

SESAM

USER MANUAL

StableLines

ON-BOTTOM STABILITY DESIGN OF SUBMARINE PIPELINES

DET NORSKE VERITAS

SESAM
User Manual

StableLines

ON-BOTTOM STABILITY DESIGN OF SUBMARINE PIPELINES

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Valid from program version 1.4
Developed by Pipeline Technology

Developed and marketed by
DET NORSKE VERITAS

DNV Software Report

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Table of Contents

1 INTRODUCTION 1-1

2 FEATURES 2-1

3 GETTING STARTED 3-1

3.1 INTRODUCTION 3-1
3.1.1 Licensing 3-1
3.1.2 User Interface 3-1
3.1.3 Performing an Analysis 3-1
3.1.4 Warnings and Recommendations 3-2
3.2 MAIN SHEET INPUT 3-3
3.2.1 General 3-3
3.2.2 Buttons 3-3
3.2.3 Pipeline and Coating Data 3-4
3.2.4 Environmental Parameters 3-5
3.2.5 Soil Interaction 3-6
3.2.6 Return period values for Wave and Current 3-8
3.3 VIEWING RESULTS OUTPUT 3-10
3.3.1 Numerical Results 3-10
3.3.2 Graphical Results 3-11
3.3.3 Report Sheet 3-12
3.3.4 Plots Sheet 3-12
3.4 PARAMETRIC RUNS 3-15
3.4.1 General 3-15
3.4.2 Functionality 3-15
3.4.3 Buttons 3-15

4 REFERENCES 4-1

Appendix A Report sheet
Appendix B Parametric runs example case

1 INTRODUCTION

STABLELINES is a Microsoft Excel VBA spreadsheet developed by DNV for design and assessment of on-bottom stability for submarine pipeline in compliance with DNV-RP-F109 "On-Bottom Stability Design of Submarine Pipelines", issued October 2010. DNV-RP-F109 has replaced the design code DNV-RP-E305, which has been used extensively by the industry since it was issued in 1988. The main objectives of this new revision are found in ref. /1/ and presented below:

- Harmonise the design approach for on-bottom stability with the design method in DNV-OS-F101 "Submarine Pipeline Systems".
- Present a design method with calibrated safety factors that ensure absolute stability.
- Expand the window of applicability for sandy and clayey seabed allowing a displacement of up to 10 pipe diameters.
- Present requirements for on-bottom stability design based on full dynamic analysis in more detail.

2 FEATURES

STABLELINES is a Microsoft Excel Visual Basic (VBA) based spreadsheet that incorporates the design principles of DNV-RP-F109, ref. /1/, for on-bottom stability design of submarine pipelines.

STABLELINES v1.4 provides the following features:

- **STABLELINES** includes design modules for both pipelines and umbilicals.
- Pipeline/Umbilical dimensions and weights are automatically calculated by defining wall thickness, coating thicknesses; cut back length (for field joint coating (FJC)) and densities of the different layers: Steel/Armour, Coating/Jacket, Marine growth and FJC.
- Two different criteria for calculating stability:
  - Absolute lateral static stability method
  - Generalized lateral stability method with displacements up to 10D
- Four different pre-defined soil models: Sand, Clay, Rock and Coulomb friction (user defined).
- Short term, stationary and irregular sea states are modelled based on the JONSWAP spectrum.
- Wave induced particle velocities at seabed level is automatically calculated based on user inputs significant wave height (H_s) and peak period (T_p).
- Optional reduction of current velocity due to boundary layer near the seabed.
- Reduction of both current and wave induced velocities based on directionality with independent specification of wave and current directions.
- Possibility of user-defined reduction factor due to added seabed penetration of Pipeline/Umbilical.
- Pipeline in empty condition and in operational condition are calculated simultaneously.
- **STABLELINES** suggests added steel and concrete/armour thicknesses to make unstable Pipelines/Umbilicals stable.
- Iteration module calculates optimal necessary pipe weight and concrete thickness for the absolute stability method. (Not for the generalized method.)
- Graphical presentations of:
  - Required submerged weight as function of direction.
  - Required concrete/armour thickness as function of concrete/armour density.
  - Required submerged weight as function of current velocity.
  - Dimensionless weight parameter L as function of K (Keulegan-Carpenter number) and sensitivity to M (ratio of current velocity to wave induced particle velocity).
- Report of final and intermediate results ready for “copy-paste” into Technical reports.
- Powerful tool to analyse stability of a large number of cases simultaneously (Parametric Runs).

3 GETTING STARTED

3.1 Introduction

3.1.1 Licensing

STABLELINES v1.4 is licensed through FlexLM License Manager. A valid license file is required to run **STABLELINES** v1.4. Please contact Software.Support@DNV.com if any questions.

3.1.2 User Interface

STABLELINES is a Microsoft Excel Visual Basic (VBA) program. Hence, it is based on Microsoft Excel 2010 and the user interface is the same as in a typical Excel spreadsheet with direct input into cells, push buttons and pull-down menus.

The program has been designed so that the input and results are located on the Main sheet. The user can see all the necessary information from this sheet without navigating between windows. There are four kinds of sheets available within **STABLELINES**:

- Main sheet - contains all the important input and output data.
- Plots sheet – contains results for graphical presentation and additional useful results.
- Report sheet – contains results and useful intermediate calculations that could be printed and used as appendix sheet directly in reports etc.
- Parametric runs sheet – used to run several on-bottom stability cases simultaneously (these sheets are created when the “Make new Parametric runs sheet” button on the Main sheet is pushed).

The user can copy the Parametric runs sheet, but the program can only operate with a single Main sheet.

The sheets have been designed so that the user can modify input cells only. This is to prevent corruption of the input data, formulae and the routines. Cells with input access are white, whereas cells that do not allow user access are coloured. Some of the cells change access rights according to specific selections. This occurs when some of the User Options have been changed.

3.1.3 Performing an Analysis

The procedure to follow when assessing a single on-bottom stability case is briefly described below:

1. Give input data in the Main sheet:
    a. Pipe and coating data
    b. Soil interaction data
    c. Environmental parameters
2. Enter the relevant wave and current data, including relevant directions considered.
3. Choose soil type.
4. Choose stability criterion.
5. Choose design condition.
6. Push Calculate button in the Main sheet to perform calculations and update all on-bottom stability results, including graphs.

The results are presented on the Main sheet in terms of submerged weights and necessary concrete/armouring and steel thicknesses for both empty and operational conditions for pipe and operational condition only for umbilical.

3.1.4 Warnings and Recommendations

When the calculate button is clicked, the first step is to read input data and perform a validation check on these parameters. This is because some parameters have restrictions on their range of usage; intervals where they are valid for the model. For user guidance warnings and recommendations message boxes are given for parameters that are outside its specified validity range. These messages provide the user with information on which parameter that is not valid and thus should be changed.

Note that the calculation of significant wave velocity U_s and mean zero up-crossing period T_u in **STABLELINES** are based on linear wave theory, as described in DNV-RP-F109, Ref. /1/ . Some combinations of return period values for significant wave height H_s, peak period T_p and water depth d may represent sea states that are not adequately described by linear wave theory. Whether linear wave theory is applicable for the given input data must be validated by the user.

3.2 Main sheet input

3.2.1 General

The main structure of the Main sheet of **STABLELINES** is described in Figure 1 below.

