Offshore Pipeline Free Spanning Analysis Based On DNV Design Code

by

Hazlinda Binti Mohd Hanifa

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JAN 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Offshore Pipeline Free Spanning Analysis Based On DNV Design Code

by

Hazlinda Binti Mohd Hanifa

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(Associate Prof. Dr. Narayanan Sambu Potty)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JAN 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

HAZLINDA BINTI MOHD HANIFA

ABSTRACT

Offshore pipeline has proven the most economical means of large scale transportation method for crude oil, natural gas, and their products for oil and gas exploration. Problems faced during pipeline mechanical design is free span formation due to seabed unevenness, scouring action, and exposure to current and wave flow. This work presents proper free span assessment to avoid excessive loads and deformation as pipeline could undergo oscillatory force, excessive bending stresses, and buckling. Analysis spreadsheets were created for free span analysis according to latest Det Norske Veritas (DNV) design codes; DNV-RP-F105 "Free Spanning Pipelines, February 2006". Results obtained were presented in graphs and tables. Parametric studies were performed to determine the span length for different outside diameter, safety factor and boundary condition. Results indicated that pipeline failure occurred if span length is longer than the permitted length. This can be solved by rerouting, span correction, installation of grout bag support or mattresses.

ACKNOWLEDGEMENTS

In the Name of Allah, The Most Merciful and Compassionate, praise to Allah, He is the Almighty. Eternal blessings and peace upon the Glory of the Universe, our Beloved Prophet Muhammad (S.A.W), his family and companions.

I like to express my highest appreciation to everyone who has contributed directly or indirectly towards making my Final Year Project a successful and memorable. My biggest gratitude goes to my Supervisor, Assoc. Prof. Dr. Narayanan Sambu Potty for supervising and giving me support throughout the project. I would also like to thank his colleague, Assoc. Prof. Dr. Kurian V. John for his endless guidance and advice regarding the spreadsheet preparation.

I am much indebted to all Pipeline Department staffs at Ranhill WorleyParsons especially to the Head Department cum Plant Supervisor, Ir. Muhammad Hazlalin Ibrahim who have aided me with valuable advises and opinions regarding the project despite his hectic schedule. Last but not least, I like to thank my beloved parents and family for their continuous love and support.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
CF	Cross-flow
DNV	Det Norske Veritas
FE	Finite Element
IL	In-line
LAT	Lowest Astronomical Tide
MAOP	Maximum Allowable Operating Pressure
MAOT	Maximum Pipeline Operating Temperature
ROV	Remotely-operated Vehicle
SMYS	Specified Minimum Yield Strength
VIV	Vortex Induced Vibrations
WDP	Water Distribution Platform
WHP	Water Hub Platform
YR	Year

CHAPTER 1
INTRODUCTION

1. INTRODUCTION

This section will include the background of the project, the problem statement, objective(s) and the scope of study.

1.1 Background of Study

Offshore pipeline often experience condition where the contact between pipeline and seabed is lost for substantial distance due to irregular seabed profile and the exposure of pipeline to the dynamic loads from waves and currents action (Guo et al., 2005).

Palmer & King (2004) noted that pipeline tends to forms free spans rather than conform perfectly to the seabed profile when laid on the uneven seabed. As the span might be overstressed, it presents a possibility for the occurrence of fatigue damage due to vortex-excited oscillations. Free span is also exposed to hooking by fishing gear and anchors which might lead to pipeline failure or damage.

According to J P Kenny Design Guideline (2001), for various pipeline loading conditions, this unsupported weight of the pipeline section (i.e. free span) can be divided into two categories. The span length can either be longer than the permitted value, presenting a risk of pipeline failure or it can be shorter than the allowable span length limit which has no effect on the structural integrity of the system.

For that reason, a proper free span assessment is required to determine the limits on the allowable span length for various span criteria and pipeline loading conditions such as during pipeline installation, commissioning and pipeline operation. This assessment is normally based on conservative criteria to ensure that the pipeline will not experience short-term or long-term damage.

From the assessment, if the actual span exceed the allowable length, correction is necessary to reduce the span in order to avoid pipeline damage due to excessive yielding and fatigue. Correction may consist of rerouting, span correction, installation of mattresses and grout bag support, or rock dumping (Guo et al., 2005; Palmer & King, 2004).

1.2 Problem Statement

Even though the spanning analysis is important during pipeline mechanical design, however, there were very few standard codes that can be referred. Three of these available codes that solely focus on free span assessment are Guideline 14 "Free Spanning Pipelines" (Det Norske Veritas, 1998), Shell's Standard, and Petronas Standards. Other codes only give general information on this matter.

In February 2006, Det Norske Veritas had published the code, DNV-RP-F105 "Fee Spanning Pipelines". This code replaced the earlier Guideline 14 and was updated based on the feed-back from projects done, research and development (R&D) effort for pipe in trench, VIV response model updates, hydrodynamical coefficients, structural response estimates, soil stiffness, force model (frequency domain) and also the recommended S-N Curves.

As this code was recently published, most oil and gas companies are still unfamiliar with the criteria considered for the assessment. Therefore, it was decided that for this project, to study the code thoroughly and to produce spanning analysis spreadsheets that can be use for static and dynamic free span assessment. The criterion considered for the spreadsheets are mainly taken from DNV-RP-F105 with references to other related codes.

1.3 Objectives and Scope of Study

The main objectives of this project are:

- To study the fundamental details of pipeline free span
- To produce analysis spreadsheets for free spanning
- To perform several spanning analysis using the spreadsheet prepared
- To perform parametric study using the spreadsheet prepared

The scope of study would include:

- Understanding the methodology of pipeline free span by doing research through journals, books, and other related reading materials.

- Produce analysis spreadsheets by considering all factors and criteria that are related to free spanning pipelines.

- Performing several spanning analysis using the spreadsheet created and analyzing the results obtained by doing some parametric studies and comparison.

CHAPTER 2
LITERATURE REVIEW

2. LITERATURE REVIEW

In this section, all the relevant theories, hypotheses, facts and data which are relevant to the objective and the findings of the project will be discussed in details.

2.1 Free Span Assessment

Basically, free spans should be check against two criteria which are:

1. Stress criteria (static span criteria)
2. Vortex shedding criteria (dynamic span criteria)
    - In-line
    - Cross-flow

Static span analysis is required to prevent pipeline failure due to yielding caused by excessive bending stresses or buckling. Bending stresses is due to the pipeline weight and the environmental loads. In static span cases, buckling is normally not a problem as deflection is limited by the proximity to the seabed. Static span analysis is governed by the pipeline selfweight, pipeline coatings, environmental loading, and the weight of the pipe content (Kvaerner E & C Guideline, 2002).

On the other hand, vortex shedding is a periodic instability that occurs in the wake behind bluff bodies, most notably cylinders. When fluid flows across a pipeline, the flow splits, and vortices are shed alternatively at the top and bottom of pipeline at a rate determined by the flow velocity. Each time a vortex is shed, it will change the local pressure distributions which will cause the oscillatory force to be exerted on the span at the frequency of vortex shedding (Guo et al., 2005; Palmer & King, 2004).

Basically, the type of oscillations depends on the flow velocity and the span length value. The shedding frequency becomes closer to the pipeline natural frequency as the flow velocity increases. Hence, the amplitude of the pipe movement increase and drives the vortex shedding and small vortex cells shed timing together. Here, the vortices will correlate and shed about 15D lengths of a long cell. The span vibrations 'lock-in' at pipeline natural frequency where the vortex shedding is controlled by the pipe oscillations rather than the flow velocity (Jee Limited, 2006).

The span vibration passes through a number of oscillation modes as the velocity increases. The vortices are shed symmetrically from top and bottom of the pipe, giving an in-line oscillation mode (oscillations in-line with the direction of current flow) at lower velocity. As seen in Figure 2.1, the vortices collapse into an alternate pattern just behind the cylinder for symmetric vortex shedding results in in-line oscillation. (Guo et al., 2005; J P Kenny Group, 2000; Jee Limited, 2006; Palmer & King, 2004).

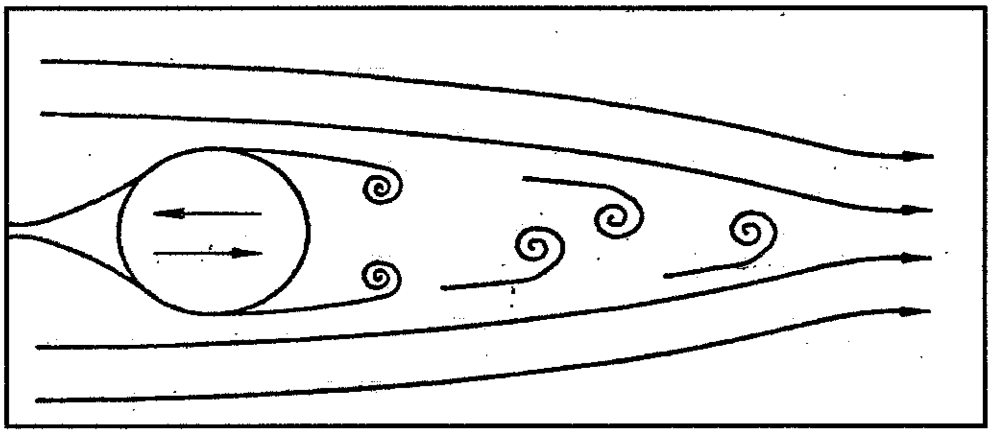

Figure 2.1: In-line Oscillations (symmetric vortex shedding)

Source: J P Kenny (2000)

At higher velocity, the vortices are shed asymmetrically, giving initially a further mode of in-line oscillation and cross-flow mode (oscillations across the flow direction). For weak alternate vortex shedding, it will results in in-line oscillations (Figure 2.2) while strong alternate vortex shedding will results in cross-flow oscillations (Figure 2.3).

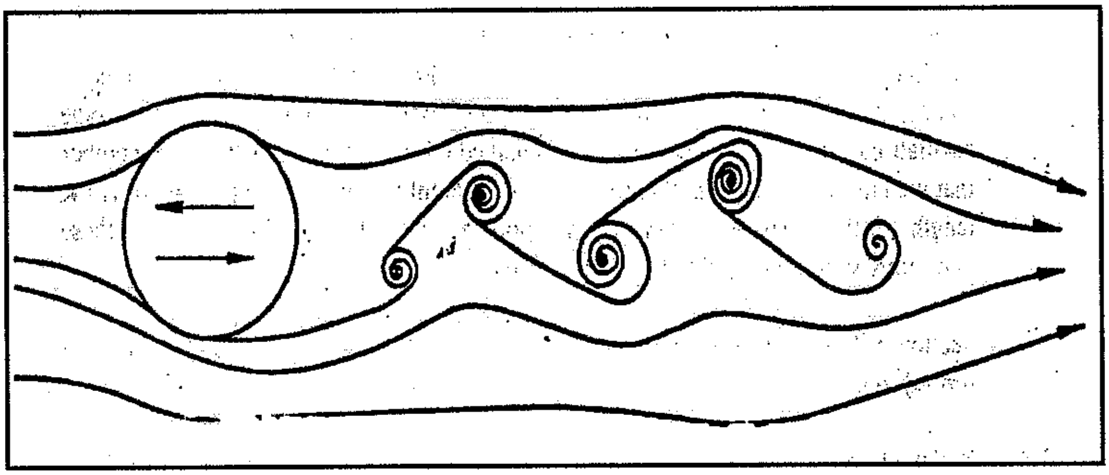

Figure 2.2: In-line Oscillations (weak alternate vortex shedding)

Source: J P Kenny (2000)

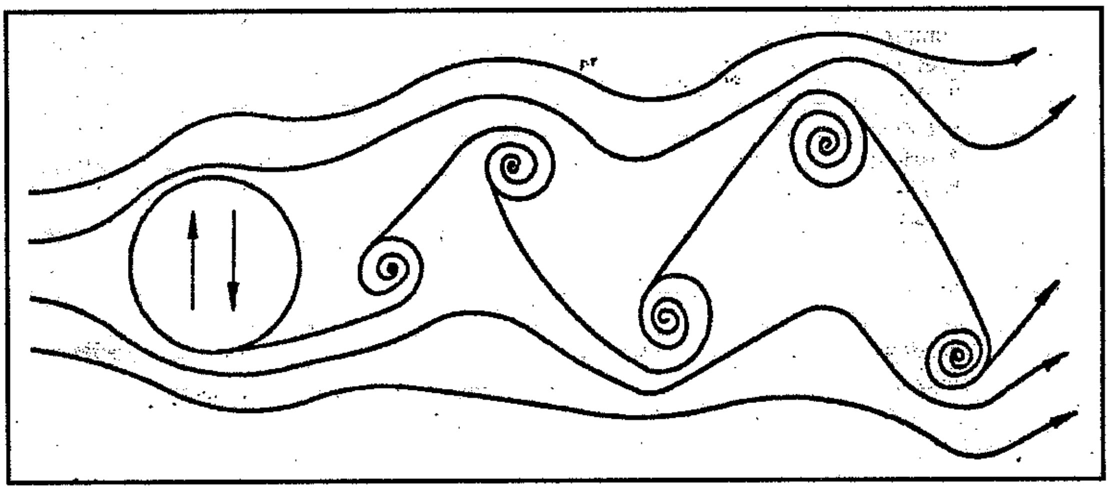

Figure 2.3: Cross-flow Oscillations (strong alternate vortex shedding)

Source: J P Kenny (2000)

In-line oscillations are small in amplitude which is less than 20% of cross-flow direction. In-line oscillation is a concern if they continued for a long time period as it may lead to pipeline fatigue failure. Cross-flow oscillations in contrast, have higher response amplitude and occur at larger velocities. Thus, cross-flow oscillations are dangerous as they show higher potential of pipeline damage after a few oscillations. Cross-flow is not normally the governing factor. (Guo et al., 2005; J P Kenny Group, 2000).

The consequence of vortex-induced vibrations (VIV) is pipeline fatigue which will shorten the pipeline life. Therefore, proper pipeline free span assessment is required to avoid short-term or long-term damage.

2.2 Potential For Vibration

Guo et al. (2005) mentioned that the potential for vibration can be determine using parameters like reduced velocity, V_R and the stability parameter, K_s.

