

P	pressure	9.8	Mpa		
D	diameter	762	mm	24.9936	feet
t	thickness	14.3	mm		
v	poisson ratio	0.3			
E	young's modulus	2.07E+05	Mpa		
α	coefficient of thermal expansion	1.17E-05	per deg		
T1	installation temp	20	$^{\circ}$ C		
T2	operational temp	60	$^{\circ}$ C		
tc	thickness coat	3.2	mm		
tcc	thickness concrete	0	mm		
Rc	radius of curvature	1600000	mm		
SMYS		485	mpa	70343.28	psi
F	design factor	0.9			

ρ_{pipe}	Density of the pipe	7850	kg/m ³		
ρ_{coat}	Density of the coat	900	kg/m ³		
ρ_{cc}	Density of the concrete	2400	kg/m ³		
ρ_{content}	Density of the content	56.47	kg/m ³		
id	inner diameter	733.4	mm		
D w	dia with coat	768.4	mm		
γ	unit soil wt	1800	kg/m ³		
H	bury depth	1.2	m		

Longitudinal tensile stress in pipe due to internal pressure, S_p

$$S_p = PD_v / 2t$$

$$S_p = 78.33146853 \text{ Mpa}$$

Longitudinal compressive stress due to temperature change

$$S_n = E\alpha (T_2 - T_1)$$

$$S_n = 96.876 \text{ Mpa}$$

Longitudinal flexure stress due to existing elastic curvature

$$S_c = ED/2R$$

$$S_c = 49.291875 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = S_p + S_n + S_c$$

$$SE_1 = S_p + S_n - S_c$$

$$SE_1 = 125.9156 \text{ Mpa}$$

$$SE_2 = SE + S_n + S_c$$

$$SE_2 = 224.4993 \text{ Mpa}$$

SL = Maximum of SE₁ or SE₂ which should be less than SMYS

Hence ok

Allowable bending stress considering $S_b = 0.75 \text{ SMYS} - S_p + \text{or} - S_c$

$$S_b = 236.126 \text{ Mpa}$$

Finding weight of the pipe, coat, content and soil

ANALYSIS IN A PIPELINE

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{Pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2585.423\text{N/m}$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

$$W_{coat} = 67.8837\text{N/m}$$

$$W_{cont} = \frac{\Pi ID^2 \rho_{cont}g}{4 \times 10^6}$$

$$W_{cont} = 233.9046\text{N/m}$$

$$W_{soil} = \gamma b(D + 2tc + 2tcc)9.81/1000$$

$$W_{soil} = 16282.09.4072\text{N/m}$$

$$W_{tot} = \text{Total load per meter}$$

$$W_{tot} = W_{pipe} + W_{coat} + W_{content} + W_{soil}$$

$$W_{tot} = 19169.3\text{N/m}$$

Section modulus, S

$$S = \pi[D^4 - (D-2t)^4] / [32 * D * 10^9]$$

$$S = 0.00616 \text{ m}$$

Allowable pipeline span, L

$$L = \sqrt{\frac{12 * S * S_B}{W_r}}$$

$$L = 30.1756 \text{ m}$$

Hoop Stress, SH

$$SH = (P * D) / (2 * t)$$

$$Sh = 261.1049 \text{ Mpa}$$

$$\text{Using Von moises equation, } Seq = \sqrt{S_H^2 + S_L^2 - S_H * S_L}$$

$$Seq1 = \sqrt{S_H^2 + S_{E1}^2 - S_H * S_{E1}}$$

$$Seq1 = 226.171\text{Mpa}$$

$$Seq2 = \sqrt{S_H^2 + S_{E2}^2 - S_H * S_{E2}}$$

ANALYSIS IN A PIPELINE

$$\text{Seq2} = 244.8629 \text{ Mpa}$$

Seq1 and Seq2 is less than the SMYS

Hence ok

4.3 Pipe Expansion analysis

Pipeline has to be designed to have sufficient flexibility to prevent thermal expansion or expansion due to pressure in the pipe. The pipeline expansion length ΔL due to the effects of design pressure and temperature difference in the pipe and soil friction are calculated for different wall thickness and diameter.

Expansion Force due to Change in Temperature $F_{ex}(T)$

$$F_{ex}(T) = E\alpha A(T_2 - T_1)$$

Pressure force $F_{ex}(P)$

$$F_{ex}(p) = A(.5 - \nu)Sh$$

where

$$Sh = PD / (2tg)$$

A - Area of the wall thickness

ν - Poisson ratio

Total expansion force - F_{ex}

$$F_{ex} = F_{ex}(T) + F_{ex}(P)$$

Frictional Force F_f

$$F_f = \mu((2W_{soil}) + W_{total})$$

Where

Total Weight W_{total} = weight of pipe + weight of the pipe coat + weight of the content

Length of Virtual Anchor - L_a

$$L_a = \text{Total expansion force} / \text{Frictional Force}$$

End expansion due to pressure effect

ANALYSIS IN A PIPELINE

$$\Delta L_p = (0.5 - \nu) \cdot Sh \cdot L_a / E$$

End expansion due to temperature change

$$\Delta L_t = \alpha (T_2 - T_1) \cdot L_a$$

End expansion due to soil friction

$$\Delta L_f = F_f \cdot L_a^2 / (2 \cdot \gamma \cdot t \cdot D \cdot E)$$

Net Expansion length ΔL

$$\Delta L = \Delta L_p + \Delta L_t + \Delta L_f$$

4.3.1 Pipe Expansion analysis for 30 X 14.3 Wall Thickness

Basic data

P	pressure	9.8	Mpa
D	diameter	762	mm
t	thickness	14.3	mm
ν	poisson ratio	0.3	
E	young's modulus	2.07E+05	Mpa
α	coefficient of thermal expansion	1.17E-05	per deg
T1	installation temp	20	$^{\circ}C$
T2	operational temp	60	$^{\circ}C$
tc	thickness of the coat	3.2	mm
tcc	Thickness of the concrete	0	mm
Rc	radius of curvature	1600000	mm
SMYS		485	mpa
F	design factor	0.9	
ρ_{pipe}	Density of the pipe	7850	kg/m ³

ρ_{coat}	Density of the coat	900	kg/m ³
ρ_{cc}	Density of the concrete	2400	kg/m ³
$\rho_{content}$	Density of the content	56.47	kg/m ³
id	inner diameter	733.4	mm
D w	dia with coat	768.4	mm
γ	unit soil wt	1800	kg/m ³
H	bury depth	1.2	m

$$F_{ex}(T) = E\alpha A(T_2 - T_1)$$

$$F_{ex}(T) = 3.32E+05 \text{ Kg}$$

$$Sh = PD / (2tg)$$

$$Sh = 26616197.26 \text{ Kg/m}^2$$

$$F_{ex}(p) = A(.5 - \nu)Sh$$

$$F_{ex}(p) = 178718.318 \text{ Kg}$$

$$F_{ex} = F_{ex}(T) + F_{ex}(P)$$

$$F_{ex} = 5.10E+05 \text{ kg}$$

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{Pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2585.423728 \text{ N/m}$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

$$W_{coat} = 67.88379364 \text{ N/m}$$

$$W_{cont} = \frac{\Pi ID^2 \rho_{cont}g}{4 \times 10^6}$$

$$W_{cont} = 233.9043309 \text{ N/m}$$

$$W_{total} = w_{pipe} + w_{coat} + w_{cont}$$

ANALYSIS IN A PIPELINE

$$W_{total} = 2887.211853\text{N/m}$$

$$W_{soil} = \gamma_b(D + 2t_c + 2t_{cc})9.81/1000$$

$$W_{soil} = 16282.08864\text{N/m}$$

$$\text{Friction force } F_f = \mu((2W_{soil}) + W_{total})$$

$$F_f = 10635.41674\text{N/m}$$

$$= 1084.14034\text{Kg/m}$$

$$L_a = \text{Total expansion force} / \text{Frictional Force}$$

$$L_a = 4.71\text{E}+02\text{m}$$

$$\Delta L_p = (0.5 - \nu) \cdot S_h \cdot L_a / E$$

$$\Delta L_p = 1.19\text{E}-01\text{m}$$

$$\Delta L_t = \alpha \cdot (T_2 - T_1) \cdot L_a$$

$$\Delta L_t = 0.220262712\text{m}$$

$$\Delta L_f = F_f \cdot L_a^2 / (2 \cdot \gamma \cdot t \cdot D \cdot E)$$

$$\Delta L_f = 2.55\text{E}-01\text{m}$$

$$\Delta L = \Delta L_p + \Delta L_t + \Delta L_f$$

$$\Delta L = 5.94\text{E}-01\text{m}$$

$$= 5.94\text{E}+02\text{mm}$$

4.4 Pipe Stability Analysis for crossings

In order to prevent flotation of pipeline in marshy areas, low laying areas, river crossing etc. concrete weight coating shall be provided as per design requirement.

Condition for liquefaction:

Critical factors for sediments to be prone to liquefaction. The sediment must be:

- 1). Saturated with ground water
- 2). compacted fairly loose

ANALYSIS IN A PIPELINE

Buoyancy effects are probably of great concern in area such as flood plains and estuaries where massive liquefaction could take place in a large earth quake. When the surface liquefies the pipe keeps uplifting at most to position where a portion of pipe is at ground surface near the center of the liquefied zone. however when a non liquefied layer is present as a cover liquefied layer, the pipe come to rest at the interface of the non-liquefied and liquefied layer

Total weight of the pipe

$$W_P = W_{\text{pipe}} + W_{\text{coat}} + W_{\text{concrete}}, \text{ N/m}$$

$$W_P = \text{Net downward pipe weight}$$

$$W_{\text{pipe}} = \text{Steel pipe weight, N/m}$$

$$W_{\text{coat}} = \text{PE coating weight, N/m}$$

$$W_{\text{concrete}} = \text{Concrete coating weight, N/m}$$

$$W_B = \left(\frac{\pi}{4} D^2 \right) \times \text{density of water, N/m}$$

$$D = \text{Total outside diameter of the pipe including concrete coating}$$

$$\text{Factors of Safety} = W_P / W_B > 1.3$$

The vertical stability analysis will be carried out based on the soil data and should confirm no undue settlement of the pipeline.

Submerged weight of the pipe per unit run ($W_p - W_b$)

$$\text{Submerged density of the pipe per unit run} = (W_p - W_b) / A_t$$

Where

$$A_t - \text{Area of the trench}$$

$$\text{Submerged density of soil} - \rho_{\text{sum soil}} = \gamma - \rho_w$$

$$\gamma - \text{Unit weight of the soil}$$

$$\rho_w - \text{density of water}$$

$$\text{Weight of Displaced Fluid WDF} = A_t - \rho_{\text{sum soil}}$$

$$\text{Required Buoyancy WRB} = \text{WDF} * \text{FS}$$

If $wrb < w_p$ design is safe

$$\text{net upward thurst} = ((\rho_{\text{sum}} - \rho_{\text{pipe}}) \pi D_{\text{tot}}^2 / 4) / D_{\text{tot}}$$

$$\text{Shear strength } S = C + \tan \Psi$$

Pipeline stability has been checked for possible buoyancy, floatation and sinking.

Uplift pressure of pipe is calculated and compared with the shear strength of soil.

The pipe sinkage is determined as the depth at which the applied pipe pressure equals the soil bearing resistance

4.4.1 Pipe Stability Analysis for 30"x14.3 Wall thickness

D	diameter	762	mm
t	thickness	14.3	mm
t _c	Thickness of the coat	3.2	mm
t _{cc}	thickness of the concrete	120	mm
P	pressure	9.8	mpa
id	inner diameter	733.4	mm
D _c	Diameter of the pipe with coat	768.4	mm
D _{cc}	Diameter of the pipe with concrete	1008.4	mm
ρ_{pipe}	density pipe	7850	kg/m ³
ρ_{coat}	density coat	900	kg/m ³
ρ_{cc}	density conc	2400	kg/m ³
ρ_w	density water	1000	kg/m ³
Fs	factor of safety	1.3	
H	burial depth	1	m
ρ_{cont}	density content	56.47	

γ	unit weight of soil	1800	
c	cohesion factor	10	kpa
Ψ		0	

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{Pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2585.423728\text{N/m}$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

$$W_{coat} = 67.88379364\text{N/m}$$

$$W_{conc} = \frac{\Pi(D_{conc}^2 - D_{coat}^2)\rho_{conc}g}{4 \times 10^6}$$

$$W_{conc} = 7881.33328\text{N/m}$$

$$W_{cont} = \frac{\Pi ID^2 \rho_{cont}g}{4 \times 10^6}$$

$$W_{cont} = 233.9043309\text{N/m}$$

$$W_p = W_{pipe} + W_{coat} + W_{concrete}$$

$$W_p = 10768.54513\text{N/m}$$

$$W_b = \frac{\Pi(D_{conc}^2)\rho_{water}g}{4 \times 10^6}$$

$$W_b = 7830.767652\text{N/m}$$

$$\text{Factors of Safety} = W_p / W_b$$

$$F_s = 1.37518 > 1.3$$

Hence ok

$$\text{Submerged weight of the pipe per unit run } (W_p - W_b) = 2937.777482\text{N/m}$$

$$\text{Submerged density of the pipe per unit run} = (W_p - W_b) / A_t = 927.80436\text{Kg/m}^3$$

$$\text{Submerged density of soil} = \rho_{sum \text{ soil}} = 800\text{Kg/m}^3$$

$$\text{Weight of Displaced Fluid WDF} = A_t * \rho_{sum \text{ soil}}$$

$$A_t = \Pi D H$$

ANALYSIS IN A PIPELINE

$$A_t = 3.166376 \text{ m}^2$$

$$WDF = 24849.71885 \text{ N/m}$$

$$\text{Required Buoyancy WRB} = WDF * FS$$

$$WRB = 32304.6345 \text{ N/m}$$

$wrb < w_p$ total hence safe

$$\text{net upward thrust} = ((\rho_{\text{sum}} - \rho_{\text{pipe}}) \pi D_{\text{tot}}^2 / 4) / D_{\text{tot}}$$

$$\text{Net upward thrust} = 5580.7377 \text{ N/m}^2 = 5.5807377 \text{ Kpa}$$

$$\text{Overburden pressure} = \rho_{\text{sum soil}} * D_{\text{conc}} = 806.72 \text{ Kg/m}^2$$

$$\text{Shear strength} = S = C + \tan \Psi = 10.00 \text{ kpa}$$

Net upward thrust < shear strength hence floatation will not occur

4.5 Crossing analysis

Crossing analysis is done based on the standard API 1102. It is applicable for the construction of pipelines crossing under railroads and highways and to the adjustment of existing pipelines crossed by railroad or highway construction.