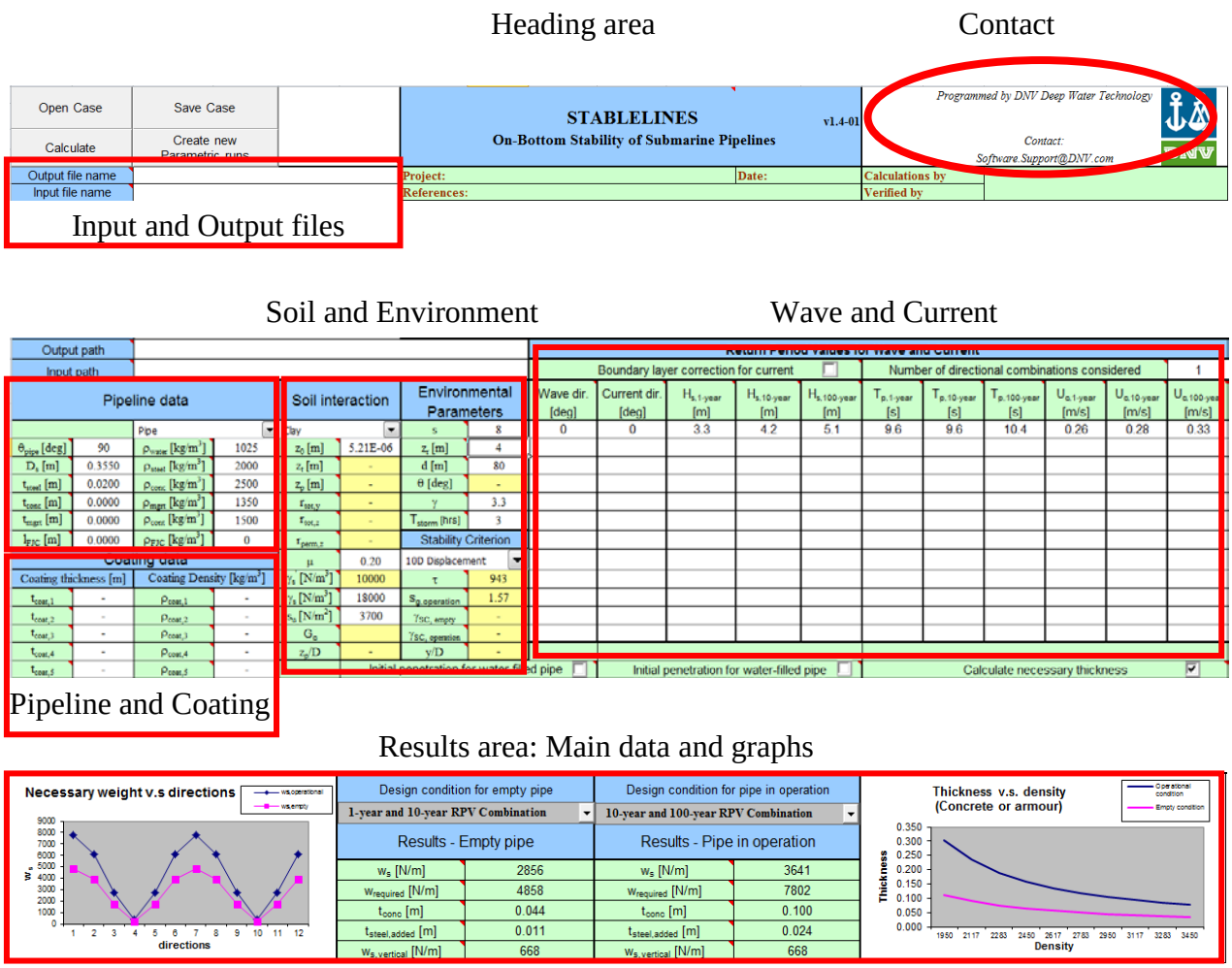


Figure 1 Main sheet structure

All input and output parameters presented in the main sheet are introduced with SI units. In addition, the **STABLELINES** main sheet contains a comprehensive list of comments describing the various parameters entering the analysis. The comments are shown when the cursor is held over the cells with a red triangle in the upper right corner.

3.2.2 Buttons

All main sheet buttons are located in the upper left corner of the heading area. Below follows a short description of button functionality.

Calculate - The calculation routine in the Main sheet is initiated using the Calculate button. To update the main sheet results, the Calculate button has to be pushed/clicked.

Save case – This button saves the actual case with all input data presented in the main sheet as a .txt file in the input directory and file given by the user.

Open case - This button opens a case from the output directory and file given by the user, saved earlier, and presents it in the Main sheet. To retrieve the results for this case, press the Calculate button.

Parametric runs – This button makes a clean Parametric runs sheet. This sheet may be used to perform sensitivity analyses of parameters etc. For keeping several parametric run cases, rename the sheet from Parametric runs to another name. For further description of the usage of this sheet, see chapter 5.

3.2.3 Pipeline and Coating Data

The user should enter all pipe and coating details into this section, see Figure 2 below. The input data can be either for Pipe or Umbilical mode. Typical Pipes and umbilical geometries are shown in Figure 3.

Pipeline data			
		Pipe	
θ_{pipe} [deg]	90	ρ_{water} [kg/m^3]	1025
D_s [m]	0.9140	ρ_{steel} [kg/m^3]	7850
t_{steel} [m]	0.0450	ρ_{conc} [kg/m^3]	3000
t_{conc} [m]	0.0000	ρ_{mgrt} [kg/m^3]	1350
t_{mgrt} [m]	0.0000	ρ_{cont} [kg/m^3]	150
l_{FJC} [m]	0.0000	ρ_{FJC} [kg/m^3]	0
Coating data			
Coating thickness [m]		Coating Density [kg/m^3]	
$t_{coat,1}$	0.0003	$\rho_{coat,1}$	1300
$t_{coat,2}$	0.0003	$\rho_{coat,2}$	900
$t_{coat,3}$	0.0024	$\rho_{coat,3}$	900
$t_{coat,4}$	-	$\rho_{coat,4}$	-
$t_{coat,5}$	-	$\rho_{coat,5}$	-

Pipeline data			
		Umbilical, dry	
θ_{pipe} [deg]	90	ρ_{water} [kg/m^3]	1025
D_o [m]	0.2000	ρ_{jacket} [kg/m^3]	850
t_{jacket} [m]	0.0010	ρ_{armour} [kg/m^3]	7500
t_{armour} [m]	0.0050	ρ_{mgrt} [kg/m^3]	1350
t_{mgrt} [m]	0.0000	w_{dry} [N/m]	1000
l_{FJC} [m]	-	ρ_{FJC} [kg/m^3]	-
Coating data			
Coating thickness [m]		Coating Density [kg/m^3]	
$t_{coat,1}$	-	$\rho_{coat,1}$	-
$t_{coat,2}$	-	$\rho_{coat,2}$	-
$t_{coat,3}$	-	$\rho_{coat,3}$	-
$t_{coat,4}$	-	$\rho_{coat,4}$	-
$t_{coat,5}$	-	$\rho_{coat,5}$	-

Figure 2 Pipeline and Coating input data for Pipe mode and Umbilical mode.

Pipeline data

Pipe direction, θ_{pipe}, is specified with a direction relative to geographic north.

Pipe dimensions including steel outer diameter, thicknesses of steel wall, concrete coating, marine growth and cut back length are specified in Pipe mode. In Umbilical mode the total outer diameter, jacket thickness and armour thickness are specified.

Densities for steel, concrete, water, marine growth, field joint coating and content are specified in Pipe mode. Density of jacket and armour material and the dry/submerged weight of the umbilical are specified in Umbilical mode.

