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|  |  |
| VM Stress Theory | |
| User Manual | |
| May 1, 2018 | |



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| Rev | Description | Date | Prep | Chk'd | Apprv'd |
| 01 | New Document |  |  |  |  |
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Revision History

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| Rev | Description | Section | Pages |
| 01 | New document | - | - |
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# INTRODUCTION

The three principal stresses should be calculated at all critical locations in the riser. At locations with axisymmetric geometry such as plain pipe, the principal stresses will usually be in the axial, hoop and radial directions. For nonaxisymmetric geometry, the directions may be different.

# THEORY

# VM Stress (Riser Code, API-RP-2RD)

* This section applies to metal risers made of steel or titanium.

|  |  |  |
| --- | --- | --- |
| **Primary** | Any normal or shear stress that is necessary to have static equilibrium of the imposed forces and moments. A primary stress is not self-limiting. Thus, if a primary stress substantially exceeds the yield strength, either failure or gross structural yielding will occur. | |
| **Membrane** | σp is the average value across the thickness of a solid section excluding the effects of discontinuities and stress concentrations. For example, the general primary membrane stress in a pipe loaded in pure tension is the tension divided by the cross-sectional area. Σp may include global bending as in the case of a simple pipe loaded by a bending moment. |
| **Bending** | σb is the portion of primary stress proportional to the distance from the centroid of a cross section, excluding the effects of discontinuities and stress concentrations. |
| **Secondary** | σq is any normal or shear stress that develops as a result of material restraint. This type of stress is self-limiting which means that local yielding can relieve the conditions that cause the stress, and a single application of load will not cause failure. | |

Table 1 –Stresses To Consider

### Combined Stresses

Principal stress components at each critical section should be combined using the von Mises yield criterion defined by the following equation.

(1)

Where

σ*e* = von Mises equivalent stress

σ1, σ2, σ3 =Principal stresses.

### Allowable Stresses

The von Mises equivalent stresses should be less than the allowable stresses defined by the right hand side of the following inequalities.

(2)  (3)

(4)

Where

σ*a* = *Ca*σ*y* = basic allowable combined stress.

*Ca* = allowable stress factor, *Ca* = 2/3

σ*y* = material minimum yield strength, defined for

Steel or titanium as the tensile stress required to

Produce a total elongation of 0.5 percent of the

Test specimen gage length.

*Cf* = design case factor

### Allowable Stress in Plain Pipe

For plain round pipe, where transverse shear and torsion are negligible, the three principal stress components of primary membrane stress (average stress across pipe wall) are σpr, σpθ, and σpz, where r, θ, and z refer to radial, hoop, and axial stresses. Thus,

(5)

For Thick Wall Pipe

(6)

(7)

(8)

Where:

Pi = internal pressure.

Po = external pressure.

Do, Di = outside, inside diameters.

t = pipe wall thickness.

A = .

T = true wall tension in pipe at section being analyzed.

M = global bending moment in pipe.

I = moment of inertia = .

Note that the criteria for (σp + σb)e and (σp + σb + σq)e are never controlling for this case.

Substituting Equations 6, 7, and 8 into Equation 5 gives, following a little algebra,

Where

Teff = T – PiAi + PoAo

And

Ai = πDi2 / 4

Ao = πDo2 / 4.

# API STD 2RD

### Burst Pressure

The minimum burst pressure of pipe is determined by Equation 1:

Where

k is a parameter to account for variability in mechanical properties and wall thickness, and is equal to 0.45 for API 5L or API SeT pipe;

D is the outside diameter of the pipe;

T is the nominal thickness of the pipe reduced for corrosion, wear and/or erosion as appropriate;

S is the specified minimum yield strength of the pipe;

U is the specified minimum ultimate strength of the pipe.

### Collapse Due to External Pressure

The collapse pressure for pipes can be calculated as a function of nominal wall thickness as per

Equation 2.

Where

P y is the yield collapse pressure, given by Equation 3;

Pel is the elastic collapse pressure, given by Equation 4.

Where

E is Young's modulus;

v is Poisson's ratio.

The collapse pressure may alternatively be calculated as a function of the elastic capacity, plastic

Capacity and the Ovality of the pipe.