This practice applies to welded steel pipelines. The provisions give primary emphasis to public safety. The provisions set forth in this practice adequately provide for safety under conditions normally encountered in the pipeline industry.

Prior to the construction of a pipeline crossing, arrangements should be made with the authorized agent of the facility to be crossed.

The recommended design procedure is explained below

. It consists of the following steps:

a) Begin with the wall thickness for the pipeline of given diameter approaching the crossing. Determine the pipe, soil, construction, and operational characteristics.

b) Use the Barlow formula to calculate the circumferential stress due to internal pressure, S_{Hi} (Barlow). Check

S_{Hi} (Barlow) against the maximum allowable value.

- c) Calculate the circumferential stress due to earth load, S_{He} .
- d) Calculate the external live load, w , and determine the appropriate impact factor, F_i .
- e) Calculate the cyclic circumferential stress, ΔS_H , and the cyclic longitudinal stress, ΔS_L due to live load.
- f) Calculate the circumferential stress due to internal pressure, S_{Hi} .
- g) Check effective stress, S_{eff} as follows:
 - 1) Calculate the principal stresses, S_1 in the circumferential direction, S_2 in the longitudinal direction, and S_3 , in the radial direction.
 - 2) Calculate the effective stress, S_{eff} .
 - 3) Check by comparing S_{eff} against the allowable stress, $S_{MYS} \times F$.
- h) Check welds for fatigue as follows:
 - 1) Check with weld fatigue by comparing ΔS_L against the girth weld fatigue limit, $S_{FG} \times F$.
 - 2) Check longitudinal weld fatigue by comparing, ΔS_H against the longitudinal weld fatigue limit, $S_{FL} \times F$.
- i) If any check fails, modify the design conditions in Item a appropriately and repeat the steps in Items b through h

4.5.1 Rail Crossing

- 1) Check Allowable Barlow Stress

$$S_{hi} = (pd)/2t$$

Check $S_{hi} < E * F * T * S_{MYS}$

- 2) Circumferential Stress Due to Earth Load

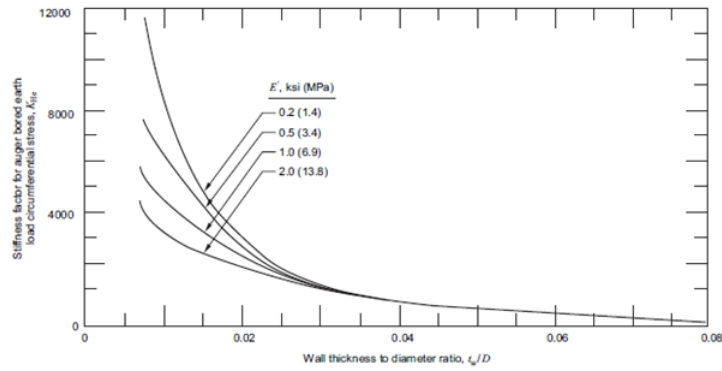
$$S_{He} = K_{He} B_{eE} D \gamma$$

K_{He} = Stiffness factor for circumferential stress earth load

B_e = Burial factor for earth load

E_e = Excavation factor for earth load

ANALYSIS IN A PIPELINE



NOTE See Table A-1 for soil descriptions.

Figure 3—Stiffness Factor for Earth Load Circumferential Stress, K_{Ee}

Figure 17 Stiffness factor due to earth load

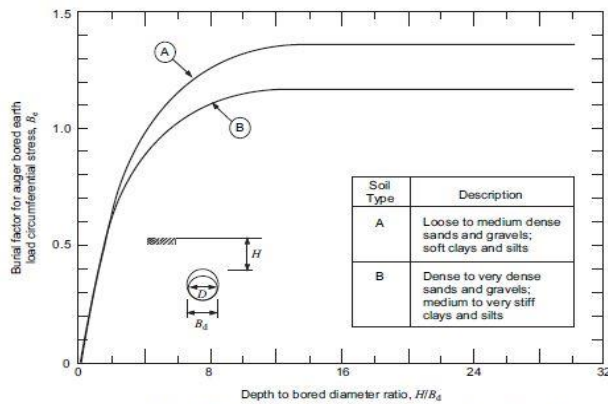


Figure 4—Burial Factor for Earth Load Circumferential Stress, B_e

Figure 18 Burial Factor for earth load

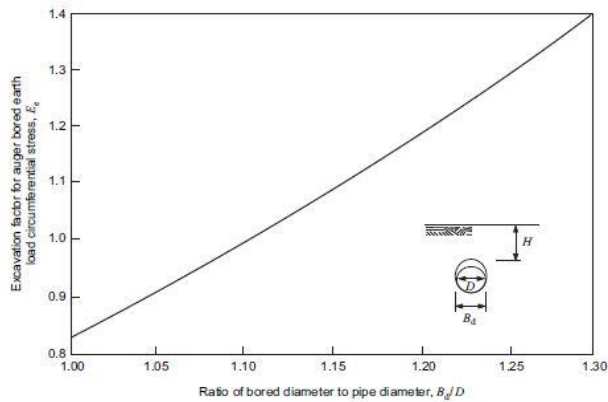


Figure 5—Excavation Factor for Earth Load Circumferential Stress, E_e

Figure 19 Excavation factor for earth load

Impact factor F_i

ANALYSIS IN A PIPELINE

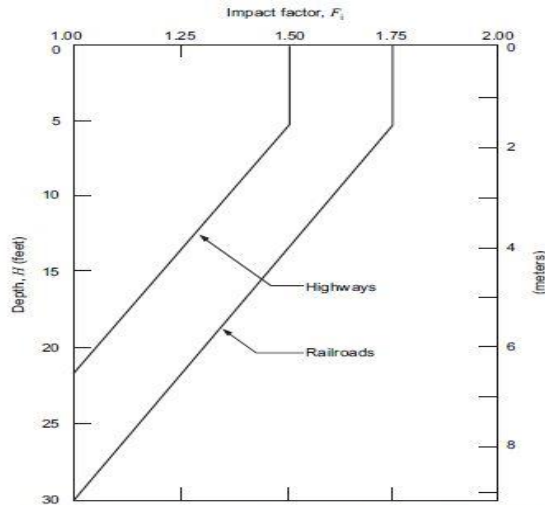


Figure 7—Recommended Impact Factor Versus Depth

Figure 20 Impact factor versus depth

3) Cyclic circumferential stress ΔSh

$$\Delta Sh_r = K_H r G_H N_H F_i w$$

$K_H r$ is the railroad stiffness factor for cyclic circumferential stress.

$G_H r$ is the railroad geometry factor for cyclic circumferential stress.

N_H is the railroad single or double track factor for cyclic circumferential stress.

F_i is the impact factor.

w is the applied design surface pressure, in psi or kPa.

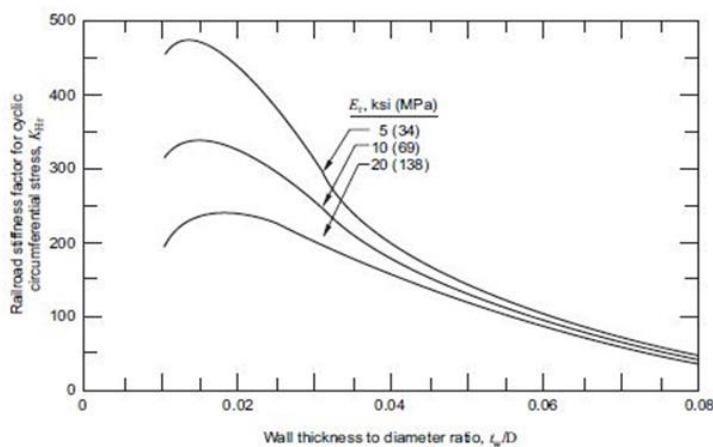


Figure 8—Railroad Stiffness Factor for Cyclic Circumferential Stress, K_{Hr}

Figure 21 Railroad stiffness factor for cyclic circumferential stress

ANALYSIS IN A PIPELINE

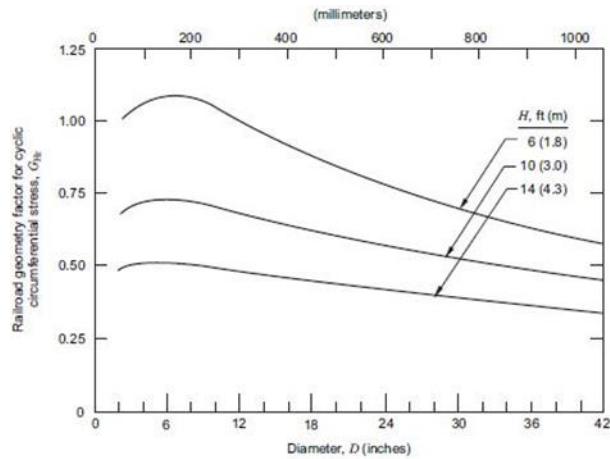


Figure 22 Geometry factor versus diameter

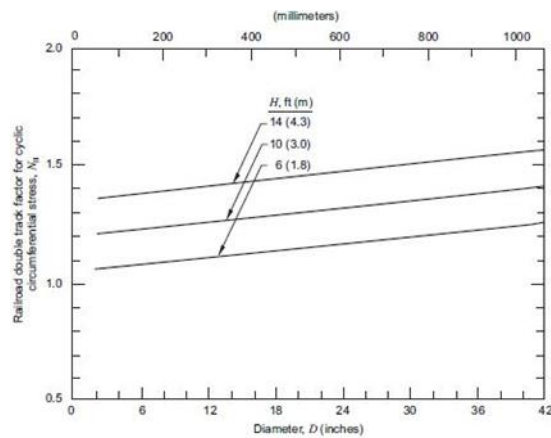


Figure 10—Railroad Double Track Factor for Cyclic Circumferential Stress, N_H

Figure 23 Railroad track factor for cyclic circumferential stress

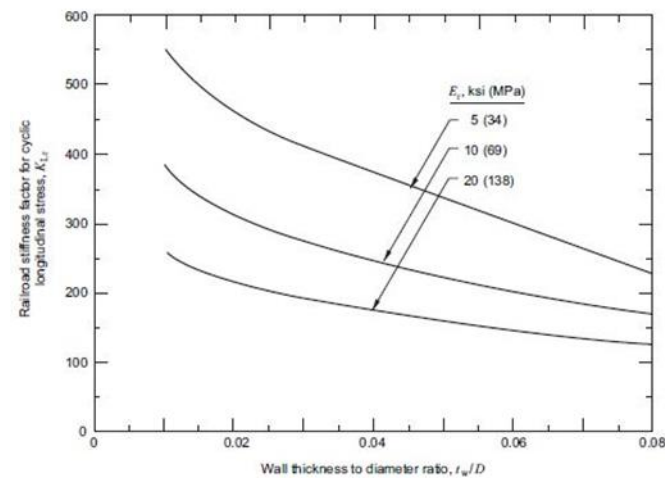


Figure 11—Railroad Stiffness Factor for Cyclic Longitudinal Stress, K_L

Figure 24 Rail road stiffness factor for cyclic longitudinal stress

4) Cyclic longitudinal stress, ΔS_{lh}

ANALYSIS IN A PIPELINE

$$\Delta S_{lr} = K_{Lr} G_{Lr} N L F i w$$

K_{Lr} is the railroad stiffness factor for cyclic longitudinal stress.

G_{Lr} is the railroad geometry factor for cyclic longitudinal stress.

NL is the railroad single or double track factor for cyclic longitudinal stress.