Note that marine growth is only included in the calculations for pipe in operation.

Coating data

Five layers of external coating can be introduced into the calculations. These coating layers are specified with their respective thicknesses and material densities. Coating data can only be specified in Pipe mode.

Cross Sections

Calculations of submerged weights and necessary thickness of concrete, steel and armour are performed using the pipe and umbilical cross sections illustrated in Figure 3 below.

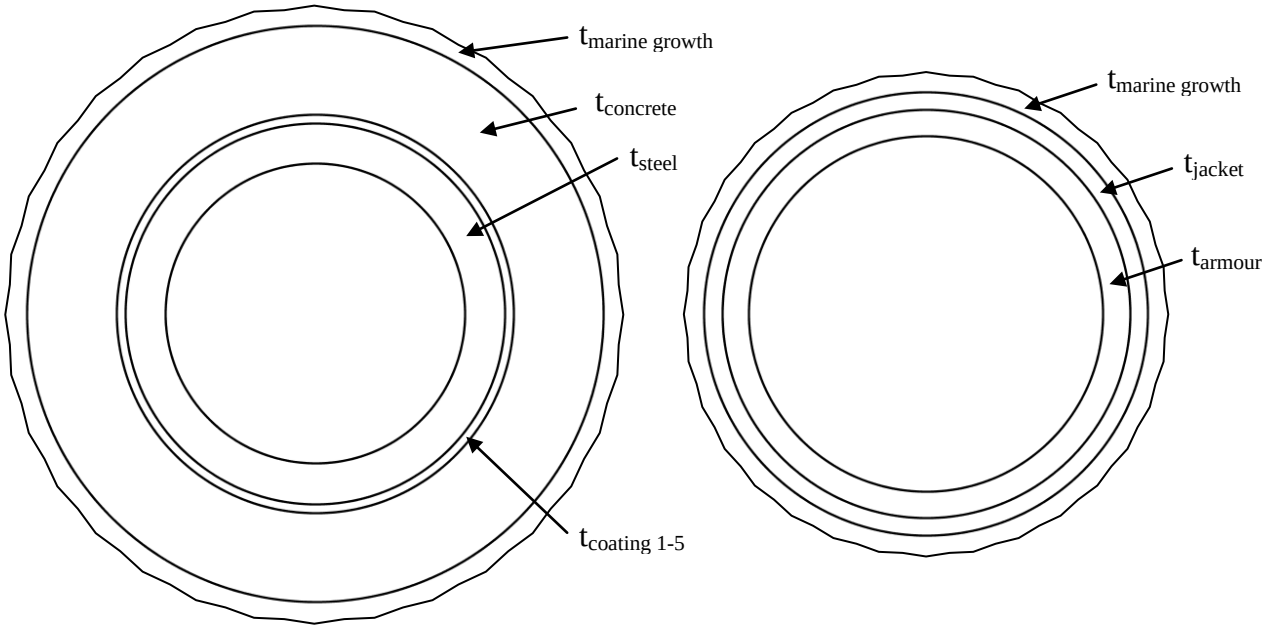


Figure 3 Pipe (left) and umbilical (right) cross sections used in STABLELINES

The cross section used in Pipe mode is shown to the left in Figure 3. When **STABLELINES** calculates necessary concrete thickness in order to obtain required pipe weight, the concrete is added externally without affecting the outer steel diameter and other coating layers, except for marine growth where only the thickness is kept constant. **STABLELINES** also calculates the steel thickness that must be added to the original steel thickness for the submerged pipe weight to match required submerged weight. In this case, the inner steel diameter and the thickness of external coating layers are kept constant, while the outer steel diameter is changed.

The umbilical geometry is shown to the right in Figure 3. When the necessary armour thickness is calculated in umbilical mode, the diameter and weight of the inner core, as well as the jacket and marine growth thicknesses, are kept constant. Thus, only the outer diameter, armour thickness and the weight of the umbilical are changed (the weight is set equal to the $w_{s,final}$ parameter from the results in Main sheet).

See also Section 3.3.1 for description of the output parameters t_{conc}, $t_{steel,added}$ and t_{armour}.

3.2.4 Environmental Parameters

The user should enter all environmental data, except for those parameters with yellow background colour. These parameters are either given as helpful output or not used (-) in the calculations with the selected stability criterion.

Environmental Parameters	
s	8
z_r [m]	0.2
d [m]	40
θ [deg]	
γ	3.3
T_{storm} [hrs]	3
Stability Criterion	
Absolute Stability	
τ	943
$S_{g,operation}$	1.57
$\gamma_{SC,\ empty}$	1
$\gamma_{SC,\ operation}$	1.4
y/D	-

Environmental Parameters	
s	8
z_r [m]	0.2
d [m]	40
θ [deg]	-
γ	3.3
T_{storm} [hrs]	3
Stability Criterion	
.5D Displacement	
τ	943
$S_{g,operation}$	1.57
$\gamma_{SC,\ empty}$	-
$\gamma_{SC,\ operation}$	-
y/D	-

Figure 4 Environmental parameters for the stability criteria, absolute stability (left) and the generalized stability criterion 0.5D and 10D displacement (right)

A pull down menu allow the user to choose from the following Stability criteria:

- **Absolute Stability** no pipeline movement
- **.5D Displacement** 0.5OD allowable movement
- **10D Displacement** 10OD allowable movement
- **Intermediate** 0.5OD – 10OD allowable movement (specify y/D)

The environmental parameters can be summarised as:

s	Spectral spreading exponent used for wave reduction factor calculation
z_r	Reference height for current measurement
d	Water depth
θ	Trench wall angle, only relevant for the Absolute stability case
γ	Peak enhancement factor
T_{storm}	Storm duration specified in hours
τ	Number of oscillations during the actual storm
$s_{g,operation}$	Pipe specific density (initial value), given for information
$\gamma_{SC,empty}$	Safety factor for empty condition used for Absolute stability
$\gamma_{SC,operation}$	Safety factor for operational condition used for Absolute stability
y/D	Relative displacement limit for intermediate displacement criterion

3.2.5 Soil Interaction

The user should enter all soil interaction data, except for those parameters with yellow background colour. These parameters are either given as helpful output or not used (-) for the stability criterion and soil type chosen.

However, μ can be set lower than the default values given by ref. /1/.

Soil interaction	
Sand	
z_0 [m]	4.00E-05
z_t [m]	
z_p [m]	
$r_{tot,y}$	-
$r_{tot,z}$	-
$r_{perm,z}$	1
μ	0.60
γ_s' [N/m^3]	10000
γ_s [N/m^3]	18000
s_u [N/m^2]	10000
G_c	-
z_p/D	

Soil interaction	
Coulomb friction	
z_0 [m]	4.00E-05
z_t [m]	
z_p [m]	
$r_{tot,y}$	-
$r_{tot,z}$	-
$r_{perm,z}$	1
μ	0.75
γ_s' [N/m^3]	10000
γ_s [N/m^3]	18000
s_u [N/m^2]	10000
G_c	-
z_p/D	-

Soil interaction	
Clay	
z_0 [m]	5.00E-06
z_t [m]	
z_p [m]	
$r_{tot,y}$	-
$r_{tot,z}$	-
$r_{perm,z}$	1
μ	0.20
γ_s' [N/m^3]	10000
γ_s [N/m^3]	18000
s_u [N/m^2]	2000
G_c	
z_p/D	

Figure 5 Soil interaction for the stability criteria, absolute stability (left), absolute stability with Coulomb friction (middle) and the generalized stability criterion 10D (and 0.5D) displacement (right).

