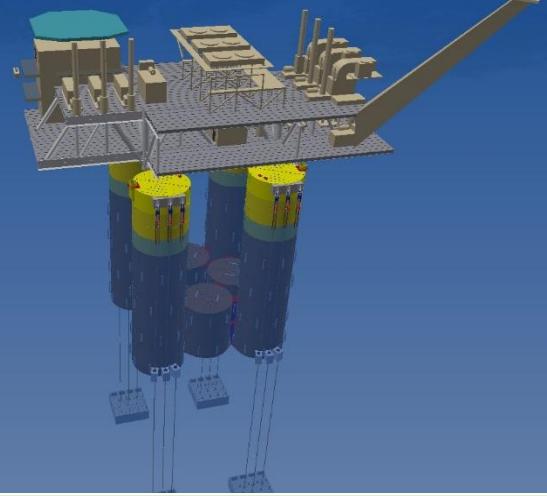
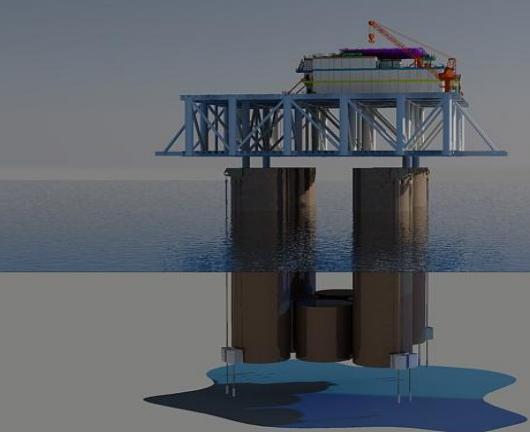
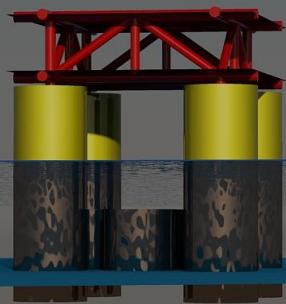


