

SESAM

USER MANUAL

PET

Pipeline engineering tool

DET NORSKE VERITAS

SESAM
User Manual

PET

Pipeline engineering tool

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Valid from program version 3.1
Developed by Pipeline Technology

Developed and marketed by
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DNV Software Report

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Published by:
Det Norske Veritas
Veritasveien 1
N-1322 Høvik
Norway

Telephone: +47 67 57 99 00
Facsimile: +47 67 57 72 72
E-mail, sales: software.sesam@dnv.com
E-mail, support: software.support@dnv.com
Website: www.dnvsoftware.com

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1 INTRODUCTION

1.1 General

PET (pipeline engineering tool) is a program to support early phase pipeline design. The following calculation modules are included:

- DNV-OS-F101 design checks.
- Weight and volume.
- Expansion.
- Upheaval buckling.
- Stability.
- Free span.
- Reel straining.
- Reel packing.
- J-lay.
- S-lay.
- Cathodic protection design.

This user manual also contains descriptions of the calculations performed by the program and one verification example per module. It is assumed that the user is able to assess the validity range and accuracy of the calculations. It should be emphasised that several of the calculation modules are based on simplified calculations and/or models and should not be used for detailed design.

1.2 Acronyms frequently used in the manual

DNV	Det Norske Veritas
PET	Pipeline engineering tool

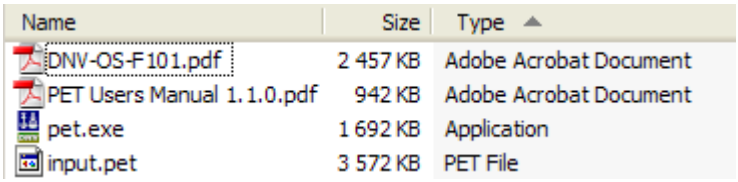
1.3 Status list

Updated status lists are available through the SESAM download system. The PET status list can be accessed from the DNV Software home page: http://www.dnv.com/software.

2 GETTING STARTED

2.1 Program start

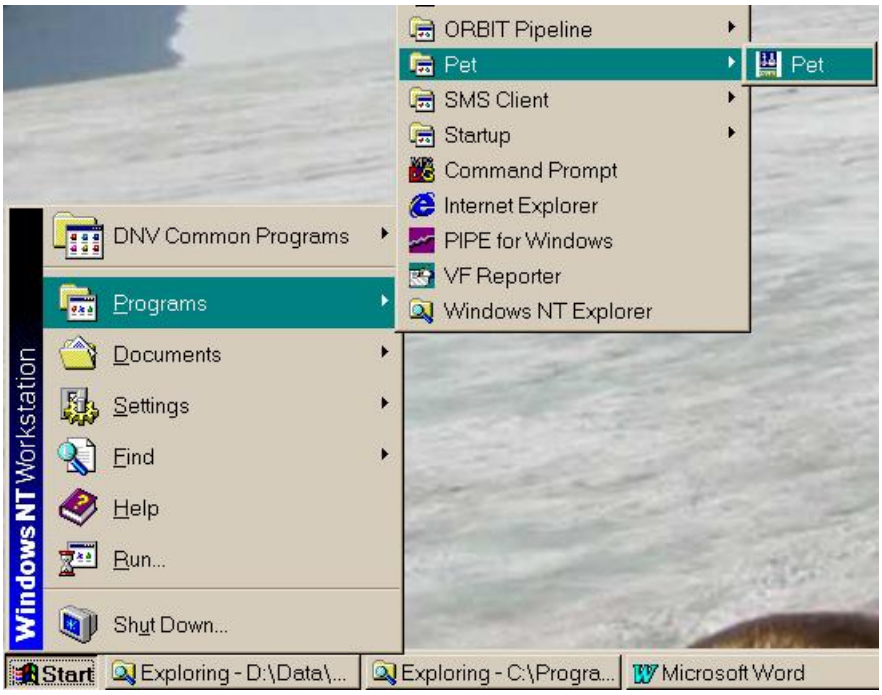
The setup procedure has copied four files onto the PC under the directory specified in the setup (here `C:\Program Files\PET`):



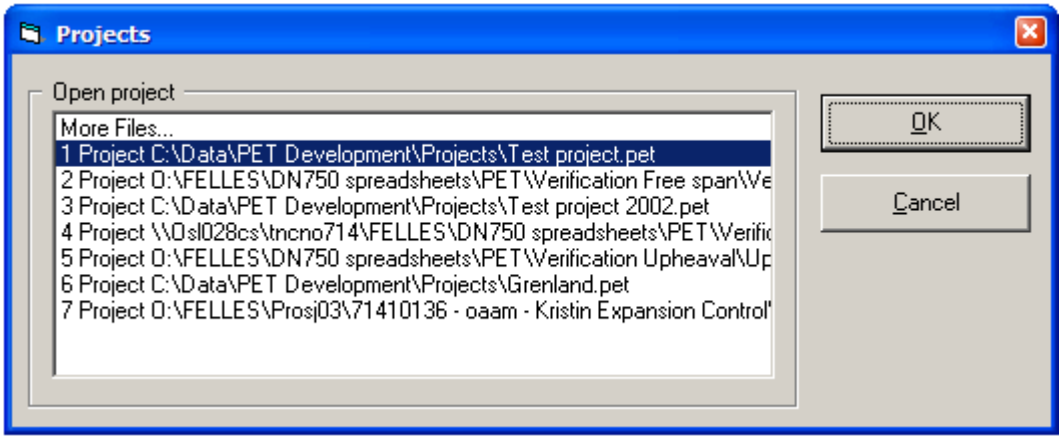
`Input.pet`:	An input file (with pipeline data) following the installation.
`pet.exe`:	The actual executable program.
`OS-F101.pdf`	DNV-OS-F101 on electronic format.
`Users Manual.pdf`	PET's User's Manual on electronic format.

The `Input.pet` file is a project specific file containing data for one particular pipeline. Hence, this file may be moved to a project folder.

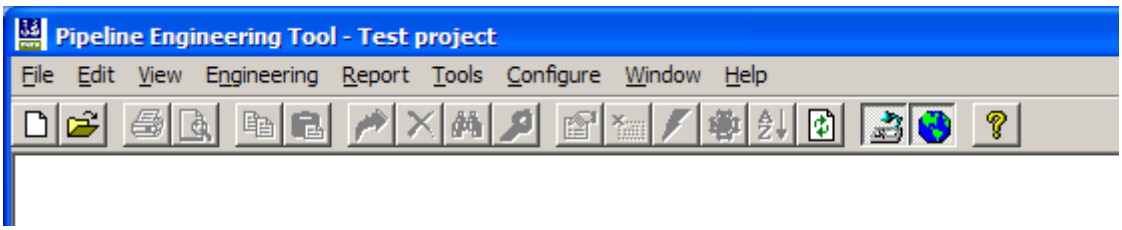
The program may now be executed by double clicking on the `pet.exe` file above, or via the short cut in the menu as specified during installation:



The window below will appear:

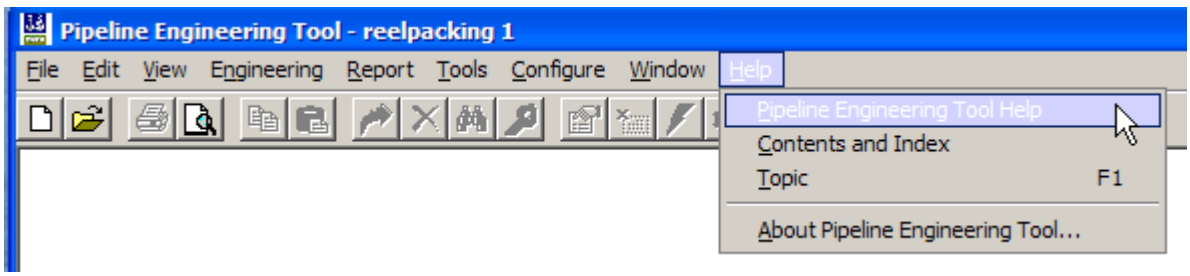


Normally, one will open an existing project file as the program suggests above by highlighting the file `Test project.pet` that was the last edited input file for this particular program version. After clicking OK the main window for PET appears:



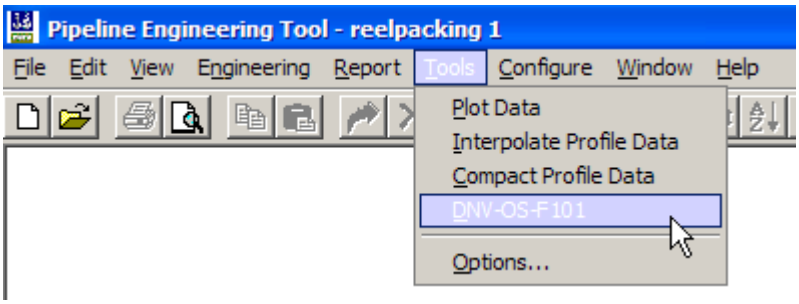
2.2 User manual

The PET user manual is located under: >Help >Pipeline Engineering Tool Help > PET Users Manual 3.1.pdf:



2.3 DNV-OS-F101

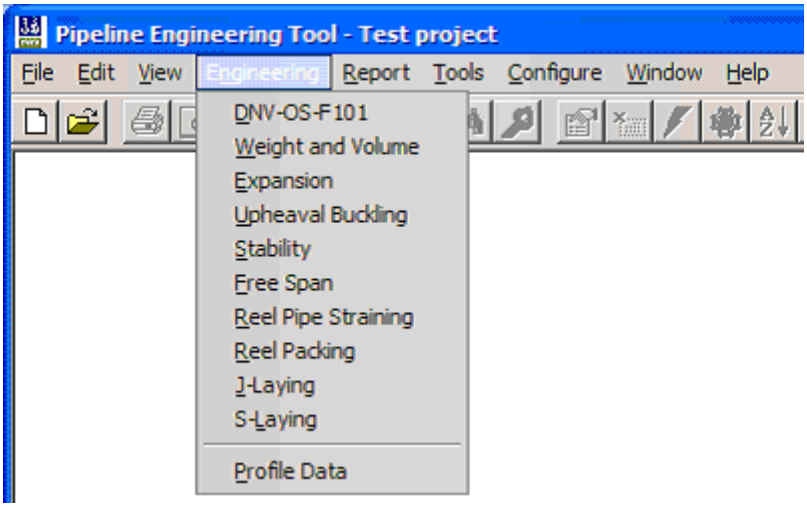
The offshore standard, DNV-OS-F101, is located under: >Tools > DNV-OS-F101:



3 CALCULATION FORMS

3.1 General

Under the main menu Engineering ten calculation modules are made available:



The following general rules apply:

- Calculations are updated when a cell loses focus (i.e., cursor is moved from an input cell).
- Yellow text boxes are user input to the calculations.
- Input values are checked and response is given in the lower right field on the window. If a warning is given, the calculations are performed, on error the calculations are terminated.
- When an input cell gets focus, some information for this input parameter is given in the lower left field on the window.
- Bold fonts indicate that this is a parameter that is calculated by the program and is locked for editing.
- SI system assumed in formulae below, units are given on module windows.

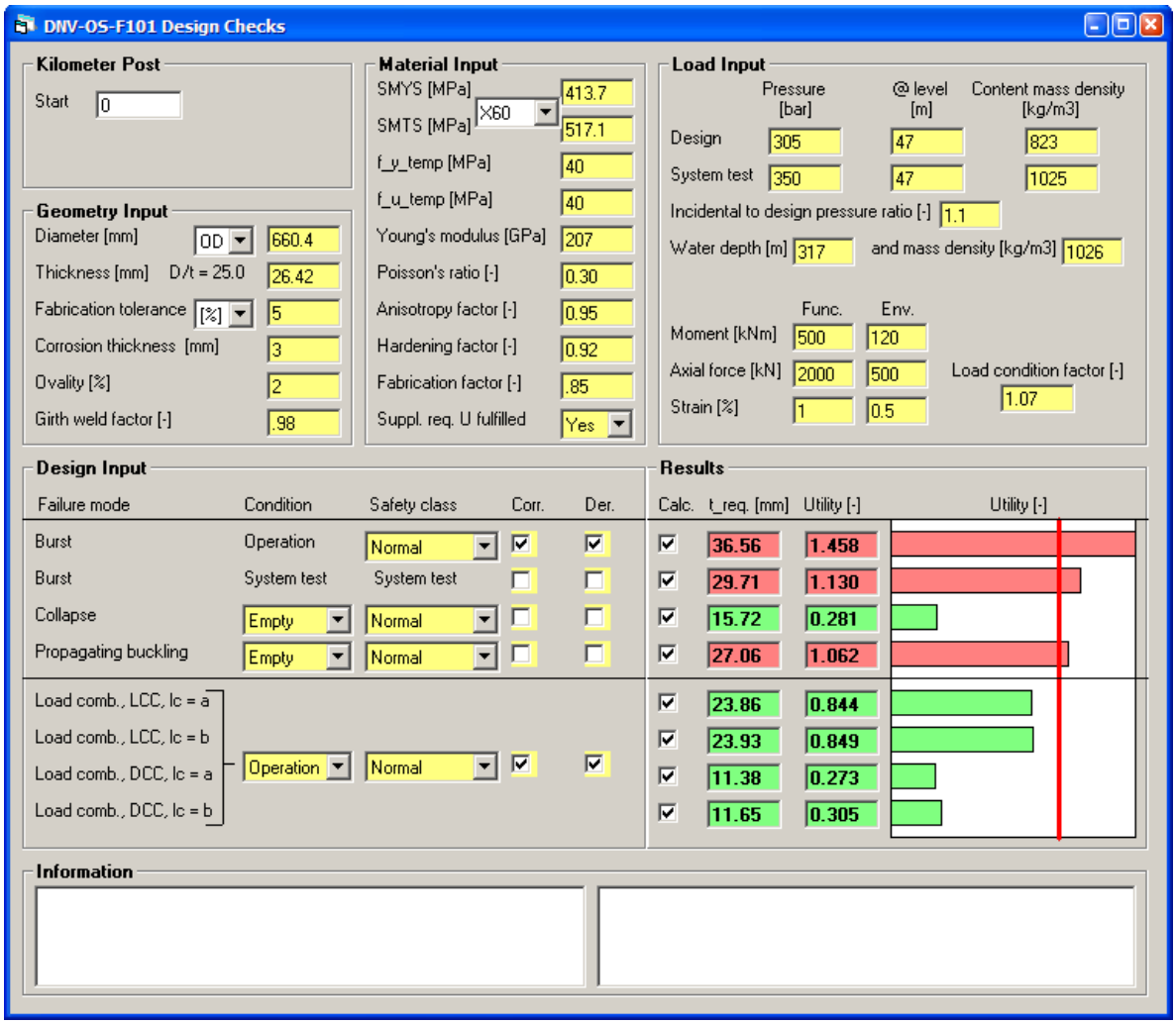
Definition of parameters

D	Steel pipe outer diameter.
t	Steel wall nominal thickness.
D_{po}	Overall outer diameter of pipe including all coating layers.
A_s	Steel area = $\frac{\pi}{4}\left(D^2 - (D - 2 \cdot t)^2\right)$
I	Steel second order moment of inertia = $\frac{\pi}{64}\left(D^4 - (D - 2 \cdot t)^4\right)$
$SMYS$	Specified minimum yield stress.
$SMTS$	Specified minimum tensile strength.
E	Young's modulus.
ν	Poisson's ratio.
α	Coefficient of thermal expansion.
w_s	Pipe submerged weight including all coating layers, additional submerged weight and weight of content where appropriate.
S_{eff}	Total effective compressive force = $H + S_T + S_\nu + S_{pA}$.
H	Lay tension (negative as tension).
S_T	Axial force component due to temperature elevation = $\alpha \cdot \Delta T \cdot E \cdot A_s$
S_{pA}	Axial force component due to the end cap effect = $\Delta p_i \cdot \frac{\pi \cdot (D - 2 \cdot t)^2}{4}$
S_ν	Axial force component due to the Poisson's effect = $\Delta p_i \cdot \frac{D - 2 \cdot t}{2 \cdot t} \cdot \nu \cdot A_s$
ΔT	Temperature elevation from installation condition to relevant condition for calculations, typically design condition or system pressure test condition.
Δp_i	Internal pressure elevation from installation condition to relevant condition for calculations, typically design condition or system pressure test condition.