Depending on stability criterion chosen, there are different options in the soil interaction pull down menu.

Absolute stability:

- **Sand**
- **Clay**
- **Rock**
- **Coulomb friction**

Different friction factors are specified for the different soil types. The coefficient of friction is taken as 0.6 on sand, 0.2 on clay and 0.6 on rock, but can be set lower. The Coulomb friction is given as input by the user, given as 0.75 in Figure 5.

Generalized stability method (μ cannot be greater than the values specified above, but can be set lower if properly documented by the user):

- **Sand**
- **Clay**

The soil interaction parameters can be summarised as:

z_0 Seabed roughness, depending on soil

z_t Trench depth, only valid for Absolute stability

z_p Penetration depth, in additional to the initial penetration calculated directly in **STABLELINES**, from movement, piping, trench etc. The added penetration depth must however be calculated and validated by the user.

$r_{tot,y}$ Total horizontal resistance factor, given as output to provide sensitivity check when changing z_t and z_p.

$r_{tot,z}$	Total vertical resistance factor, given as output to provide sensitivity check when changing z_t and z_p.
$r_{perm,z}$	Reduction factor on lift load due to permeable seabed. Only used for Absolute stability.
μ	Friction factor
γ_s'	Submerged unit soil weight (sand)
γ_s	Dry unit soil weight (clay)
s_u	Un-drained clay shear strength
G_c	Soil strength parameter, informative output parameter only valid for soil type clay
z_p/D	Relative soil penetration for operation condition

Initial penetration is calculated in order to determine passive soil resistance for Absolute stability assessments. When the boxes in Figure 6 are checked, the initial penetration will be calculated for pipe filled with fresh water (ρ_{water} = 1000 kg/m^3). The box for empty condition has been included for cases where the pipe is installed water-filled. If the boxes are not checked, initial penetration is calculated for empty pipe and by using the content density specified in the Pipeline data section for operational condition. The checkboxes are only used for the Absolute stability criterion in Pipe mode.



Figure 6 Check-box for specifying whether initial penetration shall be calculated for water-filled pipe during Absolute stability assessments.

3.2.6 Return period values for Wave and Current

The user should enter all Wave and Current details into this section, see Figure 7. All directions are given as relative to geographic north and the possible numbers of directions are between 1 and 12 for every case specified. Wave-induced flow and current can be specified independently in **STABLELINES**. The most conservative case is when wave-induced flow and current are assumed co-linear, i.e. they act in the same direction.

When using omni-directional values, the specified direction should be 90 degrees relative to the given pipeline direction.

Return Period Values for Wave and Current										
Boundary layer correction for current ☑					Number of directional combinations considered					12
Wave dir. [deg]	Current dir. [deg]	$H_{s,1\text{-year}}$ [m]	$H_{s,10\text{-year}}$ [m]	$H_{s,100\text{-year}}$ [m]	$T_{p,1\text{-year}}$ [s]	$T_{p,10\text{-year}}$ [s]	$T_{p,100\text{-year}}$ [s]	$U_{c,1\text{-year}}$ [m/s]	$U_{c,10\text{-year}}$ [m/s]	$U_{c,100\text{-year}}$ [m/s]
0	0	8	9	10	9	10	11	0.4	0.5	0.6
30	30	8	9	10	9	10	11	0.4	0.5	0.6
60	60	8	9	10	9	10	11	0.4	0.5	0.6
90	90	8	9	10	9	10	11	0.4	0.5	0.6
120	120	8	9	10	9	10	11	0.4	0.5	0.6
150	150	8	9	10	9	10	11	0.4	0.5	0.6
180	180	8	9	10	9	10	11	0.4	0.5	0.6
210	210	8	9	10	9	10	11	0.4	0.5	0.6
240	240	8	9	10	9	10	11	0.4	0.5	0.6
270	270	8	9	10	9	10	11	0.4	0.5	0.6
300	300	8	9	10	9	10	11	0.4	0.5	0.6
330	330	8	9	10	9	10	11	0.4	0.5	0.6

Figure 7 Wave and Current input for the relevant directions relative to geographic north.

For deciding on which Return Period Values (RPV) for wave and current to use, design condition for both empty and operational condition must be specified by the user, see Figure 8.

Design condition for empty pipe	Design condition for pipe in operation
1-year and 10-year RPV Combination ▼	1-year and 10-year RPV Combination ▼

Figure 8 Design condition pull down menu

A pull down menu allow the user to choose from the following Design conditions:

- **1-year and 1-year RPV Combination**
- **1-year and 10-year RPV Combination**
- **1-year and 100-year RPV Combination**
- **10-year and 10-year RPV Combination**
- **10-year and 100-year RPV Combination**
- **100-year and 100-year RPV Combination**

As specified in RP-F109, for permanent operational conditions and temporary phases with duration over 12 months, a 100-year return period applies. When detailed information about current and wave joint probability is not available, the RPV Combination 10-year and 100-year applies. For temporary phases with duration less than 12 months and in excess of three days, a 10-year seasonal condition applies. For this case an approximate condition would be the RPV Combination 1-year and 10-year.

3.3 Viewing Results Output

3.3.1 Numerical Results

The main results output are given by **STABLELINES** as shown in Figure 9 below.

Design condition for empty pipe		Design condition for pipe in operation	
1-year and 10-year RPV Combination		10-year and 100-year RPV Combination	
Results - Empty pipe		Results - Pipe in operation	
w_s [N/m]	629	w_s [N/m]	1370
$w_{s,required}$ [N/m]	781	$w_{s,required}$ [N/m]	1116
t_{conc} [m]	0.016	t_{conc} [m]	0.000
$t_{steel,added}$ [m]	0.002	$t_{steel,added}$ [m]	0.000
$w_{s,vertical}$ [N/m]	97	$w_{s,vertical}$ [N/m]	97

Figure 9 Numerical results given in the Main sheet for Pipe mode.

The pull down RPV menu is taken as input during calculations, but do also work as an integrated part of the results section. The worst case of the 1-year wave, 10-year current and 1-year current, 10-year wave is presented for the empty pipe. The worst case of the 10-year wave, 100-year current and 10-year current, 100-year wave is presented for pipe in operation.

The main results can be summarised as:

w_s Actual submerged weight, calculated from the user-specified pipe data.

$w_{required}$ Required submerged weight needed to achieve stable pipeline for the lateral stability criterion chosen (outer diameter = as specified).

$w_{s,vertical}$ Necessary submerged weight to fulfil the vertical stability criterion in water (outer diameter = as specified).

t_{conc} Necessary concrete thickness to fulfil the stability criterion, by introducing this concrete thickness value into pipe data and pushing calculate the pipe will be stable, thus w_s will be equal to $w_{required}$ (outer diameter = changed). Can be turned off.

$t_{steel,added}$ Additional steel thickness needed to achieve a stable pipe. The inner diameter is kept constant, thus the outer diameter increases by $2*t_{steel,added}$. Can be turned off.

To achieve a stable pipe, w_s should be equal to or larger than $w_{required}$ and $w_{s,vertical}$.

A different set of output is given in the Main sheet for Umbilical mode, see Figure 10.

Design condition for pipe in operation	
10-year and 100-year RPV Combination	
Results - Pipe in operation	
w_s [N/m]	434
$w_{s,required}$ [N/m]	505
t_{armour} [m]	0.002
$w_{dry,final}$ [N/m]	840
$w_{s,vertical}$ [N/m]	32

Figure 10 Numerical results given in the Main sheet for Umbilical mode.