Introduction to Riser Design and Analysis



Riser Sizing Using API 1111

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Introduction

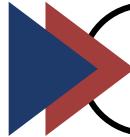


Overview

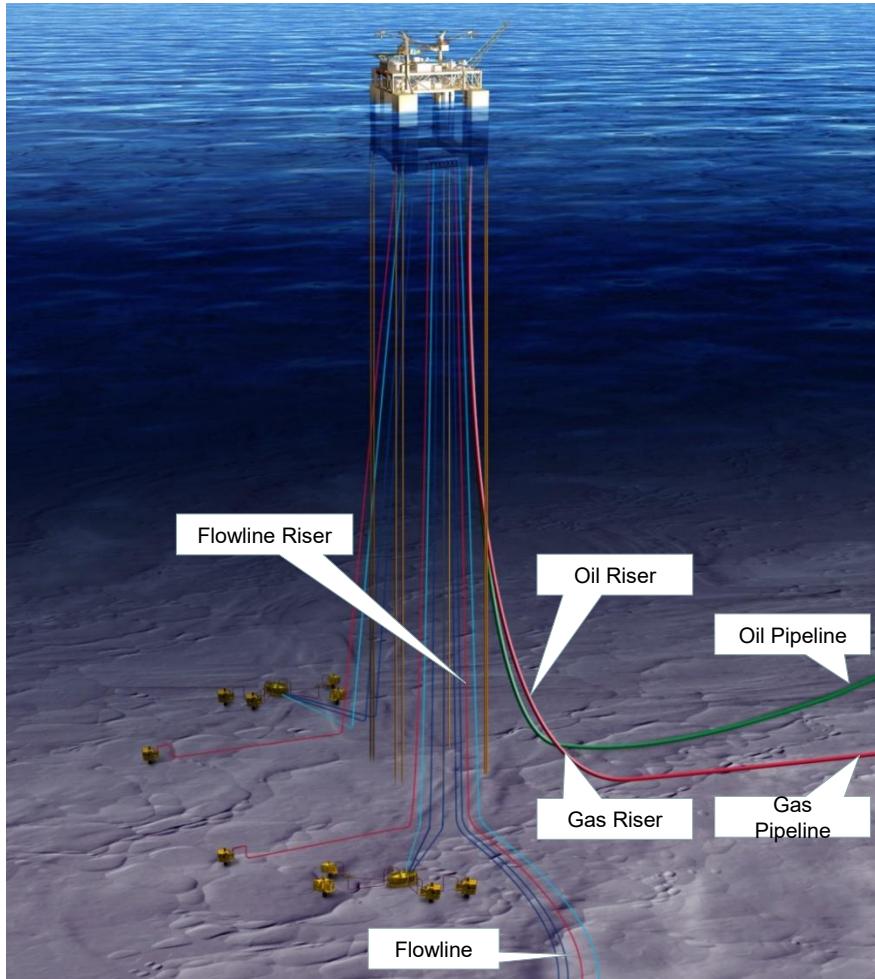
Riser

- Design Condition
- Design Criteria
- Pressure Design of Components

Functional Requirement

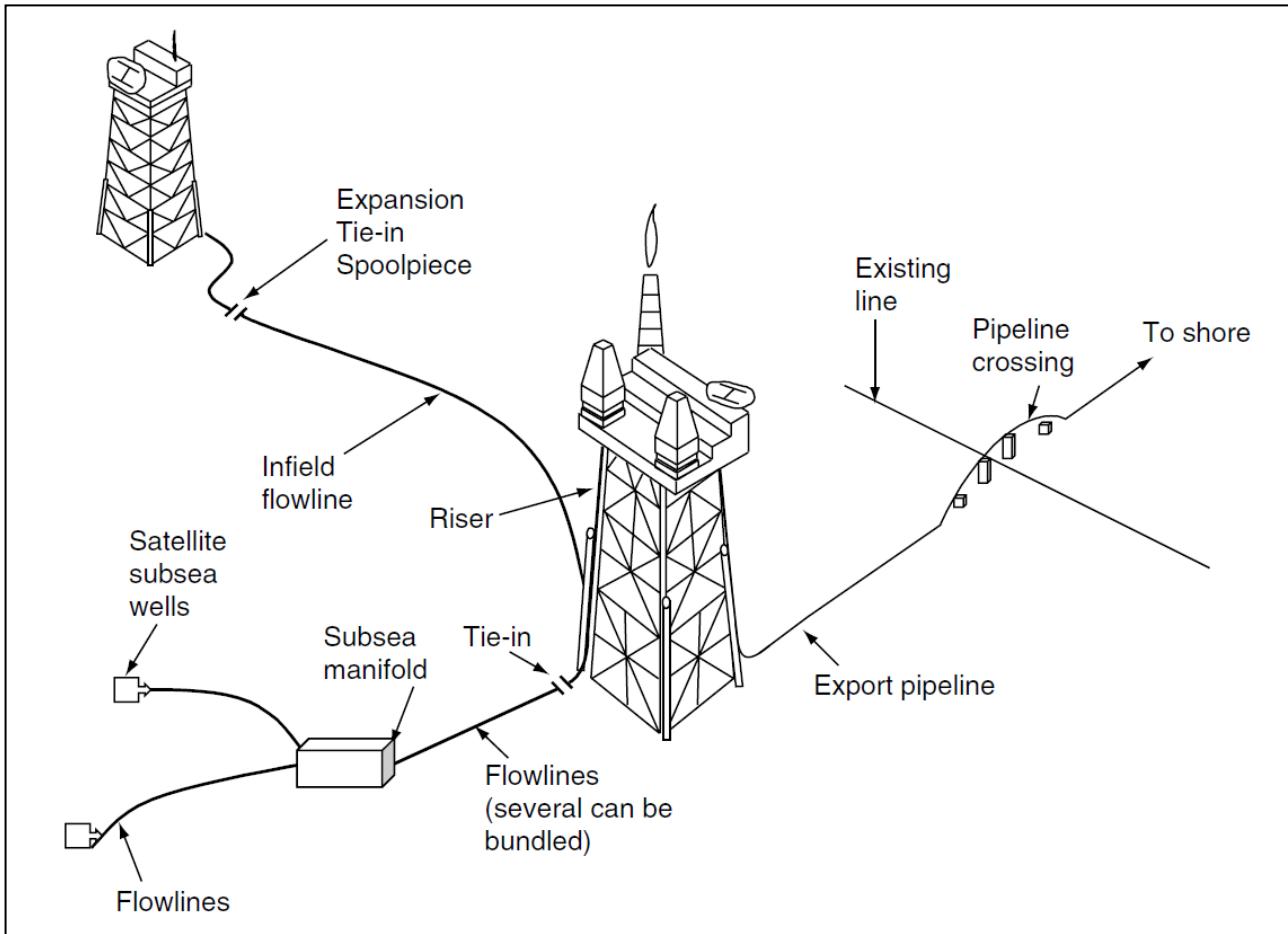


Risers Attached to Semisubmersible



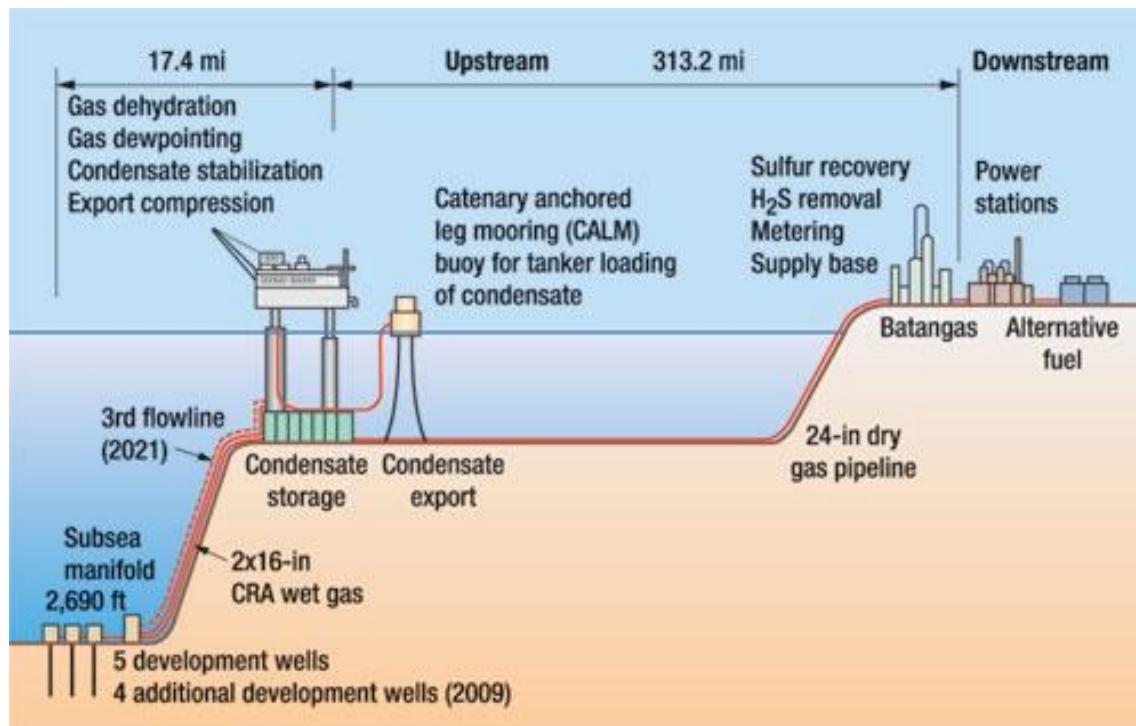
Functional Requirement

Risers Attached to Jacket Platform



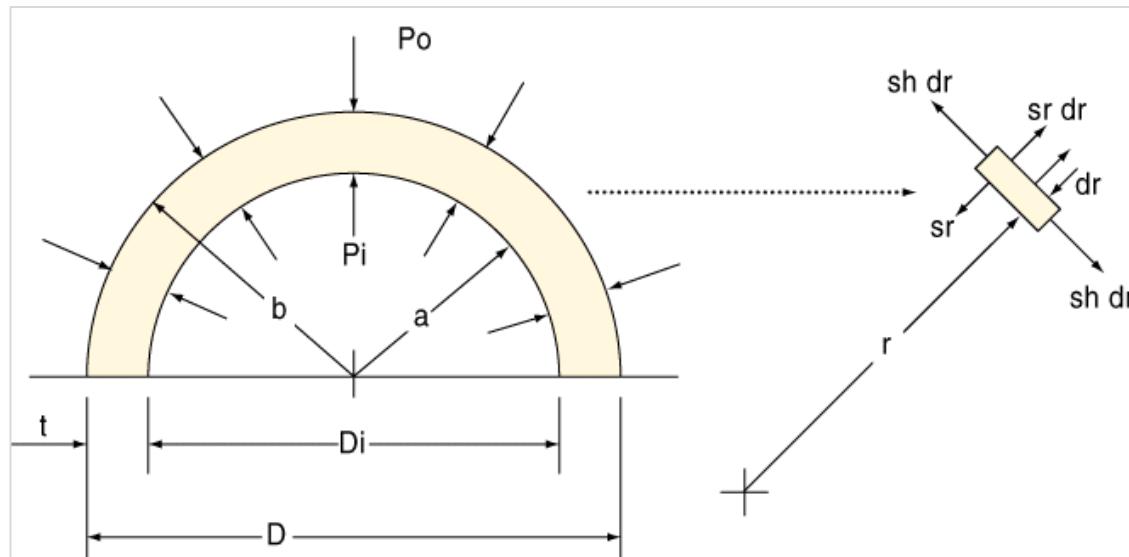
Functional Requirement

Project Example (Malampaya)



Design Condition