3.2 DNV-OS-F101 Design Checks

3.2.1 Introduction

The window for performing design checks according to DNV-OS-F101, Ref. /1/ is opened by clicking on the main menu as shown above. The following window appears:



This module performs design checks according to the following four limit states (failure modes):

- Burst, during operation (design conditions) and during the system pressure test.
- Collapse.
- Propagating buckling.
- Load combination, load controlled and displacement controlled, load combinations *a* and *b*.

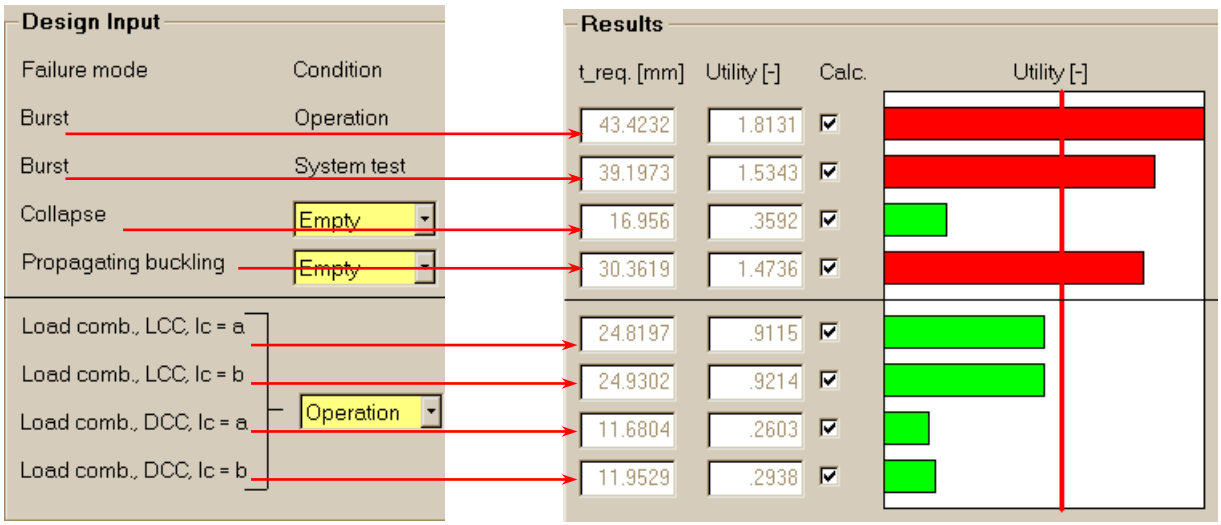
3.2.2 Input

Input to this module is explained in DNV's *Offshore Standard DNV-OS-F101 Submarine Pipeline Systems*, Ref. /1/.

3.2.3 Results

Minimum required wall thickness and utilisation are given for eight set of design checks:

1. Burst during operation.
2. Burst during system pressure test.
3. Collapse.
4. Propagation buckling.
5. Load combination, load controlled (LCC), load combination *a*.
6. Load combination, load controlled (LCC), load combination *b*.
7. Load combination, displacement controlled (DCC), load combination *a*.
8. Load combination, displacement controlled (DCC), load combination *b*.



Burst (pressure containment) is calculated according to Eq. (5.14) in Ref. /1/ and the utilisation ratio is defined as:

$$\gamma_m \gamma_{SC} \frac{p_{li} - p_e}{p_b} \qquad \textbf{(3.1)}$$

Collapse is calculated according to Eq. (5.22) in Ref. /1/ and the utilisation ratio is defined as:

$$\gamma_m \gamma_{SC} \frac{p_e}{p_c} 1.1 \qquad \textbf{(3.2)}$$

Propagating buckling is calculated according to Eq. (5.27) in Ref. /1/ and the utilisation ratio is defined as:

$$\gamma_m \gamma_{SC} \frac{p_e (D/t)^{2.5}}{35 f_y \alpha_{\text{fab}}} \tag{3.3}$$

Load controlled load combination is calculated according to Eqs. (5.23) and (5.24) in Ref. /1/ and the utilisation ratio is defined as:

$$\begin{cases} \gamma_{SC}\gamma_m \left(\frac{S_d}{\alpha_c S_p}\right)^2 + \gamma_{SC}\gamma_m \left(\frac{M_d}{\alpha_c M_p}\sqrt{1-\left(\frac{\Delta p_d}{\alpha_c p_b(t_2)}\right)^2}\right) + \left(\frac{\Delta p_d}{\alpha_c p_b(t_2)}\right)^2 & p_i \geq p_e \\ \left(\gamma_{SC}\gamma_m \left(\frac{M_d}{\alpha_c M_p}\right) + \gamma_{SC}\gamma_m \left(\frac{S_d}{\alpha_c S_p}\right)^2\right)^2 + \left(\gamma_{SC}\gamma_m \frac{p_e}{p_c}\right)^2 & p_i < p_e \end{cases} \tag{3.4}$$

Displacement controlled load combination is calculated according to Eqs. (5.25) and (5.26) in Ref. /1/ and the utilisation ratio is defined as:

$$\begin{cases} \gamma_\varepsilon \frac{\varepsilon_d}{\varepsilon_c} & p_i \geq p_e \\ \left(\gamma_\varepsilon \frac{\varepsilon_d}{\varepsilon_c}\right)^{0.8} + \gamma_{SC}\gamma_m \frac{p_e}{p_c} & p_i < p_e \end{cases} \tag{3.5}$$

Reference is made to Table 5-6 in Ref. /1/ for interpretation of load combinations *a* and *b*.

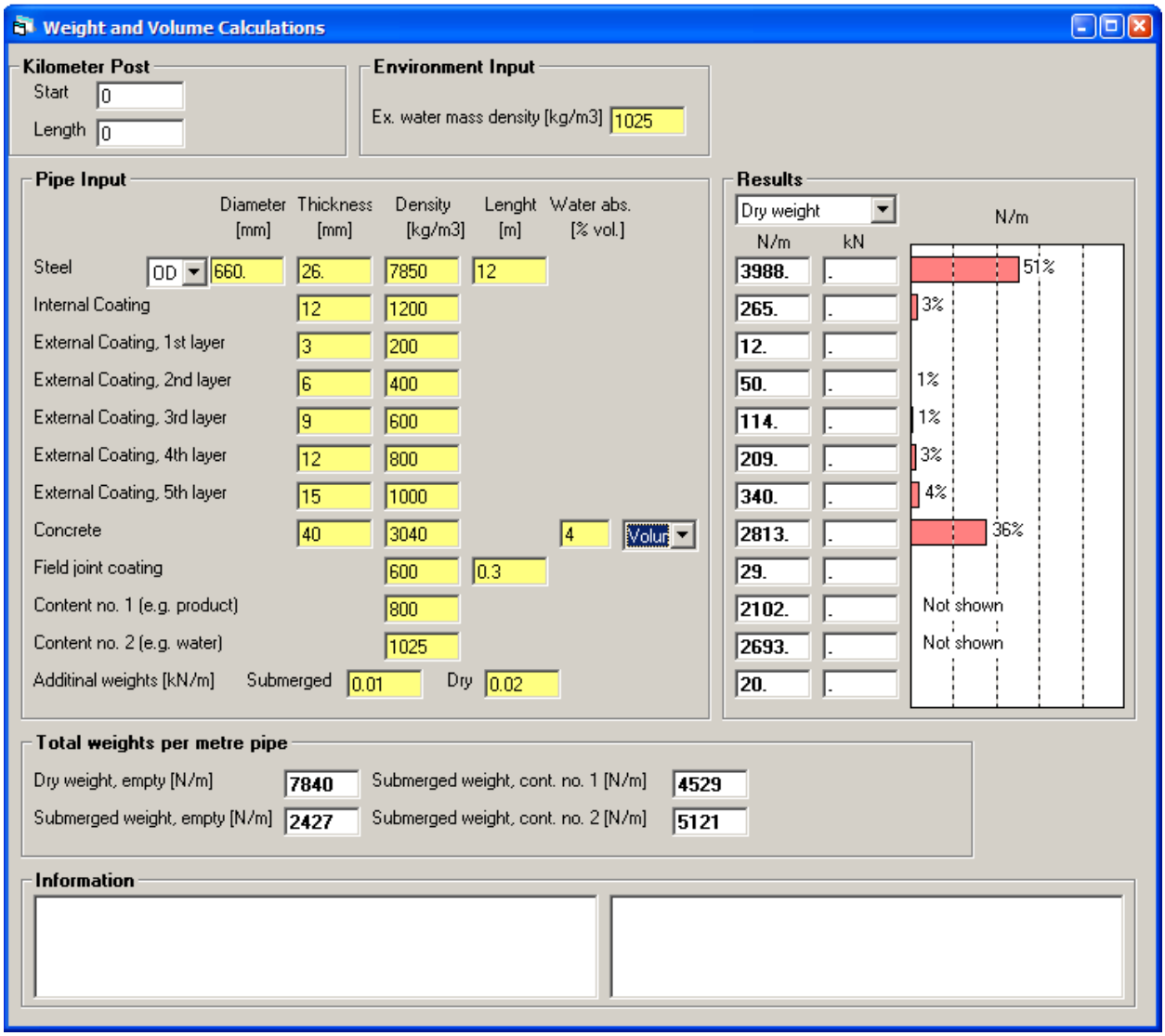
Utilisation is also presented graphically in a lateral column diagram. The vertical red line represents unity, whereas the eight lateral columns present the proportional utilisation for each design check. The columns appear in a green colour if the utilisation ratio is less than or equal to one, i.e. the design check is passed, and in a red colour if utilisation is greater than one, i.e., the design check is violated.

Note that the user can check off the design checks that one will apply (to the left of the graphical presentation). Input boxes that are required for the design checks will appear with a yellow colour.

3.3 Weight and Volume

3.3.1 Introduction

The main purpose of this module is to calculate the volume, mass and dry weight of the components that constitute a pipeline, i.e., steel, coating layers and content. Volume, mass and dry weight are calculated individually and totally, per metre pipeline and totally for a given length of the pipeline.



3.3.2 Input

The size of the pipe is determined by the steel diameter. Input is typically the volume (per metre) of each layer, inner coating, steel, outer coating, concrete coating and additional weights, e.g., anodes.

Water absorption can be given in per cent concrete volume or concrete weight.

The joint length and cut back length are given in order to determine the relative volume of concrete coating and field joint coating.

Mass density is given in order to calculate buoyancy.

3.3.3 Results

The volume of each layer is calculated per metre as:

$$V_i = \frac{\pi}{4}\left(D_{o,i}^2 - D_{i,i}^2\right)\cdot L_i \qquad \textbf{(3.6)}$$

where $D_{o,i}$ and $D_{i,i}$ are the outer and inner diameter of layer no. i and L_i is the length of the layer. The sequence of the layers from the inside and outward is:

1. Internal coating.
2. Steel.
3. External coating no. 1.
4. External coating no. 2.
5. External coating no. 3.
6. External coating no. 4.
7. External coating no. 5.
8. Concrete and filed joint coating.

L_i is only different from unity for the concrete and field coating. The volumes of these layers are smeared over the unit length according to their partial lengths over one pipe joint length. If the pipe joint length is denoted L_{jt} and the cut back length is denoted L_{cb}, then

$$L_{concrete} = \frac{L_{jt} - 2\cdot L_{cb}}{L_{jt}} \text{ and } L_{fieldcoat} = \frac{2\cdot L_{cb}}{L_{jt}} \qquad \textbf{(3.7)}$$

The mass and weight of each layer is calculated per metre as:

$$m_i = \rho_i \cdot V_i \qquad \textbf{(3.8)}$$

where ρ_i is the mass density of layer no. i.

$$w_i = g \cdot m_i \qquad \textbf{(3.9)}$$

where g is the acceleration of gravity (= 9.81m/s^2).
The volume of the content is calculated according to (3.6) with an inner diameter equal to zero.
Buoyancy per metre pipe is calculated according to the following formula:

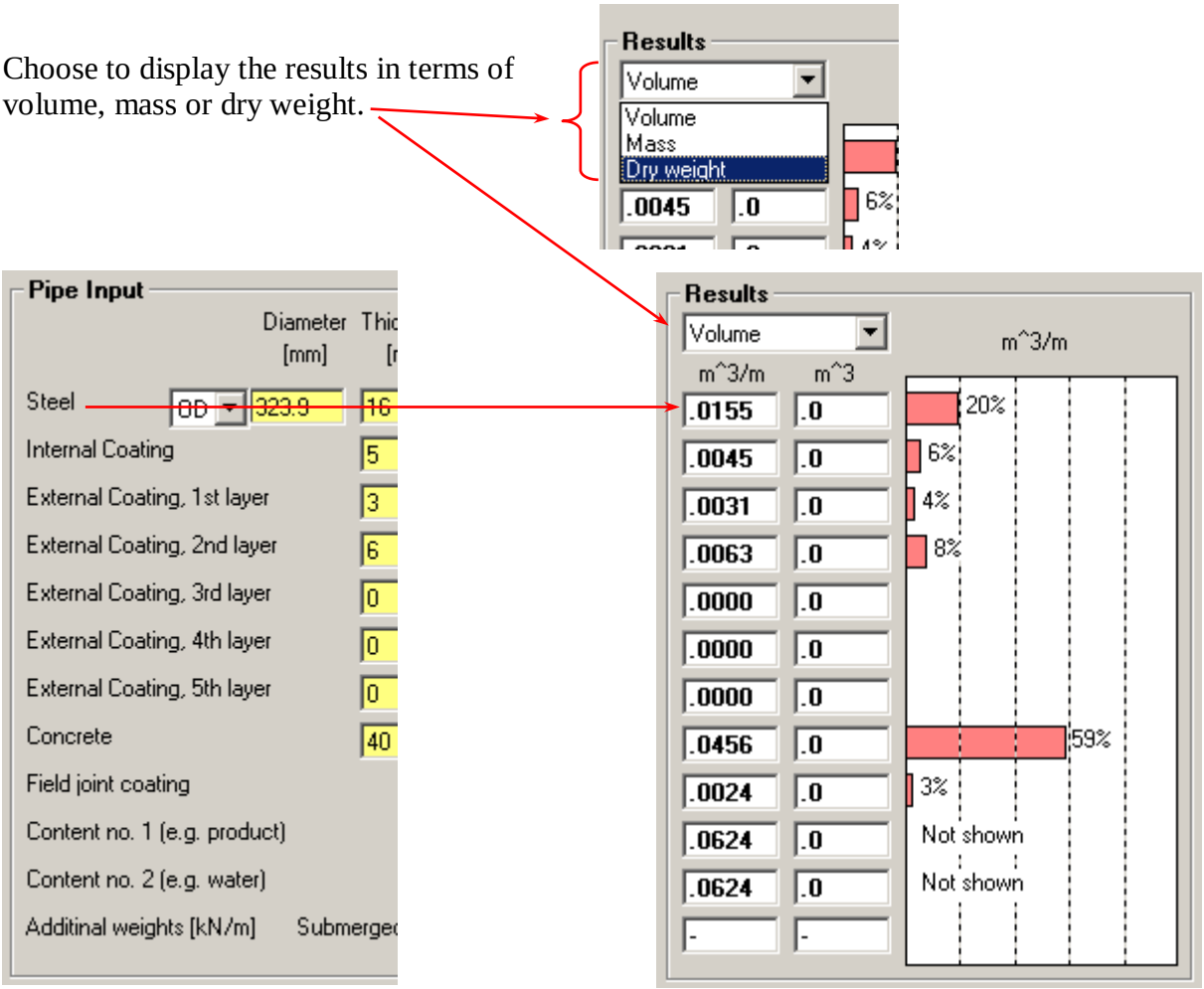
$$w_b = g \cdot \rho_w \cdot \frac{\pi}{4} \cdot D_o^2 \qquad \textbf{(3.10)}$$

where ρ_w is the mass density of water and D_o is the outer diameter of the outer-most layer defined.