Where

is pipe Ovality

Pp is the plastic collapse pressure of a pipe

Where

αfab is the fabrication factor

1.0 seamless pipe

αfab = 0.85 UOE pipe

0.925 UO/TRB pipe

The initial departure from circularity of pipe and pipe ends (i.e. the initial ovality).

The initial ovality shall not be taken less than 0.0025 (0.25 %). Ovalization caused during the construction and installation phase shall be included in the ovality. The ovalization due to external pressure or moment in the as-installed position shall not be included.

Collapse Due to Pure Bending

Pure bending can result in wrinkling of the pipe wall or flattening of the cross section. Both conditions are known as buckling due to bending. The bending strain that can result in such deformation can be calculated

### Tension

The tension capacity may be calculated by Equation 10.

Where

A is the pipe cross-section area, given by Equation 11.

### Internal Pressure

The casing pressure equal to the pressure caused by a tubing leak, extreme pressure in a drilling riser, hydrostatic test pressure, incidental pressure, and/or design pressure shall not exceed the pressure determined by Equation 14.

Where

Pe is the external pressure;

Pi is the internal pressure;

FD is a design factor and is given by Equation 15.

0.81 Production casing with tubing leak

0.81 Drilling riser with extreme pressure

FD = 0.90 Hydrostatic test

0.67 Incidental pressure

0.60 Design pressure

**Method 1**

The load combinations and associated design factors for Method 1 are given in Equations 18 and 19.

Where

T = Ta - PiAj + PeAo is the effective tension in the pipe;

Ta = σaA

σa is the axial stress in the pipe wall;

Ao, is the external cross section of the pipe

Ai is the internal cross section of the pipe

M is the moment in the pipe;

FD is a design factor, given by Equation 20.

**Method 2**

Method 2 limits axial load based on yield tension including the effect of internal pressure. The load combinations and associated design factors

Where

FD is a design factor,

0.80 SLS, ULS

FD =

1. ALS

**Method 3**

Method 3 is based on DNV-OS-F201, which uses a load and resistance factor design (LRFD) format. For load controlled conditions, refer to the section in F201 on Combined Load Criteria for Riser Pipes. For displacement controlled conditions, refer to the F201 section labeled Displacement Controlled Conditions. When the calculated moment exceeds 90 % of the plastic moment,

**Method 4**

Method 4 sets limits on combined axial load and pressure, without considering bending. Refer to API 1111 for further explanation. Bending limits are set based on bending strain.

**NOTE** there are cases such that the plastic moment limit set by Method 2 does not result in excessive bending strain (Le. the loading condition is displacement controlled).

The load combinations and associated criteria are given by

Where

FD is a design factor,

0.80 SLS, ULS

FD =

1. ALS

For sizing, limiting the load combination in Equation 24 to 0.67 (F D = 0.67) using static effective tension and normal operating pressure will usually provide a design that meets SLS, ULS and ALS conditions.

Method 4 sets limits for bending strain for cases of internal or external overpressure. The criteria are given by

ε ≤ F Dεb (internal overpressure)

Where

c is the bending-induced strain in the pipe;

F D is a design factor;

fc is the collapse factor for use with combined pressure and bending loads; see Equation 29.

0.5 SLS, ULS

FD =

1. ALS

0.6 cold expanded pipe (e.g. DSAW)

Fc = 0.7 seamless pipe

# API 6A

Calculation for pressure vessels subjected to stress from internal pressure, axial loads and an external bending moment.

|  |  |
| --- | --- |
| Material | API |
| Sy | 80000 psi |
| Syt | 80000 psi |
| Sut | 95000 psi |

Table 2 Material Data

Design Stress intensity at Operating Condition

2/3.Sy otherwise

Maximum Stress Intensity at Hydrotest Condition

5/6.Syt otherwise

Maximum Combined Primary and Secondary Stress Intensity

2.Sy otherwise

# ASME B31.8

### Steel Pipe Design Formula

The design pressure for steel gas piping systems or the nominal wall thickness for a given design pressure shall be determined by the following formula (for limitations).

Where

D nominal outside diameter of pipe, in.

E longitudinal joint factor obtained

F design factor obtained

P design pressure

S specified minimum yield strength, psi, stipulated in the specifications under which the pipe was purchased from the manufacturer or determined in accordance

T temperature derating factor obtained

t nominal wall thickness, in.