Reduced velocity is the velocity at which the vortex shedding oscillations may occur. From the DNV code, the resonant in-line vortex shedding induced oscillation may occur when $1.0 < V_R < 2{,}2$, the shedding will be symmetrical and for $V_R > 2.2$, the shedding will be alternate.

As for stability parameter, it represents the damping for a given mode shape. The equation is shown as below:

$$K_s = \frac{4.\pi.m_e.\zeta_T}{\rho.D^2} \qquad \text{(DNV-RP-F105, Section 4.1.8)}$$

Where,

m_e	-	Effective mass (mass per unit length)
	-	Total pipe mass + added mass (a function of the gap between the seabed and the pipe)
ζ_T	-	Total modal damping ratio at a given vibration mode comprising soil, structural and hydrodynamic damping
D	-	Outer pipe diameter including coating (hydrodynamic diameter)
ρ	-	Seawater density
	-	1025 – 1030 kg/m^3

Structural damping is due to the internal friction forces of the pipe material and depends on the strain level and the associated deflection. If no information is available, a structural modal damping ratio of $\zeta = 0.005$ can be assumed. If concrete is present, the sliding at the interface between the concrete and corrosion coating may further increase the damping to typically 0.01-0.02. Flexible span have a high degree of structural damping and accordingly are not prone to VIV.

The other factor that significantly affects the vibration is the stiffness and damping in the pipe, which moderates the amplitude of vibration.

2.3 Screening Fatigue Criteria

Screening criteria proposed by the DNV code is applied to fatigue caused by Vortex Induced Vibrations (VIV) and direct wave loading in combined current and wave loading conditions. The screening criteria have been calibrated against full fatigue analyses to provide a fatigue life in excess of 50 years. However, if the screening fatigue criteria are violated, a more detailed fatigue analyses should be performed.

2.3.1 In-line natural frequencies

In-line natural frequency $f_{n,IL}$ must fulfill:

$$\frac{f_{n,IL}}{\gamma_{IL}} > \frac{U_{c,100year}}{V_{R,onset}^{IL} D}\left(1-\frac{L/D}{250}\right)\frac{1}{\bar{\alpha}}$$ (DNV-RP-F105, Section 2.3.3)

Where,

γ_{IL}	-	*Screening factor for in-line*
$\bar{\alpha}$	-	Current flow ratio $\max\left(\frac{U_{c,100year}}{U_{w,1year}+U_{c,100year}};0.6\right)$
D	-	*Outer pipe diameter including coating*
L	-	*Free span length*
$U_{c,100year}$	-	*100 year return period value for the current velocity at the pipe level*
$U_{w,1year}$	-	*Significant 1 year return period value for the wave induced flow velocity at the pipe level corresponding to the annual significant wave height $H_{s,1year}$*
$V_{R,onset}^{IL}$	-	*In-line onset value for the reduced velocity*

If the above criterion is violated, then a full in-line VIV fatigue analysis is required.

2.3.2 Cross-flow Natural Frequencies

The cross flow natural frequency $f_{n,CF}$ must fulfill:

$$\frac{f_{n,CF}}{\gamma_{CF}} > \frac{U_{c,100year} + U_{w,1year}}{V_{R,onset}^{CF}\, D} \qquad \text{(DNV-RP-F105, Section 2.3.4)}$$

Where,

γ_{CF}	-	*Screening factor for cross-flow*
$V_{R,onset}^{CF}$	-	*Cross-flow onset value for the reduced velocity*

If the above criterion is violated, then a full in-line and cross flow VIV fatigue analysis is required.

2.3.3 Fatigue Analysis Due to Direct Wave Action

Fatigue analysis due to direct wave action is not required provided:

$$\frac{U_{c,100year}}{U_{w,1year} + U_{c,100year}} > \frac{2}{3} \qquad \text{(DNV-RP-F105, Section 2.3.6)}$$

If the above criterion and the criteria for in-line VIV are fulfilled, fatigue analysis due to direct wave action is not required. However, if this criterion is violated, then a full fatigue analyses due to in-line VIV and direct wave action is required.

2.4 Pipeline Natural Frequency

The equation for fundamental natural frequency of free spanning pipeline is given by:

$$f_1 \approx C_1\sqrt{1+CSF}\sqrt{\frac{EI}{m_e L_{eff}^{\;4}}\left(1+\frac{S_{eff}}{P_{cr}}+C_3\left(\frac{\delta}{D}\right)^2\right)} \qquad \text{(DNV-RP-F105, Section 6.7.2)}$$

Where,

m_e	-	Effective mass (mass per unit length)
	-	Total pipe mass + added mass (a function of the gap between the seabed and the pipe)
D	-	Outer pipe diameter including coating (hydrodynamic diameter)
ρ	-	Seawater density
	-	1025 – 1030 kg/m^3

C_1-C_3	-	Boundary condition coefficients
E	-	Youngs modulus for steel
I	-	Moment of inertia for steel
CSF	-	Concrete stiffness enhancement factor
L_{eff}	-	Effective span length
P_{cr}	-	Critical buckling load= $(1+CSF)C_s\pi^2 EI/ L_{eff}^2$ (+ve sign)
$\delta\,\delta$	-	Static deflection (ignored for in-line direction)
S_{eff}	-	Effective axial force (-ve in compression)

Guo et al. (2005) noted that the pipeline natural frequency depends on the end conditions of the pipe span, the span length, effective mass, and the pipe stiffness.

According to Guo et al., (2005), the end condition is used to determine the pipeline span support condition. The selection is critical as it can influence the calculated critical span length by 50 percent. Pipeline can be pinned-pinned, fixed-fixed, or pinned-fixed. Pinned-pinned condition is used for span where each end is allowed to rotate about the pipe axis. Fixed-fixed condition should only be use for spans that are fixed in place by some sort of anchor at both ends of the spans. Normally, pinned-fixed end fixity is assumed during spanning analysis.

As mention above, pipeline natural frequency also depends on the effective mass value. Basically, effective mass (mass per unit length) is the sum of the total unit mass of the pipe, the unit mass of the pipe content and the added mass (unit mass of the displaced water).

2.5 Loading Case

For the analysis of free spanning pipelines, three loading cases have to be considered. The pipeline condition and the environmental data for each loading cases are shown in Table 2.1.

Table 2.1: Pipeline Cases and Conditions

Case	Pipeline Condition	Analysis
Installation (static stress)	-empty pipeline (air-filled) -pipeline resting on the seabed prior to commissioning -assumed uncorroded	1-year return period significant wave loading plus 1-year return period design current
Hydrotest/ Commissioning (static stress)	-pipeline is filled with water at ambient and at hydrotest pressure -zero corrosion allowance	1-year return period significant wave loading plus 1-year return period design current
Operation (vortex shedding)	-maximum content density (cater for worst possible condition) -pipeline is assumed corroded	100-year return period significant wave loading plus 100-year return period design current

The first two loading cases are static analysis while the third one is dynamic analysis. Static analysis will consider different conditions that the pipeline will experience. This including the installation of the pipeline onto the seabed whereby it is air filled, and then the pipe is flooded with seawater. If there is a change in axial forces due to internal pressure, a span check should be performed with the pipe flooded under both un-pressurized and hydrotest condition. For operational conditions, the pipeline is assumed corroded and the design return event environmental conditions are applied.

2.6 Span Correction

Palmer & King (2004) mentioned that there are several techniques available for span corrections such as rerouting, trenching, rock dumping, and installation of sand bags, grout bags, or mattresses. These methods can be used singly or in combinations.

J P Kenny Design Guideline (2000) noted that mattresses, sand bags or grout bag is usually used for small scale intervention whereby it is used to eliminate or shorten the free span. They may be built up around or on top of the span if the span has a small clearance.

Generally, the abundance of sand everywhere makes it the most readily available option. Hereby, the sand bag is filled with cement or sand mixture so that they harden in place. It will then be placed under the pipeline by the divers. This method is suitable for post lay intervention but not appropriate for long term as they often shift due to its small weight and from the wave and scour action (J P Kenny Group, 2000; Palmer & King, 2004).

Compared to sand bag, grout bag is larger and more stable. The divers or remotely-operated vehicles (ROVs) will pull the bag under the pipeline and then filled the bag with cement grout pumped from the surface. The bag will rises like a pillow and prevents pipeline oscillation or settlement. Similar to sand bag, it is suitable for post lay intervention (J P Kenny Group, 2000; Palmer & King, 2004).

Palmer & King (2004) also stated another method for span amendment which is mattress installation. Basically, mattresses consist of rectangular or hexagonal concrete units linked together by rope and serve the purpose of providing support and damping to prevent oscillations. It can be dragged under a free span or laid across the line and is usually used for prelay or postlay intervention. However, this method is not very effective as the wave action may lift the mattress edge or flip it over. Sometimes, the wave may carry the mattresses away.

CHAPTER 3
METHODOLOGY

3. METHODOLOGY

This chapter will discuss on the methods/procedure used to achieve the objective(s) of the project.

3.1 Research Methodology

The flow chart of the overall work process is shown in Figure 3.1.

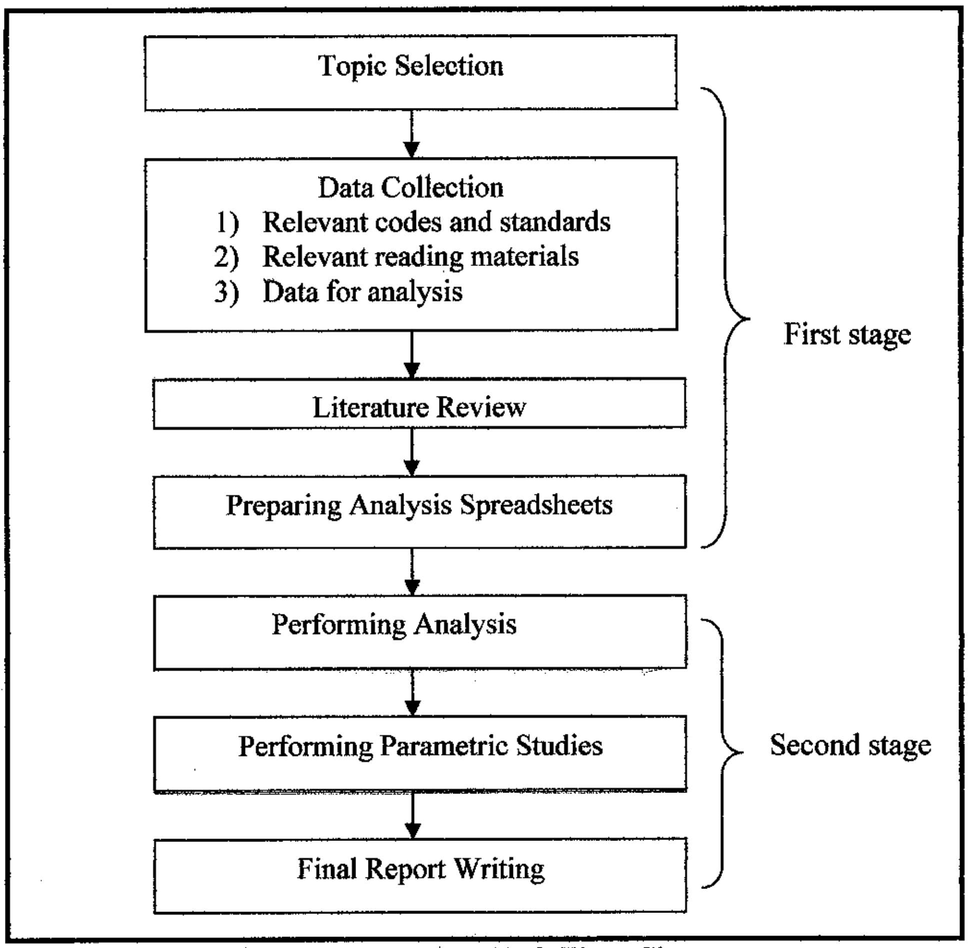

Figure 3.1: Process Work Flow Chart

3.2 Project Activities

The Final Year Project consist of two stages, as mentioned below:

3.2.1 First Stage

Subsequent to confirmation of project topic, all the relevant standard codes, journals, reference books, and also information from the internet were collected. Self-study on the fundamental of pipeline free span is conducted with help and guidance from respective supervisor and offshore specialize lecturers. Hereby, all the relevant theories, hypotheses, facts and data which are appropriate to the objective and the findings of the project will be compiled in the literature review. The preparation of the literature review (i.e. preliminary research work) will be carried out at the beginning of this project (first half semester) and continuously upgraded throughout this project.

All the data use for analysis purposes such as the environmental data (current data, wave data, water depth, etc.) and pipeline data (outside diameter, coating thickness, etc.) were also collected. These data will be use in the second stage during the analysis.

In addition, analysis spreadsheets will be produced for pipeline free span assessment by considering all criteria, factor causing free spanning, loading condition, and etc. The software used for this project is mathCAD and Microsoft Excel. The spreadsheets created will cover both static and dynamic free span assessment. The flow chart of the analysis spreadsheet is discussed in Section 3.3.

3.2.2 Second Stage

For analysis purposes, data are taken from one of the company's on-going project. For this project, a 10" branch line is proposed between two production wells for water injection. The mechanical design of this pipeline consists of performing wall thickness analysis, on bottom stability analysis, pipeline end expansion and pipeline spanning analysis. For Final Year Project, the pipeline free spanning analysis is carried out for installation, hydrotest, and operation case. The data used for this analysis are included in Section 3.4.

Hereby, parametric studies are carried out by varying some of the parameters such as water depth, pipe diameter, and safety factor in order to see how this will affect the governing span length. The results obtained will be presented using figures, and tables.

The last stage for this project is preparation of the report. All the findings and results obtained from the analysis are included and discussed in detail in the final report.

3.2.3 Discussions and Meeting

Weekly meeting were held where all the arising matters, findings, and uncertainties were discussed in detailed with the respective supervisor. Visits to Ranhill WorleyParsons, Kuala Lumpur were done from time to time in order to seek advices from experience engineers for the preparation of analysis spreadsheet.

3.2.4 Gantt Chart

The proposed gantt chart of this project is shown in Table 3.1.