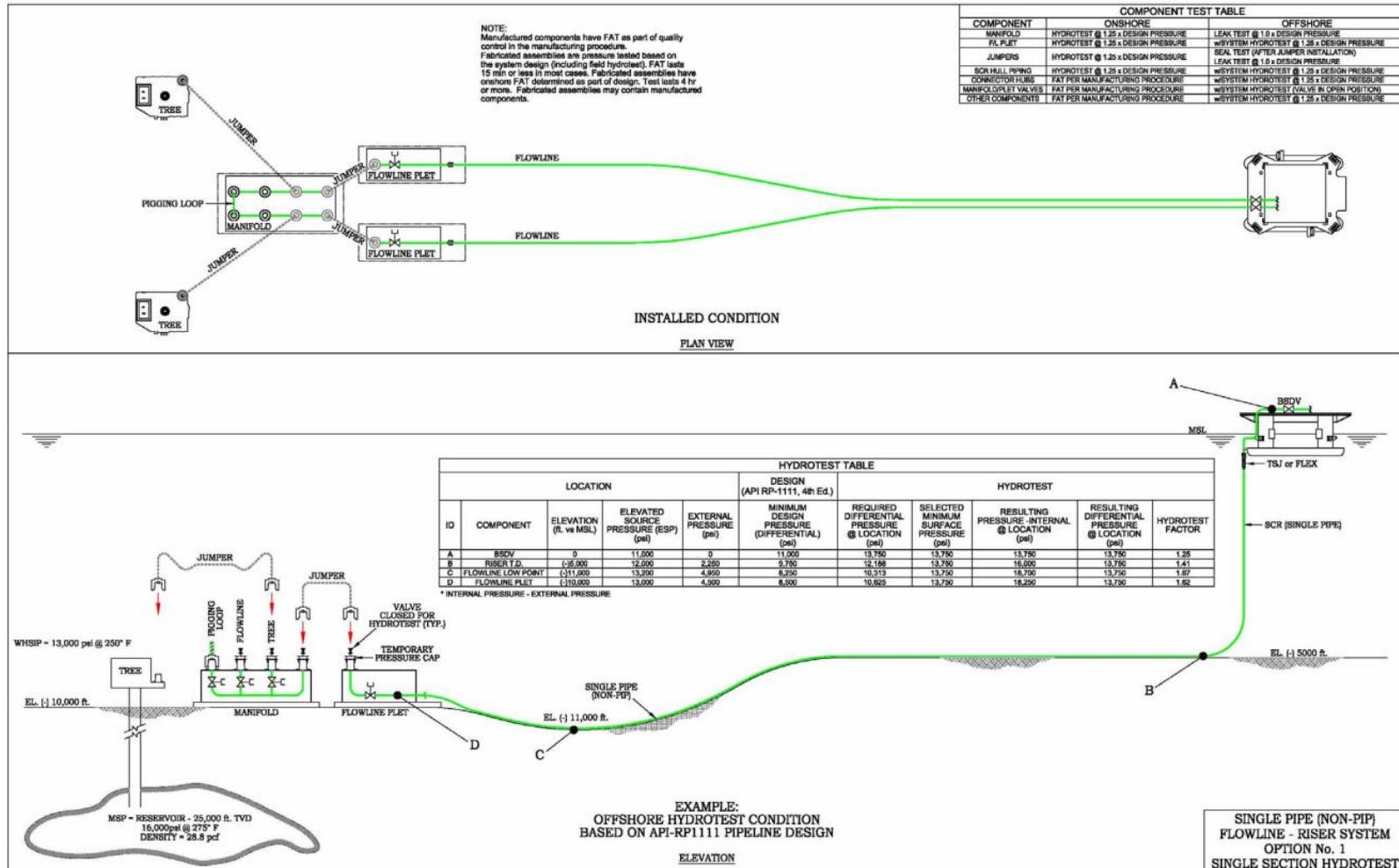
Internal And External Pressure



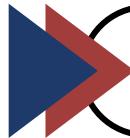
Stresses in pipe subject to internal and
external pressure

Design Condition

Example



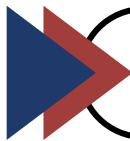
Design Condition



Overview

- Burst due to net internal pressure.
- Combined bending and tension during installation and operation.
- Collapse due to external pressure, with the pipe either empty or filled.
- Buckling and collapse due to combined bending and external pressure.
- Effects of thermal expansion and contraction.
- Fatigue due to hydrodynamic and operational loading.

