

SESAM

USER MANUAL

SimBuck

SIMPLIFIED GLOBAL BUCKLING ANALYSIS OF SUBMARINE PIPELINES

DET NORSKE VERITAS

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Valid from program version 1.12
Developed by Pipeline Technology

Developed and marketed by
DET NORSKE VERITAS

DNV Software Report

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1 INTRODUCTION

1.1 General

SIMBUCK is a Microsoft Excel VBA spreadsheet developed by DNV for preliminary design and verification of global buckling potential for submarine pipelines in compliance with DNV-RP-F110 "Global Buckling of Submarine Pipelines – Structural Design due to High Temperature / High Pressure", issued October 2007. DNV-RP-F110 /1/ has been used extensively by the industry since its issue. **SIMBUCK** covers global buckling assessment both for exposed pipeline on even seabed triggered by imperfection without trawling load (DNV-RP-F110, Section 6) and for buried pipelines (DNV-RP-F110, Section 8). The functionality of **SIMBUCK** may be summarised as follows:

- For exposed pipeline on even seabed:
    - Performs pre buckling assessment and determines whether global buckling is likely a problem.
    - Presents a comprehensive post buckling assessment based on semi-analytical solutions, and calculates key parameters including feed-in length, buckle length, axial compressive force within a buckle, pitch length, and the condition safety factor.
    - Proposes possible mitigation measure in terms of the required rock dumping length and required radius at adjacent buckle to ensure sharing between buckles.
- For buried pipelines:
    - Advises whether pipe is likely to float in liquefied soil if installed empty.
    - Checks for upheaval buckling potential based on soil conditions and associated possible failure modes.
    - Provides an additional check on upheaval buckling potential based on method suggested by Palmer, et al., (1990) /8/.

1.2 Verification

Two verification reports are produced:

- Simbuck Verification – Theory, ref. /2/
- Simbuck Verification, ref. /3/

The first report contains the details of the equations and programming and discussion, and is for internal DNV use only. The latter contains verification of Simbuck output in terms of independent FE analyses and hand calculations.

2 FEATURES

SIMBUCK is a Microsoft Excel Visual Basic for Application (VBA) based spreadsheet that incorporates the design principles of DNV-RP-F110 /1/ for preliminary design and verification of global buckling potential for submarine pipelines.

SIMBUCK v1.12 provides the following features related to lateral buckling assessment:

- **SIMBUCK** offers preliminary design solutions on pre-buckling assessment, post-buckling pipe integrity check and sharing criterion evaluation.
- Derived parameters such as pipeline's second moment of area (I), steel's cross-sectional area (A_s) and submerged weight per metre (q_{sub}) are automatically calculated by defining diameters, wall thicknesses and densities of the different pipeline layers: steel, pipeline coatings (up to 5 layers) and concrete.
- Calculation of the effective residual lay tension (H_{eff}) complies with the provisions in DNV-OS-F101:2007 /5/
- Pre-buckling assessment is based on the Hobbs infinite buckling mode /4/ assuming large axial soil-pipe friction. The thermal expansion coefficient (α_T) and Poisson's ratio (v) of the steel layer, the effective residual lay tension (H_{eff}), the local internal design operational pressure p_i, the local design temperature difference relative to installation conditions (ΔT) and the horizontal imperfection radii are input parameters to this module. The calculation procedure complies with provisions in /1/ assuming lower-bound soil properties.
- Post-buckling pipeline integrity check uses best-estimate soil properties and computes values for buckle length (L_{buckle}), feed-in length, maximum compressive force within the buckle (S_{buckle}) and pitch-length (L_{pitch}) based on the selected Hobbs buckling mode /4/ and associated analytical solutions. Indicative value for the condition safety factor (γ_c) is also provided assuming no trawling interference.
- Sharing criterion is evaluated using lower-bound soil properties in accordance with DNV-RP-F110 /1/. For cases where the sharing criterion is violated, **SIMBUCK** suggests the required length of rock cover as a possible mitigation measure.
- Hobbs buckling modes 1-4 corresponding to different post-buckling geometries and boundary conditions are available as combo-box selection so that they can be checked independently for each case.
- **SIMBUCK** offers four different options for specifying soil-pipe friction in the axial direction:
    - "Specify soil properties": submerged soil unit weight (γ'_{seab}), the inter-granular friction angle of the seabed soil (φ'), the rock cover height measured to the pipe crown (H_{TOP}), and the residual friction coefficient between pipe and seabed soil (μ_{seab}) and between pipe and rock fill (μ_{fill}) can be specified manually. The axial rock berm resistance on pipe (R_{ax}) is then computed automatically.
    - "Typical Sand": a set of pre-defined parameters for sandy seabed will be applied automatically. Only H_{TOP} is required as an input.
    - "Typical Clay": a set of pre-defined parameters for clayey seabed will be applied automatically. Only H_{TOP} is required as an input.
    - "Specify manually": allows direct definition of R_{ax} without involving soil parameter input.