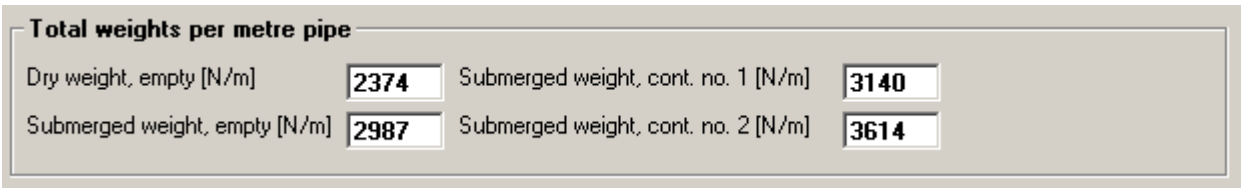
The results are given individually for each pipe component, including steel, all coating layers, two defined contents and additional weights, by following a horizontal line from the input frame at the left to the result frame at the right, see figure below. The results can be given as volume, mass or weight depending on the choice in the combo box above the results. One column gives the result per metre pipeline and one column gives the results for the whole pipeline profile.

The results per metre pipeline are also displayed graphically to the very right.

Choose to display the results in terms of volume, mass or dry weight.



At the lower part of the window, some additional results are given:



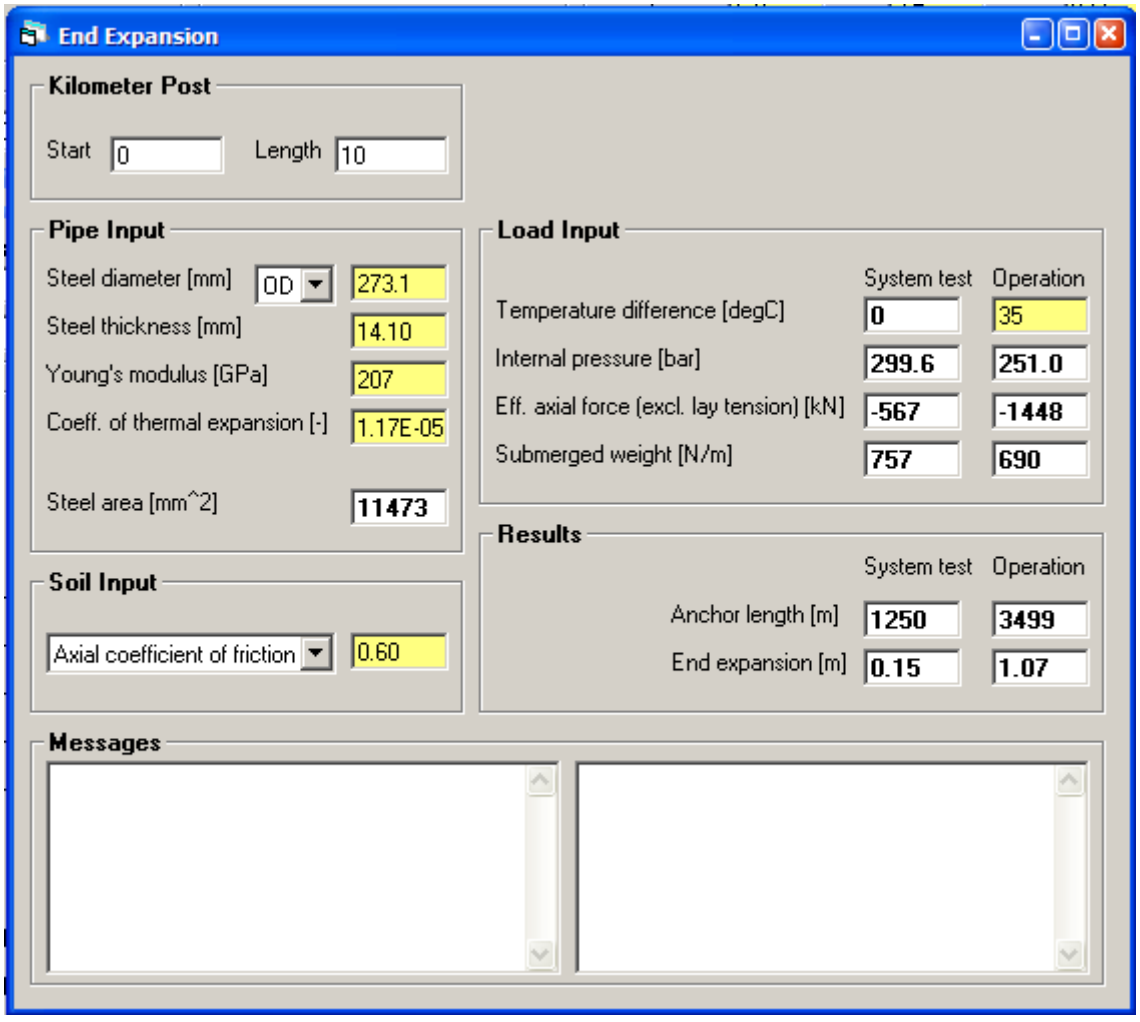
The following notes apply:

- Absorbed water in concrete is not included in the mass and dry weight results.
- The field coating length is measured from the end of the concrete coating to the weld, i.e. the total field coating length on one pipe joint is twice the given length.
- Additional dry weight is not included in submerged weight results.
- Additional submerged weight is not included in mass and dry weight results.
- Volume is not calculated for additional weights.

3.4 Expansion

3.4.1 Introduction

The purpose of this module is to calculate the end expansion due to temperature and internal pressure. The anchor length is also calculated. These two results are presented for the system pressure condition and the design condition.



3.4.2 Input

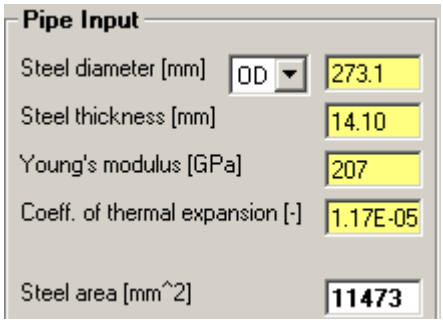
The input is as follows:

Pipe length



L_p Pipe length.in km.

Steel cross section



D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.

t Steel wall thickness.

A_s Steel area = $\pi \cdot (D^2 - (D - t)^2)/4$ is calculated, not specified by user.

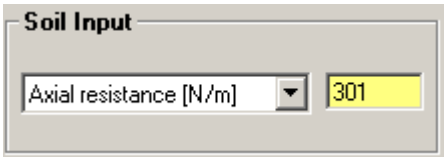
E Young's modulus.

α Coefficient of thermal expansion.

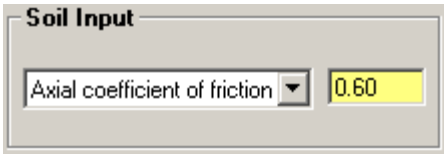
μ Axial coefficient of friction.

ΔT_d Temperature difference between installation condition and design condition.

Soil parameters



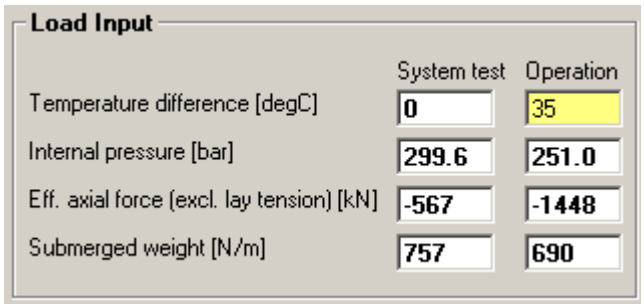
f_a Axial resistance.



μ Axial coefficient of friction.

The soil parameter input can be chosen as either axial resistance or axial friction coefficient. In the latter case, the resistance is calculated as $f_a = \mu \cdot w_s$.

Load input



ΔT Temperature difference

Δp_i Steel wall thickness.

S_{eff} Effective axial force

w_s Submerged weight

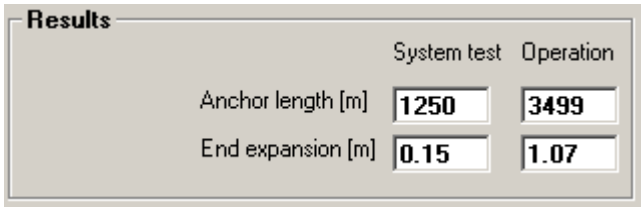
Effective axial force and submerged weight enters the equation for anchor length and end expansion.

Reference is made to the Weight and Volume module regarding calculation of submerged weight w_s and the input parameters for this calculation.

Parameters that determine internal pressure difference Δp_i and hence the associated components in the effective axial force, (reference pressure, content mass density, depth etc.) are given on the DNV-OS-F101 Design Check Module.

3.4.3 Results

The results produced by this module:



L_a Anchor length

δ_e End expansion

The anchor length L_a and end expansion δ_e are calculated according to the following formulae, note that the anchor length does not exceed half the given pipeline length:

$$L_a = \frac{S_{eff}}{f_a} \leq \frac{L_p}{2} \qquad \textbf{(3.11)}$$

and

$$\delta_e = \frac{1}{2} \cdot \frac{S_{eff} \cdot L_a}{E \cdot A_s} \qquad \textbf{(3.12)}$$

where the contributing effective axial force is

$$S_{eff} = E \cdot A_s \cdot \alpha \cdot \Delta T + (1 - 2 \cdot \nu) \cdot A_i \cdot \Delta p_i \qquad \textbf{(3.13)}$$

Note that the temperature ΔT and the internal pressure Δp_i are both assumed to be elevations compared to the installation condition.

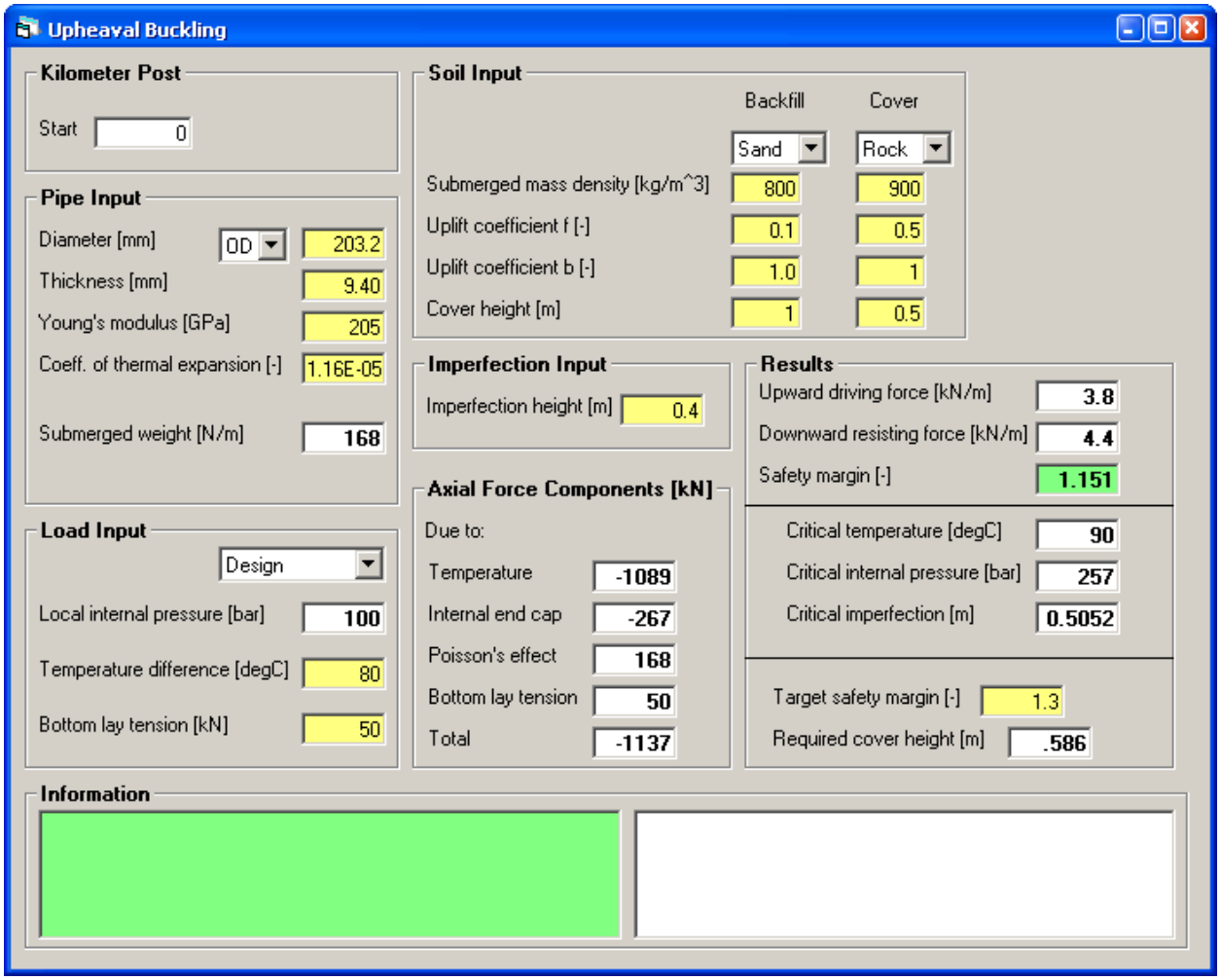
D is in the equation above the *outer* steel wall diameter irrespective of which diameter is specified by the user.