Design Condition

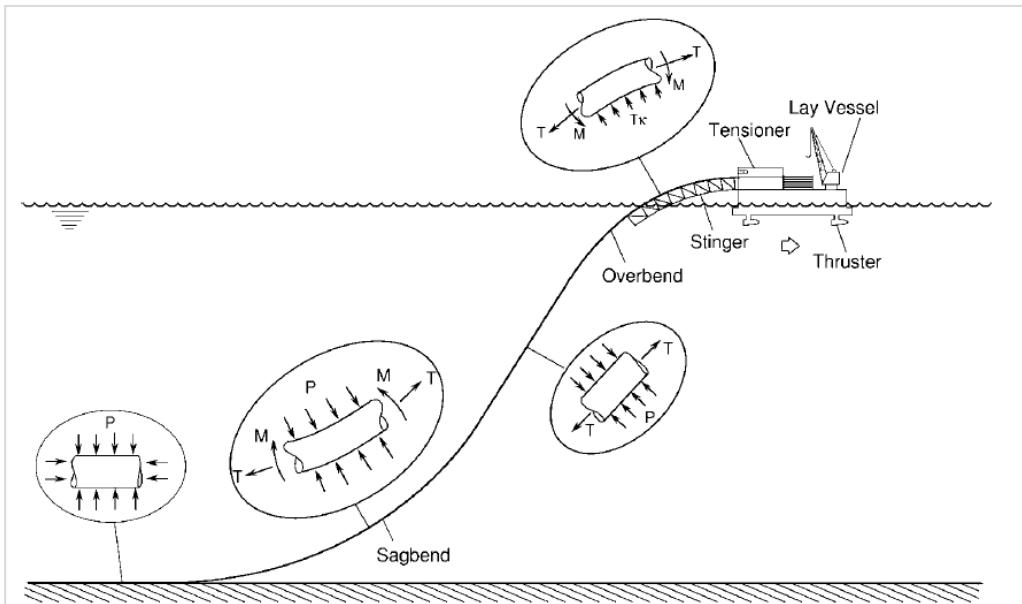
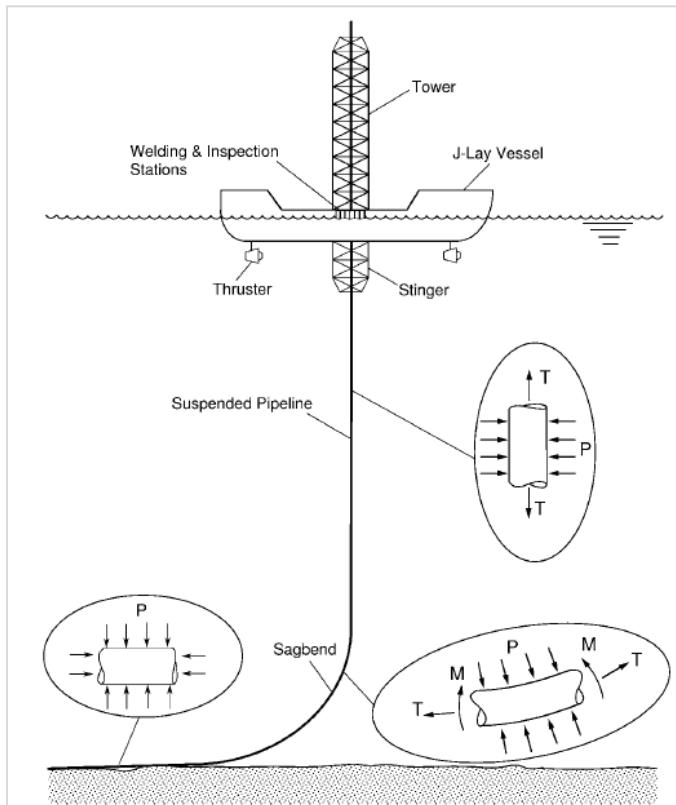


Burst due to net internal pressure



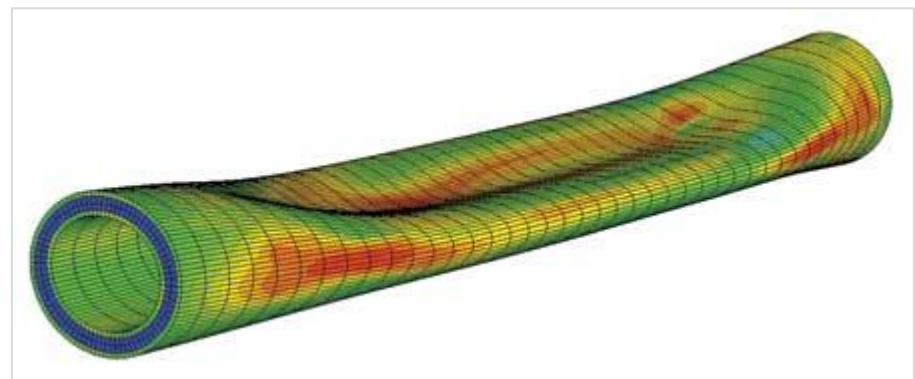
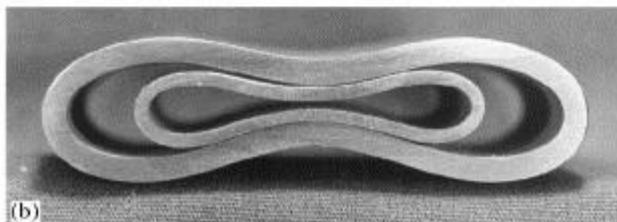
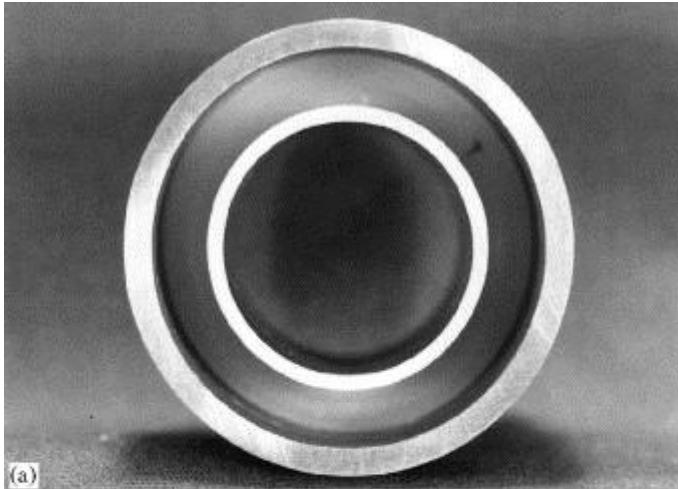
Design Condition