Table 3.1: Gantt Chart For Final Year Project (FYP)

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	FYP Topic Confirmation	■														
2	Project Work Continue - Literature review on previous related works - Preparing Chapter 1-3 of the report - Preparing analysis spreadsheets	■	■	■												
3	Submission of Progress Report 1			■												
4	Project Work Continue - Continue preparing analysis spreadsheets - Performing analysis using spreadsheet created - Preparing Chapter 4-5				■	■	■	■								
5	Submission of Progress Report 2							■								
6	Project Work Continue - Compilation of analysis results - Conclusion and recommendation - Compilation of report									■	■	■	■			
7	Poster Exhibition - Poster design and presentation											■	■			
8	Submission of Dissertation (soft bound)													■		
9	Oral Presentation														■	
10	Submission of Project Dissertation (Hard Bound)															■

3.3 Analysis Methodology

The flow chart of the analysis spreadsheet is shown in Figure 3.2.

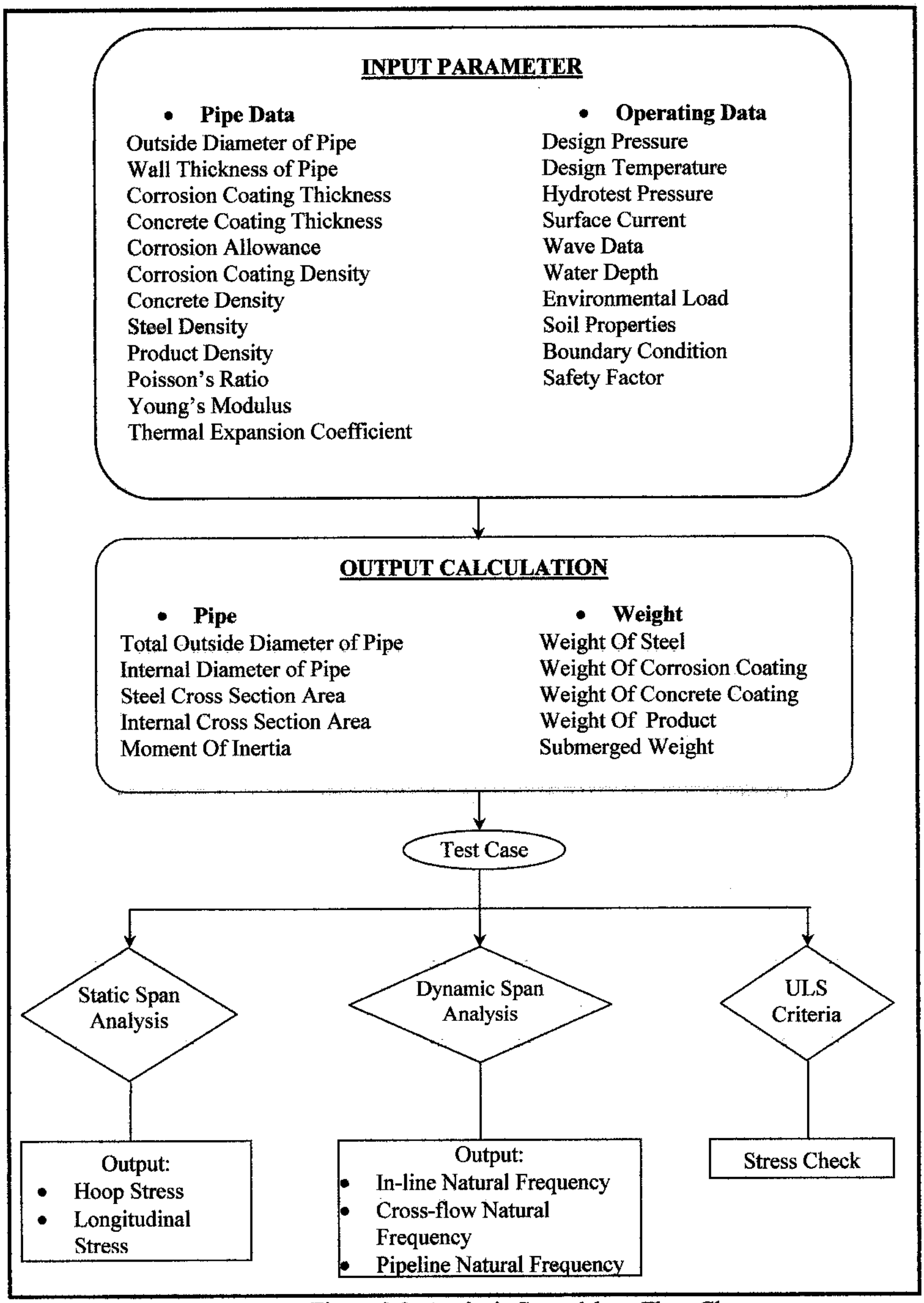

Figure 3.2: Analysis Spreadsheet Flow Chart

3.4 Analysis Data

Data are taken from one of the company's on-going project whereby a 10" branch line is proposed between two production wells for water injection. Below are the data used for the analysis purposes:

3.4.1 Design Life

The design life of all pipelines is 30 years.

3.4.2 Design Process Data

Table 3.2 presents the process data to be used for the design:

Table 3.2: Pipeline Process Data

Parameter	10" Pipeline
ANSI / ASME Class Rating	1500#
Maximum Operating Pressure	12.5 MPa (1813 psig)
Maximum Design Pressure (1)	22.4 MPa (3250 psig) (2)
Maximum Operating Temperature	38 °C (104 °F)
Maximum Design Temperature	65 °C (149 °F)
Minimum Design Temperature	15 °C (59 °F)
Hydrotest Pressure (3)	28 MPa (4062.5 psi.g)
Maximum Contents Density	1140 kg/m^3 (71.17 lb/ft^3)
Minimum Contents Density (4)	1012 kg/m^3 (63.25 lb/ft^3)

NOTES:

(1) The maximum design pressure. All pipelines shall be designed to this maximum pressure.

(2) The unit psig is pounds per square inch times the gravitational constant

(3) The hydrotest pressure shall be 1.25 x design pressure or pressure that produces hoop stress equal to 90% SMYS of pipe material, whichever is lower (Refer to section 437.4.1, ASME B31.4).

(4) The hydrotest seawater density is considered same as minimum contents density.

3.4.3 Mechanical Design Data

Table 3.3 presents the pipeline mechanical data to be used for the design:

Table 3.3: Pipeline Mechanical Data

Parameter	10" Pipeline
From / To	WHP / WDP-1
Length (km)	4.193
Pipeline Outside Diameter (mm, in)	(273.1,10)
Internal Corrosion Allowance [(1)](mm, in)	(3.0 0.118)
External Corrosion Allowance [(2)] (mm)	0.0
Material Standard / Grade [(3)]	API 5L X-52
External Corrosion Coating	FBE
External Corrosion Coating Thickness (mm/in)	(0.5/0.020)
Riser Splash Zone Coating	Monel
Riser Splash Zone Coating Thickness (mm/in)	(12.7/0.5) [(4)]
Internal Corrosion Coating	FBE
Internal Corrosion Coating Thickness (mm/in)	(0.75/0.030)

NOTES:

(1) Internal corrosion allowance is selected based on the assumption that the pipe will be provided with corrosion control measures (scraping and chemical treatment)

(2) Pipe is coated with FBE and protected by bracelet anodes; hence no external corrosion allowance is considered herein

(3) Pipe grade API 5L X52 is selected for the design purpose.

(4) The thickness is based on the minimum recommended thickness.

3.4.4 Pipeline Steel Properties

Table 3.4 presents the pipeline steel properties to be used for the design:

Table 3.4: API 5L Pipeline Steel Properties

Parameter	API 5L – X52
Steel Density	7850kg/m^3 (490lb/ft3)
Modulus of Elasticity	207GPa (3.002E7psi)
Poisson's Ratio	0.3
Coefficient of Thermal Expansion	11.7×10^{-6}
Thermal Conductivity	45 W/m°K (326lbxft/s^3°K)
SMYS	359MPa (52000psi)
Ultimate Tensile Strength	455MPa (65992psi)

3.4.5 Corrosion Coating Properties

Table 3.5 presents the pipeline corrosion coating properties to be used for the design:

Table 3.5: Pipeline Corrosion Coating Properties

Parameter	FBE
Density	1450 kg/m^3 (90.5 lb/ft^3)
Thermal Conductivity	0.25 W/m°K (1.81 lbxft/s^3°K)

3.4.6 Concrete Coating Properties

Table 3.6 presents the concrete weight coating material properties to be used for the design:

Table 3.6: Concrete Weight Coating Material Properties

Parameter	Data
Concrete Density (without water absorption)	3040kg/m^3(189.8lb/ft^3)
Modulus of Elasticity	38GPa(5.51E6psi)
Thermal Conductivity	2.2W/m°K (15.9lbxft/s^3°K)
Minimum 28 Days Compressive Strength	28MPa (4060psi)
Water Absorption Assumption	3.0%
Cutback length	304.8 mm- 381 mm (12"-15")
Field Joint Material	HDPU
Field Joint Density	1600 kg/m^3 (10 lb/ft^3)
Taper Angle	30 - 45 Deg

3.4.7 Environmental Design Data

Table 3.7 presents locations for 10" Pipeline at which analysis was done:

Table 3.7: Analyzed Locations for 10" Pipeline

Location	Coordinates		Water Depth (LAT)
	Northing (m)	Easting (m)	max/min (m)
WHP	3 145 765.00	291 695.00	22.4/19.5
WDP-1	3 149 125.00	293 660.00	20.7/19.5

3.4.8 Wave and Current Data

The wave and current data for 1-year, 10-year and 100-year return conditions are presented in the tables below:

Table 3.8(a): Omni-Directional Wave Data at Maximum Water Level

Parameter	Symbol	Unit	1 YR	10 YR	100YR
Maximum Wave Height	H_{max}	m (ft)	4.6 (15.1)	7.3 (23.9)	9.0 (29.5)
Associated Period of Maximum Wave	T_{max}	sec	6.6	8.2	9.1
Significant Wave Height	H_S	m (ft)	2.5 (8.2)	3.9 (12.8)	4.8 (15.7)

Table 3.8(b): Omni-Directional Wave Data at Minimum Water Level

Parameter	Symbol	Unit	1 YR	10 YR	100YR
Maximum Wave Height	H_{max}	m (ft)	4.2 (13.8)	6.6 (21.7)	8.1 (26.6)
Associated Period of Maximum Wave	T_{max}	sec	6.4	8.1	9.1
Significant Wave Height	H_S	m (ft)	2.3 (7.6)	3.5 (11.5)	4.4 (14.4)

Table 3.8(c): Design Current Data

% Water Depth	Unit	Omni-directional Design Current		
		1YR	10YR	100YR
0	m/s (ft/sec)	0.000	0.000	0.000
10	m/s (ft/sec)	0.436 (1.43)	0.574 (1.883)	0.664 (2.178)
20	m/s (ft/sec)	0.482 (1.581)	0.634 (2.080)	0.733 (2.405)
30	m/s (ft/sec)	0.510 (1.673)	0.672 (2.205)	0.777 (2.549)
40	m/s (ft/sec)	0.532 (1.745)	0.700 2.297)	0.810 (2.657)

3.4.9 Seawater Data

Table 3.9 presents the seawater properties used for the design:

Table 3.9: Seawater Properties

Parameter	**Data**
Density	1033kg/m^3 (64. 48lb/ft^3)
Minimum Winter Temperature	15°C (19°F)
Maximum Summer Temperature	33°C (91.4°F)

3.4.10 Marine Growth Data

Table 3.10 presents the marine growth data:

Table 3.10: Pipeline Marine Growth Data

Parameter	**Elevation**	**Value**
Thickness	-5.0m below LAT to 0 m above LAT	102 mm
	Mudline to -5.0 m below LAT to – 20.0 m below LAT	51 mm
	Mudline to -20.0 m below LAT	None
Density	All	1400 kg/m^3

3.4.11 Hydrodynamic Coefficients

Table 3.11: Hydrodynamic Coefficients for Pipeline On-Bottom Stability Analysis

Parameter	DNV Simplified Method (1)
Drag Coefficient	0.70 – 1.20 (2)
Inertia Coefficient	3.29
Lift Coefficient	0.90

NOTES:

(1) The hydrodynamic coefficients were calibrated specifically for use with the DNV RP E305 simplified method. The hydrodynamic coefficients are automatically calculated by the program

(2) The drag coefficient shall be determined based on the flow Reynold number and current to wave velocity ratio

3.5 Hazard Analysis

Final Year Project: Offshore Pipeline Free Spanning Analysis Based on DNV Design Code mainly based on researches, communications via email, and usage of computer software. Therefore, the tools involved are personal computer and printer. Below is the analysis of the working condition.

Work place	:	Personal work place and Computer Based Training (CBT) Laboratory.
Hazard checklist	:	• Computer Vision Syndrome (CVS) • Computer Eyestrain • Repetitive Strain Injury (RSI) • Carpal Tunnel Syndrome (CTS)

The study of hazard analysis is very important to ensure that the student is able to work under healthy and safe working condition. Workstations must be designed carefully to meet the ideal condition. By improving these entire characteristic, the research development of the project will be more effective.

Sources for this section are taken from the internet including OSHA Main Website and are mentioned in the Reference Section.

3.5.1 Computer Vision Syndrome (CVS)

Computer Vision Syndrome (CVS) is characterized by eye strain due to prolonged use of computers.

Symptoms:

- Eye irritation such as dry eye
- Red, itchy and watery eye
- Fatigue such as eyelids heaviness or forehead heaviness
- Eye focusing difficulties
- Headaches
- Back and shoulders stiffness
- Muscle spasms.

Causes:

- Poor lighting
- Prolong computer use;
  - Decreased in blinking frequency will caused dry and sore eye
  - Blur vision and lesser focus ability will result in headaches and neck pain.
- Receptive stress of the eye muscle due to action of one's focusing and refocusing to keep the image sharp.

Preventions:

- Positioned the monitor is 20-26 inches away from the eye
- Positioned the computer screen 20-24 inches away from eye at 20° below eye level
- Good lighting – light sources are arranged in position that minimize screen reflection and glare, dim the overhead lights, keep desk lamps low and properly adjusted to avoid light entering eyes or fall on screen.
- Frequent blinking to moisture the eyes
- Every half an hour, take a stretch break or vision breaks from the computer
- If use a document holder, placed it near and same height with the screen.
- If use paperwork, placed it close enough to avoid the need to refocused when switching from screen to paper.
- Focusing on distant objects every 15 minutes to relax the muscles.
- Use an anti-reflective filter on screen if necessary

3.5.2 Computer Eyestrain

Symptoms:

- Eye irritation such as dry eye
- Red, itchy and watery eye

Causes:

- Poor lighting
- Prolong computer use
- Improper sitting position and poor posture

Prevention:

- The same prevention tips for Computer Vision Syndrome are applied for computer eyestrain.