- Graphical presentations of:
    - Effective force within a buckle as a function of Hobbs buckle length based on all four Hobbs buckling modes
    - Bending moment as a function of feed-in length
    - Total buckled section length as a function of the bending moment
    - Total buckled section length as a function of feed-in length
- Powerful tool to analyse global buckling potential of a large number of cases simultaneously ("Parametric runs" sheet).

In addition, **SIMBUCK** v1.12 also provides the following features related to upheaval buckling assessment:

- Advice on pipeline floatation potential if installed in air-filled condition in liquefiable soils
- Upheaval buckling potential calculation according to inputted soil type based on DNV-RP-F110, incorporating:
    - Localized failure mode for undrained soils
    - Global failure mode for undrained soils
    - Global failure mode for drained soils
- Additional upheaval buckling potential calculation based on recommendations by Palmer, et al., (1990) /8/.

3 GETTING STARTED

3.1 Introduction

3.1.1 Licensing

SIMBUCK v1.12 is licensed through FlexLM License Manager. A valid license file is required to run **SIMBUCK** v1.12. Please contact Software.Support@DNV.com if any questions.

3.1.2 User Interface

SIMBUCK is a Microsoft Visual Basic for Applications (VBA) based program. It runs on Microsoft Excel 2007/2010 and shares the same user interface with a typical Microsoft Excel spreadsheet featuring direct input into cells, push buttons and combo-box pull-down menus. The program is not compatible with Excel for Mac, or earlier versions of Microsoft Excel for PC.

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 **SIMBUCK**:

- "Main" sheet - contains all the important input and output data related to lateral buckling assessment.
- "Plots" sheet – contains results for graphical presentation and additional useful results related to lateral buckling assessment
- "Parametric runs" sheet – used to run several lateral buckling cases simultaneously (this sheet is cleared of previous results when the Parametric runs button on the "Main" sheet is pushed).
- "UHB" sheet – provides additional functionality for upheaval buckling assessment

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 when, for example, the Inside Rock Cover combo-box selection is changed.

3.1.3 Performing a Lateral Buckling Analysis

The procedure to follow when assessing a single pipeline lateral buckling case is briefly described below:

1. Enter the required input parameters in the "Main" sheet:
    a. Cross section data: D_s, t_{steel}, ρ_{steel}, t_{conc}, ρ_{conc}, $t_{coat,1}$, $\rho_{coat,1}$, $t_{coat,2}$, $\rho_{coat,2}$, $t_{coat,3}$, $\rho_{coat,3}$, $t_{coat,4}$, $\rho_{coat,4}$, $t_{coat,5}$ and $\rho_{coat,5}$
    b. Material parameters: E, α_T and ν
    c. Functional Loads: H_{eff}, p_i, ΔT, ρ_{cont} and ρ_{water}
    d. Geotechnical parameters (exposed on seabed): μ_{axial}^{LB}, μ_{axial}^{BE}, μ_{axial}^{UB}, $\mu_{lateral}^{LB}$, $\mu_{lateral}^{BE}$ and $\mu_{lateral}^{UB}$
    e. Design bending moment resistance: M_{Rd}
    f. Horizontal imperfection data: R_1^{LB}, R_2^{m} and R_2^{UB}
2. Select the inside Rock Cover soil type through the combo-box pull-down menu.