3.5 Upheaval Buckling

3.5.1 Introduction

The purpose of this module is to:

- estimate the safety level with respect to upheaval buckling for the given set of input,
- predict the temperature, internal pressure and imperfection height that will trigger upheaval buckling and
- estimate the cover height to prevent upheaval buckling for a given safety level.



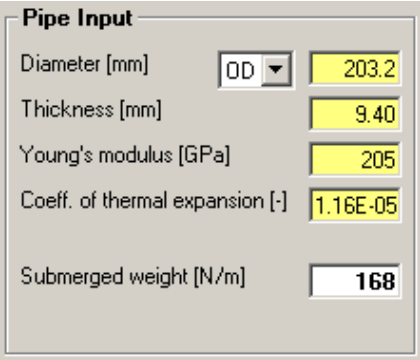
The model used here is a modification of that described in Ref. /4/.

Warning: The user is warned that this simplified method is semi-empirical, and that on its own will normally not be adequate for design. It has been calibrated against more refined models, but does not always yield conservative results, especially if there is a possibility of plastic deformation of the pipe wall.

3.5.2 Input

The input parameters are separated in five groups:

1: Input related to the steel cross section:



D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.

t Steel wall thickness.

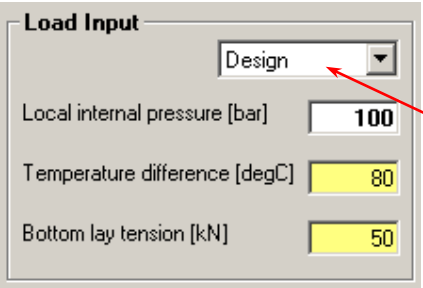
E Young's modulus.

ν Poisson's ratio.

α Coefficient of thermal expansion.

w_s Submerged weight which is calculated, not specified by the user. Reference is made to the Weight and Volume Module.

2: Input related to loads contributing to the effective axial compression:



Δp_i Local internal pressure which is calculated, not specified by the user. Editing is done on the DNV-OS-F101 Design Check Module.

Note that depending on the specification of the condition in the combo box, internal pressure is taken from the design condition or the system pressure test condition.

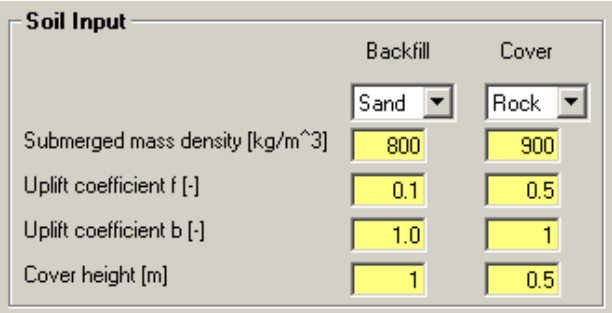
Δp_e Local external pressure which is calculated as $\rho_w \cdot g \cdot d$, not specified by the user. Editing is done on the DNV-OS-F101 Design Check Module.

ΔT Temperature elevation relative to the installation condition.

H Lay tension.

3: Input related to soil cover:

Typical input values are inserted by the program depending on the user's selection on the two combo boxes. In the following the sub scripts "*bf*" and "*c*" are used to denote back fill and cover, respectively.



ρ_{bf} and ρ_c The soils' submerged mass density

f_{bf} and f_c Uplift coefficient.

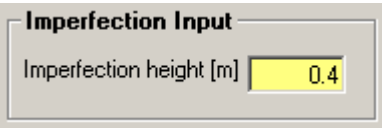
b_{bf} and b_c Uplift coefficient.

h_{bf} and h_c Cover height.

The following values are recommended for the uplift coefficients:

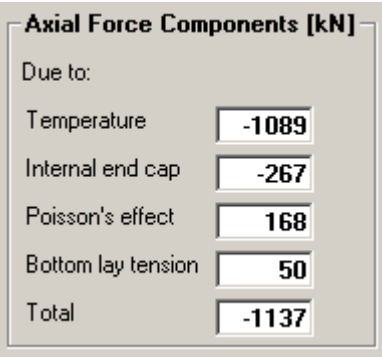
Cover type	*f*	*b*
Rock	0.5	1.0
Sand and silt	0.1	1.0
Clay	0.0	1.5

4: Input related to imperfection:



δ_{imp} Imperfection height.

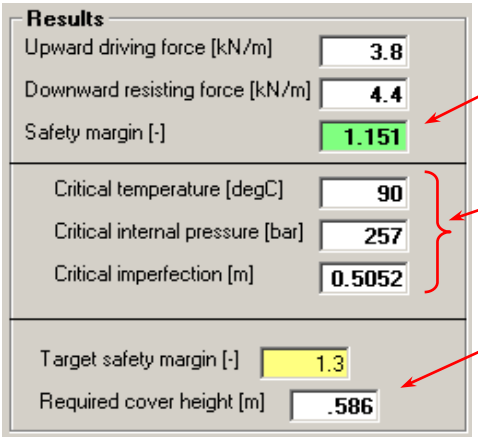
5: Effective compressive axial force, individual components and the total:



These are intermediate parameters for estimating the safety level with respect to upheaval buckling. All are calculated automatically by the program, and not specified by the user.

3.5.3 Results

The results produced by this module are:



Safety margin with respect to upheaval buckling for the given set of input.

The temperature, internal pressure and imperfection height that will trigger upheaval buckling.

Required cover height to prevent upheaval buckling for a given safety level (the target safety margin is user input).

The safety margin with respect to upheaval buckling is defined as:

$$SM_{uh-b} = \frac{W_{d-r}}{W_{u-l}} \tag{3.14}$$

where the downward resistance W_{d-r} and the uplifting driving load W_{u-l} are defined as follows:

$$W_{d-r} = (h_{bf} \cdot \rho_{bf} \cdot b_{bf} + h_c \cdot \rho_c \cdot b_c) \cdot D_o \cdot g + \left(h_{bf}^2 \cdot \rho_{bf} \cdot f_{bf} + h_c^2 \cdot \rho_{bf} \cdot f_c\right) \cdot g \tag{3.15}$$

and

$$W_{u-l} = 1.16 \cdot S_{eff} \cdot \sqrt{\frac{\delta_{imp} \cdot w_s}{EI}} - 4.76 \cdot w_s \tag{3.16}$$

See Eq. (3.13) for calculation of effective axial force S_{eff}.

Note that the uplifting load may be negative and thus give a negative safety margin.

Note also that that if the backfill *and* cover is specified with certain properties, this will lead to a somewhat lower safety margin compared to the case where backfill *or* cover is specified with the same properties and the same total height. This is due to the non-linear relation between h_i and resistance and the fact that $h_{bf}^2 + h_c^2 \le \left(h_{bf} + h_c\right)^2$

Critical temperature is the temperature that initiates upheaval buckling for the given set of input (including the given internal pressure and imperfection height).

Critical internal pressure is the pressure that initiates upheaval buckling for the given set of input (including the given temperature and imperfection height).

Critical imperfection height is the imperfection height that initiates upheaval buckling for the given set of input (including the given temperature and internal pressure).

These three parameters are found by an iterative algorithm. For extreme input data, the program may fail in finding these parameters.

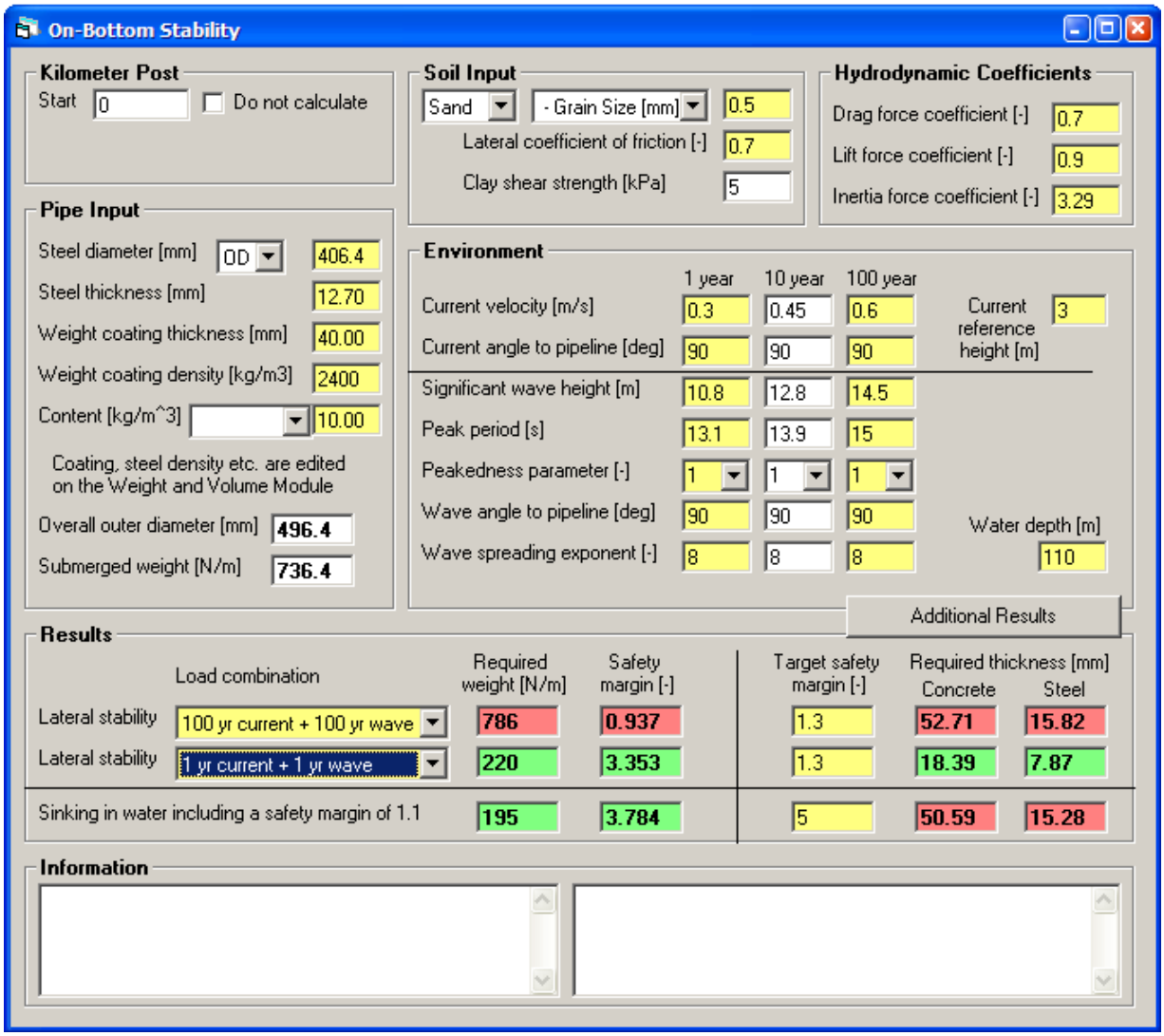
Warning: The user is warned that this simplified method is semi-empirical, and that on its own will normally not be adequate for design. It has been calibrated against more refined models, but does not always yield conservative results, especially if there is a possibility of plastic deformation of the pipe wall.

3.6 Stability

3.6.1 Introduction

This module estimates the:

- safety level with respect to stability for the given set of input,
- weight coating required to ensure stability for a given safety level and
- steel wall thickness required to ensure stability for a given safety level.

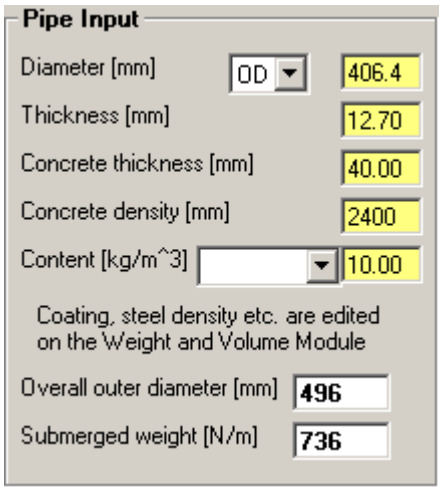


Reference is made to DNV-RP-E305 *On-Bottom Stability Design of Submarine Pipelines*, Ref. /2/.

3.6.2 Input

The input parameters (excluding the choice of load cases) are separated in four groups:

1: Input related to the steel cross section:



D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.

t Steel wall thickness.

t_w Weight coating thickness.

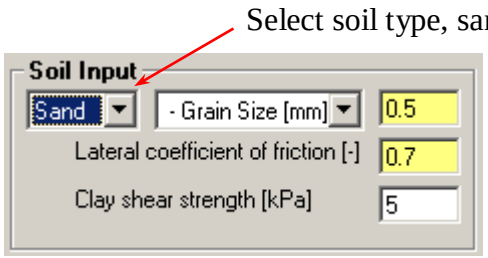
ρ_w Weight coating mass density.

ρ_i Content mass density.

D_{po} Pipe outer diameter including all external coating layers is calculated, not specified by the user. Reference is made to the Weight and Volume Module.

w_s Submerged weight is calculated, not specified by the user. Reference is made to the Weight and Volume Module.

2: Input related to soil:

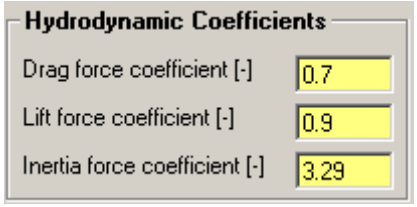


d_{50} Grain size, combo box may be used to select default values as per Ref. /2/. Only relevant for sand.

μ_{lat} Coefficient of lateral friction. Only relevant for sand.

s_u Shear strength, only relevant for clay.

3: Hydrodynamic force coefficients:

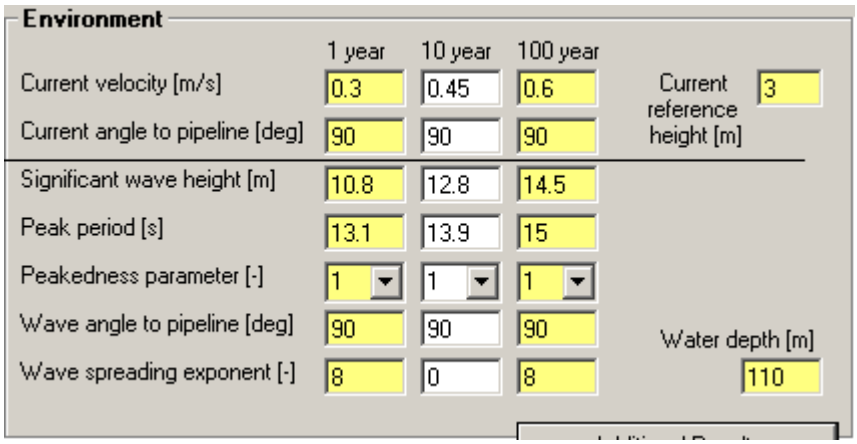


C_D Drag force coefficient.