The main results can be summarised as:

w_s Actual submerged weight, given as user-specified input data.

$w_{required}$ Required submerged weight needed to achieve a stable umbilical for the selected lateral stability criterion (outer diameter = as specified).

$w_{s,vertical}$ Necessary submerged weight to fulfil the vertical stability criterion in water (outer diameter = as specified).

t_{armour} Necessary armouring thickness to fulfil the selected stability criterion (outer diameter = changed). The inner diameter, the weight of the umbilical core, the jacket thickness and the densities of jacket and armour are kept constant while calculating the necessary armour thickness. Can be turned off.

$w_{dry,final}$ The dry weight needed to achieve a stable umbilical. The iteration procedure can be turned off.

3.3.2 Graphical Results

There are two graphs presented in the Main sheet, both are updated automatically when pushing the calculate button, as shown in Figure 11 and Figure 12.

Figure 11 is found to the left of the numerical results. This graph is very illustrative, showing which wave and current direction that gives the largest weigth requirements.

Figure 12 is found to the right of the numerical results. The concrete density interval is a set range between 1950 and 3450 kg/m^3 taken from experience in several on-bottom stability projects to cover all possible densities. The armour density interval is a set range between 6000 and 8000 kg/m^3. This graph is helpful for understanding what effect the choice of concrete coating or armour density has to the stability, when deciding on which coating to use.

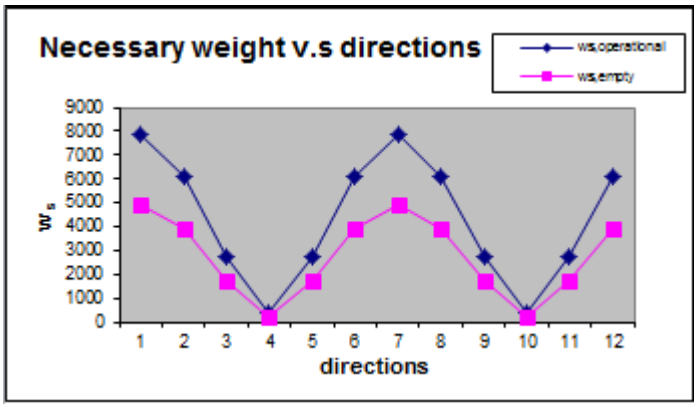


Figure 11 Required weight versus wave and current direction.

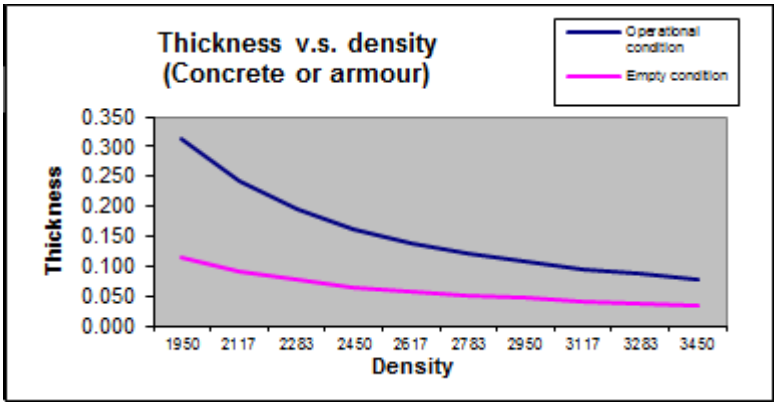


Figure 12 Necessary concrete or armour thickness for varying density

3.3.3 Report Sheet

When the Calculate button in the Main sheet is pushed the actual case is calculated and the numerical results are showed on this Report sheet with input and output together with some additional intermediate results. This result sheet is suitable for usage as appendix sheet directly in reports. Example sheets for both Pipe and Umbilical mode are found in Appendix A.

3.3.4 Plots Sheet

This sheet includes additional helpful results and plots.

When performing on-bottom stability calculations, both RPV combinations are calculated for the empty and the operational case, to find out which wave and current combination that have the largest weight requirement. Therefore, to be able to verify the results for all four RPV combinations, they are presented here in the plots sheet.

Results - All RPV Combinations				
RPV combination	1-year Current and 10-year Wave	10-year Current and 1-year Wave	10-year Current and 100-year Wave	100-year Current and 10-year Wave
w_s [N/m]	2856	2856	3641	3641
$w_{necessary}$ [N/m]	4755	4858	7184	7802

Figure 13 Results for all four RPV combinations

When performing calculations with **STABLELINES**, the current velocity is varied between zero and its maximum value V. This is done for all given direction combinations of current and wave introduced. Figure 14 shows an excerpt from the Plot sheet where the necessary weight is presented as a function of current velocity.

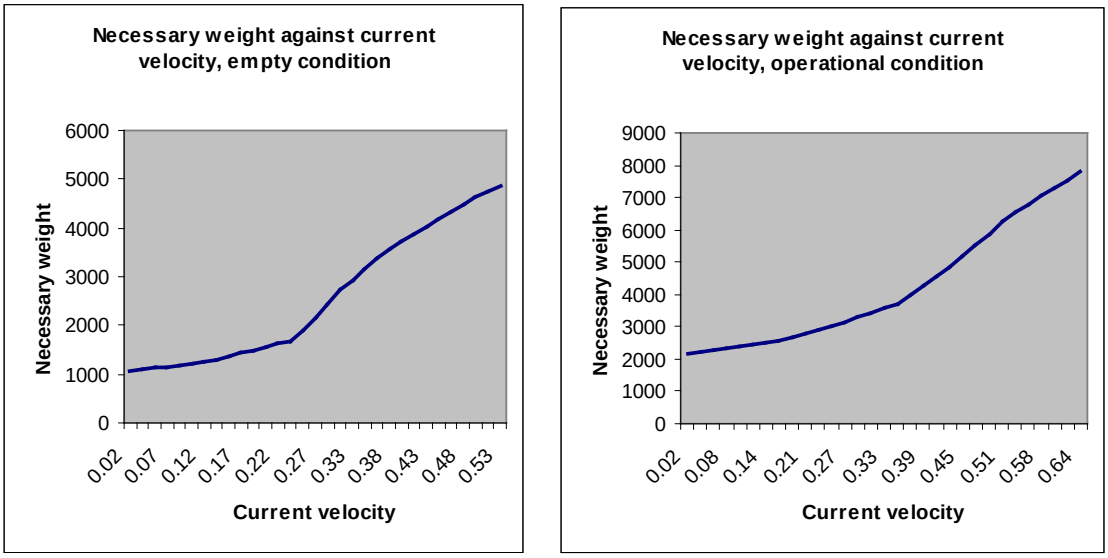


Figure 14 Necessary weight as a function of current velocity for empty and operational condition.

There are also two graphs presenting the sensitivity of the stability parameter L versus the steady to oscillatory velocity ratio M and the Keulegan-Carpenter number K. These two graphs are presented in Figure 15.