Combined bending and tension during installation and operation



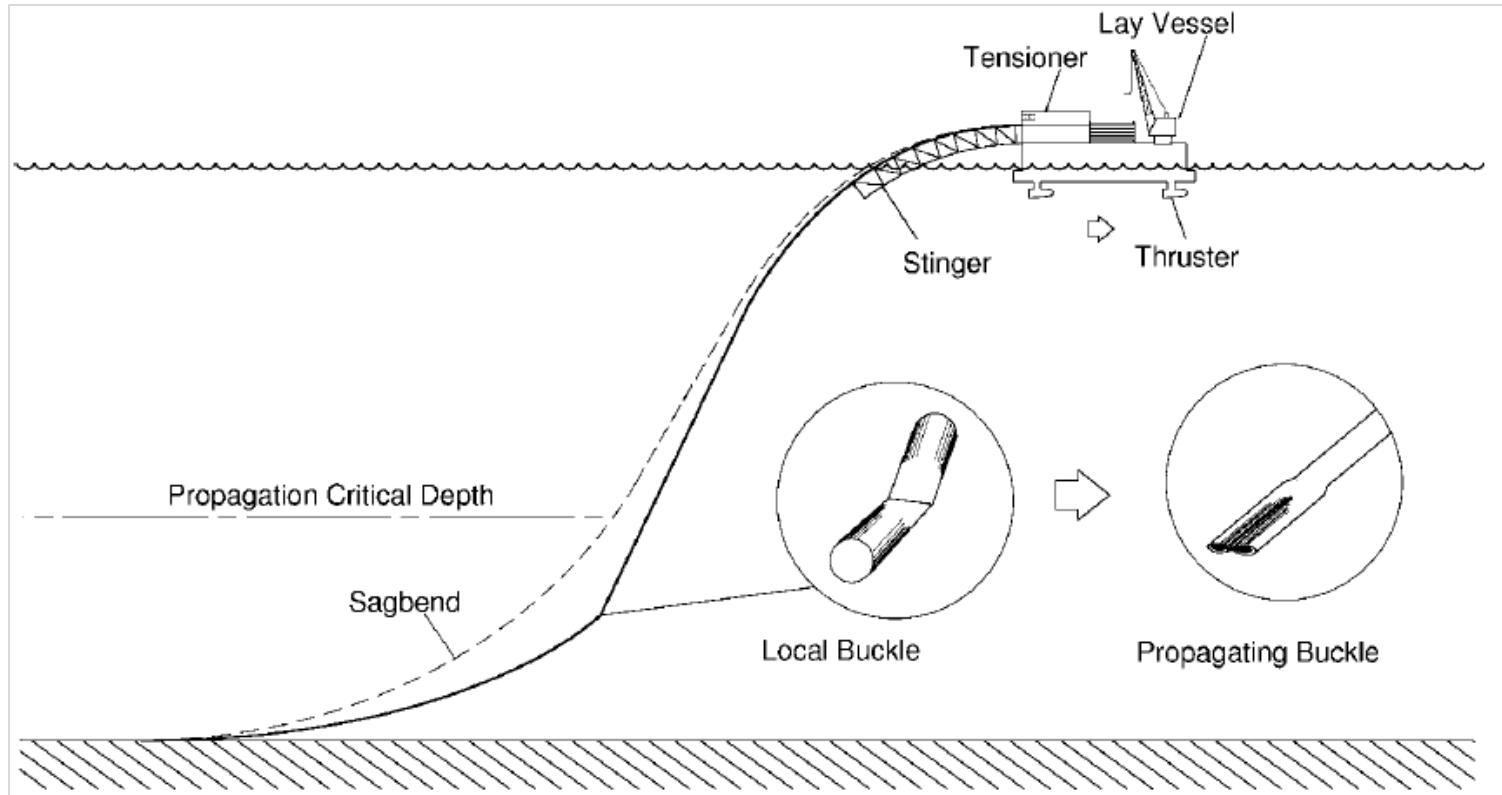
VIV Parameters Design Condition

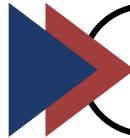
 Collapse due to external pressure, with the pipe either empty or filled



Design Condition

Buckling and collapse due to combined bending and external pressure





Maximum Operating Pressure Limits

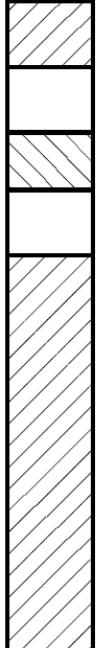
The Maximum Operating Pressure (MOP) should not exceed any of the following:

- **The design pressure of any component, including pipe, valves, and fittings**
- **80% of the applied hydrostatic test pressure**

Design Criteria

Pressure Level Relations

		Max. fraction of P_b	
	Pipeline	Riser	
Burst pressure, the limit state	P_b	1.000	1.000
Hydrostatic test pressure	$P_t \leq f_d f_e f_t P_b$	0.900	0.750
Incidental overpressure	$P_a \leq 0.90 P_t$	0.810	0.675
Design pressure	$P_d \leq 0.80 P_t$	0.720	0.600
Maximum operating pressure	$MOP \leq P_d$		
Operating pressure (OP) normal range	$OP \leq MOP$		
Atmospheric pressure		0.000	0.000





Pressure Design Components

Internal Pressure (Burst) Design



Step 1: Compute Burst Pressure (P_b)

For low D/t pipe ($D/t < 15$)

$$P_b = 0.45(S + U) \ln \frac{D}{D_i}$$

for $D/t > 15$.

$$P_b = 0.90(S + U) \frac{t}{D - t}$$

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

$D_i = D - 2t$ = inside diameter of pipe, in mm (in.),

S = specified minimum yield strength (SMYS) of pipe, in N/mm² (psi) (See API Specification 5L, ASME B31.4, or ASME B31.8 as appropriate.),

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

U = specified minimum ultimate tensile strength of pipe, in N/mm² (psi),

\ln = natural log.

Internal Pressure (Burst) Design

Pipe Material and Grades

Grade	(1)		(2)		(3)	(4)
	Yield Strength, Minimum	Grade	Ultimate Tensile Strength, Minimum	Grade	Elongation in 2 in. (50.8 mm), Minimum, Percent	
	psi	MPa		psi	MPa	
A25	25,000	(172)	45,000	(310)	a	
A	30,000	(207)	48,000	(331)	a	
B	35,000	(241)	60,000	(414)	a	
X42	42,000	(290)	60,000	(414)	a	
X46	46,000	(317)	63,000	(434)	a	
X52	52,000	(359)	66,000	(455)	a	
X56	56,000	(386)	71,000	(490)	a	
X60	60,000	(414)	75,000	(517)	a	
X65	65,000	(448)	77,000	(531)	a	
X70	70,000	(483)	82,000	(565)	a	