C_L Lift force coefficient.

C_M Inertia force coefficient.

4: Environmental data:



u_{cr} Extreme current velocity with 1, 10 and 100 years return period,

α_c Associated angles between current directions and pipe.

z_r Reference height above seabed at which current velocities are given.

H_s Extreme values for significant wave height with 1, 10 and 100 years return period,

T_p Associated peak periods.

γ Associated peakedness parameters

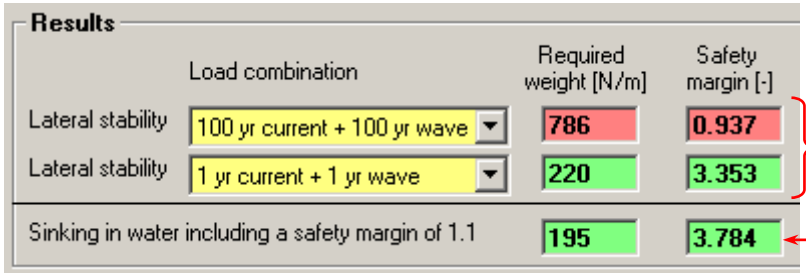
α_w Associated angles between wave directions and pipe.

N Wave spreading exponent.

d Water depth.

3.6.3 Results

The main results produced by this module are the safety margins with respect to lateral stability and sinking in sea water.



lateral stability for two load cases specified by the user

and

the pipe to sink in water.

The safety margin with respect to lateral stability is defined as the ratio between actual submerged weight (see pipe input data) and the required weight calculated by the program:

$$SM_{stb-l} = \frac{w_s}{w_{req-l}} \tag{3.17}$$

The required submerged weight for lateral stability is taken as the maximum value

$$w_{req-l} = \left(\frac{F_D(\theta) + F_I(\theta) + \mu_{lat} \cdot F_L(\theta)}{\mu_{lat}} \right) \cdot F_W \tag{3.18}$$

when the wave phase angle θ runs from zero to 360 degrees.
The hydrodynamic forces are:

$$\begin{aligned} F_D &= \frac{1}{2} \cdot \rho_w \cdot D_{po} \cdot C_D \cdot (u_w \cdot \cos\theta + u_c) | u_w \cdot \cos\theta + u_c | \\ F_L &= \frac{1}{2} \cdot \rho_w \cdot D_{po} \cdot C_L \cdot (u_w \cdot \cos\theta + u_c)^2 \\ F_I &= \frac{\pi \cdot D_{po}}{4} \cdot \rho_w \cdot C_M \cdot a_w \cdot \sin\theta \end{aligned} \tag{3.19}$$

The calibration factor F_W is taken from Figure 5.12 in Ref. /2/
The safety margin with respect to sinking is defined as the ratio between actual submerged weight (see pipe input data) and the required weight calculated by the program, including a safety factor of 1.1:

$$SM_{stb-v} = \frac{w_s}{w_{req-v}} \tag{3.20}$$

The required submerged weight is taken as:

$$w_{req-v} = 0.1 \cdot \frac{\pi \cdot D_{po}^2}{4} \cdot \rho_w \cdot g \tag{3.21}$$

Parameters that influence the water particle velocity are calculated according to Ref. /2/:

U_s and T_u are taken from Figures 2.1 and 2.2, respectively, using approximate formulae and $u_w = R \cdot U_s \cdot \cos\alpha_w$ where R is the reduction factor due to spreading.

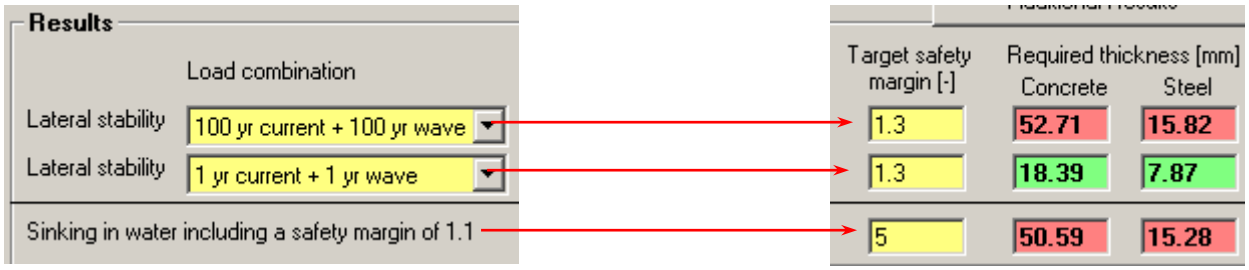
$$\begin{aligned} a_w &= 2\pi \cdot \frac{U_s}{T_u} \\ A_0 &= \frac{U_s \cdot T_p}{2\pi} \\ K_C &= \frac{U_s \cdot T_u}{D_{po}} \end{aligned} \tag{3.22}$$

$$z_0 = \frac{2.5 \cdot d_{50}}{30}$$

z_{0a} is taken from Figures A.1 to A.7 using approximate formulae.

$$u_c = \frac{u_{cr} \cdot \cos\alpha_c}{\ln\left(\frac{z_r}{z_{0a}} + 1\right)} \cdot \left\{\left(1 + \frac{z_{0a}}{D}\right) \cdot \ln\left(\frac{D}{z_{0a}} + 1\right) - 1\right\}$$

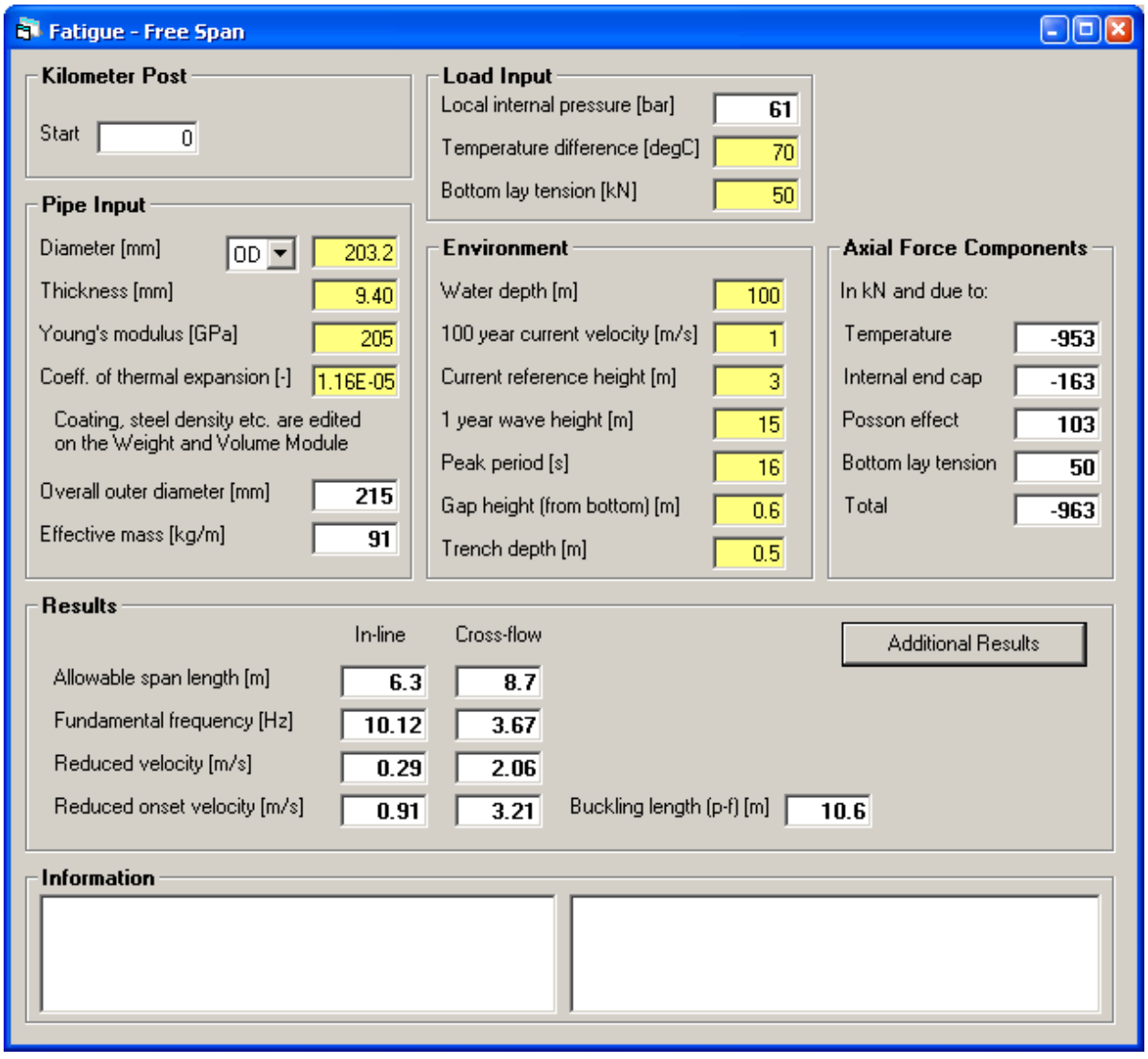
Other results produced by this module are the required concrete thickness (with the specified steel wall thickness) and required steel wall thickness (with no concrete) with respect to lateral stability and vertical sinking. In both cases, the target safety margin is specified by the user.



3.7 Free Span

3.7.1 Introduction

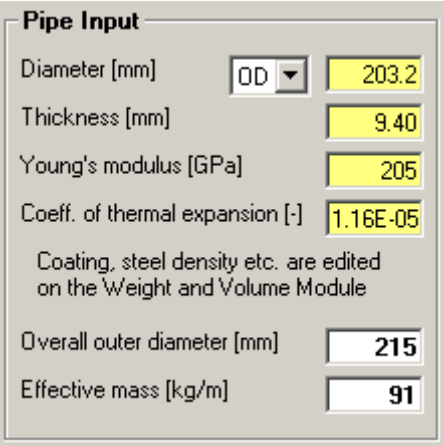
The purpose of this module is to calculate the allowable free span length considering in-line and cross-flow vortex induced vibrations. The module also gives the buckling length (pinned-fixed condition) for the given effective axial force.



3.7.2 Input

The input parameters are separated in four groups:

1: Input related to the pipe:



D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.

t Steel wall thickness.

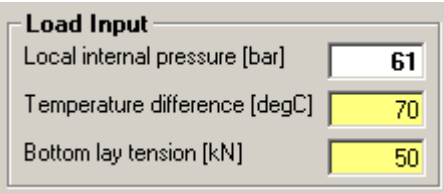
E Young's Modulus.

α Coefficient of thermal expansion.

D_{po} Pipe outer diameter including all external coating layers is calculated, not specified by the user. Reference is made to the Weight and Volume Module.

m_e Effective mass is calculated, not specified by the user. Reference is made to the Weight and Volume Module.

2: Input related to the axial compressive force:

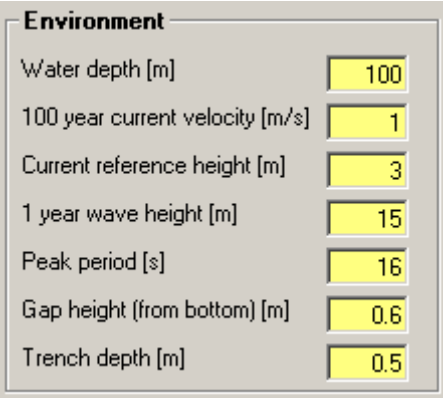


p_i Local internal pressure (edited on the DNV-OS-F101 module).

ΔT Temperature difference.

S_{lay} Lay tension.

3: Environmental data:



d Water depth

$U_{c,100yr}$ Extreme value for current velocity with 100 years return period.

z_r Reference height for the given current velocity.

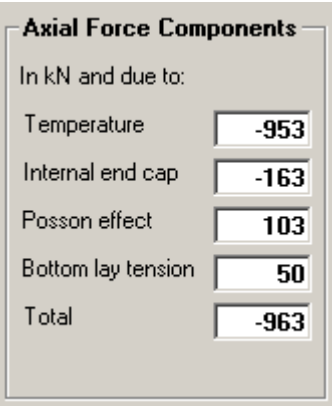
$H_{w,1yr}$ Extreme value for significant wave height with 1 year return period.

T_p Corresponding peak period.

e Gap height between pipe and sea bed.

d_t Trench depth taken three pipe diameters away from the pipe.

4: Compressive axial force components:

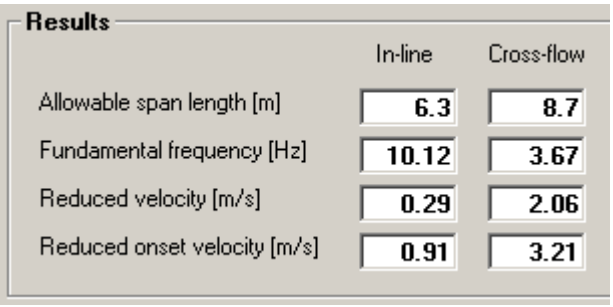


Tension is positive.

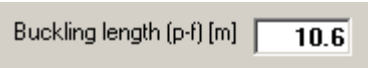
Note that these values are all calculated by the program and cannot be edited.

3.7.3 Results

The screening criterion as outlined in DNV-RP-F105 is applied with safety factors that have been calibrated against full fatigue analyses to provide fatigue life in excess of 50 years. This means that the method cannot readily be applied for shorter design lives, e.g. temporary phases.



The main results from this module are allowable span lengths for in-line and cross-flow vibrations.
In addition, the program gives the associated fundamental frequency, reduced velocity and at which reduced particle velocity vibrations are set on.



The program also presents the buckling length for the calculated compressive axial force assuming pinned-fixed boundary conditions.

The allowable span lengths are limited by the two expressions below:
The in-line fundamental frequency $f_{0\text{-}in}$ must fulfil:

$$\frac{f_{0-in}}{\gamma_f} \geq \frac{U_{c,100yr}}{V_{R-onset}^{il} \cdot D} \cdot \left(1 - \frac{L}{250 \cdot D}\right) \cdot \frac{\gamma_{il}}{\overline{\alpha}} \qquad \textbf{(3.23)}$$

And the cross-flow fundamental frequency $f_{0\text{-}cr}$ must fulfil:

$$\frac{f_{0-cr}}{\gamma_f} \geq \frac{U_{c,100yr} + U_{w,1yr}}{V_{R,onset}^{cf} \cdot D} \cdot \gamma_{cf} \qquad \textbf{(3.24)}$$

where:

$U_{c,100yr}$ is 100 year current velocity at the pipeline level.

$U_{w,1yr}$ is 1 year wave induced velocity at the pipeline level.

$V_{R-onset}^{in}$ is the in-line onset value for reduced velocity.

$V_{R-onset}^{cr}$ is the cross-flow onset value for reduced velocity.