3. Fill in required input soil parameters based on the soil type chosen: γ'_{seab}, φ'_{seab}, $\mu_{seab,r}$, H_{TOP}, μ_{fill} and R_{ax}. Some parameter values may not be editable depending on the soil type chosen.
4. Select the Hobbs Buckling Mode through the combo-box pull-down menu.
5. Push the "*Update Sheet*" button to refresh the "Main" sheet based on this particular case.
6. Push "*Calculate*" button in the "Main" sheet to perform calculations and update all pipeline global buckling analysis results, including graphs.

The results are presented on the "Main" sheet in terms of pre-buckling assessment, post-buckling pipeline integrity check and sharing criterion evaluation.

3.1.4 Performing an Upheaval Buckling Analysis

The procedure to follow when assessing a single pipeline upheaval buckling case is briefly described below:

1. Input/Edit the basic pipe and seabed parameters in the "Main" sheet:
    a. Cross section data: D_s, t_{steel}, ρ_{steel}, t_{conc}, ρ_{conc}, $t_{coat,1}$, $\rho_{coat,1}$, $t_{coat,2}$, $\rho_{coat,2}$, $t_{coat,3}$, $\rho_{coat,3}$, $t_{coat,4}$, $\rho_{coat,4}$, $t_{coat,5}$ and $\rho_{coat,5}$
    b. Material parameters: E, α_T and ν
    c. Functional Loads: H_{eff}, p_i, ΔT, ρ_{cont} and ρ_{water}
    d. Seabed soil properties, γ'_{seab} and φ'_{seab}
2. Input additional parameters specific to upheaval buckling analysis in the "UHB" sheet:
    a. Desired Factor of Safety against upheaval buckling, $FoS_{desired}$
    b. Trenching Method selection via the combo-box pull-down menu
    c. Seabed Soil Type selection via the combo-box pull-down menu
    d. Primary soil cover properties: H and $S_{u,avg}$
    e. Additional Cover Type selection via the combo-box pull-down menu
    f. Additional cover properties: γ'_{cover}, H_{cover} and φ'_{cover}
    g. Uplift Factor specification method selection via the combo-box pull-down menu
    h. Uplift factors for primary and additional covers: f_{seab} and f_{cover}
    i. Mobilisation Distance specification method selection via the combo-box pull-down menu
    j. Mobilisation distance: δ_{mob}
    k. Vertical Imperfection height: δ_{imp}
    l. Pipe Surface Roughness selection via the combo-box pull-down menu
3. Push the "Update UHB Sheet" button to refresh the "UHB" sheet based on this particular case.
4. Push the "*Calculate UHB*" button in the "UHB" sheet to perform calculations.

The results are presented on the "UHB" sheet in terms of empty pipe floatation check, assessment result based on DNV-RP-F110 and Palmer, et al., (1990).

3.1.5 Warnings and Recommendations

When the "*Calculate*" or "*Calculate UHB*" 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.

3.1.6 Limitations on Usage

Note that the intention of the **SIMBUCK** software is for preliminary check for global buckling potential of submarine pipelines. For lateral buckling assessment, this is limited to imperfection-triggered lateral buckling of exposed pipelines lying on even seabed. For upheaval buckling, this is limited to single buckle analysis without sliding or cyclic ratcheting. **SIMBUCK** cannot be used in more complicated design scenarios, such as when trawling interference is present, when seabed is uneven, or when multiple upheaval buckles may be combined. The "Maybe Buckling" design scenario corresponding to lateral buckling assessment in DNV-RP-F110 is not covered by **SIMBUCK** to simplify output.

Perfect conditions are assumed throughout the **SIMBUCK** software. Therefore, its outputs are indicative and should not be used for final design. For example, the calculated value for the condition factor (γ_c) assumes zero values for the coefficient of variation associated with trawling interference, $CoV(X_C)$ and axial soil resistance, $CoV(X_A)$. For more detailed evaluation of γ_c, the user must follow the procedures in Section 9 of DNV-RP-F110 and perform non-linear FE analyses.