Internal Pressure (Burst) Design

Step 2: Compute Hydrostatic Test Pressure Resistance ($f_d f_e f_t P_b$) and Design Pressure Resistance ($0.8 f_d f_e f_t P_b$)

$$\text{Hydrostatic Test Pressure Resistance} = f_d f_e f_t P_b$$

$$\text{Design Pressure Resistance} = 0.8 f_d f_e f_t P_b$$

f_d = internal pressure (burst) design factor, applicable to all pipelines
= 0.90 for pipelines
= 0.75 for pipeline risers,

f_e = weld joint factor, longitudinal or spiral seam welds. See ASME B31.4 or ASME B31.8. Only materials with a factor of 1.0 are acceptable,

f_t = temperature de-rating factor, as specified in ASME B31.8
= 1.0 for temperatures less than 121°C (250°F),

P_a = incidental overpressure (internal minus external pressure), in N/mm² (psi),

P_b = specified minimum burst pressure of pipe, in N/mm² (psi),

P_d = pipeline design pressure, in N/mm² (psi),

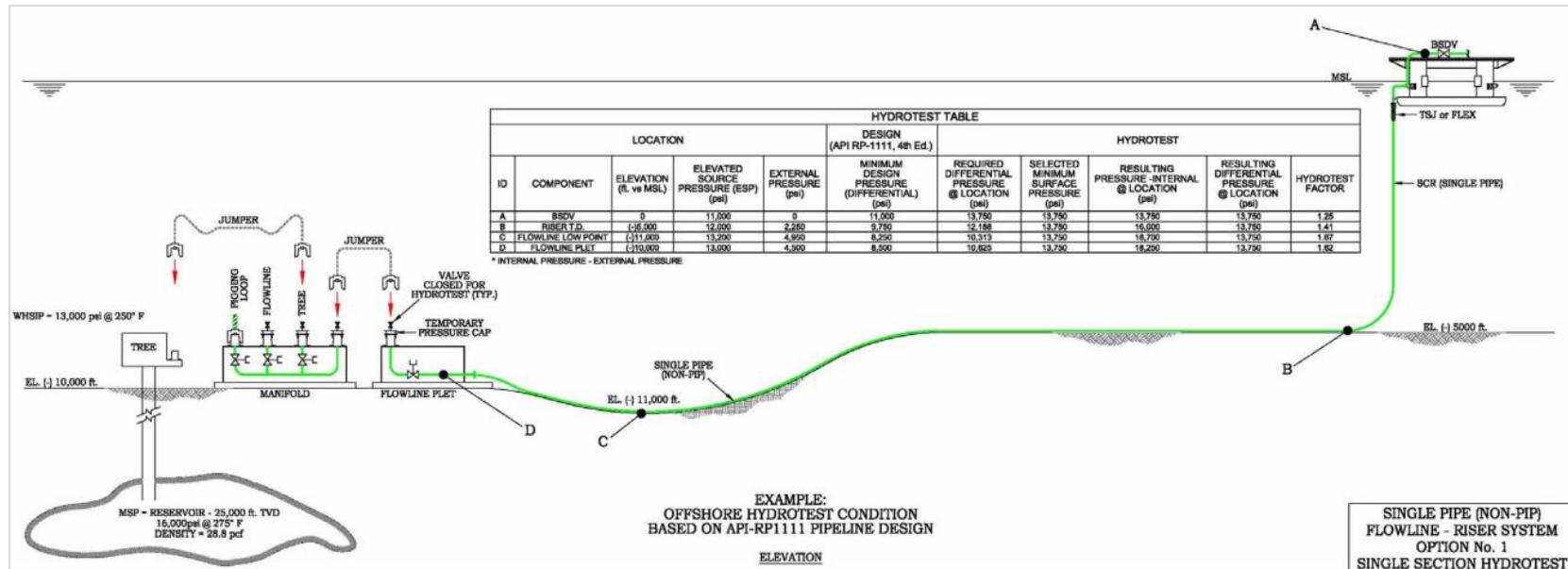
P_t = hydrostatic test pressure (internal minus external pressure), in N/mm² (psi).

Internal Pressure (Burst) Design

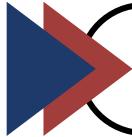
Step 3 and 4

Step 3: Determine Maximum Operating Pressure (P_i) and External Pressure (P_o) at Each Location

Step 4: Compute Hydrostatic Test Pressure ($P_t = \frac{P_i}{0.8}$)



Internal Pressure (Burst) Design



Step 5 and 6

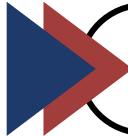
Step 5: Compute Safety Factor for Design Pressure

$$\text{Design Pressure SF} = \frac{0.8 f_d f_e f_t P_b}{P_i - P_o}$$

Step 6: Compute Safety Factor for Hydrostatic Test Pressure

$$\text{Hydrostatic Test Pressure SF} = \frac{f_d f_e f_t P_b}{P_t}$$

External Pressure (Collapse) Design



Step 1: Compute Collapse Pressure Resistance

$$\text{Collapse Pressure Resistance} = f_o P_c$$

f_o = collapse factor

0.70 for seamless (SMLS) pipe (API-RP-1111)

0.75 for seamless or electric resistance welded (ERW) API pipe (API-2RD)

0.60 for double-submerged arc welded (DSAW) or internally cold expanded API pipe (API-2RD and API-RP-1111)

P_c = collapse pressure of the pipe, in N/mm^2 (psi)

External Pressure (Collapse) Design

Overview

$$P_c = \frac{P_y P_e}{\sqrt{P_y^2 + P_e^2}}$$

$$P_y = 2S \left(\frac{t}{D} \right)$$

$$P_e = 2E \frac{\left(\frac{t}{D} \right)^3}{(1 - \nu^2)}$$

where

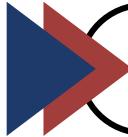
E = modulus of elasticity, in N/mm² (lb/psi),

P_e = elastic collapse pressure of the pipe, in N/mm² (psi),

P_y = yield pressure at collapse, in N/mm² (psi),

ν = Poisson's ratio (0.3 for steel).