3.5.3 Repetitive Strain Injury (RSI)

Repetitive Strain Injury is any of various musculoskeletal disorders (as carpal tunnel syndrome or tendinitis) that are caused by cumulative damage to muscles, tendons, ligaments, nerves, or joints (as of the hand, wrist, arm, or shoulder) from highly repetitive movements of particular body parts such as computer strokes or the use of vibrating equipment. It is easier to prevent than cure once contracted. Repetitive Strain Injury is also known as cumulative trauma disorder, repetitive motion injury, repetitive stress injury, repetitive stress syndrome, or overuse syndrome.

Symptoms:

Pain, tingling, swelling, or loss of feeling of the affected body part

Causes:

- Long periods of clutching and dragging the mouse and thousands of repeated keystrokes
- Unnecessary stress on tendons and nerves in hand, wrist, arms, shoulders, and neck due to wrong typing technique and body positions.
- Usage of excessive force and inadequate rest and breaks
- Permanent disable, disability to perform tasks as driving or dressing oneself (serious case)
- Action of hunching forward to read tiny little fonts will put pressure on nerves and blood vessels in neck and shoulders.

Preventions:

- By practicing correct typing technique and posture;
  - Proper posture is achieved by setting the chair and keyboard position where thighs and forearms become level or sloping slightly down away from the

body while wrists position is straight and level (not bent far down or way back).

  - Adapt a straight sitting position (not slouching). Make sure that one's does not have to stretch forward to reached the keys or read the screen.
  - Wrists should not bend up, down, at the side, or resting on anything while typing. Arms should move hands around instead of resting the wrist and stretching to hit keys with the finger. Fingers should be in a straight line with the forearm when typing.
  - Hand should be put on lap or sides instead of leaving fingers on keyboard.
  - Always move and shift positions after prolong computer used.

- Use the right equipment setup or use ergonomic gadgets like split keyboards or wrist rests
- Increased the font sizes to avoid the action of hunch toward screen when reading. Considered using color schemes that ease the eyes to read like shades of gray for text documents.
- Avoid pounding the keys, use two hands to perform double-key operations instead of twisting one hand, and moving the whole hand to hit function keys.
- Avoid gripping and hard squeeze on the mouse. Place the mouse close to keyboard to avoid the need to reach far to use it.
- Good work habits by taking plenty of breaks to stretch and relax.
- Avoid talking on phone while typing. The action of tucking the phone between shoulder and ear will aggravate the neck, shoulders, and arms.

3.5.4 Carpal Tunnel Syndrome (CTS)

Carpal tunnel syndrome is a disorder caused by compression at the wrist of the median nerve supplying the hand, causing numbness and tingling. The carpal tunnel is an area in the wrist where the bones and ligaments create a small passageway for the median nerve. The median nerve is responsible for both sensation and movement in the hand, in particular the thumb and first three fingers. When the median nerve is compressed, an individual's hand will feel as if it has "gone to sleep."

Symptoms:

- Numbness, tingling and pain sensations in the thumb, forefinger, middle finger and the thumb side of the fourth finger.
- Aching pain extending from wrist through the shoulder

Causes:

- Work or actions that involve repetitive motions such as working at assembly lines, continuous actions of typing the keyboard or clicking the mouse, professions involving manufacturing, packing, or cleaning.

Effects:

- Difficulties in grasping objects, answering phone, reading a book, opening door
- Pain radiating up to arm
- Happened more to women – have smaller cross section of carpal tunnel than in men.

Prevention/Treatments:

- Avoiding activities that aggravate symptoms
- Use proper posture and wrist positions when using computers.
- Immobilization with a splint. Splint used to relieve pressure on the median nerve
- Surgery to release compression of median nerve

CHAPTER 4
RESULTS AND DISCUSSION

4. RESULTS

This section includes the results obtained from the analysis and parametric studies done using the spreadsheet created for the purpose.

4.1 Analysis Results

The corresponding span lengths for each loading case are shown in Table 4.1.

Table 4.1: Corresponding Span Lengths for Installation, Hydrotest, and Operation Case

Cases	Installation		Hydrotest		Operation	
Zones	Zone 1 (pipeline)	Zone 2 (riser)	Zone 1 (pipeline)	Zone 2 (riser)	Zone 1 (pipeline)	Zone 2 (riser)
Allowable Static Span (m)	92	82	75	71	76	72
Span Length for VIV criteria (m)	23	26	16	18	15	15
Span Length for ultimate ULS criteria(m)	38	50	23	29	24	25
Governing Span Length (m)	**23**	**26**	**16**	**18**	**15**	**15**

4.2 Discussions

From this results, it is shown that for zone 2 (pipeline riser), the allowable static span length value is smaller than zone 1 (pipeline) as at zone 2 location, the pipeline riser is restraint and a higher safety factor is considered to ensure the safety of the people and the platform.

Zone 2 portions include the pipeline system located at a platform riser from pig trap down to the riser bottom bend including a length of seabed pipe of at least 500 meters beyond the base of the seabed bend where as zone 1 covers the remainder of the pipeline system (source taken from PTS 20.196, Section 3.4.1).

The value obtained for VIV test is the smallest value for both in-line and cross-flow case. It is to ensure that this value cater for both type of vibrations. For VIV test, the span length obtained for operational case is smaller compare to pipeline installation and hydrotest. Reasons are; low safety class is used for installation case and hydrotest. On the other hand, for operating case, zone 1 considers normal safety class while zone 2 considered high safety class. It is to cater for the worst possible case.

The span length value for VIV (Vortex Induced Vibration) criteria is smaller compare to static span criteria as VIV assessment in DNV-RP-F105 is more conservative to ensure that the pipeline will not experience short-term or long-term damage.

The governing span length value is taken from the smallest value obtained from all test. Comparing to the previous DNV code for free spanning, Guideline 14, this new code, DNV-RP-F105 gives smaller value for span as more defined criteria, higher safety factor value, and more conservative method is considered.

4.3 Parametric Studies Results

The parametric studies are done using operation case at zone 2 (pipeline riser) pipeline data. Results are shown in tables and figures as below:

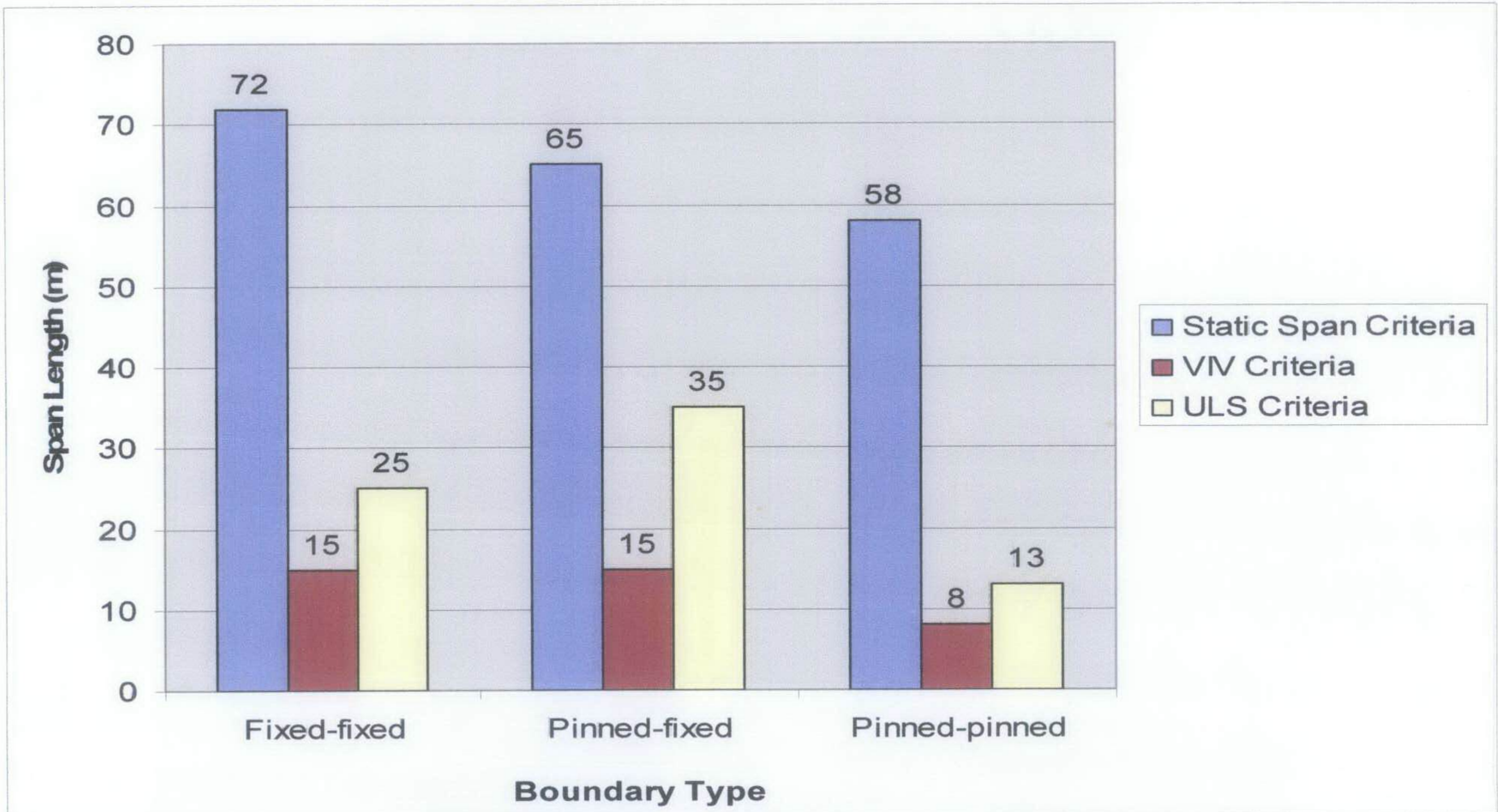

Figure 4.1: Pipeline Span Length at Different Boundary Condition

Table 4.2: Pipeline Span Length for Different Pipeline Outside Diameter

Cases	Operation						
Zones	Zone 2 (riser)						
Outside Diameter (Pipe OD) (mm)	273.1	272.1	271.1	270.1	269.1	268.1	267.1
Allowable Static Span (m)	72	71	71	71	71	71	N\A
Span Length for VIV criteria (m)	15	15	15	15	15	15	N\A
Span Length for ultimate ULS criteria(m)	25	25	25	25	25	25	N\A
Governing Span Length (m)	**15**	**15**	**15**	**15**	**15**	**15**	**N\A**

N\A = No corresponding span length obtained when wall thickness is fixed at 15.9 mm for pipeline riser in operation case.

Figure 4.2: Pipeline Span Length for Different Pipeline Safety Value

4.4 Discussions

Figure 4.1 shows that static span criteria provides the highest span length value while vortex-induced vibrations (VIV) criteria provide the smallest value for all boundary types. In addition, as the boundary type become less rigid, from fixed-fixed to pinned-pinned condition, the governing span values become smaller. For fixed-fixed and pinned-fixed condition, the governing span length value is 15 m while pinned-pinned condition gives 8 m.

On the other hand, varying the outside diameter while fixed other parameters does not show any changes to the span length value. For pipeline with 267.1 mm outside diameter, no corresponding span length is obtained because the pipeline wall thickness is fixed at 15.9 mm. Results in Table 4.2 show slightly or no variation for the span length value for all criteria.

Based on Figure 4.2, the results shows that by changing the safety value type from low to high, the span length value for VIV and ULS criteria is affected while static span criteria is not effected by this parameter. The governing span length value for low safety value is 18 m, 17 m for normal safety type, and 15 m for high safety value. High safety value type provides the smallest span length to cater the worst possible condition and during the pipeline operation.

From these parametric analysis, it is shown that VIV test value is smallest compared to other test to ensure that this value cater for both type of vibrations; in-line and cross-flow vibration. The governing span length value is taken from the smallest value obtained from all tests which is the VIV test value.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5. RESULTS

This section highlights the most significant findings in relation to the objective(s) of the project and also include recommendations for future project work.

5.1 Conclusion

Hereby, the objectives of the project have been met. Detailed study on the pipeline free span methodology is done in order to fully understand the free span fundamental such as the causes, the effect, and all the necessary parameters needed for the spreadsheet preparation. Analysis spreadsheets are completed within time and the validity of the spreadsheet is tested by performing several analysis and parametric studies.

From the analysis done, it is found out that the DNV-RP-F105 give smaller value for span compare to Guideline 14, indicating that a more conservative method is considered in this guideline. It can also be concluded that the loads used for calculating the maximum stresses or strains for comparison with maximum allowable values are based on the maximum allowable operating pressure for the pipeline (MAOP), the maximum pipeline operating temperature (MAOT) predicted at the span location, the maximum fluid density, and design currents and maximum waves associated with the relevant return period.

As for VIV and fatigue damage calculation, the loads should be based on the pipeline operating pressure, temperature, and fluid density predicted for span location under planned operating conditions and design currents and significant waves associated with the relevant return period.

5.2 Recommendation

For future improvement, it is suggested that the span to be modelled using Finite Element (FE) Modelling such as ABAQUS and SAGE Program. Some conservatism inherent with simplified beam modelling can be removed by modelling the span using FE modelling. It also allows the pipe-seabed interaction to include the beneficial effect of additional pipe settlement near the span ends and allows the effect of span tensioning due to sagging to be modelled. This will not be done during this project due to the unavailability of this expensive software, lack of knowledge on using this software and time constraint.

REFERENCES

ASME B31.8 (1992). *Gas Transmission and Distribution Piping Systems.*

Chakrabarti, S. K. (2001). *Hydrodynamics of Offshore Structures.* United Kingdom: WIT Press.

Det Norske Veritas (1998) Guideline No 14: June 1998. *Free Spanning Pipelines.* Norway, DNV.

Det Norske Veritas (2002) Recommended Practice DNV-RP-F105: March 2002. *Free Spanning Pipelines.* Norway, DNV.