Seabed soil parameters are different from site to site. The inside rock cover soil parameters corresponding to "Typical clay" and "Typical sand" selections on the "Main" sheet may not be applicable in every case worldwide even if the seabed soil classification is the same. Wherever possible, the "Specify soil properties" or "Specify manually" options should be used.

The upheaval buckling assessment module in **SIMBUCK** is based on deterministic approach according to DNV-RP-F110. Extra care should be taken when specifying the uplift factors and mobilisation distance as the assessment result is very sensitive to their values. It should also be noted that for H/D ratios outside the prescribed range in DNV-RP-F110, the upheaval buckling assessment result from **SIMBUCK** may not be conservative.

3.2 "Main" Sheet Input

3.2.1 General

The structure of the "Main" sheet of **SIMBUCK** is described in Figure 1 below.

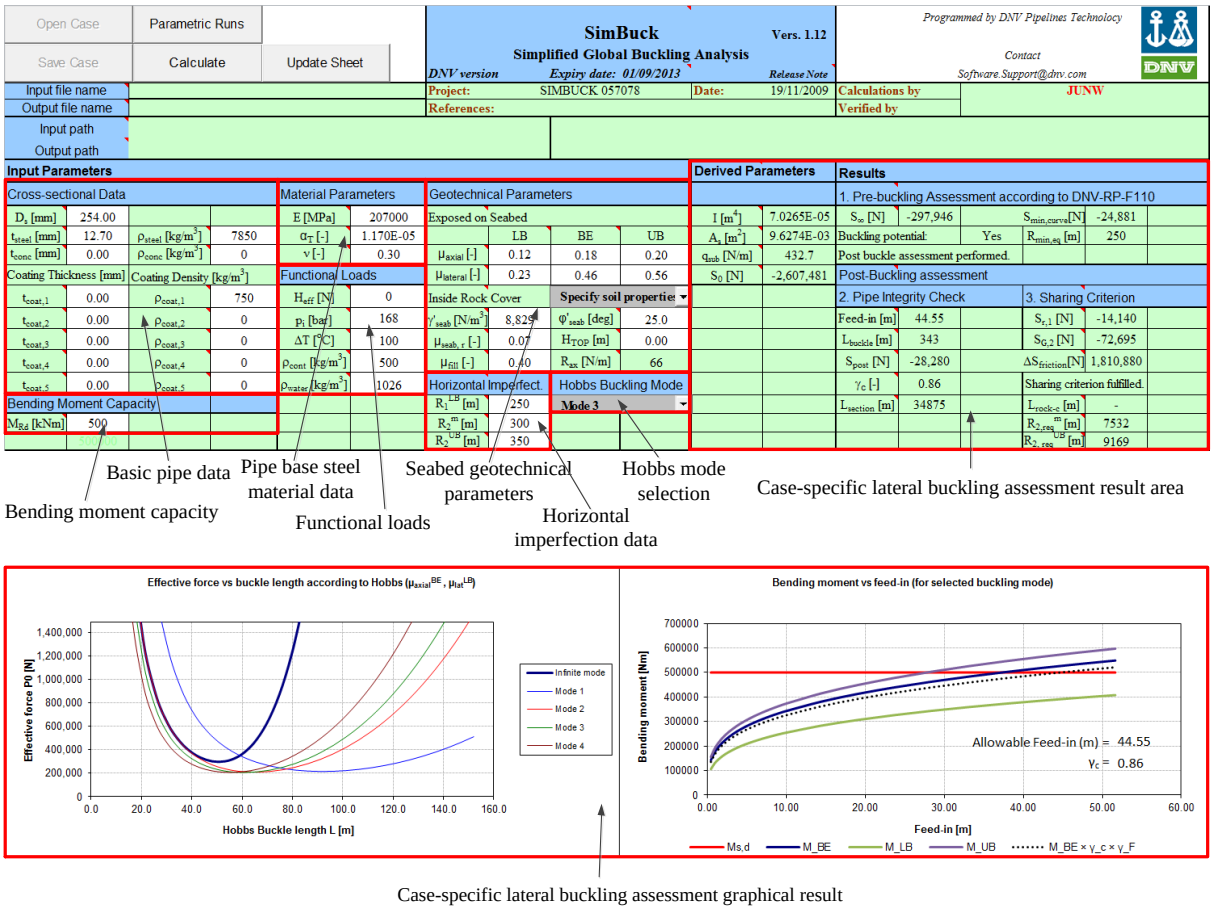


Figure 1 "Main" sheet structure

All input and output parameters presented in the "Main" sheet are introduced with SI units. In addition, the **SIMBUCK** "Main" sheet contains a comprehensive list of comments describing the various parameters entering the analysis.

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.

Update Sheet - This button, when pushed, updates the "Derived Parameters" section based on the input parameters currently in place. It does not, however, update the global-buckling analyses results. This button should be clicked before the "*Calculate*" button during every analysis.

Calculate - All the calculation routines in the program are initiated using the "*Calculate*" button in the "Main" sheet. To update all results, the "*Calculate*" button has to be clicked.

Save case - Currently not applicable to **SIMBUCK**.

Open case - Currently not applicable to **SIMBUCK**.

Parametric runs - This button copies the "Main" sheet input case into the third excel sheet named "Parametric runs". This sheet is used to perform sensitivity analyses on parameters. When clicked, all previous analyses data on the "Parametric runs" sheet will be cleared. The user is advised to save any previous analysis data, or to copy the previous "Parametric runs" sheet to another location, before performing a new parametric runs analysis. A message box suggesting such will also be prompted whenever this button is clicked. For further description of the usage of this sheet, see section 3.4.