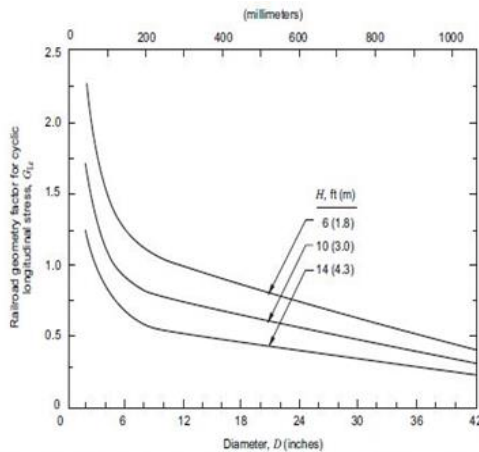


Figure 12—Railroad Geometry Factor for Cyclic Longitudinal Stress, G_{Lr}

Figure 25 railroad geometry factor for cyclic longitudinal stress

$$S_{hi} = (pd)/2t \quad \text{Circumferential Stress Due to Internal Pressurization}$$

Maximum Circumferential stress S_1

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

Maximum Longitudinal Stress S_2

$$S_2 = \Delta S_1 - (E\alpha(t_2 - t_1)) + v(S_{He} + S_{Hi})$$

Maximum radial Stress S_3

$$s_3 = - \text{maximum operating pressure}$$

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

Check S_{eff} is less than $SMYS \cdot f$

4.5.2 Highway Crossing

1) Check Allowable Barlow Stress

$$S_{hi} = (pd)/2t$$

Check $S_{hi} < E \cdot F \cdot T \cdot SMYS$

2) Circumferential Stress Due to Earth Load

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

K_{He} = Stiffness factor for circumferential stress earth load

B_e = Burial factor for earth load

Ee = Excavation factor for earth load

3) Cyclic circumferential stress ΔS_h

$$\Delta S_h = K_{Hh} G_{Hh} R L F i w$$

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

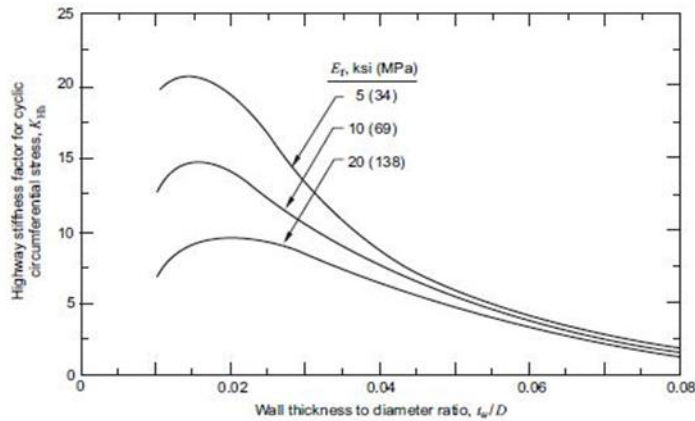


Figure 14—Highway Stiffness Factor for Cyclic Circumferential Stress, K_{Hh}

Figure 26 Highway stiffness factor for cyclic circumferential stress

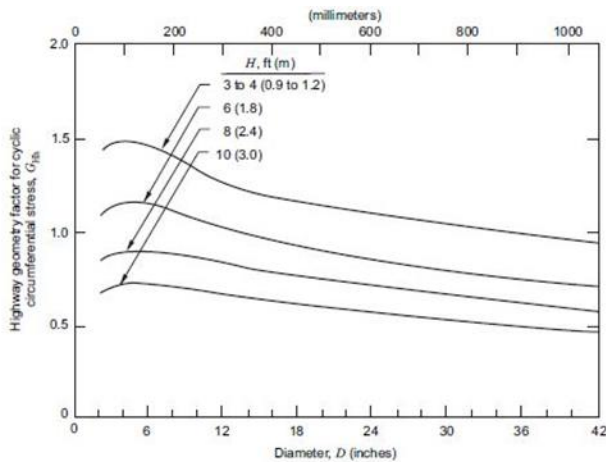


Figure 15—Highway Geometry Factor for Cyclic Circumferential Stress, G_{Hh}

Figure 27 Highway geometry factor for cyclic circumferential stress

4) Cyclic longitudinal stress, ΔS_{lh}

$$\Delta S_{lh} = K_{Lh} G_{Lh} R L F i w$$

K_{Lh} = Highway stiffness factor for cyclic longitudinal stress

G_{Lh}=Highway geometry factor for cyclic longitudinal stress

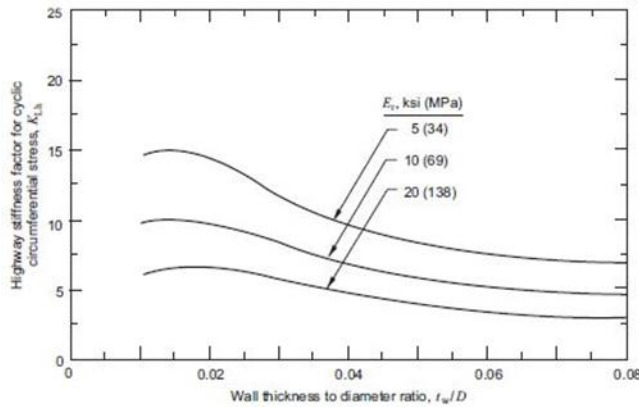


Figure 16—Highway Stiffness Factor for Cyclic Longitudinal Stress, \bar{K}_{Lh}

Figure 28 Highway Stiffness factor for longitudinal stress

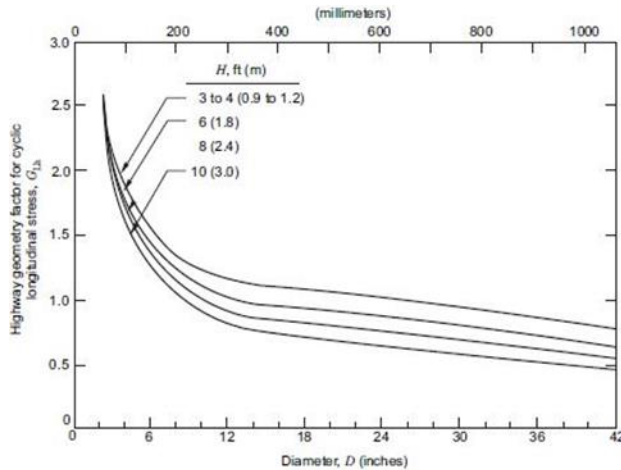


Figure 17—Highway Geometry Factor for Cyclic Longitudinal Stress, G_{Lh}

Figure 29 Highway factor for cyclic longitudinal stress

$S_{hi} = (pd)/2t$ Circumferential Stress Due to Internal Pressurization

Maximum Circumferential stress S1

$$S1 = S_{He} + \Delta SH + S_{Hi}$$

Maximum Longitudinal Stress S2

$$S2 = \Delta S1 - (E_s \alpha (t_2 - t_1)) + v(S_{He} + S_{Hi})$$

Maximum radial Stress S3

s3 = - maximum operating pressure

$$S_{eff} = [0.5 \{ (S1 - S2)^2 + (S2 - S3)^2 + (S3 - S1)^2 \}]$$

Check S_{eff} is less than $SMYS \cdot f$

4.5.3 Rail crossing analysis for 30"X15.9 wall thickness

D	762	mm
t	15.9	mm
γ	18000	N/m ³
E	2.07E+05	Mpa
α	1.17E-05	
ν	0.3	
t1	20	$^{\circ}$ c
t2	60	$^{\circ}$ c
p	9.8	Mpa
F	0.6	
SYMS	485	Mpa
CA	0	
db	813	mm
soil type	A	
E'	3.4	Mpa
E _r	69	Mpa
E	1	
T	1	
H	1800	mm
t/d	0.020866	
h/db	2.214022	
Db/d	1.066929	

$$Shi = (pd)/2t$$

$$Shi = 234.8301\text{Mpa}$$

$$E * F * T * SMYS = 291\text{Mpa}$$

$$Shi < E * F * T * SMYS$$

Circumferential Stress Due to Earth Load

from figure 3 api 1102 t/d vs E'

$$Khe = 2500$$

ANALYSIS IN A PIPELINE

from figure 4 api 1102 h/db vs Be

$$Be = 0.65$$

from figure 5 api 1102 Db/d vs Ee

$$Ee = 0.94$$

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

$$S_{He} = 20951190 \text{ pa} = 20.95119 \text{ Mpa}$$

Figure 7 api 1102 Fi vs H

$$F_i = 1.63$$

$$W = 96 \text{ kpa}$$

figure 8 APi1102 t/d vs Khr

$$K_{hr} = 300$$

figure 9 APi1102 D vs Ghr

$$G_{hr} = 0.75$$

figure10

$$N_h = 1.1$$

$$\Delta S_{hr} = K_{hr} G_{hr} N_h F_i w$$

$$\Delta S_{hr} = 38728.8 \text{ Kpa} = 38.7288 \text{ Mpa}$$

figure 11 APi1102 t/d vs Klh

$$K_{lh} = 340$$

figure 12 APi1102 D vs Glh

$$G_{lh} = 0.8$$

figure13

$$N_l = 1.1$$

$$\Delta S_{lr} = K_{lr} G_{lr} N_l F_i w$$

$$\Delta S_{lr} = 46818.816 \text{ Kpa} = 46.818816 \text{ Mpa}$$

Circumferential Stress Due to Internal Pressurization

$$S_{hi} = (pd)/2t$$

$$S_{hi} = 225.0301887 \text{ Mpa}$$

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

$$S_1 = 284.7101787 \text{ Mpa}$$

$$S_2 = \Delta S_l - (E_s \alpha (t_2 - t_1)) + v (S_{he} + S_{hi})$$

ANALYSIS IN A PIPELINE

$$\begin{aligned}
 S2 &= 23.7372296\text{Mpa} \\
 s3 &= \text{- maximum operating pressure} \\
 S3 &= -9.8\text{Mpa} \\
 \text{Seff} &= [0.5\{(S1-S2)^2 + \{(S2-S3)^2 + \{(S3-S1)^2\}\}] \\
 \text{Seff} &= 279.2560396\text{Mpa} \\
 \text{syms*f} &= 291\text{Mpa} \\
 \text{Seff is less than SMYS*f}
 \end{aligned}$$

Hence ok

4.5.4 Highway crossing analysis for 30”X15.9 wall thickness

Basic Data

D	762	mm
t	15.9	mm
γ	18000	N/m ³
E	2.07E+05	Mpa
α	1.17E-05	
ν	0.3	
t1	20	^o c
t2	60	^o c
p	9.8	Mpa
F	0.6	
SYMS	485	Mpa
CA	0	
db	813	Mm
soil type	A	
E'	3.4	Mpa
E _r	69	Mpa
E	1	
T	1	
H	1800	Mm
t/d	0.020866	

h/db	2.214022	
Db/d	1.066929	

$$S_{hi} = (pd)/2t$$

$$S_{hi} = 234.8301 \text{ Mpa}$$

$$E * F * T * S_{MYS} = 291 \text{ Mpa}$$

$$S_{hi} < E * F * T * S_{MYS}$$

Circumferential Stress Due to Earth Load

from figure 3 api 1102 t/d vs E'

$$K_{he} = 2500$$

from figure 4 api 1102 h/db vs Be

$$B_e = 0.65$$

from figure 5 api 1102 Db/d vs Ee

$$E_e = 0.94$$

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

$$S_{He} = 20951190 \text{ pa} = 20.95119 \text{ Mpa}$$

Figure 7 api 1102 Fi vs H

$$F_i = 1.63$$

$$W = 479 \text{ kpa}$$

figure 14 APi1102 t/d vs Khh

$$K_{hh} = 13.5$$

figure 15 APi1102 D vs Ghh

$$G_{hh} = 1.1$$

$$R = .9$$

$$L = 1$$

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

$$\Delta S_{hr} = 9602.7525 \text{ Kpa} = 9.60275 \text{ Mpa}$$

figure 17 APi1102 t/d vs Klh

$$K_{lh} = 9.5$$

figure 18 APi1102 D vs Glh

$$G_{Lh} = 0.75$$

ANALYSIS IN A PIPELINE

$$R = 0.9$$

$$L = 1$$

$$\Delta S_{lh} = K L_h G L_h R L F i w$$

$$\Delta S_{lr} = 4607.38125 \text{Kpa} = 4.60738125 \text{Mpa}$$

Circumferential Stress Due to Internal Pressurization

$$S_{hi} = (pd)/2t$$

$$S_{hi} = 225.0301887 \text{Mpa}$$

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

$$S_1 = 253.9725 \text{Mpa}$$

$$S_2 = \Delta S_1 - (E_s \alpha (t_2 - t_1)) + v (S_{he} + S_{hi})$$

$$S_2 = -18.9577 \text{Mpa}$$

$$s_3 = \text{- maximum operating pressure}$$

$$S_3 = -9.8 \text{Mpa}$$

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

$$S_{eff} = 268.4685152 \text{Mpa}$$

$$s_{yms} * f = 291 \text{Mpa}$$

S_{eff} is less than $SMYS * f$

Hence ok

4.6 Seismic Analysis

In most cases, the seismic hazards cannot be quantified precisely. Hence, based on available data and experience, reasonable assumptions should be made to define proper model for the seismic hazard.