Det Norske Veritas (2005) Offshore Standard DNV-OS-F101: Amended October 2005. *Submarine Pipeline Systems.* Norway, DNV.

Det Norske Veritas (2006) Recommended Practice DNV-RP-F105: February 2006. *Free Spanning Pipelines.* Norway, DNV.

Guo, B., Song S., Chacko J., & Ghalambor A. (2005). *Offshore Pipelines.* Oxford: Elsevier Inc.

J P Kenny Group (2000) 05-8050-94-Q-4-420:2001 *Company Standards: Pipeline Spans Design Guideline*, p. 6.

Jee Limited (2006) Design Of Subsea Pipelines. *Presented during Subsea Pipeline Training.* Kuala Lumpur.

Kvaerner E&C Singapore Pte Ltd (2002) 3000.21-PLP-004:2002 *Company Standards: Pipeline Allowable Span Calculation.*

Larsen, C. M., & Koushan K. (2002). *Frequency and Time Domain Analysis of Vortex Induced Vibrations for Free Span Pipelines*. Norwegian University of Science and Technology, NTNU.

Palmer, A. C., & King, R. A. (2004). *Subsea Pipeline Engineering.* Oklahoma: PennWell Corporation.

Petronas Technical Standards (1994) PTS 20.196: Rev 1, April 2004. *Pipeline Engineering Manual and Supplementary to* PTS 20.196

Petronas Technical Standards (1997) PTS 31.40.10.15: December 1997. *Manual: Analysis of Spans for Submerged Pipelines*

United States Department of the Interior Minerals Management Service (1997) *Analysis and Assessment of Unsupported Subsea Pipeline Spans.* 97058, Los Angeles: Project Consulting Services Inc.

REFERENCES FOR HAZARD ANALYSIS

U.S. Department of Labor, Occupational Safety and Health Administration (2008) *Computer Workstations* [online]. Available from: http://www.osha.gov/SLTC/etools/computerworkstations/index.html [Assessed 1st April 2008].

T-edge Solutions Pvt. Ltd. (no date) *The Wellness Site* [online]. Available from: http://www.aarogya.com/conditions/computer/vision.asp [Assessed 1st April 2008].

Wikipedia, The Free Encyclopedia (2008) *Carpal Tunnel Syndrome* [online]. Available from: http://en.wikipedia.org/wiki/Carpal_tunnel_syndrome [Assessed 1st April 2008].

WorldwideHealth.Com, Alternative Medicine, Complementary Health Directory & Resources (2008) *What is CVS (Computer Vision Syndrome) and is there a solution?* [online]. Available from: http://www.worldwidehealth.com/article.php?id=317 [Assessed 1st April 2008].

APPENDIX A
ANALYSIS SPREADSHEET

SPANNING ANALYSIS (INSTALLATION CASE)

ITRODUCTION

ıning Criteria and Ultimate Limit State (ULS) Criteria check are performed for a pipeline freespan subjected to ined wave and current loading.

nethodology is in accordance with DNV RP-F105 (2006), "Free Spanning Pipelines", with additional ınces made to other DNV standards and publications (refer list of References in Section 2.0).

ınalysis are considered:

Combined Loading Criteria Static Stress (ASME B31.4)
Vortex Induced Vibration - in-line and cross-flow (DNV RP F105)
a) Screening Fatigue Criteria
b) ULS Criterion

EFERENCES

V Recommended Practice RP-F105 Free Spanning Pipelines, 2006

V Offshore Standard OS-F101 Submarine Pipeline Systems, 2005

ME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, 2006

IPUT DATA

PE PARAMETER

Case(LC) = **1** Installation, **2** Hydrotest or **3** Operating — $LC := 1$

ition (Cond = **1** Unrestrained, **2** Restrained) — $Cond := 2$

f Pipe — $OD := 273.1mm$ $OD = 10.752 \times in$

S — $SMYS := 359MPa$

Thickness Selected — $t := 15.9mm$

ısion Allowance — $CA := 3mm$

ıntage of CA Loss — $Loss := 10\%$

ted Wall Thickness $t_{sel} := \begin{cases} t - (CA \times Loss) & \text{if } LC = 3 \\ t & \text{otherwise} \end{cases}$ — $t_{sel} = 15.9 \times mm$

g's Modulus (Steel) — $E_{steel} := 2.07 \times 10^{5} MPa$

on's Ratio — $\nu := 0.3$

nal Expansion — $\alpha := 11.7 \times 10^{-6} C^{-1}$

Density — $\rho_s := 7850 \frac{kg}{m^3}$

OATING PROPERTIES

osion Coating Thickness $TCR := 0.5mm$

rete Coating Thickness $TCN := 25.4mm$

osion Coating Density $PCR := 1450\frac{kg}{m^3}$

rete Coating Density $PCN := 3040\frac{kg}{m^3}$

rete Compressive Strength $CCS := 28MPa$

RODUCT PROPERTIES

uct Density(min.) $PP_{mind} := 0\frac{kg}{m^3}$

uct Density(max.) $PP_{maxs} := 0\frac{kg}{m^3}$

vater Density $PW := 1033\frac{kg}{m^3}$

ating Temperature $Temp_{od} := 0C$

ating Pressure $OP_d := 0MPa$

otest Pressure $HT_d := 1.25 \times OP_d$ $HT_d = 0 \times MPa$

gn temperature $Temp_{ds} := 33C$

gn Pressure $DP_s := 0MPa$

otest Pressure $HT_s := 1.25 \times DP_s$ $HT_s = 0 \times MPa$

berature Derating value (Operating Temp.)
Figure 5.1, Sect 5 B600, Ref 2) $f_{ytemp} := 0MPa$

rial Strength factor
e 5-1, Sect 5 B600, Ref 2) $\alpha_U := 0.96$

NVIRONMENTAL INPUT DATA

num Water Depth $WD := 19.5m$

ice Current Velocity (1 year) $U_{c1} := 0.436\frac{m}{s}$

ice Current Velocity (100 year) $U_{c100} := 0.664\frac{m}{s}$

num Wave Height (100 year) $H_{wmax} := 9.0m$

num Wave Period (100 year) $T_{wmax} := 9.1s$

ficant Wave Height (1 year) $H_{s1} := 2.5m$

ficant Wave Height (100 year) $H_{s100} := 4.8m$

ficant Wave Period (1 year) $T_{p1} := 7.98s$

ficant Wave Period (100 year) $T_{p100} := 11.06s$

Air Temperature $Tmax_{air} := 33C$

ater Temperature (surface) $Tmax_{sur} := 33C$

ed Temperature $Tmax_{bed} := 15C$

OIL PROPERTIES Clay (Soft)

AFETY FACTORS

y Class LOW

OUNDARY CONDITIONS COEFFICIENT (TABLE 6-1, Ref 1)

dary Type:

igle Span on Seabed $EF := 2$

ed Fixed

ned Pinned

HER DATA

e angle of the hydodynamic force in the wave cycle $\theta := 90deg$

ction factor due to wave spreading,s=2 (from Fig. 3-4, Ref. 1) $R_D := 0.84$

Surface "Concrete"

ce Roughness (Table 5-1) $k_{sr} := 3.33 \times 10^{-3} m$

TATIC SPAN ANALYSIS

)MBINED LOADING STATIC STRESS (ASME B31.4)

: Stress in pipeline span

data

dary Case (BC)
ned-pinned,
ed-pinned or
ed-fixed

$BC := 3$

length for static check

$L_{stat} := 92m$

erature Derating Factor

$\kappa_T := 1.0$

Stress Design Factor

$F_1 := 0.90$

tudinal Stress Design Factor

$F_2 := 0.80$

ined Stress Design Factor

$F_3 := 0.90$

ut data

)OP STRESS

$$S_h := \left[\left(\Delta p_{is}\right)\frac{OD}{2t}\right]$$

$S_h = 0\,Pa$

$$S_{Hoop} := \begin{cases} \text{"OK"} & \text{if } S_h \le F_1(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_{Hoop} = \text{"OK"}$

)NGITUDINAL STRESS

Longitudinal Stress

$$S_{L1} := S_a - S_b$$

$S_{L1} = -295.246 \times MPa$

$$S_{L2} := S_a + S_b$$

$S_{L2} = 281.735 \times MPa$

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

$S_{LS} = 2.817 \times 10^8\,Pa$

$$S_L := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_2(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_L = \text{"OK"}$

)MBINED LOADING STRESS

: stress will only be present in a pipeline subject to torsion.
nerefore assumed to be zero with regard to spanning

$\tau := 0$

nal Moment

$S_t := 0$

$$S_u := 2\sqrt{\left(\frac{S_{LS} - S_h}{2}\right)^2 + S_t^{\,2}}$$

$S_u = 2.817 \times 10^8\,Pa$

$$S_{ULS} := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_3(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$ $S_{ULS} = \text{"OK"}$

ʏNAMIC SPAN ANALYSIS (VIV ANALYSIS)

ɩ Data

Length For Screening Criteria $SPAN := 23m$

Length For ULS Criteria $SPAN_{ULS} := 38m$

;REENING FATIQUE CRITERIA, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

ɴE

ıction Factor $R_{I\theta 1}$(Assumed) $R_{I\theta 1} := 1.00$

ıction Factor $R_{I\theta 2}$(Assumed) $R_{I\theta 2} := 1.00$

---

amental Natural Frequency, Sect. 6.7.2, Ref 1

$$C_1 \times \sqrt{1 + CSF} \times \sqrt{\frac{E_{steel} \times I_{steel}}{EM_d \times SPAN_{eff}^{\;4}} \times \left[1 - \frac{S_{effd}}{P_{cr}} + C_3 \times \left(\frac{\delta_{in}}{DCN}\right)^2\right]}$$ $f_{nf} = 1.644 \frac{1}{s}$

ɩcreening Fatigue Check (Sect. 2.3.3, Ref. 1)

$$f_{nIL} := \frac{U_{c1}}{VRIN_{onset} \times DCN} \times \left(1 - \frac{\frac{SPAN}{DCN}}{250}\right) \times \frac{\gamma_{iL}}{\alpha I}$$ $f_{nIL} = 1.625 \frac{1}{s}$

$$ne := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{nIL} > f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{inline} = \text{" SPAN VALUE OK"}$

$$Utility_{inline} := \frac{f_{nIL}}{f_{nf}}$$ $Utility_{inline} = 0.988$

SS FLOW

ɩcreening Fatigue Check (Sect. 2.3.4, Ref.1)

$$f_{ocf} := \left(\frac{U_{c1} + U_{w1}}{VRCF_{onset} \times DCN}\right) \times \gamma_{cf}$$ $f_{ocf} = 1.081 \frac{1}{s}$

$$fo_{crossflow} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{ocf} \ge f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{crossflow} = \text{" SPAN VALUE OK"}$

$$Utility_{crossflow} := \frac{f_{ocf}}{f_{nf}}$$ $Utility_{crossflow} = 0.658$

S CRTITERION, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

VIV Response Amplitude (From Fig. 1, Ref. 1) $AyD := 0.062$

; Flow Response Amplitude (From Fig. 2, Ref 1) $AzD := 0.00$

ıfore For Stress Check;

_Long_Check := | "OK" if $\sigma_{longstress} < D_{YS}$
| " NOT OK" otherwise

Stress_Long_Check = "OK"

_Equi_Check := | "OK" if $\sigma_{equivalent} < D_{YS}$
| " NOT OK" otherwise

Stress_Equi_Check = "OK"

$$Utility_{longstress} := \frac{\sigma_{longstress}}{D_{YS}}$$ $Utility_{longstress} = 0.91$

$$Utility_{equivalent} := \frac{\sigma_{equivalent}}{D_{YS}}$$ $Utility_{equivalent} = 0.91$

SPANNING ANALYSIS (INSTALLATION CASE)

ITRODUCTION

ening Criteria and Ultimate Limit State (ULS) Criteria check are performed for a pipeline freespan subjected to ined wave and current loading.

nethodology is in accordance with DNV RP-F105 (2006), "Free Spanning Pipelines", with additional ences made to other DNV standards and publications (refer list of References in Section 2.0).

analysis are considered:

Combined Loading Criteria Static Stress (ASME B31.4)
Vortex Induced Vibration - in-line and cross-flow (DNV RP F105)
a) Screening Fatigue Criteria
b) ULS Criterion

EFERENCES

V Recommended Practice RP-F105 Free Spanning Pipelines, 2006

V Offshore Standard OS-F101 Submarine Pipeline Systems, 2005

ME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, 2006

IPUT DATA

PE PARAMETER

Case(LC) = **1** Installation, **2** Hydrotest or **3** Operating — $LC := 1$

lition (Cond = **1** Unrestrained, **2** Restrained) — $Cond := 2$

f Pipe — $OD := 273.1mm$ $OD = 10.752 \times in$

S — $SMYS := 359MPa$

Thickness Selected — $t := 20.6mm$

osion Allowance — $CA := 3mm$

entage of CA Loss — $Loss := 10\%$

cted Wall Thickness $t_{sel} := \begin{cases} t-(CA \times Loss) & \text{if } LC = 3 \\ t & \text{otherwise} \end{cases}$ — $t_{sel} = 20.6 \times mm$

g's Modulus (Steel) — $E_{steel} := 2.07 \times 10^{5} MPa$

son's Ratio — $\nu := 0.3$

nal Expansion — $\alpha := 11.7 \times 10^{-6} C^{-1}$

Density — $\rho_s := 7850 \frac{kg}{m^3}$

ɔATING PROPERTIES

ısion Coating Thickness $TCR := 0.5mm$

rete Coating Thickness $TCN := 25.4mm$

ısion Coating Density $PCR := 1450 \frac{kg}{m^3}$

rete Coating Density $PCN := 3040 \frac{kg}{m^3}$

rete Compressive Strength $CCS := 28MPa$

ꓤODUCT PROPERTIES

ıct Density(min.) $PP_{mind} := 0 \frac{kg}{m^3}$

ıct Density(max.) $PP_{maxs} := 0 \frac{kg}{m^3}$

ʼater Density $PW := 1033 \frac{kg}{m^3}$

ating Temperature $Temp_{od} := 0C$

ating Pressure $OP_d := 0MPa$

ɔtest Pressure $HT_d := 1.25 \times OP_d$ $HT_d = 0 \times MPa$

ȷn temperature $Temp_{ds} := 33C$

ȷn Pressure $DP_s := 0MPa$

ɔtest Pressure $HT_s := 1.25 \times DP_s$ $HT_s = 0 \times MPa$

ɔerature Derating value (Operating Temp.)
Figure 5.1, Sect 5 B600, Ref 2) $f_{ytemp} := 0MPa$