$\overline{\alpha} = \dfrac{U_c}{U_c + U_w}$ is the current flow ratio. **(3.25)**

L is the span length.

$\gamma_f = 1.20$ is a safety factor on the fundamental frequency.

$\gamma_{il} = 1.15$ is a safety factor for the in-line screening criteria.

$\gamma_{cf} = 1.30$ is a safety factor for the cross-flow screening criteria.

The water particle velocity induced by current and waves at the pipeline level are found through the same algorithm described in relation with the stability module.

The fundamental frequency is calculated from the following general formula:

$$f_0 = C_1 \cdot \sqrt{1 + CSF} \cdot \sqrt{\frac{EI}{m_e \cdot L^4} \cdot \left(1 + C_2 \cdot \frac{S_{eff}}{P_E}\right)} \qquad \textbf{(3.26)}$$

where

C_1 and C_2 are boundary condition coefficients for pinned-fixed, $C_1 = 2.0, C_2 = 0.5$

CSF represents the stiffening effect of concrete coating, here set to zero.

EI is the pipe's bending stiffness.

m_e is the pipe's effective mass per unit length $= m_p + \dfrac{\pi \cdot D_{po}^2}{4} \cdot C_a$ **(3.27)**

C_a is the added mass coefficient = $\begin{cases} 0.68 + \dfrac{1.6}{1 + 5e/D} & \text{for } e/D < 0.8 \\ 1 & \text{for } e/D \geq 0.8 \end{cases}$

e is the gap between pipeline and seabed.

P_E is the Euler buckling load for the pinned-pinned condition $= (1 + CSF) \cdot \dfrac{\pi^2 EI}{L^2}$

S_{eff} is the effective axial force according to Eq. (3.13)

Note the factor $C_2 = 0.5$ transforming it to the pinned – fixed condition.

The onset reduced velocity for in-line motion is calculated as:

$$V_{R-onset}^{il} = \begin{cases} 1.0/\gamma_{on} & \text{for} \quad K_{sd} \le 0.4 \\ (0.6 + K_{sd})/\gamma_{on} & \text{for} \quad 0.4 < K_{sd} \le 1.6 \\ 2.2/\gamma_{on} & \text{for} \quad K_{sd} > 1.6 \end{cases} \qquad \textbf{(3.28)}$$

$K_{sd} = \dfrac{4\pi \cdot m_e \cdot \varsigma_T}{\rho_w \cdot D^2 \cdot \gamma_k}$ is the stability parameter in which the damping $\varsigma_T = 1\%$ and

$\gamma_k = 1.30$ is a safety factor on the stability parameter.

$\gamma_{on} = 1.10$ is a safety factor on the onset velocity.

The onset reduced velocity for cross-flow motion is calculated as:

$$V_{R-onset}^{cr} = \frac{3 \cdot \psi_{proxi,onset} \cdot \psi_{mass,onset} \cdot \psi_{\alpha,onset} \cdot \psi_{trench,onset}}{\gamma_{on}}$$

$$\psi_{proxi,onset} = \begin{cases} \dfrac{1}{4} \cdot (3 + 1.25 e/D) & \text{for} \quad e/D \le 0.8 \\ 1 & \text{else} \end{cases}$$

$$\psi_{mass,onset} = \begin{cases} \dfrac{1}{2} + \dfrac{1}{3} \cdot \dfrac{\rho_p}{\rho_w} & \text{for} \quad \dfrac{\rho_p}{\rho_w} \le 1.5 \\ 1 & \text{else} \end{cases} \qquad \textbf{(3.29)}$$

$$\psi_{\alpha,onset} = \begin{cases} 1 + \bar{\alpha}/3 & \text{for} \quad \bar{\alpha} \le 0.5 \\ 1.167 & \text{else} \end{cases}$$

$\psi_{trench,onset} = 1 + 0.5 \cdot \Delta/D$, $\Delta/D = (1.25 \cdot d - e)/D$, $0 \le \Delta/D \le 1$ where d is the trench depth relative to a point three diameters away from the pipe.

ρ_p is the specific mass density of the pipe, not including added mass.

The reduced velocities presented by the module are for the in-line and the cross-flow cases:

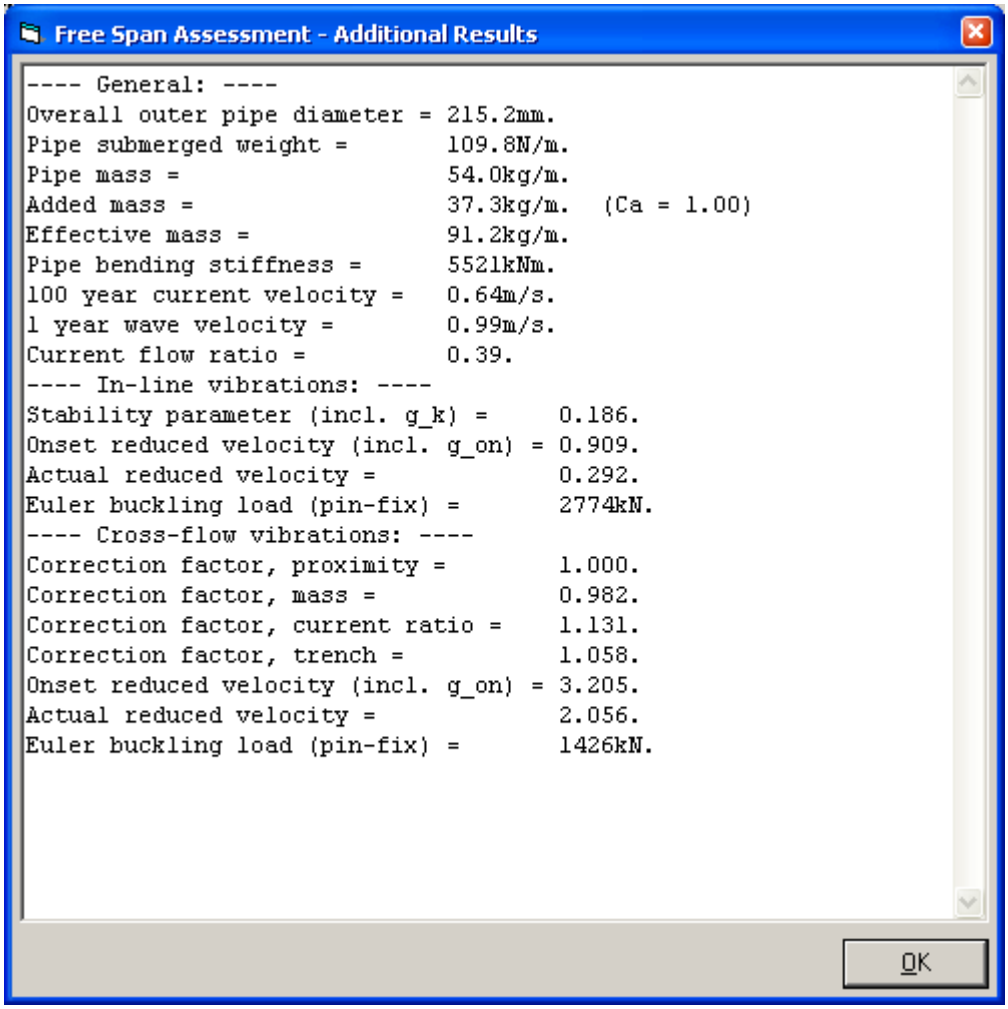
$$V_R^{il} = \frac{U_{c,100yr}}{f_{0,il} \cdot D} \text{ and } V_R^{cf} = \frac{U_{c,100yr} + U_{w,1yr}}{f_{0,cf} \cdot D} \quad \textbf{(3.30)}$$

respectively.

The Euler buckling load presented by the module is for the pinned – fixed type of boundary condition:

$$P_{E,p-f} = 2 \cdot \frac{\pi^2 EI}{L^2} \quad \textbf{(3.31)}$$

By pressing the "Additional Results" button, the following window appears showing essential parameters in the intermediate calculations:

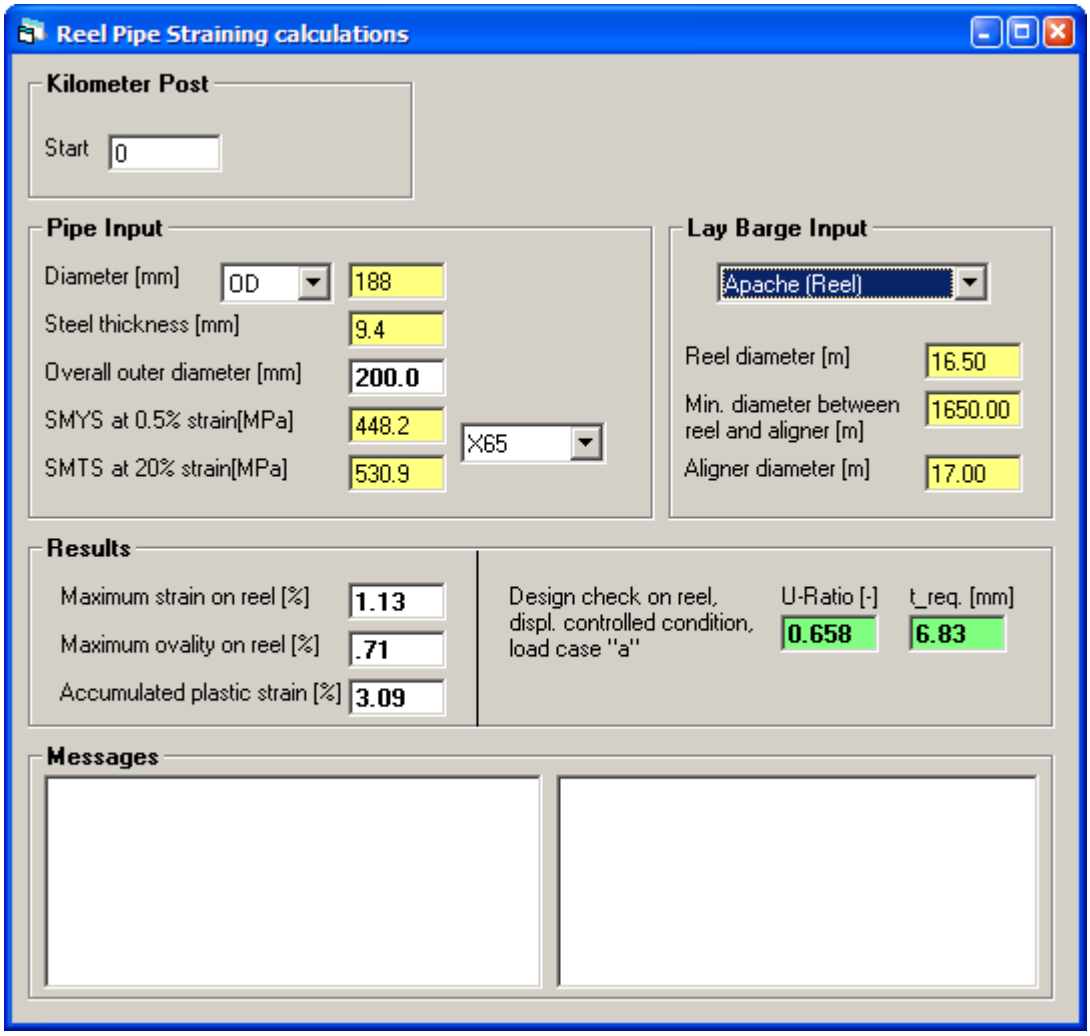


3.8 Reel Straining

3.8.1 Introduction

This module calculates:

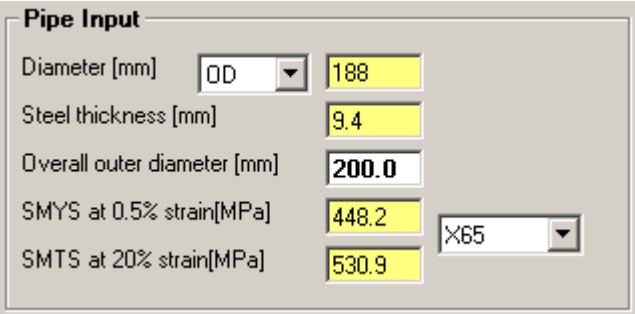
- Maximum bending strain on the reel including a code check according to DNV-OS-F101,
- corresponding ovality and
- accumulated plastic strain during reeling, unreeling, aligning and straightening.



3.8.2 Input

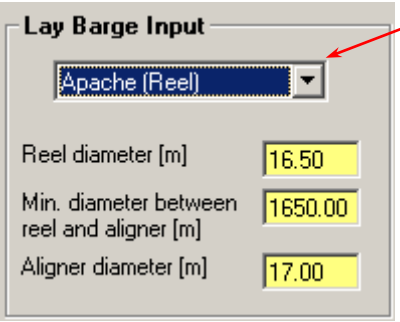
The input parameters are separated in two groups:

1: Input related to the steel cross section:



D	Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.
t	Steel wall thickness.
D_{po}	Overall outer diameter including coating is calculated, not specified by the user. Reference is made to the Weight and Volume Module.
SMYS	Specified minimum yield stress.
SMTS	Specified minimum tensile strength.

2: Input related to the reel/carousel:

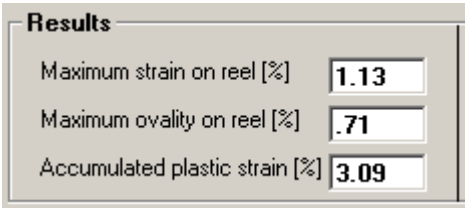


A specific barge may be selected, and values below are inserted automatically.

D_{reel}	Reel diameter.
$D_{r\text{-}al}$	Minimum bending diameter between reel and aligner determining an un-loading cycle in the accumulated plastic strain calculations. When a barge is selected, this is taken as one hundred times the reel diameter.
D_{align}	Bending diameter on the aligner. When a barge is selected, this is taken as a half metre larger than the reel diameter.

3.8.3 Results

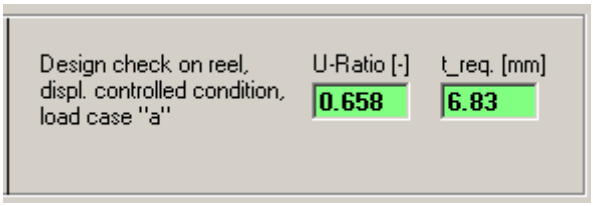
The results produced by this module are:



Maximum strain on the reel

Maximum ovality on the reel.

Accumulated plastic strain during reeling, unreeling, aligning and straightening.



Utilisation and minimum required nominal wall thickness with respect to DNV-OS-F101

Maximum strain in the pipe on the reel is calculated as:

$$\varepsilon_{reel} = \frac{D}{D_{reel} + D_{po}} \tag{3.32}$$

The code check is made according to the displacement controlled criterion with the following assumptions:

- Corrosion allowance t_{corr} = 0 mm.
- No material derating due to elevated temperature.
- No internal nor external pressure.
- Functional compressive strain ε_f = ε_{reel}.
- Environmental compressive strain ε_e = 0.0.
- Load condition factor γ_C = 0.82.
- Safety Class = LOW.