The stresses (or strains) obtained from the seismic analysis should be combined linearly with the stresses (or strains) in the pipeline during operation. When the stress-strain relationship for the pipe material is not defined, it may be approximated by Ramberg-Osgood's relationship as :

$$\epsilon = \frac{s}{E} \left[1 + \frac{n}{1+r} \left(\frac{s}{\sigma_y} \right)^r \right]$$

Where

ϵ = Engineering strain

s = Stress in the pipe

ANALYSIS IN A PIPELINE

E = Initial Young's modulus

σ_y = Yield strain of the pipe material

n, r = Ramberg - Osgood parameters

Ramberg oswood parameter for buried pipeline			
grade	yield stress	n	r
Grade B	227	10	100
X42	310	15	32
X52	358	9	10
X60	413	10	12
X70	517	5.5	16.6

Table 4 Ramberg oswood parameter for buried pipeline

The longitudinal stress in pipe due to internal pressure may be calculated as:

$$S_p = (pdv)/2t$$

The longitudinal stress in pipe due to temperature change may be calculated as:

$$S_r = E\alpha(T_2-T_1)$$

Table 5 Maximum allowable strain

Strain Component	Pipe Category	Allowable Strain	
		Tension	Compression
Continuous Oil and Gas Pipeline	Ductile Cast Iron Pipe	2%	For PGD: Onset of Wrinkling (ϵ_{cr-c}) (clause-3.9.2)
	Steel Pipe	3%	
	Polyethylene Pipe	20%	
	Bends and Tees of pipe	1%	For wave propagation: 50% to 100% of the Onset of Wrinkling (0.5 to 1 ϵ_{cr-c})
Continuous Water Pipeline	Steel and iron pipe	0.25 ϵ_u or 5%	ϵ_{c-pgd}
			ϵ_{c-wave}

For oil and gas pipeline, the maximum tensile strain should not exceed 4% in any case. For bends and tees maximum strain is restricted to 2%. The limiting compressive strain is considered as the strain at onset of wrinkling

$$\epsilon_{cr-c} = \frac{0.175 t}{R}$$

The design strain for continuous pipelines should be less than the allowable strain,
 $\epsilon_{oper} + \epsilon_{seismic} < \epsilon_{allowable}$

The soil-pipe interaction in buried pipelines is a complex problem. During earthquake, the nonlinear behavior of the soil further increases the complexity. The complexity is mainly attributed to the soil rather than the pipe.

The actual three dimensional soil-pipe interactions can be ideally modeled as a pipe resting on nonlinear soil springs . The pipe can either be modeled as a three dimensional shell element or as a two dimensional beam element depending on the pipeline geometry and loading condition. The soil surrounding the pipe is modeled as nonlinear springs. Basically four types of springs are used to model the surrounding soil as:

- a) Axial soil spring: It is to represent soil resistance over the pipe surface along its length.
- b) Lateral soil spring: It is to represent the lateral resistance of soil to the pipe movement.
- c) Vertical bearing spring: It is to represent the vertical resistance of soil at the bottom of the pipe,
- d) Vertical uplift spring: It is to represent the vertical resistance of the soil at the top of the pipe.

The maximum axial soil resistance (t_u) per unit length of the pipe can be calculated as

$$t_u = \pi D c \alpha + \pi D H \gamma \frac{1+k}{2} \tan \delta$$

The maximum lateral resistance of soil per unit length of pipe can be calculated as:

$$P_u = N c h c D + N q h \gamma H D$$

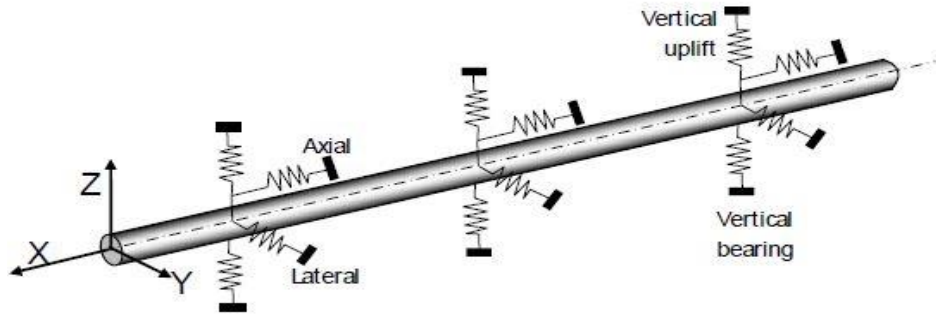


Figure 30 BNF model representing pipe soil interaction

where

N_{ch} = Horizontal bearing capacity factor for clay

N_{qh} = Horizontal bearing capacity factor for sandy soil

$$N_{qh} = a + bx + cx^2 + dx^3 + ex^4$$

$$N_{ch} = a + bx + \frac{c}{(x+1)^2} + \frac{d}{(x+1)^3} \leq 9$$

Factor	f	a	b	c	d	e
N_{ch}	0	6.752	0.065	-11.063	7.119	
N_{qh}	20	2.399	0.439	-0.03	1.09E-03	-1.75E-05
N_{qh}	25	3.332	0.839	-0.09	5.61E-03	-1.32E-04
N_{qh}	30	4.565	1.234	-0.089	4.28E-03	-9.16E-05
N_{qh}	35	6.816	2.019	-0.146	7.65E-03	-1.68E-04
N_{qh}	40	10.959	1.783	0.045	-5.43E-03	-1.15E-04
N_{qh}	45	17.658	3.309	0.048	-6.44E-03	-1.30E-04

Table 6 lateral bearing capacity of soil

The maximum soil resistance per unit length of the pipeline in vertical uplift can be calculated as:

$$Q_u = N_{cv} cD + N_{qv} \gamma HD$$

N_{cv} = Vertical uplift factor for clay

N_{qv} = Vertical uplift factor for sand

$$N_{cv} = 2 \frac{H}{D} \leq 10$$

$$N_{qv} = \frac{\phi H}{44D} < N_q$$

ANALYSIS IN A PIPELINE

The maximum soil resistance per unit length of pipeline in vertical bearing can be calculated as

$$Qd = Nc cD + Nq \gamma HD + Nr \frac{\gamma D^2}{2}$$

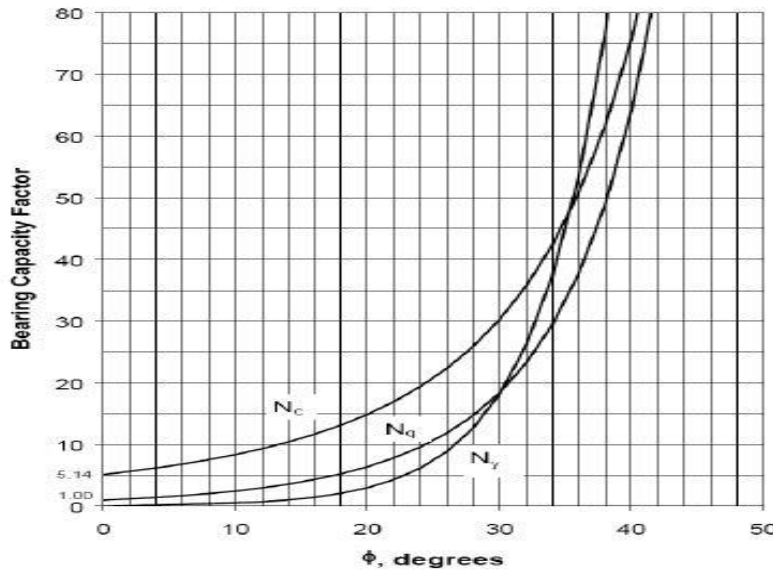


Figure 31 Bearing capacity factor of soils of different soil friction values

Nc Nq & Nr are bearing capacity factor from graph

4.6.1 Design Criteria for Permanent Ground Deformation (PGD)

The design ground displacement in longitudinal direction may be taken as:

$$\delta^l_{design} = \delta * I_p$$

δ = Maximum longitudinal ground displacement

I_p = Importance factor

Importance factor I_p of different class				Transverse and longitudinal PGD
class	Wave propagation	faulting	landslide	
1	1.5	2.3	1.5	2.6
2	1.25	1.5	1.35	1.6
3	1	1	1	1
4	*	*	*	*

Table 7 Importance Factor of different classes

Strain for both tension and compression can be calculated as

$$\varepsilon_a = \frac{T_{ul}}{2\Pi DtE} \left[1 + \frac{n}{1+r} \left(\frac{t_{ul}}{2\Pi Dt\sigma_y} \right)^r \right]$$

The design ground displacement in Transverse direction may be taken as:

$$\delta l_{design} = \delta * I_p$$

δ = Maximum longitudinal ground displacement

I_p = Importance factor

The maximum bending strain in pipe may be conservatively calculated as the least of the following two

$$\varepsilon_b = \frac{\Pi D \delta l_{design}}{w^2}$$

$$\varepsilon_b = \frac{P_u w^2}{3\Pi EtD^2}$$

4.6.2 Design Criteria for Buoyancy due to Liquefaction

The net upward force per unit length of pipeline due to buoyancy may be

$$F_b = \frac{\Pi D^2}{4} (\gamma_{sat} - \gamma_{cont}) - \Pi DEt\gamma_{pipe}$$

Bending stress induced for a relatively short section of continuous pipeline subjected to buoyancy can be calculated as

$$\sigma_b = \frac{F_b l_b}{10 Z}$$

The maximum strain corresponding to above bending stress

$$\varepsilon_b = \frac{\sigma_b}{E} \left[1 + \frac{n}{1+r} \left(\frac{\sigma_b}{\sigma_y} \right)^r \right]$$

4.6.3 Design Criteria for Fault Crossing

For Strike slip fault

Component of fault displacement in the axial direction of pipeline is

$$\delta f_{ax} = \delta s \cos \beta$$

ANALYSIS IN A PIPELINE

Component of fault displacement in transverse direction of pipeline

$$\delta f_{tr} = \delta s \sin \beta$$

β = angle of pipeline crossing the fault line

For normal fault

Component of fault displacement in the axial direction of pipeline is:

$$\delta f_{ax} = \delta n \cos \Psi \sin \beta$$

Component of fault displacement in transverse direction of pipeline

$$\delta f_{tr} = \delta n \cos \Psi \cos \beta$$

Component of fault displacement in vertical direction of pipeline

$$\delta f_{vr} = \delta n \sin \beta$$

Design fault displacement in the axial direction of pipeline is:

$$\delta_{ax \text{ design}} = \delta_{ax \text{ IP}}$$

Design fault displacement in transverse direction of pipeline is:

$$\delta_{tr \text{ design}} = \delta_{tr \text{ IP}}$$

The average pipe strain due to fault crossing can be calculated as:

$$\epsilon_a = 2 \left[\frac{\delta_{ax \text{ design}}}{2 l_a} + \frac{1}{2} \left[\frac{\delta_{tr \text{ design}}}{2 l_a} \right]^2 \right]$$

Where

l_a = Unanchored pipe length

$$l_a = \frac{E \epsilon_y \pi D t}{t_u}$$

4.6.4 Design Criteria for Seismic Wave Propagation

The design wave propagation velocity can be calculated as:

$$V_g = PGV * IP$$

To calculate PGV first we need to get values PGA and PGV/PGA from the tables below

Table 8 PGA for different seismic zone

Table 9 ratio of PGv/PGA

moment magnitud e		ratio of PGv(cm/s)/PGA(m/s ²)			seismic zone	PGAr
		0-20km	20-50km	50-100km		
					II	0.1
					III	0.16
					IV	0.24
					V	0.36
	6.5	66	76	86		
Rock	7.5	97	109	97		
	8.5	127	140	152		
	6.5	94	102	109		
Stiff	7.5	140	127	155		
soil	8.5	180	188	193		
	6.5	140	132	142		
soft	7.5	208	165	201		
soil	8.5	269	244	251		

The maximum longitudinal axial strain that can be induced in the pipeline due to wave propagation, can be approximated as:

$$\varepsilon_a = \frac{Vg}{\alpha_r C}$$

$$\varepsilon_a \leq \frac{tu \lambda}{4AE}$$

Where

tu = Peak frictional force per unit length at soil-pipe interface

λ = Apparent wavelength of seismic waves at ground surface

4.6.5 Seismic Analysis for 30"X 15.9 wall thickness pipe

Basic data

D	diameter	762	mm
t	thickness	15.9	mm
v	poission ratio	0.3	
T1	installation temperature	20	^o c
T2	operating temperature	60	^o c
P	pressure	9.8	mpa
SMYS		485	
α	coefficent of thermal expansion	1.17E-05	/deg
E	Youngs modulus	2.07E+05	mpa
n	ramberg oswood parmeter	9	table
r	ramberg oswood parmeter	10	table
H	burial depth	1.2	m
C	coefficient of cohesion	10	kpa
ϕ	angle of friction	30	deg
γ	effective unit wt of soil	18000	n/m3
CDF	coating dependent factor	0.6	
γ_{sat}	saturated unit wt of soil	19500	n/m3
γ	unit wt of pipe content	56.47	n/m3
γ	unit wt of pipe material	77009	n/m3
σ_y		358	mpa