ɾial Strength factor
ː 5-1, Sect 5 B600, Ref 2) $\alpha_U := 0.96$

ꓠVIRONMENTAL INPUT DATA

ıum Water Depth $WD := 19.5m$

ıce Current Velocity (1 year) $U_{c1} := 0.436 \frac{m}{s}$

ıce Current Velocity (100 year) $U_{c100} := 0.664 \frac{m}{s}$

num Wave Height (100 year) $H_{wmax} := 9.0m$

num Wave Period (100 year) $T_{wmax} := 9.1s$

ficant Wave Height (1 year) $H_{s1} := 2.5m$

ficant Wave Height (100 year) $H_{s100} := 4.8m$

ficant Wave Period (1 year) $T_{p1} := 7.98s$

ficant Wave Period (100 year) $T_{p100} := 11.06s$

Air Temperature $Tmax_{air} := 33C$

/ater Temperature (surface) $Tmax_{sur} := 33C$

ed Temperature $Tmax_{bed} := 15C$

OIL PROPERTIES Clay (Soft)

AFETY FACTORS

y Class LOW

OUNDARY CONDITIONS COEFFICIENT (TABLE 6-1, Ref 1)

dary Type:

ngle Span on Seabed $EF := 2$

xed Fixed

nned Pinned

THER DATA

e angle of the hydodynamic force in the wave cycle $\theta := 90deg$

iction factor due to wave spreading,s=2 (from Fig. 3-4, Ref. 1) $R_D := 0.84$

Surface "Concrete"

ice Roughness (Table 5-1) $k_{sr} := 3.33 \times 10^{-3} m$

TATIC SPAN ANALYSIS

ɔMBINED LOADING STATIC STRESS (ASME B31.4)

: Stress in pipeline span

.data

dary Case (BC)
ned-pinned,
ɘd-pinned or
ɘd-fixed

$BC := 3$

length for static check — $L_{stat} := 82m$

ɪerature Derating Factor — $\kappa_T := 1.0$

Stress Design Factor — $F_1 := 1.0$

itudinal Stress Design Factor — $F_2 := 0.80$

ɔined Stress Design Factor — $F_3 := 0.90$

ut data

ɔOP STRESS

$$S_h := \left[(\Delta p_{is})\frac{OD}{2t}\right]$$

$S_h = 0\,Pa$

$$S_{Hoop} := \begin{cases} \text{"OK"} & \text{if } S_h \le F_1(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_{Hoop} = \text{"OK"}$

ɔNGITUDINAL STRESS

Longitudinal Stress

$$S_{L1} := S_a - S_b$$

$S_{L1} = -298.742 \times MPa$

$$S_{L2} := S_a + S_b$$

$S_{L2} = 281.557 \times MPa$

$$S_{LS} := \max(S_{L1}, S_{L2})$$

$S_{LS} = 2.816 \times 10^8\,Pa$

$$S_L := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_2(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_L = \text{"OK"}$

ɔMBINED LOADING STRESS

r stress will only be present in a pipeline subject to torsion.
ɿerefore assumed to be zero with regard to spanning

$\tau := 0$

onal Moment

$S_t := 0$

$$S_u := 2\sqrt{\left(\frac{S_{LS} - S_h}{2}\right)^2 + S_t^2}$$

$S_u = 2.816 \times 10^8\,Pa$

$$S_{ULS} := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_3(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$ $S_{ULS} = \text{"OK"}$

ƗYNAMIC SPAN ANALYSIS (VIV ANALYSIS)

: Data

Length For Screening Criteria $SPAN := 26m$

Length For ULS Criteria $SPAN_{ULS} := 50m$

ꞌREENING FATIQUE CRITERIA, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

ꞮE

ıction Factor $R_{I\theta 1}$(Assumed) $R_{I\theta 1} := 1.00$

ıction Factor $R_{I\theta 2}$(Assumed) $R_{I\theta 2} := 1.00$

---

amental Natural Frequency, Sect. 6.7.2, Ref 1

$$: C_1 \times \sqrt{1 + CSF} \times \sqrt{\frac{E_{steel} \times I_{steel}}{EM_d \times SPAN_{eff}^4} \times \left[1 - \frac{S_{effd}}{P_{cr}} + C_3 \times \left(\frac{\delta_{in}}{DCN}\right)^2\right]}$$ $f_{nf} = 1.465 \frac{1}{s}$

ꞩcreening Fatigue Check (Sect. 2.3.3, Ref. 1)

$$f_{nIL} := \frac{U_{c1}}{VRIN_{onset} \times DCN} \times \left(1 - \frac{\frac{SPAN}{DCN}}{250}\right) \times \frac{\gamma_{iL}}{\alpha 1}$$ $f_{nIL} = 1.451 \frac{1}{s}$

$$ne := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{nIL} > f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{inline} = \text{" SPAN VALUE OK"}$

$$Utility_{inline} := \frac{f_{nIL}}{f_{nf}}$$ $Utility_{inline} = 0.99$

SS FLOW

ꞩcreening Fatigue Check (Sect. 2.3.4, Ref.1)

$$f_{ocf} := \left(\frac{U_{c1} + U_{w1}}{VRCF_{onset} \times DCN}\right) \times \gamma_{cf}$$ $f_{ocf} = 1.081 \frac{1}{s}$

$$fo_{crossflow} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{ocf} \ge f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{crossflow} = \text{" SPAN VALUE OK"}$

$$Utility_{crossflow} := \frac{f_{ocf}}{f_{nf}}$$ $Utility_{crossflow} = 0.738$

.S CRTITERION, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

: VIV Response Amplitude (From Fig. 1, Ref. 1) $AyD = 0.057$

s Flow Response Amplitude (From Fig. 2, Ref 1) $AzD = 0.023$

---

efore For Stress Check;

s_Long_Check := | "OK" if $\sigma_{longstress} < D_{YS}$
| " NOT OK" otherwise

Stress_Long_Check = "OK"

s_Equi_Check := | "OK" if $\sigma_{equivalent} < D_{YS}$
| " NOT OK" otherwise

Stress_Equi_Check = "OK"

$$Utility_{longstress} := \frac{\sigma_{longstress}}{D_{YS}}$$ $Utility_{longstress} = 0.999$

$$Utility_{equivalent} := \frac{\sigma_{equivalent}}{D_{YS}}$$ $Utility_{equivalent} = 0.999$

SPANNING ANALYSIS (HYDROTEST CASE)

ITRODUCTION

ening Criteria and Ultimate Limit State (ULS) Criteria check are performed for a pipeline freespan subjected to ined wave and current loading.

nethodology is in accordance with DNV RP-F105 (2006), "Free Spanning Pipelines", with additional ences made to other DNV standards and publications (refer list of References in Section 2.0).

analysis are considered:

- Combined Loading Criteria Static Stress (ASME B31.4)
- Vortex Induced Vibration - in-line and cross-flow (DNV RP F105)
  a) Screening Fatigue Criteria
  b) ULS Criterion

REFERENCES

IV Recommended Practice RP-F105 Free Spanning Pipelines, 2006

IV Offshore Standard OS-F101 Submarine Pipeline Systems, 2005

SME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, 2006

INPUT DATA

PIPE PARAMETER

d Case(LC) = **1** Installation, **2** Hydrotest or **3** Operating $LC := 2$

idition (Cond = **1** Unrestrained, **2** Restrained) $Cond := 2$

of Pipe $OD := 273.1mm$ $OD = 10.752\times in$

YS $SMYS := 359MPa$

ll Thickness Selected $t := 15.9mm$

rrosion Allowance $CA := 3mm$

rcentage of CA Loss $Loss := 10\%$

lected Wall Thickness $t_{sel} := \begin{cases} t - (CA \times Loss) & \text{if } LC = 3 \\ t & \text{otherwise} \end{cases}$ $t_{sel} = 15.9\times mm$

ung's Modulus (Steel) $E_{steel} := 2.07\times 10^{5} MPa$

isson's Ratio $\nu := 0.3$

ermal Expansion $\alpha := 11.7\times 10^{-6} C^{-1}$

eel Density $\rho_s := 7850 \frac{kg}{m^3}$

)ATING PROPERTIES

ısion Coating Thickness $TCR := 0.5mm$

rete Coating Thickness $TCN := 25.4mm$

ɔsion Coating Density $PCR := 1450\frac{kg}{m^3}$

:rete Coating Density $PCN := 3040\frac{kg}{m^3}$

:rete Compressive Strength $CCS := 28MPa$

'RODUCT PROPERTIES

luct Density(min.) $PP_{mind} := 1012\frac{kg}{m^3}$

luct Density(max.) $PP_{maxs} := 1012\frac{kg}{m^3}$

ıwater Density $PW := 1033\frac{kg}{m^3}$

erating Temperature $Temp_{od} := 33C$

erating Pressure $OP_d := 12.5MPa$

lrotest Pressure $HT_d := 1.25 \times OP_d$ $HT_d = 15.625 \times MPa$

sign temperature $Temp_{ds} := 33C$

sign Pressure $DP_s := 22.4MPa$

drotest Pressure $HT_s := 1.25 \times DP_s$ $HT_s = 28 \times MPa$

mperature Derating value (Operating Temp.)
ɔm Figure 5.1, Sect 5 B600, Ref 2) $f_{ytemp} := 0MPa$

ıterial Strength factor
ble 5-1, Sect 5 B600, Ref 2) $\alpha_U := 0.96$

) ENVIRONMENTAL INPUT DATA

ınimum Water Depth $WD := 19.5m$

ırface Current Velocity (1 year) $U_{c1} := 0.436\frac{m}{s}$

ırface Current Velocity (100 year) $U_{c100} := 0.664\frac{m}{s}$

num Wave Height (100 year)	$H_{wmax} := 9.0m$
num Wave Period (100 year)	$T_{wmax} := 9.1s$
ficant Wave Height (1 year)	$H_{s1} := 2.5m$
ficant Wave Height (100 year)	$H_{s100} := 4.8m$
ficant Wave Period (1 year)	$T_{p1} := 7.98s$
ficant Wave Period (100 year)	$T_{p100} := 11.06s$
Air Temperature	$Tmax_{air} := 33C$
rater Temperature (surface)	$Tmax_{sur} := 33C$
ed Temperature	$Tmax_{bed} := 15C$

DIL PROPERTIES Clay (Soft)

AFETY FACTORS

y Class LOW

OUNDARY CONDITIONS COEFFICIENT (TABLE 6-1, Ref 1)

dary Type:

ngle Span on Seabed

$EF := 2$

ed Fixed

nned Pinned

THER DATA

e angle of the hydodynamic force in the wave cycle	$\theta := 90deg$
iction factor due to wave spreading,s=2 (from Fig. 3-4, Ref. 1)	$R_D := 0.84$
Surface	"Concrete"
ice Roughness (Table 5-1)	$k_{sr} := 3.33 \times 10^{-3} m$

TATIC SPAN ANALYSIS

OMBINED LOADING STATIC STRESS (ASME B31.4)

: Stress in pipeline span

t data

dary Case (BC)
ned-pinned,
ed-pinned or
ed-fixed

$BC := 3$

i length for static check $L_{stat} := 75m$

perature Derating Factor $\kappa_T := 1.0$

o Stress Design Factor $F_1 := 0.90$

gitudinal Stress Design Factor $F_2 := 0.80$

ibined Stress Design Factor $F_3 := 0.90$

put data

HOOP STRESS

$$S_h := \left[\left(\Delta p_{is}\right) \frac{OD}{2t} \right] \qquad S_h = 2.388 \times 10^8 \, Pa$$

$$S_{Hoop} := \begin{vmatrix} \text{"OK"} & \text{if } S_h \le F_1(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{vmatrix} \qquad S_{Hoop} = \text{"OK"}$$

LONGITUDINAL STRESS

al Longitudinal Stress

$$S_{L1} := S_a - S_b \qquad S_{L1} = -306.679 \times MPa$$

$$S_{L2} := S_a + S_b \qquad S_{L2} = 280.899 \times MPa$$

$$S_{LS} := \max\left(S_{L1}, S_{L2}\right) \qquad S_{LS} = 2.809 \times 10^8 \, Pa$$

$$S_L := \begin{vmatrix} \text{"OK"} & \text{if } S_{LS} \le F_2(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{vmatrix} \qquad S_L = \text{"OK"}$$

COMBINED LOADING STRESS

ear stress will only be present in a pipeline subject to torsion.
s therefore assumed to be zero with regard to spanning $\tau := 0$

rsional Moment $S_t := 0$

$$S_u := 2 \left[\sqrt{\left(\frac{S_{LS} - S_h}{2} \right)^2 + S_t^2} \right] \qquad S_u = 4.213 \times 10^7 \, Pa$$

$$S_{ULS} := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_3(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$ $S_{ULS} = \text{"OK"}$

)YNAMIC SPAN ANALYSIS (VIV ANALYSIS)

t Data

ı Length For Screening Criteria $SPAN := 16m$

ı Length For ULS Criteria $SPAN_{ULS} := 23m$

CREENING FATIQUE CRITERIA, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

INE

uction Factor $R_{I\theta 1}$(Assumed) $R_{I\theta 1} := 1.00$

uction Factor $R_{I\theta 2}$(Assumed) $R_{I\theta 2} := 1.00$

damental Natural Frequency, Sect. 6.7.2, Ref 1

$$:= C_1 \times \sqrt{1 + CSF} \times \sqrt{\frac{E_{steel} \times I_{steel}}{EM_d \times SPAN_{eff}^4} \times \left[1 - \frac{S_{effd}}{P_{cr}} + C_3 \times \left(\frac{\delta_{in}}{DCN}\right)^2\right]}$$ $f_{nf} = 2.658 \frac{1}{s}$