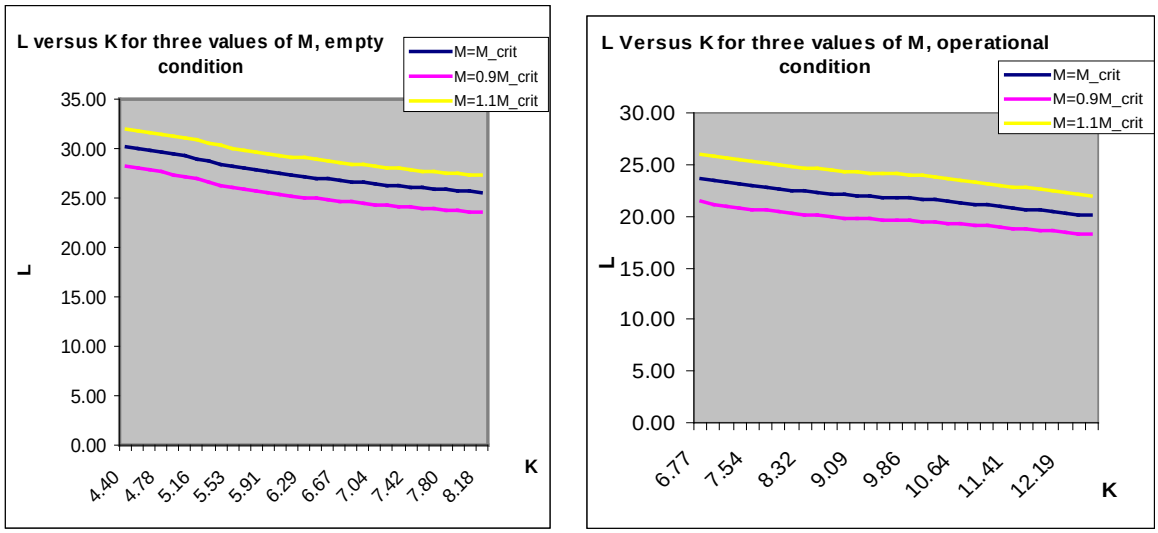


Figure 15 Sensitivity of L when varying K and M for empty and operational conditions

The critical value of K and M are retrieved from the case presented in the main sheet. So the value in the middle of the K-interval on the blue line is the same case as presented in the main sheet and the report sheet.

The data in Figure 16 are input data presented in the two graphs shown on the Main sheet.

Necessary weight for all directions					Concrete thickness for various concrete densities		
Dir. combination	Wave dir.	Current dir.	Empty	Operational	Density	Empty condition	Operational condition
1	0	0	4858	7802	1950	0.112	0.304
2	30	30	3870	6082	2117	0.090	0.234
3	60	60	1693	2708	2283	0.075	0.189
4	90	90	247	418	2450	0.064	0.157
5	120	120	1693	2708	2617	0.056	0.135
6	150	150	3870	6082	2783	0.050	0.117
7	180	180	4858	7802	2950	0.045	0.104
8	210	210	3870	6082	3117	0.041	0.093
9	240	240	1693	2708	3283	0.037	0.084
10	270	270	247	418	3450	0.035	0.077
11	300	300	1693	2708			
12	330	330	3870	6082			

Figure 16 Input data for the direction vs. $w_{required}$ graph and concrete density effect graph

When the absolute stability criterion is used, **STABLELINES** also presents the results of an iteration to obtain the optimal required pipe weight (and concrete or armour thickness), see Figure 17. The required weight determined for the initial pipe configuration is presented in the main sheet as $w_{required}$. However, when concrete coating is added, both the weight of the pipe and the diameter change. This causes the Keulegan-Carpenter number K* to change, and because of the increased submerged weight, the initial penetration and soil resistance will also increase. Thus, the new pipe configuration will give a different required weight than the initial configuration. Iteration is therefore required until convergence between w_s and $w_{required}$ is obtained.

The presentation of the iteration results in the Plots sheet also includes many useful intermediate results, such as load coefficients and initial penetration.

Note that a similar iteration is performed for the generalized lateral stability methods in order to account for increased diameter and weight. In the results for $t_{concrete}$, $t_{steel,\ added}$ and t_{armour} presented in the Main sheet the effects of increased diameter and weight are therefore taken into account.

Iteration to obtain optimal necessary pipe weight and concrete thickness for the absolute stability criterion									
Iteration no	w_s [N/m]	$w_{necessary}$ [N/m]	t_{conc} [N/m]	C^*_Y	C^*_Z	F_R [N/m]	z_{pi} [m]	$f_{tot,y}$	
	Empty Condition:								
1	2856.0	1056.1	0.0000	2.330	1.103	248.7	0.016	0.975	
	Operational Condition:								
1	3640.7	3723.2	0.0015	2.484	2.051	306.0	0.019	0.971	
2	3723.2	3728.3	0.0016	2.488	2.049	312.9	0.020	0.970	
3	3728.3	3728.6	0.0016	2.488	2.048	313.3	0.020	0.970	

Figure 17 Iteration to obtain optimal required pipe weight and concrete (or armour) thickness for the absolute stability criterion

3.4 Parametric runs

3.4.1 General

This option is used to calculate several on-bottom stability cases in one run. Thus, it is a very powerful tool that can be used for screening purposes, to perform sensitivity studies or just to analyse many separate cases in one run and keep the input and results together in one data sheet. For example, different KP's along a pipeline with varying input such as depth, soil and environment.

3.4.2 Functionality

To perform these on-bottom stability parameter studies the Create new Parametric runs button should be clicked on the Main sheet. As described in section 3.2, a new sheet will be generated containing nothing else than headings equal to input names. The input values are filled into the empty cells with the Input from Main button. The input refers to the first on-bottom stability case to be analysed. If a Parametric runs sheet has already been generated, it will be overwritten. To avoid losing results, the old Parametric runs worksheets should be renamed before commencing with the on-bottom stability case analyses.

Results are presented furthest to the left on the row. All input parameters then continue the row to the right starting with pipe data and ending with wave and current data for all directions. Kilometre point, KP, is the one additional parameter that has been introduced. This is located next to the results section, before the rest of the input data. This variable introduces the opportunity to retrieve an overview for a whole pipeline by implementing all important KP's and its relevant input.

All input parameters could be changed in the Parametric runs sheet. A calculation example with varying water depth has been introduced to illustrate typical Parametric runs sheet usage. In this example, also figures presenting results and input parameters are implemented for illustration. To view the Parametric runs calculation example, see Appendix B.

The heading area from the main sheet is also copied to the Parametric runs sheet, but with the main sheet buttons replaced by three new buttons.

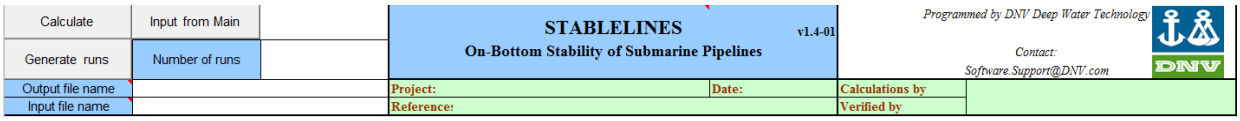


Figure 18 Parametric runs heading area

3.4.3 Buttons

Calculate - The calculation routines in the parametric runs sheet are initiated using this Calculate button. Results for all sensitivity cases (rows) are calculated and updated when the Calculate button is pushed/clicked.

Generate Runs – This button generates a number of rows/cases specified by the user by copying the input on the first row and adding the same data on consecutive rows in the Parametric runs sheet.

To generate more cases, it is also possible for the user to copy the first row of data as many times as required. The data can then be edited accordingly. Clicking the Calculate button will run the calculation for all the on-bottom stability cases, and the results are given in the sheet.

Input from Main – This button transfers all input data from Main sheet into the first input row in the Parametric runs sheet. If the first input row contains data, this data will be overwritten.

4 REFERENCES

/1/ DNV-RP-F109, *On-Bottom Stability Design of Submarine Pipelines*, October 2010.