4.6.5.1 OPERATIONAL STRAIN

$$S_p = PDv/2t$$

$$S_p = 70.4490566 \text{ Mpa}$$

$$\epsilon_p = \frac{S_p}{E} \left[1 + \frac{n}{1+r} \left(\frac{S_p}{\sigma_y} \right)^r \right]$$

$$\epsilon_p = 3.40 \text{E-}04$$

$$S_t = E\alpha(T_2 - T_1)$$

$$S_t = 9.69 \text{E+}01 \text{ Mpa}$$

$$\epsilon_t = \frac{S_t}{E} \left[1 + \frac{n}{1+r} \left(\frac{S_t}{\sigma_y} \right)^r \right]$$

$$\epsilon_t = 4.68 \text{E-}04$$

Total operational strain

$$\epsilon_{otot} = 8.08 \text{E-}04$$

4.6.5.2 Calculation of Soil Resistance

Internal angle of friction between soil and pipe

$$\delta = f * \phi$$

$$\delta = 21$$

Coefficient of soil pressure at rest, kc

$$k_c = 1 - \sin \phi$$

$$k_c = 0.5$$

Axial soil spring

Adhesion factor α

$$\alpha = (.608) - (.123C - (.274/c2 + 1) + (.695/c3 + 1))$$

$$\alpha = 1.018719$$

$$t_u = \pi D c \alpha + \pi D H \gamma \frac{1+k}{2} \tan \delta$$

$$t_u = 39253.78892 \text{ N/m}$$

$$\Delta t = 5$$

ANALYSIS IN A PIPELINE

lateral soil spring:

$$N_{ch} = a + bx + \frac{c}{(x+1)^2} + \frac{d}{(X+1)^3} \leq 9$$

$$N_{ch} = 5.602685731$$

$$N_{qh} = a + bx + cx^2 + dx^3 + ex^4$$

$$N_{qh} = 6.30E+00$$

Maximum transverse soil resistance per unit length of pipe

$$P_u = N_{ch} cD + N_{qh} \gamma HD$$

$$P_u = 1.46E+05 \text{ N/m}$$

$$\Delta p = .04 \left(H + \frac{D}{2} \right) \leq 0.01D \text{ to } 0.02d$$

$$\Delta p = 0.06324 \text{ m}$$

Vertical soil spring

$$N_{cv} = 2 \frac{H}{D} \leq 10$$

$$N_{cv} = 3.149606299$$

$$N_{qv} = \frac{\phi H}{44D} < N_q$$

$$N_{qv} = 1.07372942$$

$$Q_u = N_{cv} cD + N_{qv} \gamma HD$$

$$Q_u = 41672.72727 \text{ N/m}$$

$$\Delta h = 0.15H$$

$$\Delta h = 0.18 \text{ m}$$

BEARING

$$N_c = 30 \quad \text{from graph}$$

$$N_q = 18 \quad \text{from graph}$$

ANALYSIS IN A PIPELINE

$$N_r = 18 \quad \text{from graph}$$

$$Q_d = N_c cD + N_q \gamma HD + N_r \frac{\gamma D^2}{2}$$

$$Q_d = 618929.928 \text{ N/m}$$

$$\Delta d = 0.125D$$

$$\Delta d = 0.09525 \text{ m}$$

4.6.5.3 Longitudinal PGD

$$\delta^l = 2 \text{ m}$$

$$\delta l_{\text{design}} = \delta * I_p$$

$$\delta l_{\text{design}} = 3$$

$$W = \text{width of permanent ground displacement zone} = 40 \text{ m}$$

$$L = \text{Length of permanent ground displacement zone} = 100 \text{ m}$$

$$\epsilon_a = \frac{T_u l}{2 \Pi \Pi D t E} \left[1 + \frac{n}{1+r} \left(\frac{t_u l}{2 \Pi \Pi D t \sigma_v} \right)^r \right]$$

$$\epsilon_a = 0.00024923$$

$$\epsilon_a \pm \epsilon_{\text{oper}} < \epsilon_{\text{allowable}}$$

$$\epsilon_{\text{tensile total}} = 1.06 \text{ E-}03$$

$$\epsilon_{\text{compressive total}} = -5.59 \text{ E-}04$$

Since compressive strain is negative total strain is tensile

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

4.6.5.4 Transverse PGD

$$\epsilon_b = \frac{\Pi \Pi D \delta l_{\text{design}}}{w^2}$$

$$\epsilon_{b1} = 0.004486275$$

$$\epsilon_b = \frac{P_u w^2}{3 \Pi \Pi E t D^2}$$

$$\epsilon_{b2} = 1.30 \text{ E-}02$$

ANALYSIS IN A PIPELINE

ϵ_{b1} is less than ϵ_{b2} hence it should be used

$\epsilon_b \pm \epsilon_{oper} < \epsilon_{allowable}$

ϵ tensile total= 5.29E-03

ϵ compressive total= 3.68E-03

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

4.6.5.5 Buoyancy due to Liquefaction

F_b = net upward force per unit length of pipeline

$$F_b = \frac{\pi D^2}{4} (\gamma_{sat} - \gamma_{cont}) - \pi D E t_{pipe}$$

F_b = 5249.059865N/m

$$Z = \frac{\pi(D^4 - ID^4)}{32d}$$

Z = 0.006806128m

$$\sigma_b = \frac{F_b l_b}{10 Z}$$

L_b = 40m

σ_b = 3084902.177N/m²

$$\epsilon_b = \frac{\sigma_b}{E} \left[1 + \frac{n}{1+r} \left(\frac{\sigma_b}{\sigma_y} \right)^r \right]$$

ϵ_b = 1.49E-05

$\epsilon_b \pm \epsilon_{oper} < \epsilon_{allowable}$

ϵ tensile total= 8.23E-04

ϵ compressive total= -7.93E-04

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

4.6.5.6 Seismic Wave Propagation

Magnitude of design basis Earthquake = 6.5

Distance of site from earthquake source = 20km

PGAr = 0.36 from table

PGv/PGA= 140

PGV = 50.4cm/s = 0.504m/s

Vg = PGV*IP

Vg = 0.756m/s

IP = 1.5

$$\varepsilon_a = \frac{V_g}{\alpha_\varepsilon C}$$

C 2000m/s for s wave

C 500m/s for r wave

α_ε 2 for s wave

α_ε 1 for r wave

$$\varepsilon_a \leq \frac{tu \lambda}{4AE}$$

ε_{a1} = 0.000189

ε_{a2} = 1.27E-03

ε_{a1} is acceptable

$\varepsilon_b \pm \varepsilon_{oper} < \varepsilon_{allowable}$

ε tensile total= 9.97E-04

ε compressive total= -6.19E-04

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

ANALYSIS IN A PIPELINE

Value is less than limiting strain hence allowable

4.6.5.7 Fault crossing

δn expected normal slip fault displacement

$$\delta n = 2.5m$$

Ψ angle of dip of fault movement

$$\Psi = 35$$

β angle b/w pipeline & fault line

$$\beta = 40$$

$$\delta f_{ax} = \delta n \cos \Psi \sin \beta$$

$$\delta f_{ax} = 1.316351961m$$

$$\delta f_{tr} = \delta n \cos \Psi \cos \beta$$

$$\delta f_{tr} = 1.568767181m$$

$$\delta f_{vr} = \delta n \sin \beta$$

$$\delta f_{vr} = 1.433941089m$$

$$IP = 2.3$$

$$\delta a_{x \text{ design}} = \delta a_{x \text{ IP}}$$

$$\delta a_{x \text{ design}} = 3.02760951m$$

$$\delta t_{r \text{ design}} = \delta t_{r \text{ IP}}$$

$$\delta t_{r \text{ design}} = 3.608164516m$$

$$l_a = \frac{E \varepsilon_y \Pi D t}{t_u}$$

$$l_a = 346.9630186m$$

$$\varepsilon_a = 2 \left[\frac{\delta a_{x \text{ design}}}{2 l_a} + \frac{1}{2} \left[\frac{\delta t_{r \text{ design}}}{2 l_a} \right]^2 \right]$$

ANALYSIS IN A PIPELINE

$$\epsilon_a = 0.008753066$$

$$\epsilon_a \pm \epsilon_{oper} < \epsilon_{allowable}$$

$$\epsilon_{\text{tensile total}} = 7.94E-03$$

$$\epsilon_{\text{compressive total}} = 9.56E-03$$

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

4.6.6. Measures to prevent pipeline failure under seismic activity

Mitigation of seismic motion is an important factor in construction in earthquake-prone areas. The destabilizing action of an earthquake on constructions may be direct (seismic motion of the ground) or indirect (earthquake-induced landslides, liquefaction of the foundation soils and waves of tsunami).

Knowledge of local amplification of the seismic motion from the bedrock is very important in order to choose the suitable design solutions. Local amplification can be anticipated from the presence of particular stratigraphic conditions, such as soft soil overlapping the bedrock, or where morphological settings (e.g. crest zones, steep slopes, valleys, or endorheic basins) may produce focalization of the seismic event.

The identification of the areas potentially affected by earthquake-induced landslides and by soil liquefaction can be made by geological survey and by analysis of historical documents.

There are many strategies that can be adopted to prevent failure of pipeline under seismic hazard. These include

- ❖ Using high grade material of higher ductility in pipeline,
- ❖ Increasing thickness of the pipe for fault mitigation,
- ❖ Use of joints with enhanced expansion/contraction or rotation capability
- ❖ Methods to isolate the pipeline segment from ground movement during seismic event
- ❖ Methods to reduce ground movement

- ❖ Improving the quality of backfill soil
- ❖ Avoiding or rerouting the pipeline from the areas susceptible to damaging ground movements.

Mitigation measures for each type of seismic hazard are specific. Appropriate measures should be selected carefully after considering the economics involved. Earthquake monitoring system (EMS) also aids in emergency rupture situations. Beside all this, every operating company should have a seismic contingency plan for immediate action during emergency situations. Hazard specific mitigation measures are given below.

Mitigation strategies for fault crossing

1) Optimizing the fault angle

The pipeline fault angle plays a very important role in the pipeline performance. Hence For normal fault, effect of the pipeline-fault angle (ϕ) is studied by varying the pipeline-fault angle from 40° , 60° , 80° , 90° , 100° , 120° to 140° for the Maximum expected fault displacement.

The performance analysis of pipeline is complex due to unlike behavior of the pipeline under compression and tension. In general, under tension pipe is fail due to excessive straining of pipe material, while in case of compression in addition to the material failure geometric failure also takes place.

For reverse slip faults where compression is anticipated, pipeline should cross at oblique angles to make allow only tensile stresses to act on pipeline.

2) Pipeline wall thickness to diameter ratio

The thickness to diameter ratio has great hold on the pipeline performance crossing strike slip fault especially when pipeline subjected to the compression. The pipe with greater wall thickness subject to more geometric changes than the pipe with thinner wall thickness. Increasing pipe wall thickness imposes the pipeline to remain more sustainable under various faulting patterns and correspondingly increases the failure displacement of the pipeline

3) Check for alternate route available

If alternate routes are available which will not cross the faults then that route has to select even when the economic cost is more. For a pipeline design safety is an important parameter so it is necessary to select the safest route than the economical one.

4) Increased Width of Right-of-Way

When designing, consideration shall be made for an increased width of right-of-way. The increased width shall be used to provide access for emergency rescue, and adds flexibility for post-event track realignment and reconstructive work.

5) Depth of burial

Pipeline should be shallowly buried in fault zones to reduce the soil restraints on pipeline.

6) Angle of Trench

The angle of the top soil needs to be adequately designed and specified to ensure that spoil does not collapse towards the trench thus compressing the trench itself. The topsoil height should be limited to about 2 m, and the inclination be about 40° or lower for strike slip. Capping (typically 300 mm thick) is normally applied to avoid erosion from wind and rain.

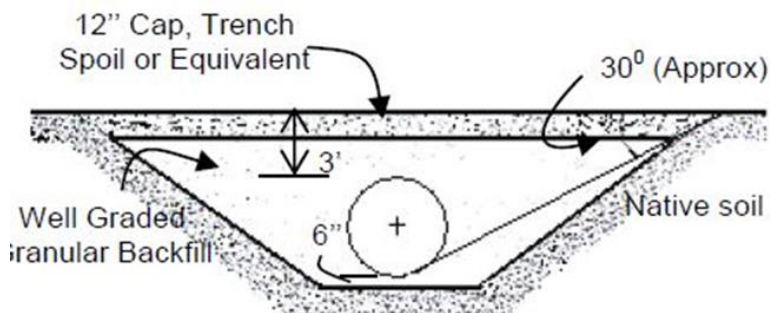


Figure 32 trench design for strike slip fault

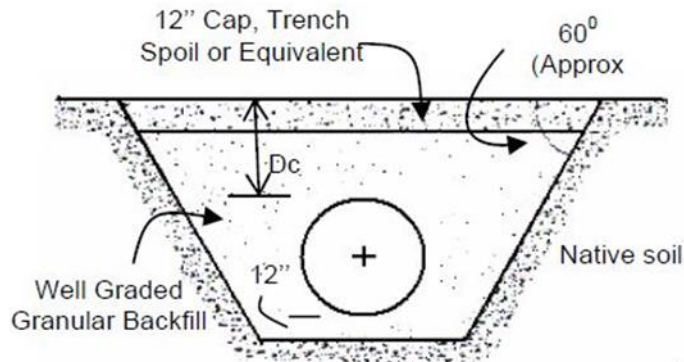


Figure 33 trench design for reverse fault

7) Improving backfill

It is necessary to excavate and restore the trench during a pipeline construction. A stable uniform trench supporting the pipe with selected materials as backfill is necessary to mitigate the ground movements. Select native materials, crushed stone, gravel, slag, coral or other granular materials are commonly used for this purpose. The amount of granular material necessary to stabilize the trench bottom will vary according to the field conditions encountered. If the native soil varies with this soil, geo wrappings should be provided to resist mixing of backfill and native soil by period. Adequate compaction must be applied to guarantee a stable reformed pipe bed.