Screening Fatigue Check (Sect. 2.3.3, Ref. 1)

$$f_{nIL} := \frac{U_{c100}}{VRIN_{onset} \times DCN} \times \left(1 - \frac{\frac{SPAN}{DCN}}{250}\right) \times \frac{\gamma_{iL}}{\alpha 1}$$ $f_{nIL} = 2.503 \frac{1}{s}$

$$\text{nline} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{nIL} > f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{inline} = \text{" SPAN VALUE OK"}$

$$Utility_{inline} := \frac{f_{nIL}}{f_{nf}}$$ $Utility_{inline} = 0.942$

ROSS FLOW

ır Screening Fatigue Check (Sect. 2.3.4, Ref.1)

$$f_{ocf} := \left(\frac{U_{c100} + U_{w1}}{VRCF_{onset} \times DCN}\right) \times \gamma_{cf}$$ $f_{ocf} = 1.356 \frac{1}{s}$

$$fo_{crossflow} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{ocf} \ge f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{crossflow} = \text{" SPAN VALUE OK"}$

$$Utility_{crossflow} := \frac{f_{ocf}}{f_{nf}}$$ $Utility_{crossflow} = 0.51$

.S CRTITERION, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

· VIV Response Amplitude (From Fig. 1, Ref. 1) $AyD := 0.00$

; Flow Response Amplitude (From Fig. 2, Ref 1) $AzD := 0.00$

;fore For Stress Check;

$$\_Long\_Check := \begin{cases} \text{"OK"} & \text{if } \sigma_{longstress} < D_{YS} \\ \text{" NOT OK"} & \text{otherwise} \end{cases}$$ Stress_Long_Check = "OK"

$$\_Equi\_Check := \begin{cases} \text{"OK"} & \text{if } \sigma_{equivalent} < D_{YS} \\ \text{" NOT OK"} & \text{otherwise} \end{cases}$$ Stress_Equi_Check = "OK"

$$Utility_{longstress} := \frac{\sigma_{longstress}}{D_{YS}}$$ $Utility_{longstress} = 0.967$

$$Utility_{equivalent} := \frac{\sigma_{equivalent}}{D_{YS}}$$ $Utility_{equivalent} = 0.847$

SPANNING ANALYSIS (HYDROTEST CASE)

ITRODUCTION

ening Criteria and Ultimate Limit State (ULS) Criteria check are performed for a pipeline freespan subjected to ined wave and current loading.

nethodology is in accordance with DNV RP-F105 (2006), "Free Spanning Pipelines", with additional ences made to other DNV standards and publications (refer list of References in Section 2.0).

analysis are considered:

Combined Loading Criteria Static Stress (ASME B31.4)
Vortex Induced Vibration - in-line and cross-flow (DNV RP F105)
a) Screening Fatigue Criteria
b) ULS Criterion

EFERENCES

V Recommended Practice RP-F105 Free Spanning Pipelines, 2006

V Offshore Standard OS-F101 Submarine Pipeline Systems, 2005

ME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, 2006

IPUT DATA

PE PARAMETER

Case(LC) = **1** Installation, **2** Hydrotest or **3** Operating — $LC := 2$

ition (Cond = **1** Unrestrained, **2** Restrained) — $Cond := 2$

f Pipe — $OD := 273.1mm$ $OD = 10.752 \times in$

S — $SMYS := 359MPa$

Thickness Selected — $t := 20.6mm$

sion Allowance — $CA := 3mm$

entage of CA Loss — $Loss := 10\%$

ted Wall Thickness $t_{sel} := \begin{cases} t - (CA \times Loss) & \text{if } LC = 3 \\ t & \text{otherwise} \end{cases}$ — $t_{sel} = 20.6 \times mm$

g's Modulus (Steel) — $E_{steel} := 2.07 \times 10^{5} MPa$

on's Ratio — $\nu := 0.3$

nal Expansion — $\alpha := 11.7 \times 10^{-6} C^{-1}$

Density — $\rho_s := 7850 \frac{kg}{m^3}$

ƆATING PROPERTIES

ɔsion Coating Thickness $TCR := 0.5mm$

rete Coating Thickness $TCN := 25.4mm$

ɔsion Coating Density $PCR := 1450\frac{kg}{m^3}$

rete Coating Density $PCN := 3040\frac{kg}{m^3}$

rete Compressive Strength $CCS := 28MPa$

ꓤODUCT PROPERTIES

ɹct Density(min.) $PP_{mind} := 1012\frac{kg}{m^3}$

ɹct Density(max.) $PP_{maxs} := 1012\frac{kg}{m^3}$

ʎater Density $PW := 1033\frac{kg}{m^3}$

ating Temperature $Temp_{od} := 33C$

ating Pressure $OP_d := 12.5MPa$

ɔtest Pressure $HT_d := 1.25 \times OP_d$ $HT_d = 15.625 \times MPa$

ɡn temperature $Temp_{ds} := 33C$

ɡn Pressure $DP_s := 22.4MPa$

ɔtest Pressure $HT_s := 1.25 \times DP_s$ $HT_s = 28 \times MPa$

ɔerature Derating value (Operating Temp.)
Figure 5.1, Sect 5 B600, Ref 2) $f_{ytemp} := 0MPa$

rial Strength factor
ꞓ 5-1, Sect 5 B600, Ref 2) $\alpha_U := 0.96$

ꓠVIRONMENTAL INPUT DATA

ɲum Water Depth $WD := 19.5m$

ɹce Current Velocity (1 year) $U_{c1} := 0.436\frac{m}{s}$

ɹce Current Velocity (100 year) $U_{c100} := 0.664\frac{m}{s}$

num Wave Height (100 year) $H_{wmax} := 9.0m$

num Wave Period (100 year) $T_{wmax} := 9.1s$

ficant Wave Height (1 year) $H_{s1} := 2.5m$

ficant Wave Height (100 year) $H_{s100} := 4.8m$

ficant Wave Period (1 year) $T_{p1} := 7.98s$

ficant Wave Period (100 year) $T_{p100} := 11.06s$

Air Temperature $Tmax_{air} := 33C$

ater Temperature (surface) $Tmax_{sur} := 33C$

ed Temperature $Tmax_{bed} := 15C$

OIL PROPERTIES Clay (Soft)

AFETY FACTORS

y Class LOW

OUNDARY CONDITIONS COEFFICIENT (TABLE 6-1, Ref 1)

dary Type:

ngle Span on Seabed $EF := 2$

ed Fixed

nned Pinned

HER DATA

e angle of the hydodynamic force in the wave cycle $\theta := 90deg$

ction factor due to wave spreading,s=2 (from Fig. 3-4, Ref. 1) $R_D := 0.84$

Surface "Concrete"

ce Roughness (Table 5-1) $k_{sr} := 3.33 \times 10^{-3} m$

;TATIC SPAN ANALYSIS

OMBINED LOADING STATIC STRESS (ASME B31.4)

: Stress in pipeline span

t data

dary Case (BC)
ned-pinned,
ed-pinned or
ed-fixed

$BC := 3$

length for static check $L_{stat} := 71m$

berature Derating Factor $k_T := 1.0$

Stress Design Factor $F_1 := 0.90$

itudinal Stress Design Factor $F_2 := 0.80$

bined Stress Design Factor $F_3 := 0.90$

ut data

OOP STRESS

$$S_h := \left[(\Delta p_{is})\frac{OD}{2t}\right]$$ $S_h = 1.843 \times 10^8\,Pa$

$$S_{Hoop} := \begin{cases} \text{"OK"} & \text{if } S_h \le F_1(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$ $S_{Hoop} = \text{"OK"}$

ONGITUDINAL STRESS

Longitudinal Stress

$$S_{L1} := S_a - S_b$$ $S_{L1} = -313.523 \times MPa$

$$S_{L2} := S_a + S_b$$ $S_{L2} = 285.007 \times MPa$

$$S_{LS} := \max(S_{L1}, S_{L2})$$ $S_{LS} = 2.85 \times 10^8\,Pa$

$$S_L := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_2(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$ $S_L = \text{"OK"}$

OMBINED LOADING STRESS

ır stress will only be present in a pipeline subject to torsion.
herefore assumed to be zero with regard to spanning $\tau := 0$

onal Moment $S_t := 0$

$$S_u := 2\sqrt{\left(\frac{S_{LS} - S_h}{2}\right)^2 + S_t^2}$$ $S_u = 1.007 \times 10^8\,Pa$

$$S_{ULS} := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_3(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_{ULS} = \text{"OK"}$

)YNAMIC SPAN ANALYSIS (VIV ANALYSIS)

t Data

ı Length For Screening Criteria

$SPAN := 18m$

ı Length For ULS Criteria

$SPAN_{ULS} := 29m$

:REENING FATIQUE CRITERIA, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

NE

ıction Factor $R_{I\theta 1}$(Assumed)

$R_{I\theta 1} := 1.00$

ıction Factor $R_{I\theta 2}$(Assumed)

$R_{I\theta 2} := 1.00$

amental Natural Frequency, Sect. 6.7.2, Ref 1

$$: C_1 \times \sqrt{1 + CSF} \times \sqrt{\frac{E_{steel} \times I_{steel}}{EM_d \times SPAN_{eff}^{\ 4}} \times \left[1 - \frac{S_{effd}}{P_{cr}} + C_3 \times \left(\frac{\delta_{in}}{DCN}\right)^2\right]}$$

$f_{nf} = 2.376 \frac{1}{s}$

;creening Fatigue Check (Sect. 2.3.3, Ref. 1)

$$f_{nIL} := \frac{U_{c100}}{VRIN_{onset} \times DCN} \times \left(1 - \frac{\frac{SPAN}{DCN}}{250}\right) \times \frac{\gamma_{iL}}{\alpha 1}$$

$f_{nIL} = 2.313 \frac{1}{s}$

$$ne := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{nIL} > f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$

$fo_{inline} = \text{" SPAN VALUE OK"}$

$$Utility_{inline} := \frac{f_{nIL}}{f_{nf}}$$

$Utility_{inline} = 0.973$

SS FLOW

;creening Fatigue Check (Sect. 2.3.4, Ref.1)

$$f_{ocf} := \left(\frac{U_{c100} + U_{w1}}{VRCF_{onset} \times DCN}\right) \times \gamma_{cf}$$

$f_{ocf} = 1.356 \frac{1}{s}$

$$fo_{crossflow} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{ocf} \ge f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$

$fo_{crossflow} = \text{" SPAN VALUE OK"}$

$$Utility_{crossflow} := \frac{f_{ocf}}{f_{nf}}$$ $Utility_{crossflow} = 0.571$

.S CRTITERION, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

: VIV Response Amplitude (From Fig. 1, Ref. 1) $AyD := 0.00$

s Flow Response Amplitude (From Fig. 2, Ref 1) $AzD := 0.00$

---

efore For Stress Check;

$$\text{s\_Long\_Check} := \begin{cases} \text{"OK"} & \text{if } \sigma_{longstress} < D_{YS} \\ \text{" NOT OK"} & \text{otherwise} \end{cases}$$ Stress_Long_Check = "OK"

$$\text{s\_Equi\_Check} := \begin{cases} \text{"OK"} & \text{if } \sigma_{equivalent} < D_{YS} \\ \text{" NOT OK"} & \text{otherwise} \end{cases}$$ Stress_Equi_Check = "OK"

$$Utility_{longstress} := \frac{\sigma_{longstress}}{D_{YS}}$$ $Utility_{longstress} = 0.963$

$$Utility_{equivalent} := \frac{\sigma_{equivalent}}{D_{YS}}$$ $Utility_{equivalent} = 0.859$

SPANNING ANALYSIS (OPERATION CASE)

NTRODUCTION

ening Criteria and Ultimate Limit State (ULS) Criteria check are performed for a pipeline freespan subjected to ined wave and current loading.

nethodology is in accordance with DNV RP-F105 (2006), "Free Spanning Pipelines", with additional ences made to other DNV standards and publications (refer list of References in Section 2.0).

analysis are considered:

Combined Loading Criteria Static Stress (ASME B31.4)
Vortex Induced Vibration - in-line and cross-flow (DNV RP F105)
a) Screening Fatigue Criteria
b) ULS Criterion

EFERENCES

V Recommended Practice RP-F105 Free Spanning Pipelines, 2006

V Offshore Standard OS-F101 Submarine Pipeline Systems, 2005

ME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, 2006

NPUT DATA

PE PARAMETER

Case(LC) = **1** Installation, **2** Hydrotest or **3** Operating $LC := 3$

lition (Cond = **1** Unrestrained, **2** Restrained) $Cond := 2$

f Pipe $OD := 273.1mm$ $OD = 10.752 \times in$

S $SMYS := 359MPa$

Thickness Selected $t := 15.9mm$

sion Allowance $CA := 3mm$

entage of CA Loss $Loss := 10\%$

cted Wall Thickness $t_{sel} := \begin{cases} t - (CA \times Loss) & \text{if } LC = 3 \\ t & \text{otherwise} \end{cases}$ $t_{sel} = 15.6 \times mm$

g's Modulus (Steel) $E_{steel} := 2.07 \times 10^{5} MPa$

son's Ratio $\nu := 0.3$

nal Expansion $\alpha := 11.7 \times 10^{-6} C^{-1}$

Density $\rho_s := 7850 \frac{kg}{m^3}$

OATING PROPERTIES

osion Coating Thickness $TCR := 0.5mm$

rete Coating Thickness $TCN := 25.4mm$

osion Coating Density $PCR := 1450\frac{kg}{m^3}$

rete Coating Density $PCN := 3040\frac{kg}{m^3}$

rete Compressive Strength $CCS := 28MPa$

RODUCT PROPERTIES

uct Density(min.) $PP_{mind} := 1012\frac{kg}{m^3}$

uct Density(max.) $PP_{maxs} := 1140\frac{kg}{m^3}$

vater Density $PW := 1033\frac{kg}{m^3}$

ating Temperature $Temp_{od} := 38C$

ating Pressure $OP_d := 12.5MPa$

otest Pressure $HT_d := 1.25 \times OP_d$ $HT_d = 15.625 \times MPa$

gn temperature $Temp_{ds} := 65C$

gn Pressure $DP_s := 22.4MPa$

otest Pressure $HT_s := 1.25 \times DP_s$ $HT_s = 28 \times MPa$

perature Derating value (Operating Temp.)
ı Figure 5.1, Sect 5 B600, Ref 2) $f_{ytemp} := 0MPa$

rial Strength factor
e 5-1, Sect 5 B600, Ref 2) $\alpha_U := 0.96$

NVIRONMENTAL INPUT DATA

num Water Depth $WD := 19.5m$

ace Current Velocity (1 year) $U_{c1} := 0.436\frac{m}{s}$

ace Current Velocity (100 year) $U_{c100} := 0.664\frac{m}{s}$

num Wave Height (100 year) $H_{wmax} := 9.0m$

num Wave Period (100 year) $T_{wmax} := 9.1s$

ficant Wave Height (1 year) $H_{s1} := 2.5m$

ficant Wave Height (100 year) $H_{s100} := 4.8m$

ficant Wave Period (1 year) $T_{p1} := 7.98s$

ficant Wave Period (100 year) $T_{p100} := 11.06s$

Air Temperature $Tmax_{air} := 33C$

rater Temperature (surface) $Tmax_{sur} := 33C$

ed Temperature $Tmax_{bed} := 15C$

DIL PROPERTIES Clay (Soft)