**Plastic Pipe and Tubing Design Formula**.

The design pressure for plastic gas piping systems or the nominal wall thickness for a given design pressure

D = Specified Outside Diameter,in

P = Design pressure, psig

S = for thermoplastic pipe and tubing, long-term hydrostatic strength determined in accordance with the listed specification at a temperature equal to 73°F, lOO°F, 120°F, or 140oP; for reinforced thermosetting plastic pipe, use 11,000 psi

t = specified wall thickness,in.

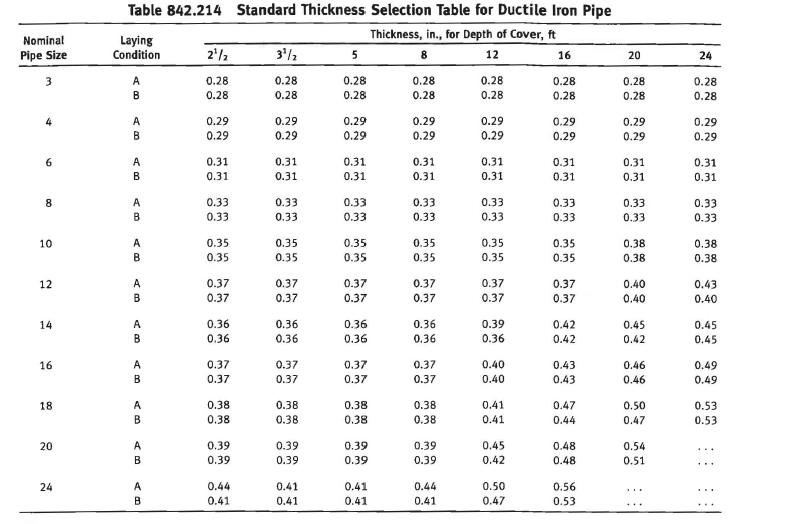


Figure 6‑1 Standard Thickness Selection Table for Ductile Iron Pipe

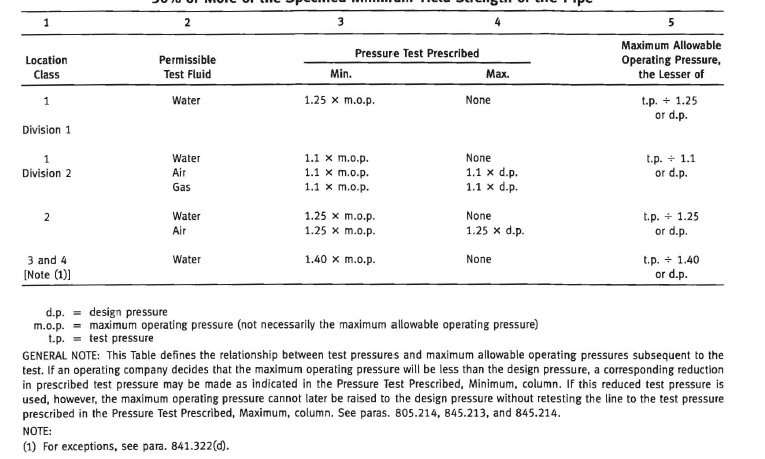


Figure 6‑2 Test Requirements for Pipelines and Mains to Operate at Hoop Stresses of

30% or More of the Specified Minimum Yield Strength of the Pipe

# API 1111

Pipe selection for most offshore pipelines is determined by considering installation and operation loads in addition to the stresses resulting from internal pressure. Design should begin with material selection and pipe sizing for flow considerations and be modified later as a result of design cycles that include the following:

a) Burst due to net internal pressure;

b) Combined bending and tension during installation and operation;

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

d) Buckling and collapse due to combined bending and external pressure;

e) Pipeline stability against horizontal or vertical displacement during construction and operation;

f) Effects of thermal expansion and contraction;

g) in-place and in-service pipeline repair capabilities;

### MOP Limits

The MOP should not exceed any of the following:

a) the design pressure of any component, including pipe, valves, and fittings;

b) 80 % of the applied hydrostatic test pressure in accordance with 8.2.