3.2.3 Pipeline, Coating and Bending Moment Capacity Data

The user should enter all pipeline, coating and bending moment capacity details into this section, see Figure 2 below. Typical Pipeline geometry is shown in Figure 3.

Cross-sectional Data			
D_s [mm]	254.00		
t_{steel} [mm]	12.70	ρ_{steel} [kg/m^3]	7850
t_{conc} [mm]	0.00	ρ_{conc} [kg/m^3]	0
Coating Thickness [mm		Coating Density [kg/m^3]	
$t_{coat,1}$	0.00	$\rho_{coat,1}$	750
$t_{coat,2}$	0.00	$\rho_{coat,2}$	0
$t_{coat,3}$	0.00	$\rho_{coat,3}$	0
$t_{coat,4}$	0.00	$\rho_{coat,4}$	0
$t_{coat,5}$	0.00	$\rho_{coat,5}$	0
Bending Moment Capacity			
M_{Rd} [kNm]	500		
	500000		

Figure 2 Pipeline, Coating and Bending Moment Capacity data

Pipeline data

Pipe dimensions including steel outer diameter, thicknesses of steel wall, concrete coating thickness and density must be specified. Negative values are not allowed in these fields. Relevant input parameters include:

D_s	Outside diameter of the pipeline's steel layer (see Figure 3)
t_{steel}	Thickness of the pipeline's steel layer (see Figure 3)
ρ_{steel}	Density of the pipeline's steel layer
t_{conc}	Thickness of the pipeline's concrete outer layer (see Figure 3)
ρ_{conc}	Density of the pipeline's concrete outer layer

Coating data

Up to five layers of corrosion coating can be introduced into the calculations. These corrosion coating layers are specified with their respective thicknesses and material densities. Relevant input parameters include:

$t_{coat,1\text{-}5}$	Thickness of the pipeline's coating layers between the steel and concrete layers. The labelling number increases from inside to outside (see Figure 3)
$\rho_{coat,1\text{-}5}$	Density of the pipeline's coating layers between the steel and concrete layers. The

labelling number increases from inside to outside (see Figure 3)

Bending Moment Capacity data

The design bending moment resistance M_{Rd} is a derived parameter as per DNV-OS-F101 (2012) /5/. It is equal to the M_{Sd} value when Equation 5.19 in /5/ equals unity. Negative values are not permitted.