AFETY FACTORS

y Class HIGH

OUNDARY CONDITIONS COEFFICIENT (TABLE 6-1, Ref 1)

dary Type:

ngle Span on Seabed $EF := 2$

ed Fixed

nned Pinned

THER DATA

e angle of the hydodynamic force in the wave cycle $\theta := 90deg$

ction factor due to wave spreading,s=2 (from Fig. 3-4, Ref. 1) $R_D := 0.84$

Surface "Concrete"

ce Roughness (Table 5-1) $k_{sr} := 3.33 \times 10^{-3} m$

;TATIC SPAN ANALYSIS

OMBINED LOADING STATIC STRESS (ASME B31.4)

; Stress in pipeline span

t data

dary Case (BC)
ned-pinned,
ed-pinned or
ed-fixed

$BC := 3$

length for static check

$L_{stat} := 76m$

perature Derating Factor

$k_T := 1.0$

Stress Design Factor

$F_1 := 0.72$

itudinal Stress Design Factor

$F_2 := 0.80$

bined Stress Design Factor

$F_3 := 0.90$

ut data

OOP STRESS

$$S_h := \left[\left(\Delta p_{is}\right)\frac{OD}{2t}\right]$$

$S_h = 1.907 \times 10^8\,Pa$

$$S_{Hoop} := \begin{cases} \text{"OK"} & \text{if } S_h \le F_1(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_{Hoop} = \text{"OK"}$

ONGITUDINAL STRESS

Longitudinal Stress

$$S_{L1} := S_a - S_b$$

$S_{L1} = -333.396 \times MPa$

$$S_{L2} := S_a + S_b$$

$S_{L2} = 286.685 \times MPa$

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

$S_{LS} = 2.867 \times 10^8\,Pa$

$$S_L := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_2(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_L = \text{"OK"}$

OMBINED LOADING STRESS

ır stress will only be present in a pipeline subject to torsion.
herefore assumed to be zero with regard to spanning

$\tau := 0$

ional Moment

$S_t := 0$

$$S_u := 2\sqrt{\left(\frac{S_{LS} - S_h}{2}\right)^2 + S_t^2}$$

$S_u = 9.601 \times 10^7\,Pa$

$$S_{ULS} := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_3(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$

$S_{ULS} = \text{"OK"}$

ɪYNAMIC SPAN ANALYSIS (VIV ANALYSIS)

ɫ Data

Length For Screening Criteria $SPAN := 15m$

Length For ULS Criteria $SPAN_{ULS} := 24m$

:REENING FATIQUE CRITERIA, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

ɴE

ıction Factor $R_{I\theta1}$(Assumed) $R_{I\theta1} := 1.00$

ıction Factor $R_{I\theta2}$(Assumed) $R_{I\theta2} := 1.00$

---

amental Natural Frequency, Sect. 6.7.2, Ref 1

$$: C_1 \times \sqrt{1 + CSF} \times \sqrt{\frac{E_{steel} \times I_{steel}}{EM_d \times SPAN_{eff}^{\ 4}} \times \left[1 - \frac{S_{effd}}{P_{cr}} + C_3 \times \left(\frac{\delta_{in}}{DCN}\right)^2\right]}$$

$f_{nf} = 2.927 \frac{1}{s}$

ɔcreening Fatigue Check (Sect. 2.3.3, Ref. 1)

$$f_{nIL} := \frac{U_{c100}}{VRIN_{onset} \times DCN} \times \left(1 - \frac{\frac{SPAN}{DCN}}{250}\right) \times \frac{\gamma_{iL}}{\alpha 1}$$

$f_{nIL} = 2.788 \frac{1}{s}$

$$ne := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{nIL} > f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$

$fo_{inline} = \text{" SPAN VALUE OK"}$

$$Utility_{inline} := \frac{f_{nIL}}{f_{nf}}$$

$Utility_{inline} = 0.953$

SS FLOW

ɔcreening Fatigue Check (Sect. 2.3.4, Ref.1)

$$f_{ocf} := \left(\frac{U_{c100} + U_{w1}}{VRCF_{onset} \times DCN}\right) \times \gamma_{cf}$$

$f_{ocf} = 1.356 \frac{1}{s}$

$$fo_{crossflow} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{ocf} \ge f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$

$fo_{crossflow} = \text{" SPAN VALUE OK"}$

$$Utility_{crossflow} := \frac{f_{ocf}}{f_{nf}}$$ $Utility_{crossflow} = 0.463$

.S CRTITERION, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

: VIV Response Amplitude (From Fig. 1, Ref. 1) AyD := 0.063

s Flow Response Amplitude (From Fig. 2, Ref 1) AzD := 0.004

---

efore For Stress Check;

$$\text{;\_Long\_Check} := \begin{cases} \text{"OK"} & \text{if } \sigma_{longstress} < D_{YS} \\ \text{" NOT OK"} & \text{otherwise} \end{cases}$$ Stress_Long_Check = "OK"

$$\text{;\_Equi\_Check} := \begin{cases} \text{"OK"} & \text{if } \sigma_{equivalent} < D_{YS} \\ \text{" NOT OK"} & \text{otherwise} \end{cases}$$ Stress_Equi_Check = "OK"

$$Utility_{longstress} := \frac{\sigma_{longstress}}{D_{YS}}$$ $Utility_{longstress} = 0.902$

$$Utility_{equivalent} := \frac{\sigma_{equivalent}}{D_{YS}}$$ $Utility_{equivalent} = 0.79$

ɔATING PROPERTIES

ɔsion Coating Thickness		$TCR := 0.5mm$
rete Coating Thickness		$TCN := 25.4mm$
ɔsion Coating Density		$PCR := 1450 \frac{kg}{m^3}$
rete Coating Density		$PCN := 3040 \frac{kg}{m^3}$
rete Compressive Strength		$CCS := 28MPa$

ꓤODUCT PROPERTIES

ɹct Density(min.)		$PP_{mind} := 1012 \frac{kg}{m^3}$
ɹct Density(max.)		$PP_{maxs} := 1140 \frac{kg}{m^3}$
ɾater Density		$PW := 1033 \frac{kg}{m^3}$
ating Temperature		$Temp_{od} := 38C$
ating Pressure		$OP_d := 12.5MPa$
ɔtest Pressure	$HT_d := 1.25 \times OP_d$	$HT_d = 15.625 \times MPa$
ɲn temperature		$Temp_{ds} := 65C$
ɲn Pressure		$DP_s := 22.4MPa$
ɔtest Pressure	$HT_s := 1.25 \times DP_s$	$HT_s = 28 \times MPa$
ɔerature Derating value (Operating Temp.) Figure 5.1, Sect 5 B600, Ref 2)		$f_{ytemp} := 0MPa$
rial Strength factor ɛ 5-1, Sect 5 B600, Ref 2)		$\alpha_U := 0.96$

ꓠVIRONMENTAL INPUT DATA

ɿum Water Depth		$WD := 19.5m$
ce Current Velocity (1 year)		$U_{c1} := 0.436 \frac{m}{s}$
ce Current Velocity (100 year)		$U_{c100} := 0.664 \frac{m}{s}$

imum Wave Height (100 year)	$H_{wmax} := 9.0m$
imum Wave Period (100 year)	$T_{wmax} := 9.1s$
ificant Wave Height (1 year)	$H_{s1} := 2.5m$
ificant Wave Height (100 year)	$H_{s100} := 4.8m$
ificant Wave Period (1 year)	$T_{p1} := 7.98s$
ificant Wave Period (100 year)	$T_{p100} := 11.06s$
Air Temperature	$Tmax_{air} := 33C$
water Temperature (surface)	$Tmax_{sur} := 33C$
bed Temperature	$Tmax_{bed} := 15C$

OIL PROPERTIES Clay (Soft)

AFETY FACTORS

ty Class HIGH

OUNDARY CONDITIONS COEFFICIENT (TABLE 6-1, Ref 1)

ndary Type:

ingle Span on Seabed $EF := 2$

ixed Fixed

inned Pinned

THER DATA

se angle of the hydodynamic force in the wave cycle	$\theta := 90deg$
uction factor due to wave spreading,s=2 (from Fig. 3-4, Ref. 1)	$R_D := 0.84$
Surface	"Concrete"
ace Roughness (Table 5-1)	$k_{sr} := 3.33 \times 10^{-3} m$

ꟅTATIC SPAN ANALYSIS

:OMBINED LOADING STATIC STRESS (ASME B31.4)

c Stress in pipeline span

t data

ıdary Case (BC)
ɔned-pinned,
ꞔed-pinned or
ꞔed-fixed

$BC := 3$

ı length for static check $L_{stat} := 72m$

perature Derating Factor $k_T := 1.0$

p Stress Design Factor $F_1 := 0.60$

ɟitudinal Stress Design Factor $F_2 := 0.80$

ıbined Stress Design Factor $F_3 := 0.90$

ɔut data

IOOP STRESS

$$S_h := \left[(\Delta p_{is})\frac{OD}{2t}\right] \qquad S_h = 1.472 \times 10^8 \, Pa$$

$$S_{Hoop} := \begin{cases} \text{"OK"} & \text{if } S_h \le F_1(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases} \qquad S_{Hoop} = \text{"OK"}$$

.ONGITUDINAL STRESS

ıl Longitudinal Stress

$$S_{L1} := S_a - S_b \qquad S_{L1} = -342.586 \times MPa$$

$$S_{L2} := S_a + S_b \qquad S_{L2} = 286.394 \times MPa$$

$$S_{LS} := \max(S_{L1}, S_{L2}) \qquad S_{LS} = 2.864 \times 10^8 \, Pa$$

$$S_L := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_2(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases} \qquad S_L = \text{"OK"}$$

:OMBINED LOADING STRESS

ar stress will only be present in a pipeline subject to torsion.
therefore assumed to be zero with regard to spanning $\tau = 0$

Ʂional Moment $S_t = 0$

$$S_u := 2\left[\sqrt{\left(\frac{S_{LS} - S_h}{2}\right)^2 + S_t^2}\right] \qquad S_u = 1.392 \times 10^8 \, Pa$$

$$S_{ULS} := \begin{cases} \text{"OK"} & \text{if } S_{LS} \le F_3(SMYS) \\ \text{"NOT OK"} & \text{otherwise} \end{cases}$$ $S_{ULS} = \text{"OK"}$

)YNAMIC SPAN ANALYSIS (VIV ANALYSIS)

t Data

ı Length For Screening Criteria $SPAN := 15m$

ı Length For ULS Criteria $SPAN_{ULS} := 25m$

:REENING FATIQUE CRITERIA, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

NE

ıction Factor $R_{I\theta 1}$(Assumed) $R_{I\theta 1} := 1.00$

ıction Factor $R_{I\theta 2}$(Assumed) $R_{I\theta 2} := 1.00$

---

amental Natural Frequency, Sect. 6.7.2, Ref 1

$$= C_1 \times \sqrt{1 + CSF} \times \sqrt{\frac{E_{steel} \times I_{steel}}{EM_d \times SPAN_{eff}^{\,4}} \times \left[1 - \frac{S_{effd}}{P_{cr}} + C_3 \times \left(\frac{\delta_{in}}{DCN}\right)^2\right]}$$ $f_{nf} = 3.065\frac{1}{s}$

;creening Fatigue Check (Sect. 2.3.3, Ref. 1)

$$f_{nIL} := \frac{U_{c100}}{VRIN_{onset} \times DCN} \times \left(1 - \frac{\frac{SPAN}{DCN}}{250}\right) \times \frac{\gamma_{iL}}{\alpha 1}$$ $f_{nIL} = 2.87\frac{1}{s}$

$$\text{ne} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{nIL} > f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{inline} = \text{" SPAN VALUE OK"}$

$$Utility_{inline} := \frac{f_{nIL}}{f_{nf}}$$ $Utility_{inline} = 0.937$

'SS FLOW

;creening Fatigue Check (Sect. 2.3.4, Ref.1)

$$f_{ocf} := \left(\frac{U_{c100} + U_{w1}}{VRCF_{onset} \times DCN}\right) \times \gamma_{cf}$$ $f_{ocf} = 1.356\frac{1}{s}$

$$fo_{crossflow} := \begin{cases} \text{"Vortex Shedding Will Occur"} & \text{if } f_{ocf} \ge f_{nf} \\ \text{" SPAN VALUE OK"} & \text{otherwise} \end{cases}$$ $fo_{crossflow} = \text{" SPAN VALUE OK"}$

$$Utility_{crossflow} := \frac{f_{ocf}}{f_{nf}}$$ $Utility_{crossflow} = 0.442$

LS CRTITERION, BASED ON SECT 2.0 AND SECT 4.0 OF, Ref 1

e VIV Response Amplitude (From Fig. 1, Ref. 1) AyD := 0.066

s Flow Response Amplitude (From Fig. 2, Ref 1) AzD := 0

refore For Stress Check;

ss_Long_Check := | "OK" if $\sigma_{longstress} < D_{YS}$
| " NOT OK" otherwise

Stress_Long_Check = "OK"

ss_Equi_Check := | "OK" if $\sigma_{equivalent} < D_{YS}$
| " NOT OK" otherwise

Stress_Equi_Check = "OK"

$$Utility_{longstress} := \frac{\sigma_{longstress}}{D_{YS}}$$ $Utility_{longstress} = 0.982$

$$Utility_{equivalent} := \frac{\sigma_{equivalent}}{D_{YS}}$$ $Utility_{equivalent} = 0.884$