APPENDIX A
REPORT SHEET

This is the report sheet calculation case for Pipe mode. The most relevant input and final results are presented. In addition, intermediate results are shown for the non-dimensional on-bottom stability parameters K, M, N, L, F_R, C_Y^*, C_Z^*, U_s, H_s, T_p, critical RPV combo and direction as well as critical and maximum current velocity.

header 1
header 2
header 3
header 4

Prepared:	Date:	Sign:	Verified:	Date:	Sign:

RELEVANT INPUT PARAMETERS:

Pipeline data							
Nominal outer steel diameter	D_s	0.35	m	Density content:	ρ_{cont}	1000	kg/m^3
Direction of pipeline:	θ_{pipe}	90	deg.	Cut back length FJC:	l_{FJC}	0	m
Density water:	ρ_{water}	1025	kg/m^3	Density FJC material:	ρ_{FJC}	0	kg/m^3
Steel thickness	t_{steel}	0.0200	m	Steel density	ρ_{steel}	7850	kg/m^3
Concrete thickness	t_{conc}	0.0000	m	Concrete density	ρ_{conc}	2500	kg/m^3
Marine growth thickness:	t_{mgrt}	0.0000	m	Density marine growth:	ρ_{mgrt}	1350	kg/m^3
Auxilliary coating layer thicknessess				**Coating layer densities**			
	$t_{coat,1}$	0	mm		$\rho_{coat,1}$	0	kg/m^3
	$t_{coat,2}$	0	mm		$\rho_{coat,2}$	0	kg/m^3
	$t_{coat,3}$	0	mm		$\rho_{coat,3}$	0	kg/m^3
	$t_{coat,4}$	0	mm		$\rho_{coat,4}$	0	kg/m^3
	$t_{coat,5}$	0	mm		$\rho_{coat,5}$	0	kg/m^3
Soil data				**Environmental data**			
Bottom roughness param. :	z_0	4.00E-05	m	Spectral spreading exp.:	s	8	
Trench depth:	z_t	0.00	m	Ref. height for current:	z_r	0.2	m
Initial penetration:	z_p	0.000	m	Water depth:	d	40	m
Total load reduction, horizontal:	$r_{tot,y}$	0.94		Trench angle:	θ	0	deg.
Total load reduction, vertical:	$r_{tot,z}$	1.00		Peak enhancement factor:	γ	3.3	
Lift reduction factor:	$r_{perm,z}$	1.00		Design storm duration:	T_{storm}	3	hrs
Friction coefficent:	μ	0.60		Abs. Stab. safety fac.	$\gamma_{SC,empty}$	1	
Submerged unit soil weigth(Sand):	γ_s'	10000	N/m^3	Abs. Stab. safety fac:	$\gamma_{SC,operation}$	1	
Dry unit soil weigth(clay):	γ_s	-	N/m^3	Soil type:		Sand	
Undrained shear strength (clay):	s_u	-	N/m^2				
Soil strength parameter (clay):	G_c	-					
Stability criterion:		**Absolute Stability**					

INTERMEDIATE RESULTS:	**Empty condition**	**Operational condition**
Crititical RPV combination	1-year Current 100-year Wave	10-year Current 100-year Wave
Critical current velocity	0.260	0.280
Maximum current velocity	0.260	0.280
Critical direction [deg]	0 0	0 0
Significant wave height - H_s	5.1	5.1
Peak period - T_p	10.4	10.4
Wave induced velocity - U_s	1.029	1.029
K	31.3	31.3
M (Critical curr. velocity)	0.253	0.272
M (Maximum curr. velocity)	0.253	0.272
N	0.010	0.010
L	4.153	3.630
F_R	42.02	104.61
C_Y^*	1.706	1.665
C_Z^*	1.639	1.577
FINAL RESULTS:		
w_s [N/m]	629	1370
$w_{necessary}$ [N/m]	1238	1116
t_{conc} [m]	0.075	0.000
$t_{steel,added}$ [m]	0.008	0.000
$w_{s,vertical}$ [N/m]	97	97

Figure 19 Report sheet example case, Pipe mode

This is the report sheet calculation case for Umbilical mode.

header 1
header 2
header 3
header 4

Prepared:	Date:	Sign:	Verified:	Date:	Sign:

RELEVANT INPUT PARAMETERS:

Pipeline data

Total outer diameter	D_o	0.2	m	Density content:	ρ_{cont}	-	kg/m^3
Direction of pipeline:	θ_{pipe}	90	deg.	Cut back length FJC:	l_{FJC}	-	m
Density water:	ρ_{water}	1025	kg/m^3	Density FJC material:	ρ_{FJC}	-	kg/m^3
Jacket thickness	t_{jacket}	0.0020	m	Density jacket	ρ_{jacket}	7500	kg/m^3
Armour thickness	t_{armour}	0.0000	m	Density armour	ρ_{armour}	6000	kg/m^3
Marine growth thickness:	t_{mgrt}	0.0000	m	Density marine growth:	ρ_{mgrt}	1350	kg/m^3

Auxilliary coating layer thicknessess

	$t_{coat,1}$	-	mm	$\rho_{coat,1}$	- kg/m^3
	$t_{coat,2}$	-	mm	$\rho_{coat,2}$	- kg/m^3
	$t_{coat,3}$	-	mm	$\rho_{coat,3}$	- kg/m^3
	$t_{coat,4}$	-	mm	$\rho_{coat,4}$	- kg/m^3
	$t_{coat,5}$	-	mm	$\rho_{coat,5}$	- kg/m^3

Coating layer densities

Soil data

Bottom roughness param. :	z_0	4.00E-05	m	Spectral spreading exp.:	s	8	
Trench depth:	z_t	0.00	m	Ref. height for current:	z_r	0.2	m
Initial penetration:	z_p	0.000	m	Water depth:	d	40	m
Total load reduction, horizontal:	$r_{tot,y}$	0.95		Trench angle:	θ	0	deg.
Total load reduction, vertical:	$r_{tot,z}$	1.00		Peak enhancement factor:	γ	3.3	
Lift reduction factor:	$r_{perm,z}$	1.00		Design storm duration:	T_{storm}	3	hrs
Friction coefficent:	μ	0.60		Abs. Stab. safety fac.	$\gamma_{SC,empty}$	-	
Submerged unit soil weigth(Sand):	γ_s'	10000	N/m^3	Abs. Stab. safety fac:	$\gamma_{SC,operation}$	1	
Dry unit soil weigth(clay):	γ_s	-	N/m^3	Soil type:		Sand	
Undrained shear strength (clay):	s_u	-	N/m^2				
Soil strength parameter (clay):	G_c	-					

Environmental data

Stability criterion:	**Absolute Stability**

INTERMEDIATE RESULTS:	**Empty condition**	**Operational condition**
Crititical RPV combination	-	10-year Current
	-	100-year Wave
Critical current velocity	-	0.000
Maximum current velocity	-	0.280
Critical direction [deg]	- -	0 0
Significant wave height - H_s	-	5.1
Peak period - T_p	-	10.4
Wave induced velocity - U_s	-	1.029
K	-	54.7
M (Critical curr. velocity)	-	0.000
M (Maximum curr. velocity)	-	0.272
N	-	0.010
L	-	4.650
F_R	-	33.37
C_Y^*	-	1.375
C_Z^*	-	1.159

FINAL RESULTS:		
w_s [N/m]	-	434
$w_{necessary}$ [N/m]	-	505
t_{armour} [m]	-	0.003
$w_{dry,final}$ [m]	-	849
$w_{s,vertical}$ [N/m]	-	32

Figure 20 Report sheet example case, Umbilical mode

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APPENDIX B
PARAMETRIC RUNS EXAMPLE CASE

This Parametric runs calculations example is set up to illustrate a typical Parametric runs sheet usage. A whole pipeline section is to be investigated for Absolute Stability. Therefore, critical KP's are defined by the user directly in the sheet to retrieve full overview. As can be seen in Figure 21, KP values are introduced between the results section and the input section.