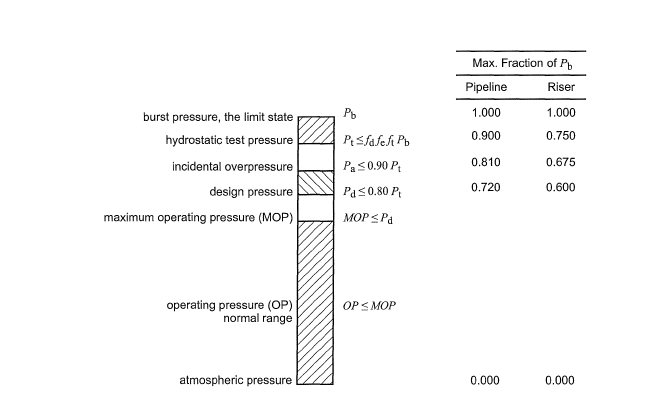


Figure 7‑1 Pressure Level Relations

### Internal Pressure (Burst) Design

The hydrostatic test pressure, the pipeline design pressure, and the incidental overpressure, including both internal and external pressures acting on the pipelines, shall not exceed that determined by the equations.

Where

fd is the internal pressure (burst) design factor, applicable to all pipelines;

0.90 for pipelines;

0.75 for pipeline risers.

fe is the weld joint factor, longitudinal or spiral seam welds. See ASME 831.4 or ASME 831.8. Only materials with a factor of 1.0 are acceptable.

ft is the temperature derating factor, as specified in ASME 831.8 [1.0 for temperatures less than 121°C (250 OF)].

Pa is the incidental over pressure (internal minus external pressure), in N/mm2 (psi).

Pb is the specified minimum burst pressure of pipe, in N/mm2 (psi).

Pd is the pipeline design pressure, in N/mm2 (psi).

Pt is the hydrostatic test pressure (internal minus external pressure), in N/mm2 (psi).

The specified minimum burst pressure (Pb) is determined by one of the following equations:

Where

D is the outside diameter of pipe, in mm (in.);

Di is D - 2t = inside diameter of pipe, in mm (in.);

S is the specified minimum yield strength (SMYS) of pipe, in N/mm2 (psi) (see API 5L, ASME 831.4, or ASME 831.8 as appropriate);

t is the nominal wall thickness of pipe, in mm (in.);

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

tn is the natural log.

### Longitudinal Load Design

The effective tension due to static primary longitudinal loads (see 4.6.2) shall not exceed the value given by.

Where

Ty=SA

A is the cross-sectional area of pipe steel, in mm2 (in. 2);

Ai is the internal cross-sectional area of the pipe, mm2 (in. 2);

Ao is the external cross-sectional area of the pipe, mm2 (in. 2);

Pi is the internal pressure in the pipe, in N/mm2 (psi);

Po is the external hydrostatic pressure, in N/mm2 (psi);

Ta is the axial (material) tension in pipe, in N (Ib);

Teff is the effective tension in pipe, in N (Ib);

Ty is the yield tension of the pipe, in N (Ib);

O"a is the axial stress in the pipe wall, in N/mm2 (psi).

The physical meaning of the term "effective" tension relates to the interaction between the pipe and other structures (sleds, anchor points, lay barge hangoff, etc.). The applied force at a boundary condition is always the effective tension. For the on-bottom portion of a pipeline, the effective tension will vary as loading conditions change. Typically, when a pipeline is just installed on the seabed, the effective tension is equal to the residual horizontal lay tension. For

a single pipeline under fully restrained condition (i.e. far from the end), the effective tension Teff is given by:

Where

Tlay is the residual lay tension;

in the case of a pipe-in-pipe (PIP) installed with the inner pipe free-standing inside the outer pipe during construction, the term 11ay will be negative (without mitigation) and additive to pressure and temperature loading.

∆Pi is the internal pressure change since laydown of the pipe;

E is Young's modulus of elasticity;

∝ is the thermal coefficient of expansion of the pipe;

∆T is the temperature change in the pipe since laydown;

v is the poisson ratio.