Any material that might damage the pipe coating should be removed from the trench bottom, including rubbish left by the construction workers. Organic materials (“biodegradable”) should also be removed as their decomposition could lead to damage to the coating and pipe.

- 8) Pipeline crossing strike slip fault should be aligned in such a way that only tension strains act on a pipeline

- 9) As far as possible the pipelines on either side of fault line should be devoid of bends, stub-ins, flanges or sharp edges which may restrict the pipeline from absorbing the stresses there by resulting in concentration of strains in local areas and leading to rupture.
- 10) Increasing the thickness of pipeline along the fault zone helps to absorb/ withstand more strains. Weld integrity should also be taken care of in this case.
- 11) Pipeline coating with smooth and hard material helps to reduce soil restraints on pipeline. This is done by reducing angle of interface friction between soil and pipe.
- 12) Placement of pipeline on aboveground sliding supports helps to isolate pipeline from ground movement during seismic event.
- 13) Making the pipeline above ground is another option although it is expensive. So an economic analysis should be done based on probabilistic studies to come to a decision on this
- 14) Shut off valves can be provided on either side of the fault line to reduce the risk of fire or other impacts to environment and public.

Mitigation strategies for PGD

- ❖ Soil improvement in the potential areas by compaction, strengthening, soil densification etc thereby reducing the ground movement. Stabilized soil mattresses for liquefiable soil deposit areas
- ❖ Appropriate coating for reducing the soil pipeline frictional force. This helps in reducing strains.
- ❖ Pipeline should be routed below the lowest depth of liquefiable soil as far as possible.
- ❖ Expansion joints can be used for compensating for expansion, contraction, rotation and bending during a seismic event.
- ❖ Trenches, deformable walls can be constructed in upslope so as not to affect the pipeline while ground movement along slope.

CHAPTER 5

RESULTS

1) Stress analysis

Stress analysis for CS pipe

Condition	Wall thickness	Pipe Size	SMYS	Longitudinal Existing stress	Total longitudinal stress
Lowering	14.3	30	485	224.499	436.5
Hydro test	14.3	30	485	263.66	345.90
Operation	14.3	30	485	221.499	244.86
Lowering	15.9	30	485	216.6169	436.5
Hydro test	15.9	30	485	251.845	314.31
Operation	15.9	30	485	216.6169	226.274

Stress analysis for HDPE pipe

Lowering	69.27	30	24	2.79	21.6
Hydro test	69.27	30	24	6.95	6.11
Operation	69.27	30	24	5.91	6.26

2) Pipeline Expansion analysis

Pipe Size	Anchor length (m)	End expansion due to pressure(m)	End expansion due to temperature(m)	End expansion due to soil friction(m)	Net Expansion(m)
30	471	1.19E-01	0.220262712	2.55E-01	5.94E-01
24	436	8.79E-02	0.203824223	2.18E-01	5.10E-01

3) Pipe Stability Analysis

Pipe size	Net Upward thrust (Kpa)
30	5.5807377
24	4.7373

4) Rail Crossing Analysis

Pipe size	Stress due to earth load (Mpa)	Cyclic circumferential stress (Mpa)	Cyclic longitudinal stress (Mpa)	Net effective stress (Mpa)
30	20.95119	38.7288	46.818816	279.2560396

5) Road Crossing Analysis

Pipe size	Stress due to earth load (Mpa)	Cyclic circumferential stress (Mpa)	Cyclic longitudinal stress (Mpa)	Net effective stress (Mpa)
30	19.33956	9.6027525	4.60738125	268.4685152

6) Seismic Analysis

Pipe size	Total operational strain	Strain due to longitudinal PGD	Strain due to Transverse PGD	Strain due to liquefaction	Strain due to seismic wave propagation	Strain due to Faulting
30	8.08E-04	0.0002492	0.0044862	1.49E-05	0.000189	0.00875

CHAPTER 6

CONCLUSION

One of the main aspects which were observed during the project was importance of analysis in a pipeline.

Following conclusions are made after Analysis

Stress induced in a pipeline while lowering a 30" pipeline of different wall thickness was found within the allowable limits

Stress induced in pipeline while hydro testing a 30" pipeline of different wall thickness was found within the allowable limits

Stress induced in pipeline while operating a 30" pipeline of different wall thickness was found within the allowable limits

Stress induced in 30" HDPE pipeline of different wall thickness was found within the allowable limits

Pipeline expansion length were found out for 24" and 30" pipeline

Crossing analysis for railroad and highway was done and the stress developed during crossing of railroad and highway was found out and is within the acceptable limit

Strain developed due to PGD, Faulting, and Buoyancy due to liquefaction and seismic wave propagation is within the allowable stress limit

Since different type of analysis was done manually it was a time consuming procedure by using software's one can do the Analysis in a pipeline easily.

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Appendix A

Lowering In-Service Pipelines 30" X 15.9 mm Wall Thickness

Symbols	Nomenclature	values	Units	Values	Units
p	pressure	9.8	Mpa		
D	diameter	762	mm	24.9936	feet
t	thickness	15.9	mm		
v	poisson ratio	0.3			
E	young's modulus	2.07E+05	Mpa		
α	coefficient of thermal expansion	1.17E-05	per degc		
T1	installation temp	20	° c		
T2	operational temp	60	° c		
tc	thickness coat	3.2	mm		
tcc	thickness concrete	0	mm		
Rc	radius of curvature	1600000	mm		
SMYS		485	mpa	70343.28	psi
F	design factor	0.9			
ppipe	density pipe	7850	kg/m3		
Δ	mid –span deflection of the pipe, in feet	5.45	m		
pcoat	Density of the coat	900	kg/m3		
pcc	Density of the concrete	2400	kg/m3		
pcontent	Density of the content	56.47	kg/m3		
id	inner diameter	733.4	mm	23.95056	Feet

D w	Diameter with coating	765.2	mm	25.09856	Feet
γ	unit soil weight	1800	kg/m ³		
H	burial depth	1	m		

$$S_p = PD_v / 2t$$

$$S_p = 70.4490566 \text{ MPA}$$

$$S_n = E\alpha (T_2 - T_1)$$

$$S_n = 96.876 \text{ Mpa}$$

$$S_c = ED/2R$$

$$S_c = 49.291875 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = S_p + S_n + S_c$$

$$SE_1 = S_p + S_n - S_c$$

$$SE_1 = 118.0331816 \text{ MPA}$$

$$SE_2 = SE + S_n + S_c$$

$$SE_2 = 216.6169 \text{ MPA}$$

$$L_t = \sqrt{\frac{((3.87 \times 10^7 \times D \times \Delta) + (7.74 \times 10^7 \times \Delta^2))}{((F_d \times SMYS) - S_e)}}$$

$$L_t = 306.8018 \text{ feet}$$

$$L_t = 93.512 \text{ m}$$

$$S_s = 2.67E \left(\frac{\Delta}{L} \right)^2$$

$$S_s = 174.40485 \text{ Mpa}$$

Allowable longitudinal stress for bending, Sb

$$S_{b1} = FD * SMYS - SE_1 - S_s$$

$$S_{b1} = 144.0619 \text{ MPA}$$

$$S_{b2} = FD * SMYS - SE_2 - S_s$$

$$S_{b2} = 45.478 \text{ Mpa}$$

Allowable longitudinal stress for bending, Sb is taken minimum of Sb1 and Sb2

Total longitudinal stress, SL1

ANALYSIS IN A PIPELINE

$$SL1 = SE1+SS+Sb1$$

$$SL1 = 436.5\text{Mpa}$$

Total longitudinal stress, SL2

$$SL2 = SE2+SS+Sb2$$

$$SL2 = 436.5\text{Mpa}$$

Total longitudinal stress should be less than SMYS

$$\text{Here } SL = 436.50 < \text{SMYS of } 485\text{Mpa}$$

Hence ok

Support spacing requirement while lowering in to the trench

$$L_s = \sqrt{\frac{0.0286S_b(D^4 - d^4)}{D^3 - 0.8724d^2D}}$$

Where D – Outer diameter of the pipeline

d- Inner diameter of the pipeline

$$L_s = 60.96144 \text{ feet}$$

Hydro test condition 30" X 15.9 mm Wall Thickness

Basic Data

P	pressure	14.7	Mpa
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Longitudinal tensile stress in pipe due to internal pressure, Sp

$$Sp = PDv / 2t$$

$$Sp = 105.672\text{Mpa}$$

Longitudinal compressive stress due to temperature change

$$S_n = E\alpha (T2 - T1)$$

$$S_n = 96.876\text{Mpa}$$

Longitudinal flexure stress due to existing elastic curvature

$$S_c = ED/2R$$

$$S_c = 49.291875 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = Sp+S_n+S_c$$

$$SE1 = Sp+S_n-S_c$$

ANALYSIS IN A PIPELINE

$$\begin{aligned} SE1 &= 153.2577099 \text{ Mpa} \\ SE2 &= SE+Sn+Sc \\ SE2 &= 251.8414599 \text{ Mpa} \\ SL &= \text{Maximum of SE1 or SE2 which should be less than SMYS} \end{aligned}$$

Hence ok

Allowable bending stress considering $S_b=0.75SMYS-S_p+or-S_c$

$$S_b = 208.7845 \text{ Mpa}$$

Finding weight of the pipe, coat, content and soil

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{Pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2868.55 \text{ N/m}$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

$$W_{coat} = 67.8837 \text{ N/m}$$

$$W_{cont} = \frac{\Pi ID^2 \rho_{cont}g}{4 \times 10^6}$$

$$W_{cont} = 4106.032 \text{ N/m}$$

$$W_{soil} = \gamma_b(D + 2t_c + 2t_{cc})9.81/1000$$

$$W_{soil} = 13568.4072 \text{ N/m}$$

$$W_{tot} = \text{Total load per meter}$$

$$W_{tot} = W_{pipe} + W_{coat} + W_{content} + W_{soil}$$

$$W_{tot} = 20610.873 \text{ N/m}$$

Section modulus, S

$$S = \frac{\pi[D^4 - (D-2t)^4]}{32 \times D \times 10^9}$$

$$S = 0.006806 \text{ m}$$

Allowable pipeline span, L

$$L = \sqrt{\frac{12 * S * S_B}{W_r}}$$

$$L = 28.7635 \text{ m}$$

Hoop Stress, SH

ANALYSIS IN A PIPELINE

$$SH = (P \cdot D) / (2 \cdot t)$$

$$Sh = 352.2457 \text{ Mpa}$$

Using Von moises equation, $Seq = \sqrt{S_H^2 + S_L^2 - S_H * S_L}$

$$Seq1 = \sqrt{S_H^2 + S_{E1}^2 - S_H * S_{E1}}$$

$$Seq1 = 314.3106 \text{ Mpa}$$

$$Seq2 = \sqrt{S_H^2 + S_{E2}^2 - S_H * S_{E2}}$$

$$Seq2 = 305.9090709 \text{ Mpa}$$

Seq1 and Seq2 is less than the smys

Hence ok

Operating condition 30" X 15.9 mm Wall Thickness

Basic Data

P	pressure	9.8	Mpa
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Longitudinal tensile stress in pipe due to internal pressure, Sp

$$Sp = PDv / 2t$$

$$Sp = 70.44906 \text{ Mpa}$$

Longitudinal compressive stress due to temperature change

$$Sn = E\alpha (T2 - T1)$$

$$Sn = 96.876 \text{ Mpa}$$

Longitudinal flexure stress due to existing elastic curvature

$$Sc = ED/2R$$

$$Sc = 49.291875 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = Sp + Sn + Sc$$

$$SE1 = Sp + Sn - Sc$$

$$SE1 = 118.0332 \text{ Mpa}$$

$$SE2 = SE + Sn + Sc$$

ANALYSIS IN A PIPELINE

$$SE2 = 216.6169 \text{ Mpa}$$

SL = Maximum of SE1 or SE2 which should be less than SMYS

Hence ok

Allowable bending stress considering $S_b = 0.75SMYS - S_p + \text{or} - S_c$

$$S_b = 244.0091 \text{ Mpa}$$

Finding weight of the pipe, coat, content and soil

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2868.55 \text{ N/m}$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

$$W_{coat} = 67.8837 \text{ N/m}$$

$$W_{cont} = \frac{\Pi ID^2 \rho_{cont}g}{4 \times 10^6}$$

$$W_{cont} = 231.8676 \text{ N/m}$$

$$W_{soil} = \gamma_b(D + 2t_c + 2t_{cc})9.81/1000$$

$$W_{soil} = 16282.09.4072 \text{ N/m}$$

$W_{tot} =$ Total load per meter

$$W_{tot} = W_{pipe} + W_{coat} + W_{content} + W_{soil}$$

$$W_{tot} = 19450.39 \text{ N/m}$$

Section modulus, S

$$S = \pi[D^4 - (D-2t)^4] / [32 * D * 10^9]$$

$$S = 0.006806 \text{ m}$$

Allowable pipeline span, L

$$L = \sqrt{\frac{12 * S * S_b}{W_r}}$$

$$L = 32.00956 \text{ m}$$

Hoop Stress, SH

$$SH = (P * D) / (2 * t)$$

$$Sh = 234.8302 \text{ Mpa}$$

ANALYSIS IN A PIPELINE

Using Von moises equation, $Seq = \sqrt{S_H^2 + S_L^2 - S_H * S_L}$

$Seq1 = \sqrt{S_H^2 + S_{E1}^2 - S_H * S_{E1}}$

Seq1 = 203.3698Mpa

$Seq2 = \sqrt{S_H^2 + S_{E2}^2 - S_H * S_{E2}}$

Seq2 = 226.274Mpa

Seq1 and Seq2 is less than the SMYS

Hence ok

Lowering In-Service HDPE Pipelines 30"