Ovality on reel:

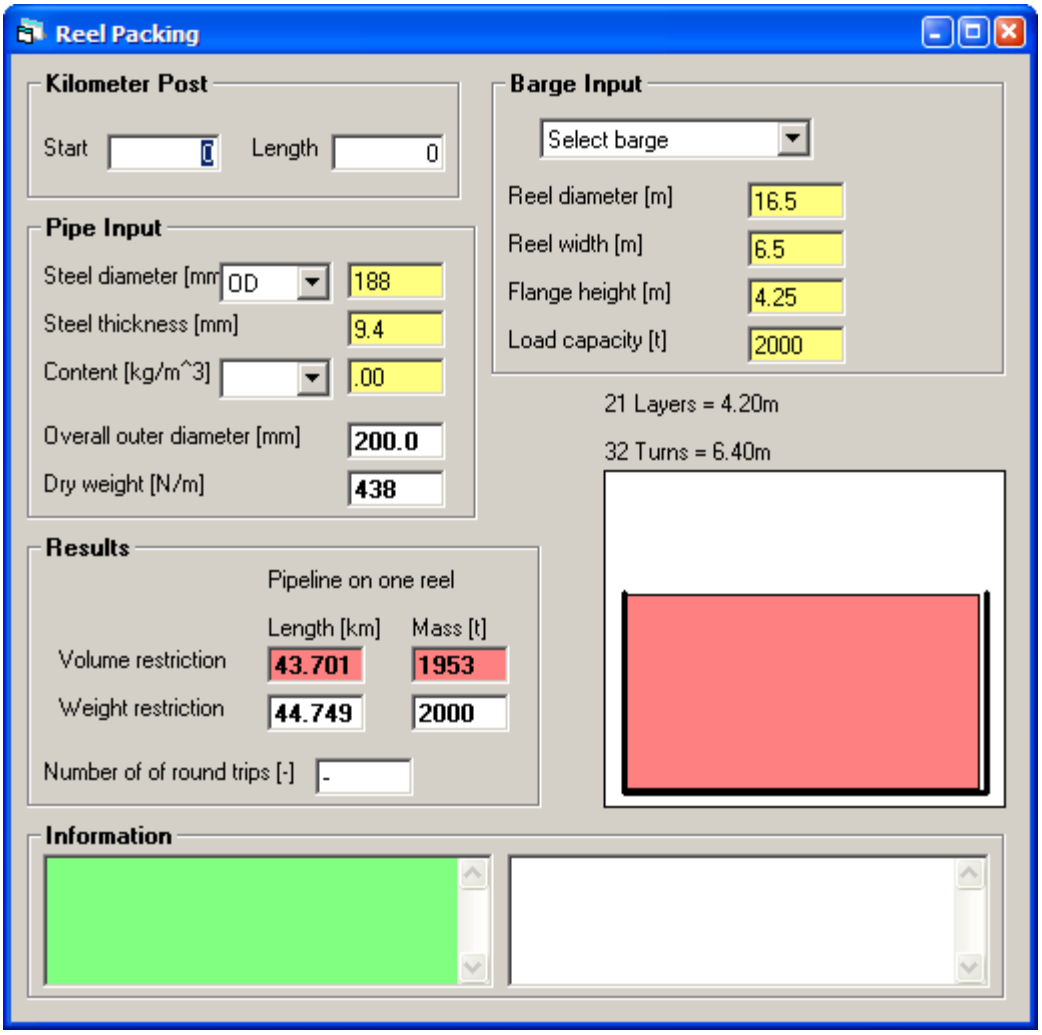
$$f_{reel} = 0.03 \cdot \left(1 + \frac{D}{120 \cdot t}\right) \cdot \left(2 \cdot \varepsilon_{reel} \cdot \frac{D}{t}\right)^2 \tag{3.33}$$

3.9 Reel Packing

3.9.1 Introduction

This module calculates:

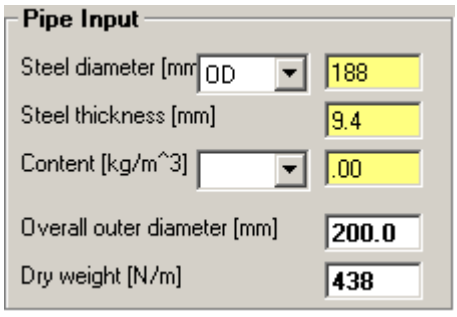
- The amount of pipe that can be packed on a reel/carousel.



3.9.2 Input

The input parameters are separated in two groups:

1: Input related to the pipe:



D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box. Does not directly enter the calculations.

t Steel wall thickness. Does not directly enter the calculations.

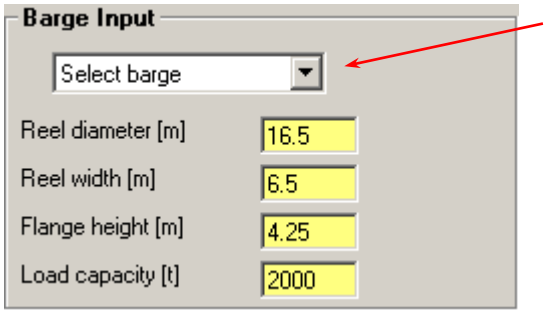
Content mass density that reduces the allowable amount of pipe if weight restriction is governing.

Overall outer diameter D_{op} including coating is calculated, not specified by the user. Reference is made

to the Weight and Volume Module.

Dry weight of pipe w_d (including content) is calculated, not specified by the user. Reference is made to the Weight and Volume Module.

2: Input related to the lay barge:



A specific barge may be selected, and values below are inserted automatically.

D_{reel} Reel diameter determines length of circumference.

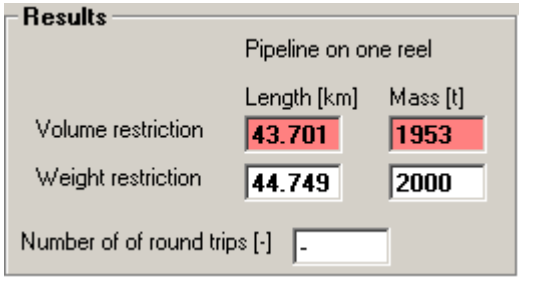
b_r Width between flanges determines number of turns.

h_f Flange height determines the number of layers (radially).

l_{cap} Barge load capacity sets weight restriction.

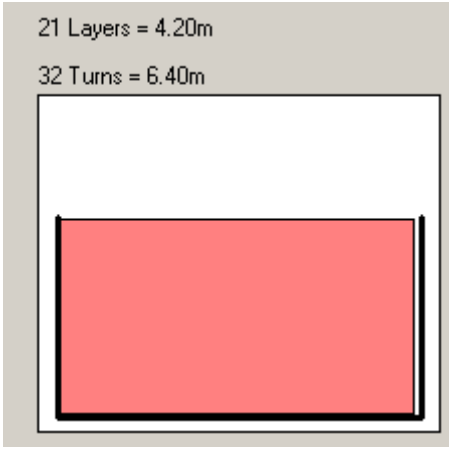
3.9.3 Results

The results produced by this module are for both volume and mass/weight restrictions:



Length of pipe.
Corresponding mass.

The text boxes with red back colour indicates what governs the load capacity, volume or weight/mass.



Layers and turns, (layers in the radial direction and turns in the width direction).

The results are presented graphically. The thick black lines represent the two flanges and the reel drum surface, and the red rectangle represents the packed pipe volume.

Number of turns and layers is calculated as:

$$n_{turns} = Int\left[\frac{b_r}{D_{op}}\right] \quad \text{and} \quad n_{layer} = Int\left[\frac{h_f}{D_{op}}\right] \tag{3.34}$$

Int[] denotes integer division, i.e. always rounding down to nearest integer. Pipe length on one reel based on the volume restriction is thus:

$$L_{vol} = \sum_{i=1}^{n_{layr}} \pi \cdot D_{r,i} \cdot n_{tunr} \tag{3.35}$$

where $D_{r,i}$ is the diameter (to centre of pipe) for layer no. *i*.
Pipe length on one reel based on the weight restriction is:

$$L_{wgt} = \frac{l_{cap}}{w_d} \text{ (with proper unit conversion (Tonne vs. Newton))} \tag{3.36}$$

Pipe mass is then:

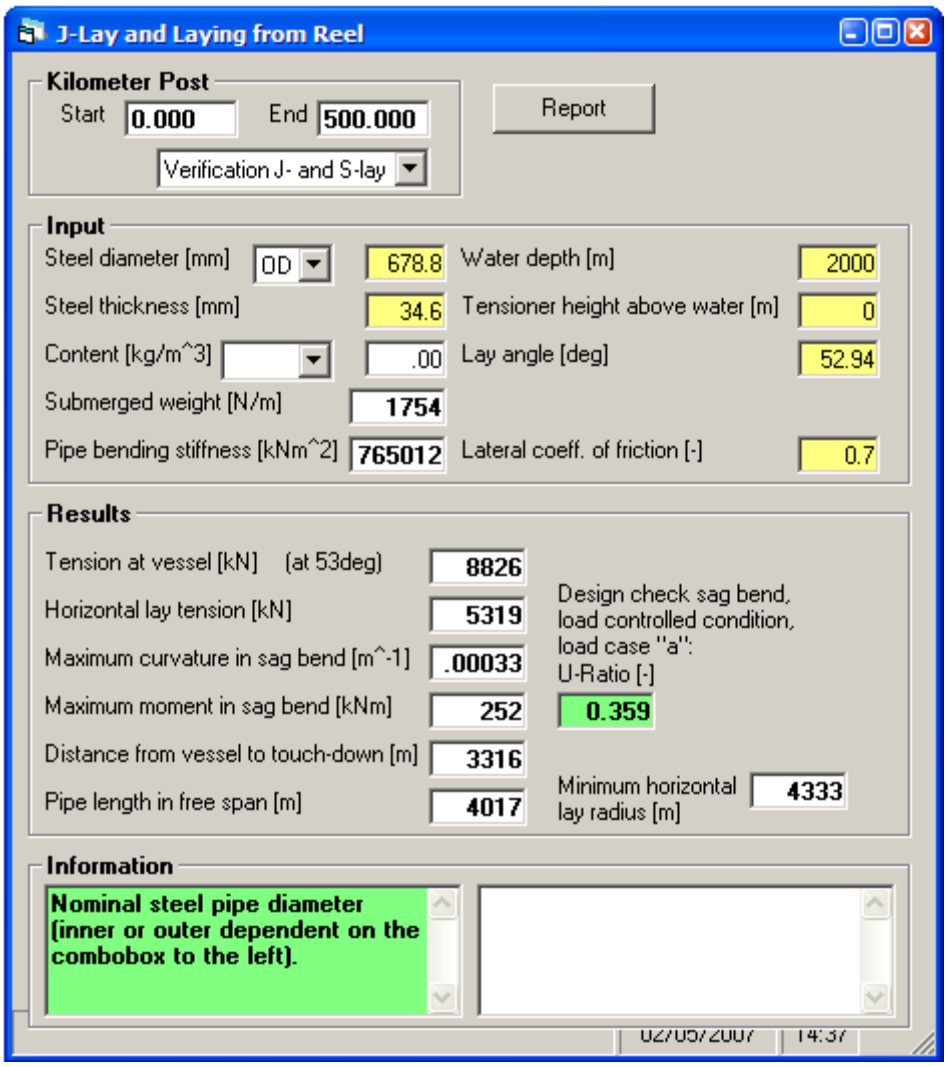
$$m_{vol} = \frac{w_d \cdot L_{vol}}{g} \text{ and } m_{wgt} = \frac{w_d \cdot L_{wgt}}{g} \tag{3.37}$$

3.10 J-Lay

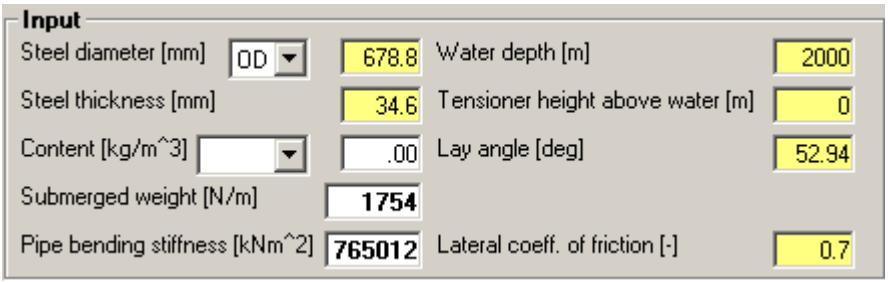
3.10.1 Introduction

This module calculates the following during pipe J-lay:

- The actual top tension (axial force in pipeline) during laying,
- horizontal top tension,
- maximum curvature and moment in the sag bend including utilisation ratio according to DNV-OS-F101,
- horizontal distance from touch down to barge,
- length of pipe in the free span and
- minimum horizontal lay radius.



3.10.2 Input



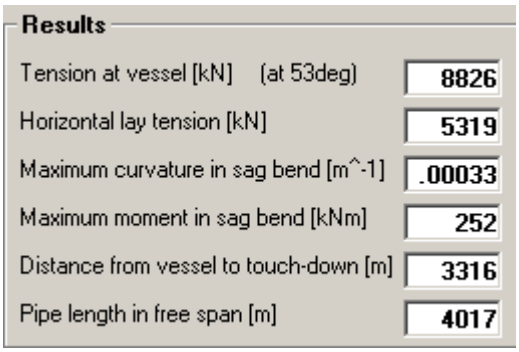
D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.

t Steel wall thickness.

ρ	Density
w_s	Submerged weight of pipe is calculated, not specified by the user. Reference is made to the Weight and Volume Module.
EI	Pipe elastic bending stiffness.
h	Tensioned height above seawater
d	Water depth.
α_{lay}	Lay angle.
μ_{lat}	Lateral coefficient of friction.

3.10.3 Results

The results produced by this module are for both volume and mass/weight restrictions:



Tension at barge (parallel to pipeline).

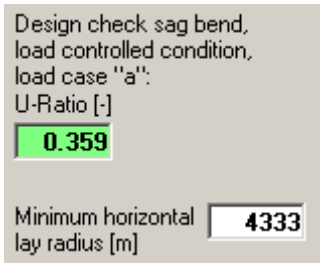
Horizontal component of barge tenion.

Maximum curvature in sag bend.

Maximum moment in sag bend.

Distance between touch down point and barge.

Pipe length in free span



Utilisation ratio according to the load combination criterion in DNV-OS-F101.

Minimum horizontal lay radius.

Warning: The calculations in this module are based on catenary behaviour and will be increasingly inaccurate for shallower depths.