### Combined Load Design

The combination of primary longitudinal load (static and dynamic) and differential pressure load shall not exceed that given by:

52

# DNV-OS-F101

## Units

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

## DNV-OS-F101.ini

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Reference/ Notes | Units |
| **[safetyClass] low\_pressureContainment** = **1.046 medium\_pressureContainment** = **1.138 high\_pressureContainment** = **1.308 low\_other** = **1.04 medium\_other** = **1.14 high\_other** = **1.26** |  | C204 | # |
| **[loadFactors]**  **functional = 1.2**  **environmental = 1.1**  **interference = 1.0**  **accidental = 1.0** |  |  | # |
| **[conditionloadEffectFactors]**  **Pipelinerestingonunevenseabed = 1.07**  **reelingonandj-tubepullin = 0.82**  **systempressuretest = 0.93**  **otherwise = 1.0** |  | G304 | # |
| **[materialResistanceFactors]**  **SLS = 1.15**  **ULS = 1.15**  **ALS = 1.15**  **FLS = 1.00** |  | C203 | # |
| **[resistanceFactors]**  **safetyClass= 1.046**  **environmental = 1.1**  **interference = 1.0**  **accidental = 1.0** |  |  | # |
| **[safetyClass]**  **low\_pressureContainment = 1.046**  **medium\_pressureContainment = 1.138**  **high\_pressureContainment = 1.308**  **low\_other = 1.04**  **medium\_other = 1.14**  **high\_other = 1.26** |  |  | # |
| **[materialStrengthFactors]**  **Normally = 0.96**  **suplementaryRequirement = 1.00** |  | C306 | # |
| **[materialFabricationFactors]**  **Seamless = 0.96**  **UO = 1.00**  **TRB = 0.93**  **ERW = 0.93**  **UOE = 0.85** |  | C307 | # |
| **[pressureTestSafetyFactors]**  **mill = {"low": 1.0, "medium" : 1.088, "high" : 1.251}**  **system = {"low": 1.03, "medium" : 1.05, "high" : 1.05}** |  | D200 | # |
| **[materialProperties]**  **young'smodolus = 3.00E+04**  **poissionsratio = 0.29**  **smys = 65**  **smts = 77**  **yieldstrength = 62.40**  **tensilestrength = 73.92**  **Beta = -0.43**  **alphaP= 3.64**  **temperatureDerateLimit = 120**  **i=0** |  | E100 | ksi |
| **[loadBendingMoment] functional** = **-639.5 environmental** = **-639.5 accidenta** = 0 |  |  |  |
| **[effectiveTension] functional** = **0 environmental** = **0 accidental** = **0** |  |  |  |
| **[loadPressure]**  **designInternal =3**  **fluidTemperature = 25**  **internal = 3**  **external=0.5**  **pbt1=1**  **plt=1.5**  **ph=1.1**  **pli=1.75**  **minimumInternal=0** |  |  |  |

### Characteristic Material Properties

The characteristic material strength fy and fu, values to be used in the limit state criteria are:

Where:

fy,temp and fu,temp are the de-rating values due to the temperature of the yield stress and the tensile strength respectively.

αU is the material strength factor

The material properties shall be selected with due regard to material type and potential temperature and/ or ageing effects and shall include:

— yield stress

— Tensile strength

— Young's modulus

— Temperature expansion coefficient.

For C-Mn steel and 13Cr this shall be considered for temperatures above 50°C, and for 22Cr and 25Cr for temperatures above 20°C.

Guidance note 1:

Field joint coating application during installation may also impose temperatures in excess of the above and shall be considered.

Guidance note 2:

If no other information of de-rating effects on the yield stress exist the recommendations for C-Mn steel, 22Cr and 25Cr Figure 2 below may be used. For 13Cr testing is normally required.

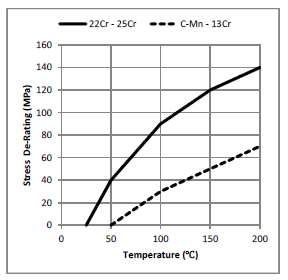


Figure 8‑1 Proposed de-rating values for yield stress of C-Mn, 13Cr, 22Cr and 25Cr

### Pressure containment (bursting)

The pressure containment shall fulfil the following criteria:

The pressure containment resistance pb(t) is given by:

Where:

Local Buckling – external over pressure only (system collapse): The external pressure at any point along the pipeline shall fulfil the following criterion (system collapse check):

Where

pmin is the minimum internal pressure that can be sustained. This is normally taken as zero for as-laid pipeline.