Basic Data

Symbols	Nomenclature	values	Units	Values	Units
p	pressure	9.8	bar		
D	diameter	762	mm	24.9936	feet
t	thickness	69.27	mm		
v	poisson ratio	0.3			
E	young's modulus	900	Mpa		
α	coefficient of thermal expansion	1.2E-04	per degc		
T1	installation temp	20	° c		
T2	operational temp	60	° c		
tcc	thickness concrete	0	mm		
Rc	radius of curvature	1600000	mm		
SMYS		24	mpa	3480.905	psi
F	design factor	0.9			
ρ pipe	density pipe	958	kg/m3		

Δ	mid –span deflection of the pipe, in feet	5.45	m		
ρ_{cc}	Density of the concrete	2400	kg/m ³		
$\rho_{content}$	Density of the content	56.47	kg/m ³		
id	inner diameter	623.46	mm		
γ	unit soil weight	1800	kg/m ³		
H	burial depth	1.2	m		

$$S_p = PD_v / 2t$$

$$S_p = 2.156085 \text{ MPA}$$

$$S_n = E\alpha (T_2 - T_1)$$

$$S_n = 4.32 \text{ Mpa}$$

$$S_c = ED/2R$$

$$S_c = 0.2143 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = S_p + S_n + S_c$$

$$SE_1 = S_p + S_n - S_c$$

$$SE_1 = 2.36 \text{ MPA}$$

$$SE_2 = SE + S_n + S_c$$

$$SE_2 = 2.7915 \text{ MPA}$$

$$L_t = \sqrt{\frac{((3.87 \times 10^7 \times D \times \Delta) + (7.74 \times 10^7 \times \Delta^2))}{((F_d \times SMYS) - S_e)}}$$

$$L_t = 1475.88 \text{ feet}$$

$$L_t = 449.8486 \text{ m}$$

$$S_s = 2.67E \left(\frac{\Delta}{L} \right)^2$$

$$S_s = 0.03276 \text{ Mpa}$$

Allowable longitudinal stress for bending, S_b

$$S_{b1} = FD * SMYS - SE_1 - S_s$$

ANALYSIS IN A PIPELINE

$$Sb1 = 19.204 \text{ MPA}$$

$$Sb2 = FD * SMYS - SE2 - SS$$

$$Sb2 = 18.775 \text{ Mpa}$$

Allowable longitudinal stress for bending, Sb is taken minimum of Sb1 and Sb2

Total longitudinal stress, SL1

$$SL1 = SE1 + SS + Sb1$$

$$SL1 = 21.6 \text{ Mpa}$$

Total longitudinal stress, SL2

$$SL2 = SE2 + SS + Sb2$$

$$SL2 = 21.6 \text{ Mpa}$$

Total longitudinal stress should be less than SMYS

$$\text{Here } SL = 21.6 < \text{SMYS of } 24 \text{ Mpa}$$

Hence ok

Support spacing requirement while lowering in to the trench

$$Ls = \sqrt{\frac{0.0286 S_b (D^4 - d^4)}{D^3 - 0.8724 d^2 D}}$$

Where D – Outer diameter of the pipeline

d- Inner diameter of the pipeline

$$Ls = 50.8170849 \text{ feet}$$

Hydro test condition for 30" HDPE pipe

Basic Data

P	pressure	14.7	bar
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Longitudinal tensile stress in pipe due to internal pressure, Sp

$$Sp = PDv / 2t$$

$$Sp = 2.4255 \text{ Mpa}$$

Longitudinal compressive stress due to temperature change

$$Sn = E\alpha (T2 - T1)$$

$$Sn = 4.32 \text{ Mpa}$$

Longitudinal flexure stress due to existing elastic curvature

ANALYSIS IN A PIPELINE

$$S_c = ED/2R$$

$$S_c = .2143 \text{ MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = S_p + S_n + S_c$$

$$SE_1 = S_p + S_n - S_c$$

$$SE_1 = 6.531 \text{ Mpa}$$

$$SE_2 = SE + S_n + S_c$$

$$SE_2 = 6.9599 \text{ Mpa}$$

$$SL = \text{Maximum of } SE_1 \text{ or } SE_2 \text{ which should be less than SMYS}$$

Hence ok

Allowable bending stress considering $S_b = 0.75 \text{ SMYS} - S_p + \text{or} - S_c$

$$S_b = 22.285 \text{ Mpa}$$

Finding weight of the pipe, coat, content and soil

$$W_{\text{pipe}} = \frac{\Pi(D^2 - ID^2)\rho_{\text{Pipe}}g}{4 \times 10^6}$$

$$W_{\text{pipe}} = 1416.033 \text{ N/m}$$

$$W_{\text{cont}} = \frac{\Pi ID^2 \rho_{\text{cont}} g}{4 \times 10^6}$$

$$W_{\text{cont}} = 2993.032 \text{ N/m}$$

$$W_{\text{soil}} = \gamma b(D + 2tc + 2tcc)9.81/1000$$

$$W_{\text{soil}} = 13568.4072 \text{ N/m}$$

$$W_{\text{tot}} = \text{Total load per meter}$$

$$W_{\text{tot}} = W_{\text{pipe}} + W_{\text{coat}} + W_{\text{content}} + W_{\text{soil}}$$

$$W_{\text{tot}} = 17977.78 \text{ N/m}$$

Section modulus, S

$$S = \pi[D^4 - (D-2t)^4] / [32 * D * 10^9]$$

$$S = 0.023959 \text{ m}$$

Allowable pipeline span, L

$$L = \sqrt{\frac{12 * S * S_B}{W_r}}$$

ANALYSIS IN A PIPELINE

$$L = 18.8787\text{m}$$

Hoop Stress, SH

$$SH = (P \cdot D) / (2 \cdot t)$$

$$Sh = 2.425595\text{Mpa}$$

Using Von moises equation, $Seq = \sqrt{S_H^2 + S_L^2 - S_H * S_L}$

$$Seq1 = \sqrt{S_H^2 + S_{E1}^2 - S_H * S_{E1}}$$

$$Seq1 = 5.718297\text{Mpa}$$

$$Seq2 = \sqrt{S_H^2 + S_{E2}^2 - S_H * S_{E2}}$$

$$Seq2 = 6.11898\text{Mpa}$$

Seq1 and Seq2 is less than the smys

Hence ok

Operating condition 30" HDPE pipe

Basic Data

P	pressure	9.8	Bar
---	----------	-----	-----

Longitudinal tensile stress in pipe due to internal pressure, Sp

$$Sp = PDv / 2t$$

$$Sp = 2.156085\text{Mpa}$$

Longitudinal compressive stress due to temperature change

$$Sn = E\alpha (T2 - T1)$$

$$Sn = 4.32\text{Mpa}$$

Longitudinal flexure stress due to existing elastic curvature

$$Sc = ED/2R$$

$$Sc = 0.214313\text{MPA}$$

Existing longitudinal stress (SE) is given by

$$SE = Sp + Sn + Sc$$

$$SE1 = Sp + Sn - Sc$$

ANALYSIS IN A PIPELINE

$$SE1 = 6.261771 \text{ Mpa}$$

$$SE2 = SE + S_n + S_c$$

$$SE2 = 6.261771 \text{ Mpa}$$

SL = Maximum of SE1 or SE2 which should be less than SMYS

Hence ok

Allowable bending stress considering $S_b = 0.75SMYS - S_p + S_c$

$$S_b = 15.6296 \text{ Mpa}$$

Finding weight of the pipe, coat, content and soil

$$W_{pipe} = \frac{\pi(D^2 - ID^2)\rho_{Pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 1416.033 \text{ N/m}$$

$$W_{cont} = \frac{\pi ID^2 \rho_{cont} g}{4 \times 10^6}$$

$$W_{cont} = 169.0338 \text{ N/m}$$

$$W_{soil} = \gamma_b(D + 2t_c + 2t_{cc})9.81/1000$$

$$W_{soil} = 16146.4072 \text{ N/m}$$

W_{tot} = Total load per meter

$$W_{tot} = W_{pipe} + W_{coat} + W_{content} + W_{soil}$$

$$W_{tot} = 17731.54 \text{ N/m}$$

Section modulus, S

$$S = \pi[D^4 - (D-2t)^4] / [32 * D * 10^9]$$

$$S = 0.023959 \text{ m}$$

Allowable pipeline span, L

$$L = \sqrt{\frac{12 * S * S_B}{W_r}}$$

$$L = 15.91944 \text{ m}$$

Hoop Stress, SH

$$SH = (P * D) / (2 * t)$$

$$Sh = 2.156085 \text{ Mpa}$$

Using Von moises equation, $Seq = \sqrt{S_H^2 + S_L^2 - S_H * S_L}$

$$Seq1 = \sqrt{S_H^2 + S_{E1}^2 - S_H * S_{E1}}$$

$$Seq1 = 5.509772 \text{Mpa}$$

$$Seq2 = \sqrt{S_H^2 + S_{E2}^2 - S_H * S_{E2}}$$

$$Seq2 = 5.914817 \text{Mpa}$$

Seq1 and Seq2 is less than the SMYS

Hence ok

Appendix B

Pipe Expansion analysis for 24" X 14.3 Wall Thickness

Basic data

P	pressure	9.8	Mpa
D	diameter	609.6	mm
t	thickness	14.3	mm
v	poisson ratio	0.3	
E	young's modulus	2.07E+05	Mpa
α	coefficient of thermal expansion	1.17E-05	per deg
T1	installation temp	20	$^{\circ}$ C
T2	operational temp	60	$^{\circ}$ C
tc	thickness of the coat	3.2	mm
tcc	Thickness of the concrete	0	mm
Rc	radius of curvature	1600000	mm
SMYS		485	mpa
F	design factor	0.9	
ρ_{pipe}	Density of the pipe	7850	kg/m ³
ρ_{coat}	Density of the coat	900	kg/m ³
ρ_{cc}	Density of the concrete	2400	kg/m ³
ρ_{content}	Density of the content	56.47	kg/m ³
id	inner diameter	733.4	mm
D w	dia with coat	768.4	mm
γ	unit soil wt	1800	kg/m ³
H	bury depth	1.2	m

$$F_{ex}(T) = E\alpha A(T_2 - T_1)$$

$$F_{ex}(T) = 2.64E+05 \text{ Kg}$$

$$Sh = PD / (2tg)$$

$$Sh = 21292957.81 \text{ Kg/m}^2$$

$$F_{ex}(p) = A(.5 - \nu)Sh$$

$$F_{ex}(p) = 113832.8364 \text{ Kg}$$

$$F_{ex} = F_{ex}(T) + F_{ex}(P)$$

$$F_{ex} = 3.78E+05 \text{ kg}$$

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2058.449573 \text{ N/m}$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