Initial penetration for water-filled pipe				FALSE	Initial penetration for water-filled pipe				FALSE	Boundary layer correction for current					TRUE	Calculate necessary thickness							TRUE
Design condition empty condition					Design condition operational condition					Pipeline data													
1-year and 10-year RPV Combination					10-year and 100-year RPV Combination																		
w_s [N/m]	$w_{s,required}$ [N/m]	t_{spring} [m]	$t_{steel,added}$ [m]	$w_{s,vertical}$ [N/m]	w_s [N/m]	$w_{s,required}$ [N/m]	t_{spring} [m]	$t_{steel,added}$ [m]	$w_{s,vertical}$ [N/m]	KP	Mode	θ_{pipe} [deg]	D_s [m]	t_{steel} [m]	t_{conc} [m]	t_{mgn} [m]	t_{FJC} [m]	ρ_{water} [kg/m^3]	ρ_{steel} [kg/m^3]	ρ_{conc} [kg/m^3]	ρ_{mgn} [kg/m^3]	ρ_{cont} [kg/m^3]
967.7107	4231.122	0.471768	0.034736	164.2149	1645.729	6433.156	1.198552	0.058211	164.2149	2	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	2287.111	0.111664	0.012731	164.2149	1645.729	3542.75	0.350607	0.020738	164.2149	58	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	1208.492	0.015756	0.002378	164.2149	1645.729	2060.565	0.046411	0.004473	164.2149	117	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	652.1281	0	0	164.2149	1645.729	1215.397	0	0	164.2149	121	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	331.3847	0	0	164.2149	1645.729	820.0263	0	0	164.2149	123	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	115.6019	0	0	164.2149	1645.729	457.112	0	0	164.2149	124	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	39.43921	0	0	164.2149	1645.729	190.1074	0	0	164.2149	130	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	25.32133	0	0	164.2149	1645.729	82.71156	0	0	164.2149	136	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	22.96651	0	0	164.2149	1645.729	55.66714	0	0	164.2149	138	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550
967.7107	21.43349	0	0	164.2149	1645.729	44.36888	0	0	164.2149	141	Pipe	90	0.4500	0.0250	0.0000	0.0000	0.0000	1025	7850	2500	1350	550

Figure 21 KP values varies between 2 and 141 for this particular case

The only parameter changed in this parametric study is the water depth as shown in Figure 22. This is one of the environmental parameters, thus this whole section is shown. Note that the water depth increases with increasing KP values.

Environmental Parameters					
s	z_r [m]	d [m]	θ [deg]	γ	T_{storm} [hrs]
8	0.2	40		3.3	3
8	0.2	50		3.3	3
8	0.2	60		3.3	3
8	0.2	70		3.3	3
8	0.2	80		3.3	3
8	0.2	90		3.3	3
8	0.2	100		3.3	3
8	0.2	110		3.3	3
8	0.2	120		3.3	3
8	0.2	130		3.3	3

Figure 22 The environmental parameter d, water depth, is varied along the pipeline length

The results for the varying water depths are shown in the Figure 23.

Initial penetration for water-filled pipe				FALSE	Initial penetration for water-filled pipe				FALSE
Design condition empty condition					Design condition operational condition				
1-year and 10-year RPV Combination					10-year and 100-year RPV Combination				
w_s [N/m]	$w_{s,required}$ [N/m]	t_{conc} [m]	$t_{steel,added}$ [m]	$w_{s,vertical}$ [N/m]	w_s [N/m]	$w_{s,required}$ [N/m]	t_{conc} [m]	$t_{steel,added}$ [m]	$w_{s,vertical}$ [N/m]
967.7107	4231.122	0.471768	0.034736	164.2149	1645.729	6433.156	1.198552	0.058211	164.2149
967.7107	2287.111	0.111664	0.012731	164.2149	1645.729	3542.75	0.350607	0.020738	164.2149
967.7107	1208.492	0.015756	0.002378	164.2149	1645.729	2060.565	0.046411	0.004473	164.2149
967.7107	652.1281	0	0	164.2149	1645.729	1215.397	0	0	164.2149
967.7107	331.3847	0	0	164.2149	1645.729	820.0263	0	0	164.2149
967.7107	115.6019	0	0	164.2149	1645.729	457.112	0	0	164.2149
967.7107	39.43921	0	0	164.2149	1645.729	190.1074	0	0	164.2149
967.7107	25.32133	0	0	164.2149	1645.729	82.71156	0	0	164.2149
967.7107	22.96651	0	0	164.2149	1645.729	55.66714	0	0	164.2149
967.7107	21.43349	0	0	164.2149	1645.729	44.36888	0	0	164.2149

Figure 23 Parametric runs results for all KP values

The necessary concrete thickness versus water depth for empty and operational condition is shown in Figure 24. The results are found to be what we expected. As mentioned above, water depth is increased downwards. The needed concrete thickness and added steel thickness decrease and is zero for larger water depths. Required submerged weight also decreases for increasing water depth. This provides the user the possibility to suggest different measures to obtain stability for the different sections of the pipeline. For instance, it is noticed that the pipeline is stable without adding steel or concrete for water depths over 70m for both empty condition and operational condition.

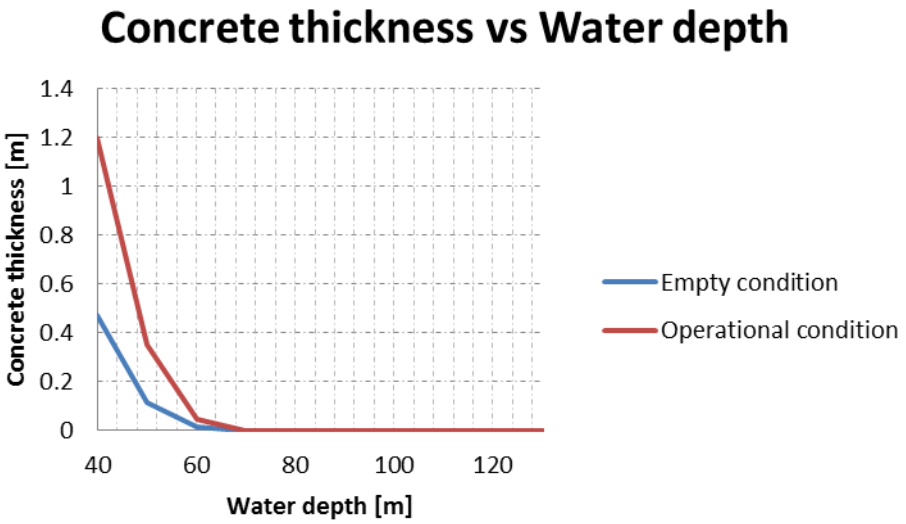


Figure 24 Necessary concrete thickness vs. water depth for empty and operational condition.

As illustrated above, the parametric runs sheet is a very illustrative and useful tool. **STABLELINES** provides the possibility of performing several on-bottom stability calculations at the same time, reducing the time for analyses by a significant factor.

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