The characteristic resistance for external pressure (pc) (collapse) shall be calculated as:

Where:

The local pressure is the internal pressure at a specific point based on the reference pressure adjusted for the fluid column weight due to the difference in elevation. It can be expressed as:

where

pli is the local incidental pressure

pinc is the incidental reference pressure at the reference elevation

ρcont is the density of the relevant content of the pipeline

g is the gravity

href is the elevation of the reference point (positive upwards)

hl is the elevation of the local pressure point (positive upwards)

plt is the local system test pressure

pt is the system test reference pressure at the reference elevation

ρt is the density of the relevant test medium of the pipeline

pd is the design pressure at the pressure reference elevation

γinc is the incidental to design pressure ratio

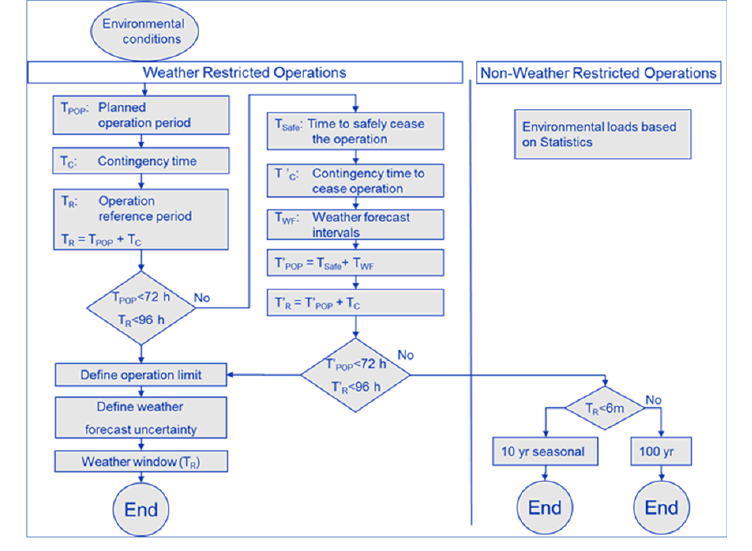
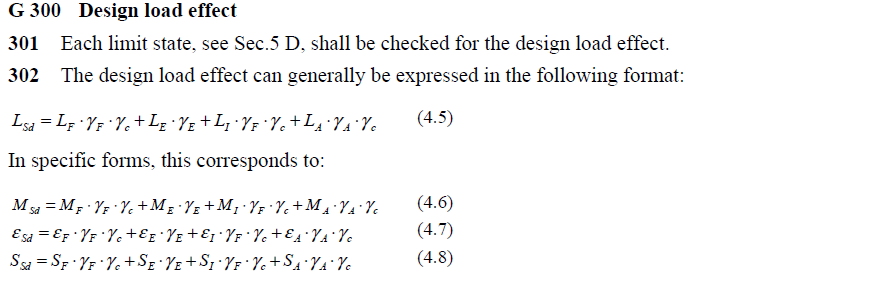
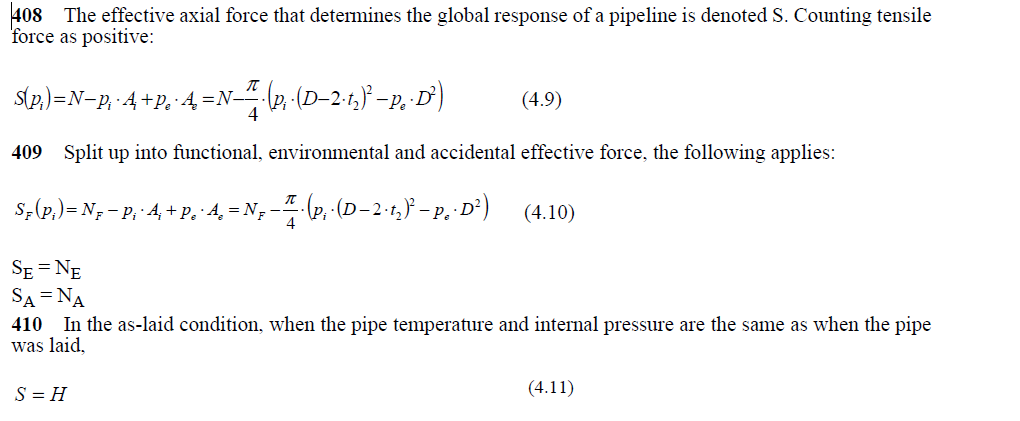