The pipeline is assumed to follow a catenary shape from the tensioner to the seabed. The effect of the dry pipe weight between the tensioner and sea level is included by using equivalent values for depth and submerged weight. The depth used in the calculations is simply increased by the height between sea level and tensioner whereas the dry weight is smeared out over the whole free spanning pipeline.

$$d' = d + h \qquad \textbf{(3.38)}$$

$$w_s' = \frac{w_s \cdot d \cdot \sin^2 \alpha_{lay} + w_d \cdot h \cdot \left(1 - \cos \alpha_{lay}\right)}{d \cdot \sin^2 \alpha_{lay} + h \cdot \left(1 - \cos \alpha_{lay}\right)}$$

Furthermore, the pipeline is assumed to exit the tensioner at the lay angle and enter horizontally onto the seabed. When a coordinate system is established with $x = z = 0$ at the touch down point, x is positive forward towards the lay barge, and z is positive upward towards the sea surface, the shape of the pipeline is described by the equation:

$$z = a \cdot \left(\cosh \frac{x}{a} - 1 \right), \qquad a = \frac{H}{w_s'} \tag{3.39}$$

where H is the horizontal component of the lay tension.

The tension (parallel to the pipeline) at the barge is given by:

$$T = w_s' \cdot \left(d' + a\right) = \frac{w_s' \cdot d'}{1 - \cos \alpha_{lay}} \tag{3.40}$$

The horizontal component of the axial force is:

$$H = T \cdot \cos \alpha_{lay} \tag{3.41}$$

Maximum curvature in the sag bend is found by differentiating the catenary equation twice and insert $x = 0$:

$$\kappa_{sb} = \frac{w_s'}{H} = \frac{1}{a} \tag{3.42}$$

Maximum moment in the sag bend is found by multiplying the corresponding curvature by the bending stiffness of the pipeline:

$$M_{sb} = \kappa_{sb} \cdot EI \tag{3.43}$$

The code check for the load combination in the sag bend is performed according to the load controlled condition, load case a in DNV-OS-F101 with the following set of input parameters:

- Corrosion allowance t_{corr} = 0mm.
- No material derating due to elevated temperature.
- Internal pressure p_i = 0
- External pressure p_e = $\rho \cdot g \cdot d$
- Functional bending moment M_f = M_{sb}
- Environmental bending moment M_e = 0.0.
- Functional effective axial force S_f = H
- Environmental effective axial force S_e = 0.0.
- Load condition factor γ_C = 1.0.
- Safety Class = LOW.

The distance between touch down point and tensioner is found by inserting $z = d'$ in Eq. (3.39) and solve for x:

$$x_{td} = a \cdot \cosh^{-1}\left(\frac{d' + a}{a}\right) \quad \textbf{(3.44)}$$

Pipe length in free span is:

$$s_{span} = a \cdot \sinh\left(\frac{x_{td}}{a}\right) \quad \textbf{(3.45)}$$

Minimum horizontal lay radius is calculated as:

$$R_{lay} = \frac{H}{\mu_{lat} \cdot w_s'} \quad \textbf{(3.46)}$$

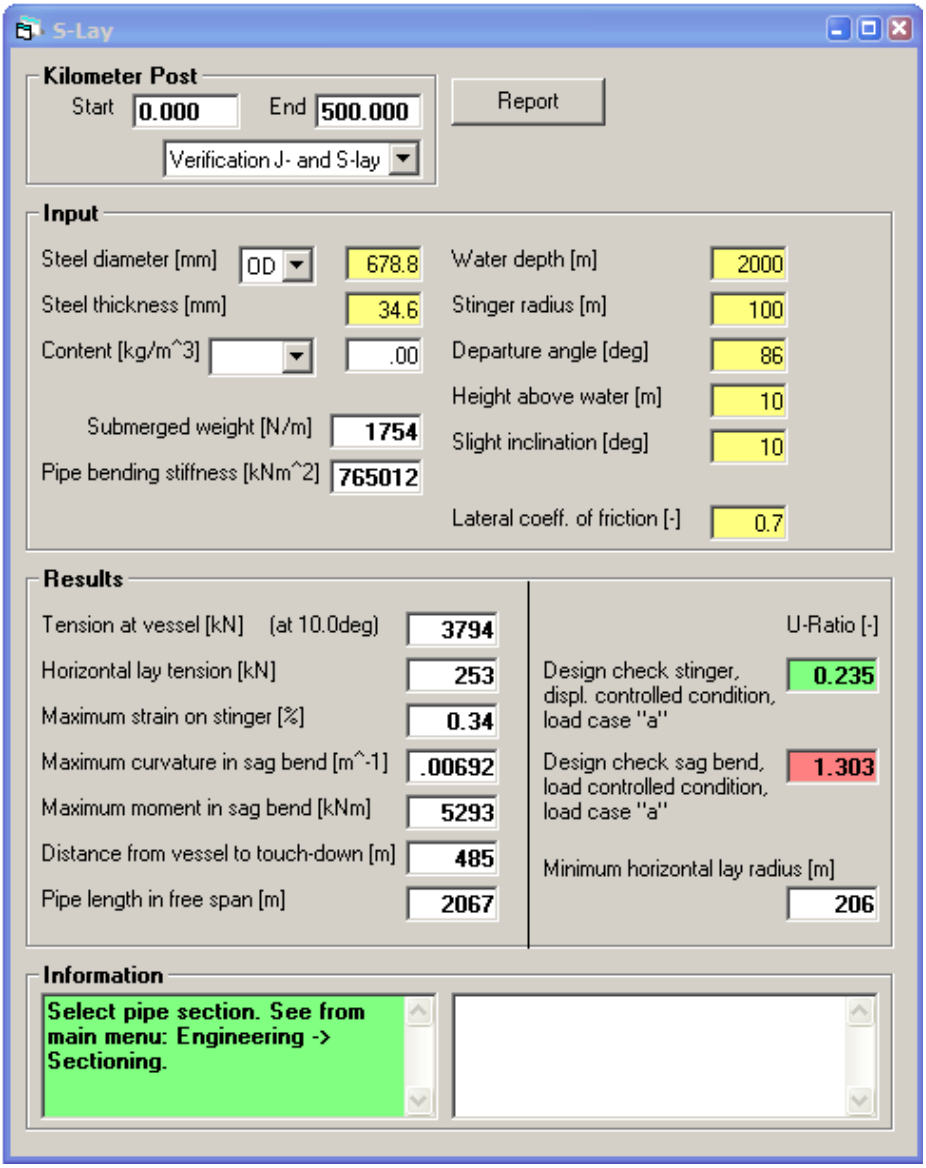
3.11 S-Lay

3.11.1 Introduction

This module calculates the following during pipe S-lay:

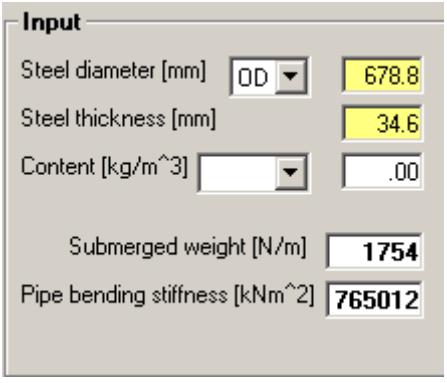
- The actual top tension (axial force in pipeline) during laying,
- horizontal effective axial tension,
- maximum strain on the stinger including utilisation ration according to DNV-OS-F101,
- maximum curvature and moment in the sag bend including utilisation according to DNV-OS-F101
- horizontal distance from touch down to barge,
- length of pipe in the free span and

  minimum horizontal lay radius.



3.11.2 Input

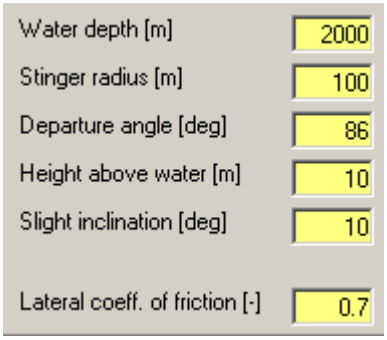
The input parameters are:



D Steel pipe diameter. Note that the user may specify inner or outer diameter depending on the selection of the combo box.

t Steel wall thickness.

w_s Submerged weight of pipe is calculated, not specified by the user. Reference is made to the Weight and Volume Module. Note that content during laying can be specified by the user.



d Water depth.

R_s Stinger radius

α_{lay} Lay angle.

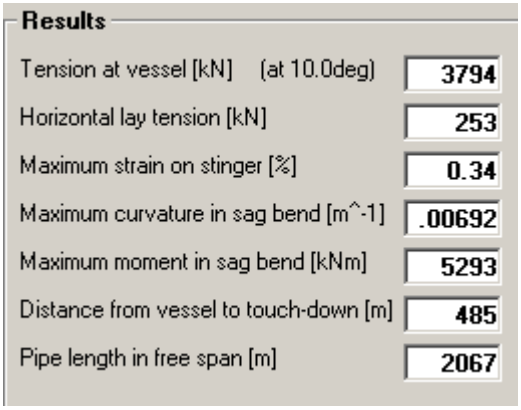
α_s Pipe angle when entering the stinger.

h Pipeline height above sea level when entering the stinger

μ_{lat} Lateral coefficient of friction between pipe and seabed.

3.11.3 Results

The results produced by this module are for both volume and mass/weight restrictions:



Tension at barge (parallel to pipeline).

Horizontal component of barge tension.

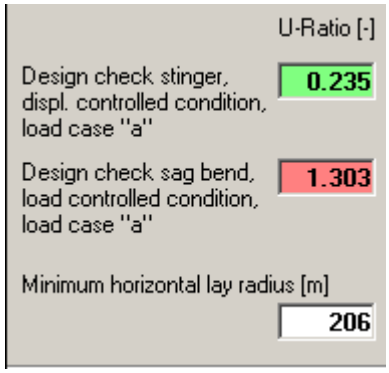
Maximum strain on the stinger.

Maximum curvature in the sag bend.

Maximum moment in the sag bend.

Distance between touch down point and barge.

Total pipe length on the stinger and in the free span.



Utilisation ratio on the stinger according to the displacement controlled load combination criterion in DNV-OS-F101.

Utilisation ratio in the sag bend according to the load controlled load combination criterion in DNV-OS-F101.

Minimum horizontal lay radius on the seabed.

Warning: Inflection point is taken at the point where the pipeline departs from the stinger. This is an approximate simplification.

Warning: The calculations in this module are based on catenary behaviour between the inflection point and the touch down point and will be increasingly inaccurate for shallower depths.

The pipe is considered from where it leaves the barge and enters the stinger at a height *h* above the sea surface and with a slight inclination angle of α_s. On the stinger the pipeline is assumed to follow the stinger curvature until it departs this at the angle α_{lay}. From here on the pipe is assumed to follow a catenary shape to the touch down point on the seabed. The effect of the dry pipe weight above the sea level is not included in the calculations.

The bending strain on the stinger is

$$\varepsilon_s = \frac{D}{2R_s + D} \qquad \textbf{(3.47)}$$

The axial tensile strain on the stinger may be significant in deep waters, say 10% of the bending strain above, but is for the sake of conservatism neglected.

The code check for the load combination on the stinger is performed according to the displacement controlled condition, load case *a* in DNV-OS-F101 with the following set of input parameters:

- Corrosion allowance t_{corr} = 0mm
- No material derating due to elevated temperature
- No internal nor external pressure
- Functional compressive strain ε_f = ε_s
- Environmental compressive strain ε_e = 0.0
- Load condition factor γ_C = 1.00
- Safety Class = LOW

The pipeline is assumed to exit the stinger at the lay, or departure, angle and enter horizontally onto the seabed. The catenary solution is assumed to be valid from this inflection point (where the pipe departs from the stinger) to the touch down point such that the modified depth *d*' to be used for this part of the pipeline is:

$$d' = d + h - R_s \cdot \left(\sin\alpha_{lay} - \sin\alpha_s\right) \qquad \textbf{(3.48)}$$

When a coordinate system is established with $x = z = 0$ at the touch down point, *x* is positive forward towards the lay barge, and *z* is positive upward towards the sea surface, the shape of the pipeline is described by the equation:

$$z = a \cdot \left(\cosh\frac{x}{a} - 1\right), \qquad a = \frac{H}{w_s} \qquad \textbf{(3.49)}$$

where *H* is the constant horizontal component of the tension in the pipeline.

The tension (parallel to the pipeline) in the pipeline on the barge is thus found by adding the tension at the inflection point, given by the catenary solution, and the weight component, parallel to the stinger, of the pipe on the stinger (friction against rollers is neglected):

$$\begin{aligned} T &= w_s \cdot \left(d' + a\right) + w_s \cdot R_s \cdot \left(\cos\alpha_s - \cos\alpha_{lay}\right) \\ &= \frac{w_s \cdot d'}{1 - \cos\alpha_{lay}} + w_s \cdot R_s \cdot \left(\cos\alpha_s - \cos\alpha_{lay}\right) \end{aligned} \qquad \textbf{(3.50)}$$

The constant horizontal tension component in the catenary solution is calculated at the inflection point as:

$$H = \frac{w_s \cdot d' \cdot \cos\alpha_{lay}}{1 - \cos\alpha_{lay}} \quad \textbf{(3.51)}$$

Note that this horizontal component is not valid in the pipe on the stinger where the rollers put loads on the pipe.

Maximum curvature in the sag bend may be found by differentiating the catenary equation twice and insert $x = 0$:

$$\kappa_{sb} = a \quad \textbf{(3.52)}$$

Maximum moment in the sag bend is found by multiplying the corresponding curvature by the bending stiffness of the pipeline:

$$M_{sb} = \kappa_{sb} \cdot EI \quad \textbf{(3.53)}$$

The code check for the load combination in the sag bend is performed according to the load controlled condition, load case a in DNV-OS-F101 with the following set of input parameters:

- Corrosion allowance t_{corr} = 0mm.
- No material derating due to elevated temperature.
- Internal pressure p_i = 0
- External pressure p_e = $\rho \cdot g \cdot d$
- Functional bending moment M_f = M_{sb}
- Environmental bending moment M_e = 0.0
- Functional effective axial force S_f = H
- Environmental effective axial force S_e = 0.0
- Load effect factor γ_C = 1.0
- Safety Class = LOW

The distance between touch down point and the stinger departure point is found by inserting $z = d'$ in Eq. (3.39) and solve for x:

$$x_{td} = a \cdot \cosh^{-1}\left(\frac{d' + a}{a}\right) \quad \textbf{(3.54)}$$

Pipe length in free span, including pipe on stinger is:

$$s_{span} = a \cdot \sinh\left(\frac{x_{td}}{a}\right) + R_s \cdot \left(\alpha_{lay} - \alpha_s\right) \quad \textbf{(3.55)}$$

Minimum horizontal lay radius is calculated as:

$$R_{lay} = \frac{H}{\mu_{lat} \cdot w_s'} \quad \textbf{(3.56)}$$

4 REFERENCES

/1/ DNV: *Offshore Standard DNV-OS-F101 Submarine Pipeline Systems*, Høvik, Norway, 2000.

/2/ DNV: *Recommended Practice DNV-RP-E305 On-Bottom Stability Design of Submarine Pipelines*, Høvik, Norway, 1988.

/3/ DNV: *Recommended Practice DNV-RP-F105 Free Spanning Pipelines*, Høvik, Norway, 2002.

/4/ Andrew C. Palmer et. al.: *Design of Pipelines Against Upheaval Buckling*, OTC 6335, Huston, Texas 1990.