External Pressure (Collapse) Design



Step 2: Compute Safety Factor for Collapse Pressure

$$\text{Collapse Pressure SF} = \frac{f_o P_c}{P_o - P_i}$$

Buckling Propagation Design



Step 1: Compute Buckling Propagation Resistance

$$\text{Buckling Propagation Resistance} = f_p P_p$$

where

$$P_p = 24S \left[\frac{t}{D} \right]^{2.4} = \begin{array}{l} \text{buckle propagation pressure,} \\ \text{in n/mm}^2 (\text{psi}) \end{array}$$

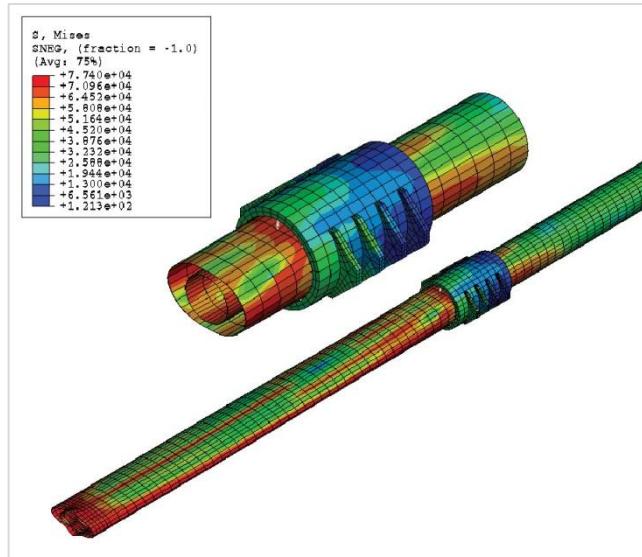
f_p = propagating buckle design factor = 0.80.

Buckling Propagation Design

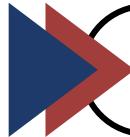
Step 2: Compute Safety Factor for Buckling Propagation

$$\text{Buckling Propagation SF} = \frac{f_p P_p}{P_o - P_i}$$

If Buckling Propagation SF < 1 Then Arrestor is required



Buckling Due to Combined Bending and External Pressure Design



Step 1: Assume/Determine Pipe Ovality (δ)

$\delta = 0.5$ for J and S Lay

$\delta = 1.0$ for Reel Lay

or

$$\delta = \frac{D_{max} - D_{min}}{D_{max} + D_{min}}$$

D_{max} = maximum diameter at any given cross section, in mm (in.),

D_{min} = minimum diameter at any given cross section, in mm (in.).



Step 2, 3 and 4

Step 2: Compute Collapse Reduction Factor ($g(\delta)$)

$$g(\delta) = (1 + 20\delta)^{-1}$$

Step 3: Compute Bending Buckling Strain(ε_b)

$$\varepsilon_b = \frac{t}{2D}$$

Step 4: Bending Strain Capacity(ε)

$$\varepsilon = \left(g(\delta) - \frac{(P_o - P_i)}{P_c} \right) \varepsilon_b$$

Step 5 and 6

Step 5: Compute Safety Factor for Bending Buckling for Installation

$$\text{Bending Buckling SF for Installation} = \frac{\varepsilon}{f_1 \varepsilon_1}$$

$$f_1 = 3.33$$

$$\varepsilon_1 = 0.0015$$

Step 6: Compute Safety Factor for Bending Buckling for Operation

$$\text{Bending Buckling SF for Operation} = \frac{\varepsilon}{f_2 \varepsilon_2}$$

$$f_2 = 2.0$$

$$\varepsilon_1 = 0.0015$$

Hoop Stress Pressure Design (ASME B31.4)



Step 1: Compute Hoop Stress Diff. Pressure Resistance

$$\text{Hoop Stress Diff. Pressure Resistance} = F_1 S_y$$

where

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

F_1 = hoop stress design factor from Table A402.3.5-1

P_e = external pressure, psi (bar)

P_i = internal design pressure, psi (bar)

S_h = hoop stress, psi (MPa)

S_y = specified minimum yield strength, psi (MPa)

t = nominal wall thickness, in. (mm)

Hoop Stress Design Factor (F_1)

0.72 for F/L or P/L

0.6 for F/L riser, oil riser

0.5 for gas riser

Hoop Stress Pressure Design (ASME B31.4)