Figure 8‑2 Determination of characteristic environmental load





# DNV-OS-F201 (Dynamic risers)

### Design Load Effects

Design load effects are obtained by multiplying the load effect of each category by their corresponding load effect factor. Specific examples are given below for bending moment and effective tension.

Design bending moment for functional and environmental induced load effects:

Where:

MF = Bending moment from functional loads

ME = Bending moment from environmental loads

MA = Bending moment from accidental loads

Design effective tension for functional and environmental induced load effects:

Where

TeF = Effective tension from functional loads

TeE = Effective tension from environmental loads

TeA = Effective tension from accidental loads

The effective tension, Te is given by

Where

Tw = True wall tension (i.e. axial stress resultant found by integrating axial stress over the

cross-section)

pi = Internal (local) pressure

pe = External (local) pressure

Ai = Internal cross-sectional area

Ae = External cross-sectional area

# Input Data Specification

### Overview

The input data required for the program is given below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | **Units** | Internal Pressure | |
| **Geometry** |  |  |  |  |
| pipeNominalOD |  | m | 0.24765 | 0.24765 |
| pipeNominalWT |  | m | 0.034925 | 0.034925 |
| pipeMinimumWT |  | m | 0.034925 | 0.034925 |
| pipeNominalID |  |  | 0.1778 | 0.1778 |
|  |  |  |  |  |
| **Material Properties** |  |  |  |  |
| Yield Strength |  | ksi | 80 |  |
|  |  | Pa | 5.52E+08 |  |
|  |  |  |  |  |
| pipeA |  | m^2 | 0.023340213 |  |
| pipeAi | Ai | m^2 | 0.024828666 |  |
| pipeAo | Ao | m^2 | 0.04816888 |  |
| pipeI | I | m^4 | 0.000135582 |  |
|  |  |  |  |  |
| **Loading** |  |  |  |  |
| pipeExternalPressure | Po |  | 0 |  |
| pipeInternalPressure | Pi | ksi | 0 |  |
| pipeTensionEffective |  | N | 0 |  |
| pipeMoment |  | Nm | -4.60E+05 |  |
|  |  |  |  |  |
| PipeTrueTension |  |  | pipeTensionEffective + (pipeInternalPressure\*pipeAi) - (pipeExternalPressure\*pipeAo) |  |
| T |  |  | Pi\*Ai |  |

### Design Matrix for Rigid Risers

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Case | Load Category | Environmental Condition | Pressure | Reduced ensioner  Capacity or One Mooring Line Broken | C a,b f |
| 1 | Operating | Maximum operating | Design | No | 1.0 |
| 2 | Extreme | Extreme | Design | No | 1.2 |
| 3 | Extreme | Maximum operating | Extreme | No | 1.2 |
| 4 | Extreme | Maximum operating | Design | Yes | 1.2 |
| 5 | Temporary | Temporary | Associated | No | 1.2 |
| 6 | Testd | Maximum operating | Testd | No | 1.35 |
| 7 | Survival | Survival | Associated | No | 1.5 |
| 8 | Survival | Extreme | Associated | Yes | 1.5 |
| 9 | Fatigue | Fatigue | Operating | No | Notec |

# References.

1. API RP 2RD 1st Ed with errata (2009) Design of Risers for FPSs and TLPs (June 2009)
2. Dropbox\0119 Programming\001 VMStress2RD\Ref
3. API STD 2RD 2nd Ed (2013) Dynamic Risers for Floating Production Systems
4. API RP 1111 4th Ed (2009) Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)
5. ASME B31.8 (2007) Gas Transportation and Distribution Piping Systems
6. DNV OS F201 (2001) Dynamic Risers
7. DNV OS F201 (2010) Dynamic Risers

– PROGRAM HISTORY

TBA

|  |  |  |
| --- | --- | --- |
| Revision Date | Features |  |
|  |  |  |

Table 4‑1.Program History

- ERROR LOG

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Table 4‑2.Error Log.