$$W_{coat} = 54.36381174 \text{ N/m}$$

$$W_{cont} = \frac{\Pi ID^2 \rho_{cont}g}{4 \times 10^6}$$

$$W_{cont} = 146.7941392 \text{ N/m}$$

$$W_{total} = w_{pipe} + w_{coat} + w_{conc}$$

$$W_{total} = 2259.607524 \text{ N/m}$$

$$W_{soil} = \gamma_b(D + 2t_c + 2t_{cc})9.81/1000$$

$$W_{soil} = 16282.08864 \text{ N/m}$$

$$\text{Friction force } F_f = \mu((2W_{soil}) + W_{total})$$

$$F_f = 8509.558 \text{ N/m}$$

$$= 867.4371475 \text{ Kg/m}$$

$$L_a = \text{Total expansion force} / \text{Frictional Force}$$

$$L_a = 4.36E+02 \text{ m}$$

ANALYSIS IN A PIPELINE

$$\Delta L_p = (0.5 - \nu) \cdot Sh \cdot L_a / E$$

$$\Delta L_p = 8.79E-02m$$

$$\Delta L_t = \alpha(T_2 - T_1) \cdot L_a$$

$$\Delta L_t = 0.203824223m$$

$$\Delta L_f = F_f \cdot L_a^2 / (2 \cdot \gamma \cdot t \cdot D \cdot E)$$

$$\Delta L_f = 2.18E-01m$$

$$\Delta L = \Delta L_p + \Delta L_t + \Delta L_f$$

$$\Delta L = 5.10E-01m$$

$$= 5.10E+02mm$$

Appendix C

Pipe Stability Analysis for 24"x14.3 Wall thickness

D	diameter	609.6	mm
t	thickness	14.3	mm
t _c	Thickness of the coat	3.2	mm
t _{cc}	thickness of the concrete	120	mm
P	pressure	9.8	mpa
id	inner diameter	581	mm
D _c	Diameter of the pipe with coat	616	mm
D _{cc}	Diameter of the pipe with concrete	856	mm
ρ_{pipe}	density pipe	7850	kg/m ³
ρ_{coat}	density coat	900	kg/m ³
ρ_{cc}	density conc	2400	kg/m ³
ρ_w	density water	1000	kg/m ³
F _s	factor of safety	1.3	
H	burial depth	1	m
ρ_{cont}	density content	56.47	
γ	unit weight of soil	1800	
c	cohesion factor	10	kpa
Ψ		0	

$$W_{pipe} = \frac{\Pi(D^2 - ID^2)\rho_{Pipe}g}{4 \times 10^6}$$

$$W_{pipe} = 2058.45N/m$$

$$W_{coat} = \frac{\Pi(D_{coat}^2 - D^2)\rho_{coat}g}{4 \times 10^6}$$

ANALYSIS IN A PIPELINE

$$W_{coat} = 54.3638 \text{ N/m}$$

$$W_{conc} = \frac{\pi(D_{conc}^2 - D_{coat}^2)\rho_{conc}g}{4 \times 10^6}$$

$$W_{conc} = 6529.34 \text{ N/m}$$

$$W_{cont} = \frac{\pi D^2 \rho_{cont} g}{4 \times 10^6}$$

$$W_{cont} = 146.794 \text{ N/m}$$

$$W_p = W_{pipe} + W_{coat} + W_{concrete}$$

$$W_p = 8788.94 \text{ N/m}$$

$$W_b = \frac{\pi(D_{conc}^2)\rho_{water}g}{4 \times 10^6}$$

$$W_b = 5642.767652 \text{ N/m}$$

$$\text{Factors of Safety} = W_p / W_b$$

$$F_s = 1.55718 > 1.3$$

Hence ok

$$\text{Submerged weight of the pipe per unit run } (W_p - W_b) = 3146.25 \text{ N/m}$$

$$\text{Submerged density of the pipe per unit run} = (W_p - W_b) / A_t = 1170.55 \text{ Kg/m}^3$$

$$\text{Submerged density of soil} = \rho_{sum \text{ soil}} = 800 \text{ Kg/m}^3$$

$$\text{Weight of Displaced Fluid WDF} = A_t * \rho_{sum \text{ soil}}$$

$$A_t = \pi D H$$

$$A_t = 3.166376 \text{ m}^2$$

$$WDF = 21094.25 \text{ N/m}$$

$$\text{Required Buoyancy WRB} = WDF * F_s$$

$$WRB = 27422.4345 \text{ N/m}$$

wrb < wp total hence safe

$$\text{net upward thurst} = ((\rho_{sum} - \rho_{pipe})\pi D^2 / 4) / D_{tot}$$

$$\text{Net upward thrust} = 4737.327 \text{ N/m}^2 = 4.7377 \text{ Kpa}$$

ANALYSIS IN A PIPELINE

$$\text{Overburden pressure} = \rho_{\text{sum soil}} \cdot D_{\text{conc}} = 684.8 \text{ Kg/m}^2$$

$$\text{Shear strength} = S = C + \tan \Psi = 10.00 \text{ kpa}$$

Net upward thrust < shear strength hence floatation will not occur

Appendix D

Seismic Analysis for 30"X 15.9 wall thickness pipe

Basic data

D	diameter	762	mm
t	thickness	69.27	mm
v	poission ratio	0.3	
T1	installation temperature	20	^o c
T2	operating temperature	60	^o c
P	pressure	9.8	bar
SMYS		24	Mpa
α	coefficient of thermal expansion	1.12E-04	/deg
E	Youngs modulus	900	mpa
n	ramberg oswood parmeter	9	table
r	ramberg oswood parmeter	10	table
H	burial depth	1.2	m
C	coefficient of cohesion	10	kpa
ϕ	angle of friction	30	deg
γ	effective unit wt of soil	18000	n/m3
CDF	coating dependent factor	0.6	
γ_{sat}	saturated unit wt of soil	19500	n/m3
γ	unit wt of pipe content	56.47	n/m3
γ	unit wt of pipe material	77009	n/m3
σ_y		20	mpa

OPERATIONAL STRAIN

$$S_p = PD_v/2t$$

$$S_p = 21.56084885 \text{ Mpa}$$

$$\epsilon_p = \frac{S_p}{E} \left[1 + \frac{n}{1+r} \left(\frac{S_p}{\sigma_y} \right)^r \right]$$

$$\epsilon_p = 6.55 \text{E-}02$$

$$S_t = E\alpha(T_2 - T_1)$$

$$S_t = 4.21 \text{E-}01 \text{ Mpa}$$

$$\epsilon_t = \frac{S_t}{E} \left[1 + \frac{n}{1+r} \left(\frac{S_t}{\sigma_y} \right)^r \right]$$

$$\epsilon_t = 4.68 \text{E-}04$$

Total operational strain

$$\epsilon_{otot} = 6.60 \text{E-}02$$

Calculation of Soil Resistance

Internal angle of friction between soil and pipe

$$\delta = f^* \phi$$

$$\delta = 21$$

Coefficient of soil pressure at rest, kc

$$k_c = 1 - \sin \phi$$

$$k_c = 0.5$$

Axial soil spring

Adhesion factor α

$$\alpha = (.608) - .123C - (.274/c2 + 1) + (.695/c3 + 1)$$

$$\alpha = 1.018719$$

$$t_u = \pi D c \alpha + \pi D H \gamma \frac{1+k_c}{2} \tan \delta$$

$$t_u = 39253.78892 \text{ N/m}$$

$$\Delta t = 5$$

ANALYSIS IN A PIPELINE

lateral soil spring:

$$N_{ch} = a + bx + \frac{c}{(x+1)^2} + \frac{d}{(X+1)^3} \leq 9$$

$$N_{ch} = 5.602685731$$

$$N_{qh} = a + bx + cx^2 + dx^3 + ex^4$$

$$N_{qh} = 6.30E+00$$

Maximum transverse soil resistance per unit length of pipe

$$P_u = N_{ch} cD + N_{qh} \gamma HD$$

$$P_u = 1.46E+05 \text{ N/m}$$

$$\Delta p = .04 \left(H + \frac{D}{2} \right) \leq 0.01D \text{ to } 0.02d$$

$$\Delta p = 0.06324 \text{ m}$$

Vertical soil spring

$$N_{cv} = 2 \frac{H}{D} \leq 10$$

$$N_{cv} = 3.149606299$$

$$N_{qv} = \frac{\phi H}{44D} < N_q$$

$$N_{qv} = 1.07372942$$

$$Q_u = N_{cv} cD + N_{qv} \gamma HD$$

$$Q_u = 41672.72727 \text{ N/m}$$

$$\Delta h = 0.15H$$

$$\Delta h = 0.18 \text{ m}$$

BEARING

$$N_c = 30 \quad \text{from graph}$$

$$N_q = 18 \quad \text{from graph}$$

ANALYSIS IN A PIPELINE

$$N_r = 18 \quad \text{from graph}$$

$$Q_d = N_c cD + N_q \gamma HD + N_r \frac{\gamma D^2}{2}$$

$$Q_d = 618929.928 \text{ N/m}$$

$$\Delta d = 0.125D$$

$$\Delta d = 0.09525 \text{ m}$$

Longitudinal PGD

$$\delta^l = 2 \text{ m}$$

$$\delta l_{\text{design}} = \delta * I_p$$

$$\delta l_{\text{design}} = 3$$

$$W = \text{width of permanent ground displacement zone} = 40 \text{ m}$$

$$L = \text{Length of permanent ground displacement zone} = 100 \text{ m}$$

$$\epsilon_a = \frac{T_u l}{2 \pi D t E} \left[1 + \frac{n}{1+r} \left(\frac{t_u l}{2 \pi D t \sigma_y} \right)^r \right]$$

$$\epsilon_a = 0.013214688$$

$$\epsilon_a \pm \epsilon_{\text{oper}} < \epsilon_{\text{allowable}}$$

$$\epsilon_{\text{tensile total}} = 7.92 \text{ E-}02$$

$$\epsilon_{\text{compressive total}} = -5.28 \text{ E-}02$$

Since compressive strain is negative total strain is tensile

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

Transverse PGD

$$\epsilon_b = \frac{\pi D \delta l_{\text{design}}}{w^2}$$

$$\epsilon_{b1} = 0.004486275$$

$$\epsilon_b = \frac{P_u w^2}{3 \pi E t D^2}$$

ANALYSIS IN A PIPELINE

$$\epsilon_{b2} = 6.87E-01$$

ϵ_{b1} is less than ϵ_{b2} hence it should be used

$$\epsilon_b \pm \epsilon_{oper} < \epsilon_{allowable}$$

$$\epsilon \text{ tensile total} = 7.05E-02$$

$$\epsilon \text{ compressive total} = -6.15E-02$$

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

BUOYANCY DUE TO LIQUEFACTION

F_b = net upward force per unit length of pipeline

$$F_b = \frac{\pi D^2}{4} (\gamma_{sat} - \gamma_{cont}) - \pi D E \gamma_{pipe}$$

$$F_b = 4584.783945 \text{ N/m}$$

$$Z = \frac{\pi (D^4 - ID^4)}{32d}$$

$$Z = 0.02395923 \text{ m}$$

$$\sigma_b = \frac{F_b l_b}{10 Z}$$

$$L_b = 40 \text{ m}$$

$$\sigma_b = 765430.923 \text{ N/m}^2$$

$$\epsilon_b = \frac{\sigma_b}{E} \left[1 + \frac{n}{1+r} \left(\frac{\sigma_b}{\sigma_y} \right)^r \right]$$

$$\epsilon_b = -8.50E-04$$

$$\epsilon_b \pm \epsilon_{oper} < \epsilon_{allowable}$$

$$\epsilon \text{ tensile total} = 6.51E-02$$

$$\epsilon \text{ compressive total} = -6.68E-02$$

ANALYSIS IN A PIPELINE

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

SEISMIC WAVE PROPOGATION

Magnitude of design basis Earthquake = 6.5

Distance of site from earthquake source = 20km

PGAr = 0.36 from table

PGv/PGA= 140

PGV = 50.4cm/s = 0.504m/s

Vg = PGV*IP

Vg = 0.756m/s

IP = 1.5

$$\varepsilon_a = \frac{V_g}{\alpha_\varepsilon C}$$

C 2000m/s for s wave

C 500m/s for r wave

α_ε 2 for s wave

α_ε 1 for r wave

$$\varepsilon_a \leq \frac{tu \lambda}{4AE}$$

ε_{a1} = 0.000189

ε_{a2} = 7.24E-02

ε_{a1} is acceptable

$\varepsilon_b \pm \varepsilon_{oper} < \varepsilon_{allowable}$

ANALYSIS IN A PIPELINE

$$\epsilon \text{ tensile total} = 6.62E-02$$

$$\epsilon \text{ compressive total} = -6.58E-02$$

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable

Fault crossing

δn expected normal slip fault displacement

$$\delta n = 2.5m$$

Ψ angle of dip of fault movement

$$\Psi = 35$$

β angle b/w pipeline & fault line

$$\beta = 40$$

$$\delta f_{ax} = \delta n \cos \Psi \sin \beta$$

$$\delta f_{ax} = 1.316351961m$$

$$\delta f_{tr} = \delta n \cos \Psi \cos \beta$$

$$\delta f_{tr} = 1.568767181m$$

$$\delta f_{vr} = \delta n \sin \beta$$

$$\delta f_{vr} = 1.433941089m$$

$$IP = 2.3$$

$$\delta a_{x \text{ design}} = \delta a_{x \text{ IP}}$$

$$\delta a_{x \text{ design}} = 3.02760951m$$

$$\delta t_{r \text{ design}} = \delta t_{r \text{ IP}}$$

ANALYSIS IN A PIPELINE

$$\delta tr \text{ design} = 3.608164516m$$

$$la = \frac{E \varepsilon_y \Pi D t}{t u}$$

$$la = 84.44583218m$$

$$\varepsilon a = 2 \left[\frac{\delta ax \text{ design}}{2 la} + \frac{1}{2} \left[\frac{\delta tr \text{ design}}{2 la} \right]^2 \right]$$

$$\varepsilon a = 0.036309092$$

$$\varepsilon a \pm \varepsilon_{oper} < \varepsilon_{allowable}$$

$$\varepsilon \text{ tensile total} = 4.29E-02$$

The limiting strain in tension for permanent ground deformation is = 3 % = 0.03

Value is less than limiting strain hence allowable