Step 2 And 3

Step 2: Compute Hoop Stress Diff. Pressure

$$S_h = (P_i - P_e) \frac{D}{2t}$$

US Customary Units

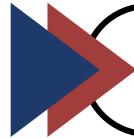
$$S_h = (P_i - P_e) \frac{D}{20t}$$

SI Units

Step 3: Compute Safety Factor for Hoop Stress Diff. Pressure

$$\text{Hoop Stress Diff. Pressure SF} = \frac{F_1 S_y}{S_h}$$

Example

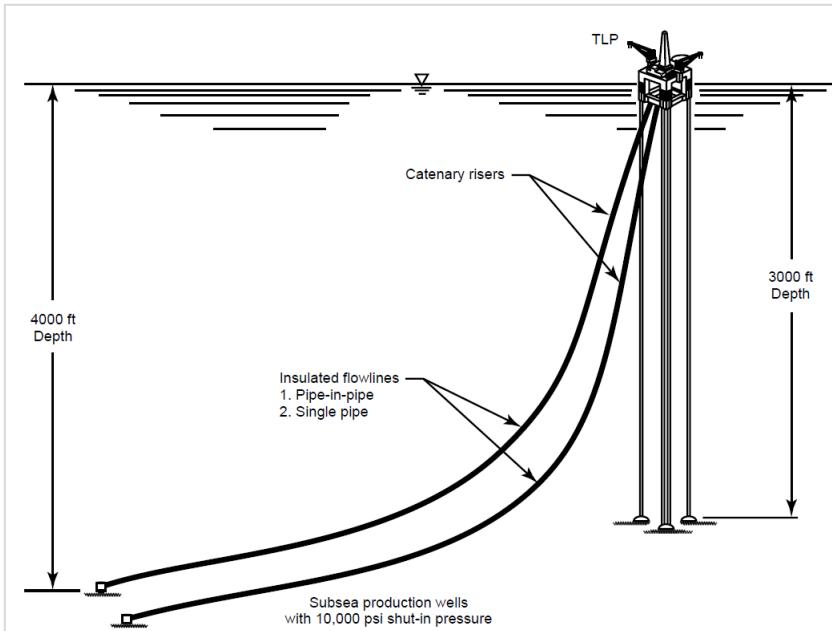


Input Data

INPUT DATA	Select Option	1	flowline		
PIPE O.D	IN.	8.625	MAXIMUM OPERATING PRESSURE AT TOP RISER, MOP	PSI	9,466.7
PIPE W.T	IN.	0.756	MAXIMUM WATER DEPTH	FT	4,000.0
PIPE SMYS (YIELD STRESS)	PSI	70,000.0	MINIMUM WATER DEPTH	FT	3,000.0
PIPE ELASTIC MODULUS [E]	PSI	2.90E+07	WATER DEPTH @ WELLHEAD	FT	4,000.0
PIPE SMUTS (ULTIMATE STRESS)	PSI	82,000.0	SHUT IN PRESSURE, SIP	PSI	10,000.0
PIPE TYPE		SMLS	LOCATION OF SHUT IN PRESSURE		1
			PRESSURE AT SUBSEA WELL OR BOTTOM	PSI	10,000.0
			OVALITY, $(D_{max}-D_{min})/(D_{max}+D_{min})$	%	0.5
CORROSION COATING THICKNESS	IN.	0.00	PIPE WALL THICKNESS TOLERANCE	%	12.5
CORROSION COATING DENSITY	PCF	90.00	PIPE WALL THICKNESS TOLERANCE	IN.	0.1
CONCRETE COATING THICKNESS	IN.	0.00	CORROSION ALLOWANCE	IN.	0.080
CONCRETE COATING DENSITY	PCF	90.00	COLLAPSE DEGRADATION FACTOR, f_o	-	0.7
CONCRETE WATER ABSORPTION	%	0.00	PROPAGATING BUCKLE DESIGN FACTOR, f_p	-	0.80
FIELD JOINT LENGTH (each end)	FT	0.00	HYDROTEST PRESSURE FACTOR	-	0.72
FIELD JOINT DENSITY	PCF	0.00	INTERNAL PRESSURE (BURST) DESIGN FACTOR, f_d	-	0.90
AMBIENT/FLOODED WATER DENSITY	PCF	64.00	SPAN CALCULATION DESIGN FACTOR		
PRODUCT DENSITY	PCF	19.20	INSTALLATION AND HYDROTEST	-	0.30
			DURING OPERATION	-	0.34

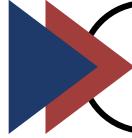
Example

Problem 1



Water depth at subsea well	= 4,000 ft
Water depth at platform	= 3,000 ft
Subsea well shut-in pressure at wellhead, P_i	= 10,000 psi
Specific gravity of fluid, gas production well	= 0.30
Specific gravity of fluid, oil production well	= 0.80

Example



Problem 1 – Cont'

Pipe Data

Flowline/Riser diameter, D, in.	8.625
Flowline pipe SMYS, S, psi	70,000
Flowline pipe ultimate strength, U, psi	82,000
Riser pipe SMYS, S, psi	65,000
Riser pipe ultimate strength, U, psi	78,000

Questions

1. How much is the internal pressure (burst) design
2. Determine the required wall thickness

Example

Problem 1 – Cont'

Calculation Procedure

Step 1 - Obtain oil/gas production fluid density at shut-in pressure condition.

This information is generally known. If unknown, a fluid specific gravity of 0.30, conservatively representing a gas-filled line, should be assumed.

Step 2 - Calculate the internal shut-in pressure at the top of the riser.

Start at the subsea wellhead for which the internal shut-in pressure is known. Calculate the shut-in pressure at the top of the riser by subtracting the pressure loss due to elevation gain in the production fluid column, using the production fluid density from Step 1.

Step 3 - Calculate the hydrotest pressure at the top of the riser.

Calculate the hydrotest pressure at the top of the riser.

Step 4 - Calculate hydrostatic test pressure along the suspended riser and at the subsea wellhead.

Start with the hydrostatic test pressure at the top of the riser where the hydrotest pressure is known. Calculate the hydrotest pressure along the riser and at the subsea wellhead by adding the hydrostatic pressure due to the water column.

Step 5 - Determine the wall thickness for riser and flowline.

Hydrostatic Test Pressure = $f_d f_{eff} t P_b$

$$P_b = 0.45(S + U) \ln \frac{D}{D_i}$$

$$P_b = 0.90(S + U) \frac{t}{D - t}$$

Example



Problem 1 – Cont'

Calculation

Given: $H_1 = 4,000 \text{ ft}$,

$H_2 = 3,000 \text{ ft}$,

$P_s = 10,000 \text{ psi}$,

γ = Seawater density, 64 lbs/cu ft,

SG = Specific gravity of produced fluid, 0.30 for gas, and 0.80 for crude oil.

P_o at riser base = $\gamma \times H_2/144 = 1333 \text{ psi}$

P_o at subsea well = $\gamma \times H_1/144 = 1778 \text{ psi}$

Step 1 - Obtain oil/gas production fluid density at shut-in pressure condition.

Given already, let's compute the wall thickness for gas flowline and riser.

Step 2 - Calculate the internal shut-in pressure at the top of the riser.

P_i at subsea wellhead = $P_s = 10,000 \text{ psi}$

P_i at top of the riser, $P_i = P_s - \gamma \times H_1/144 \times SG = 9467 \text{ psi}$

Step 3 - Calculate the hydrotest pressure at the top of the riser.

$$P_t = (P_i - P_o) / 0.8 = 11833 \text{ psi}$$

Example



Problem 1 – Cont'

Solution

Step 4 - Calculate hydrostatic test pressure along the suspended riser and at the subsea wellhead.

$$P_t \text{ at riser base} = P_t + \gamma \times H_2 / 144 - P_o \text{ at riser base} = 11833 \text{ psi}$$

$$P_t \text{ at subsea wellhead} = P_t + \gamma \times H_1 / 144 - P_o \text{ at wellhead} = 11833 \text{ psi}$$

Step 5 - Determine the wall thickness for riser and flowline.

$$P_t = f_d f_e f_t P_b$$

$$\frac{D}{t} = 1 + \frac{0.90(S + U)}{P_b}$$

For Flowline:

$$f_d = 0.9$$

$$f_e = 1.0$$

$$f_t = 1.0$$

$$P_b = \frac{11833}{0.9 \times 1.0 \times 1.0} = 13148 \text{ psi}$$

$$t = 0.756 \text{ in}$$

For Flowline Riser:

$$f_d = 0.75$$

$$f_e = 1.0$$

$$f_t = 1.0$$

$$P_b = \frac{11833}{0.75 \times 1.0 \times 1.0} = 15778 \text{ psi}$$

$$t = 0.942 \text{ in}$$

Example

Problem 2

Let's compute the wall thickness for oil flowline and riser

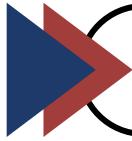
Answer:

For Flowline:

$$t = 0.691 \text{ in}$$

For Flowline Riser:

$$t = 0.862 \text{ in}$$



Questions ?