Calculation Errors

The typical errors encountered while running the calculation program are given in this section.

-test cases.

The program got to handle discontinuities as shown in figure below.

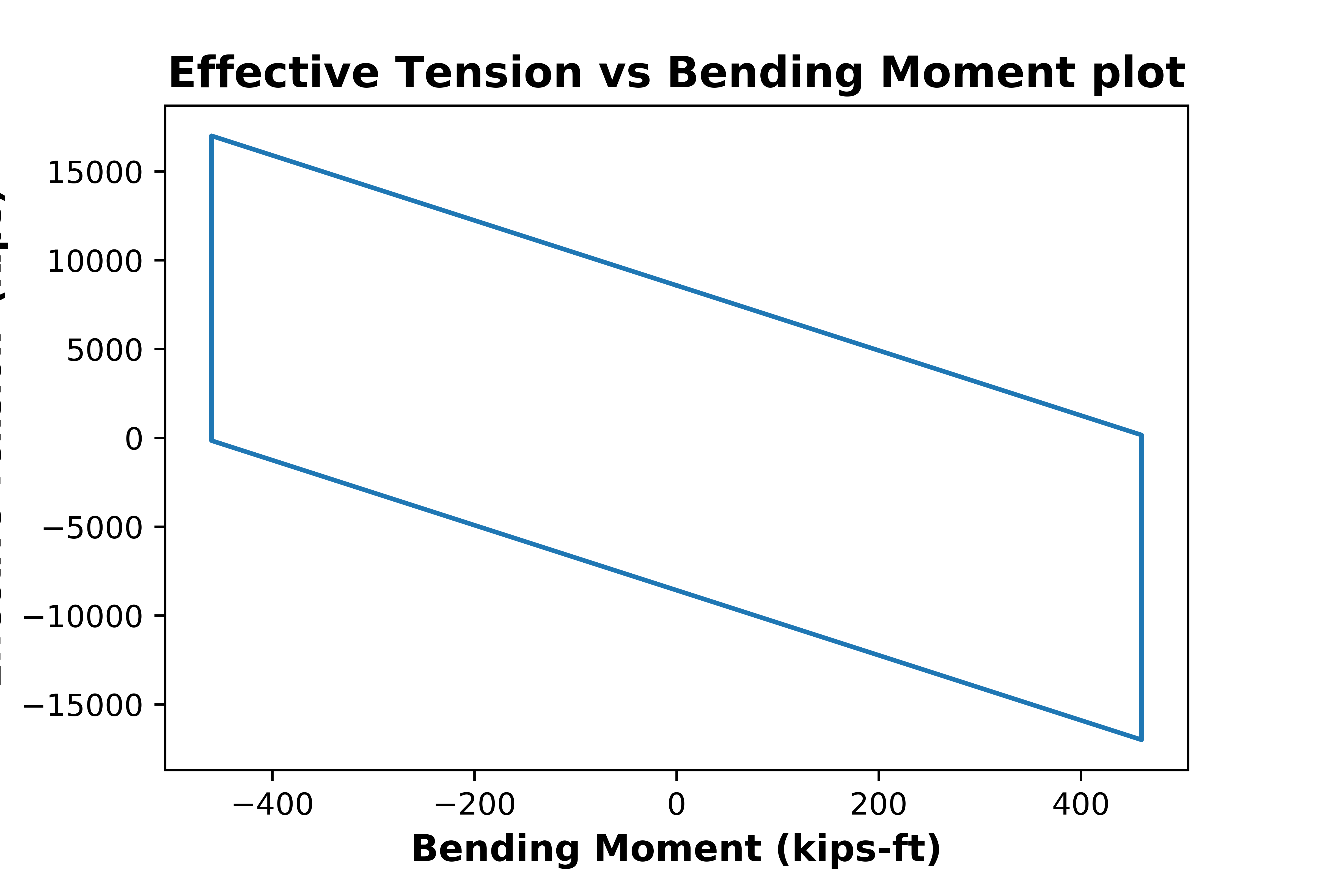


Table 5.Test Cases.