M_{Rd} Pipeline local design bending moment resistance (to be specified by the user)

Pipeline Cross-sectional Geometry

Calculation of pipeline's submerged unit weight depends on the thickness and densities of the various layers. A generalised pipeline cross-sectional geometry is assumed in the **SIMBUCK** software. This geometry is illustrated in Figure 3. **SIMBUCK** assumes a constant pipeline geometry across adjacent buckles.

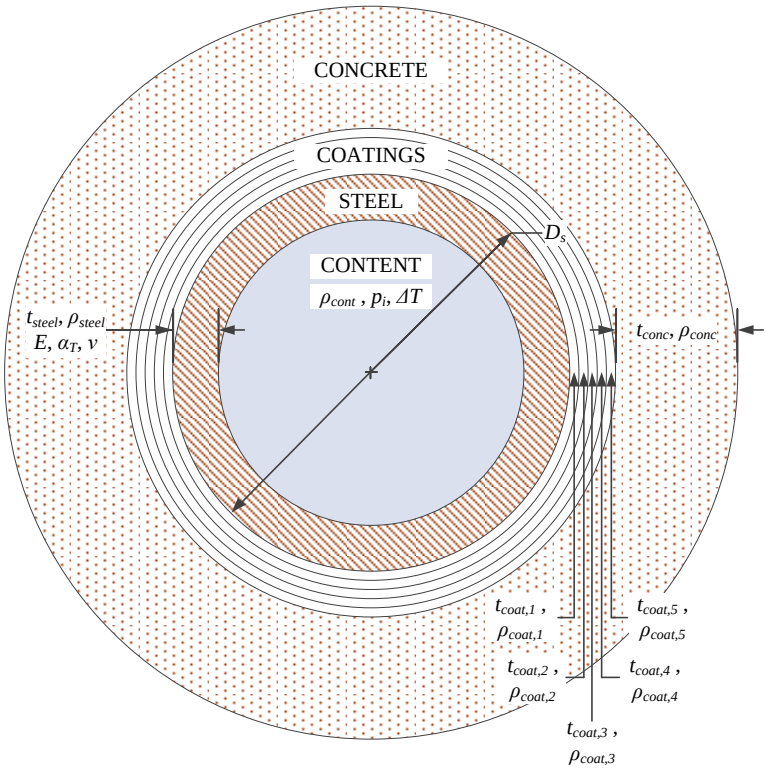


Figure 3 Pipeline cross-sectional geometry used in SIMBUCK

3.2.4 Material Parameters and Functional Loads Data

The user should enter all Material Parameters and Functional Loads data as requested by **SIMBUCK**, see Figure 4 below. Note that the material parameters should correspond to the steel section of the pipeline. Negative values are not allowed in these fields. The required data can be summarised as:

E Young's modulus of the pipeline's steel layer
α_T Thermal expansion coefficient of the pipeline's steel layer

ν Poisson's ratio of the pipeline's steel layer
H_{eff} Effective residual lay tension, i.e. residual axial force from laying /1/
p_i Local internal gauge pressure (i.e. above atmospheric pressure) during operation
ΔT Local internal temperature difference during operation compared with installation
ρ_{cont} Density of content being transported in the pipeline
ρ_{water} Seawater density

Material Parameters	
E [MPa]	207000
α_T [-]	1.170E-05
ν [-]	0.30
Functional Loads	
H_{eff} [N]	0
p_i [bar]	168
ΔT [°C]	100
ρ_{cont} [kg/m^3]	500
ρ_{water} [kg/m^3]	1026

Figure 4 Typical values for the material parameters and functional loads data

3.2.5 Geotechnical Parameters – Exposed on Seabed

The user should enter all required data in this section, see Figure 5. The labels "LB", "BE" and "UB" stand for "Lower Bound", "Best Estimate" and "Upper Bound" respectively, consistent with the terminology in /1/. It should be noted that negative values are not allowed in these fields. The user should also ensure that LB values are lowest and UB values are highest. The required data can be summarised as:

μ_{axial} Coulomb friction coefficient between pipeline external surface and seabed soil in the axial direction
$\mu_{lateral}$ Coulomb friction coefficient between pipeline external surface and seabed soil in the lateral direction

Exposed on seabed			
	LB	BE	UB
μ_{axial} [-]	0.32	0.44	0.58
$\mu_{lateral}$ [-]	0.54	0.88	1.00

Figure 5 Typical values for "Geotechnicalz Parameters - Exposed on Seabed" section

3.2.6 Geotechnical Parameters – Inside Rock Cover

The interaction between the pipeline and the seabed inside a rock cover is specified in this section. In total six parameters are involved:

γ'_{seab} Submerged (i.e. effective) unit weight of the seabed soil

φ'_{seab}	Inter-granular effective friction angle of the seabed soil
$\mu_{seab,r}$	Residual post-buckling Coulomb friction coefficient between pipeline external surface and seabed soil in the axial direction
H_{TOP}	Rock cover height measured to the pipe crown
μ_{fill}	Coulomb friction coefficient between pipeline external surface and rock cover in the axial direction
R_{ax}	Lower-bound axial resistance per metre inside the rock berm

Based on the user's selected input method, i.e. "Typical sand", "Typical clay", "Specify soil properties" or "Specify manually", different combinations of the six parameters will be enabled and become editable. A brief explanation of each input method is as follows. Figure 6 illustrates how the selected input method affects the format and typical values of the six parameters.

"Typical Sand":

Default values for typical sandy seabed will apply if this input method is selected:

γ'_{seab} = 10 kN/m^3, φ'_{seab} = 45°, $\mu_{seab,r}$ = 0.07, μ_{fill} = 0.40

These values are not editable, and neither is R_{ax}. H_{TOP} becomes the only required input parameter. Negative value is not allowed. The value for R_{ax} will be calculated automatically by **SIMBUCK** once the "*Update Sheet*" or "*Calculate*" button is clicked.

"Typical Clay":

Default values for typical sandy seabed will apply if this input method is selected:

γ'_{seab} = 9 kN/m^3, φ'_{seab} = 30°, $\mu_{seab,r}$ = 0.07, μ_{fill} = 0.40

These values are not editable, and neither is R_{ax}. H_{TOP} becomes the only required input parameter. Negative value is not allowed. The value for R_{ax} will be calculated automatically by **SIMBUCK** once the "*Update Sheet*" or "*Calculate*" button is clicked.

"Specify Soil Properties"

If this input method is selected, γ'_{seab}, φ'_{seab}, $\mu_{seab,r}$, μ_{fill} and H_{TOP} all have to be specified manually. Negative values are not allowed. The value for R_{ax} will be calculated automatically by **SIMBUCK** once the "*Update Sheet*" or "*Calculate*" button is clicked.

"Specify Manually"

If this input method is selected, the value of R_{ax} has to be specified directly by the user, and all other input parameters are disabled.

Inside Rock Cover		Typical sand	
γ'_{seab} [N/m^3]	10.000	φ'_{seab} [deg]	45.0
$\mu_{seab,r}$ [-]	0.40	H_{TOP} [m]	1.50
μ_{fill} [-]	0.40	R_{ax} [N/m]	5,130

Inside Rock Cover		Typical clay	
γ'_{seab} [N/m^3]	9,000	φ'_{seab} [deg]	30.0
$\mu_{seab,r}$ [-]	0.07	H_{TOP} [m]	1.50
μ_{fill} [-]	0.40	R_{ax} [N/m]	2,856

Inside Rock Cover		Specify soil properties	
γ'_{seab} [N/m^3]	6,000	φ'_{seab} [deg]	35.0
$\mu_{seab,\,r}$ [-]	0.30	H_{TOP} [m]	1.50
μ_{fill} [-]	0.35	R_{ax} [N/m]	4,153

Inside Rock Cover		Specify manually	
γ'_{seab} [N/m^3]	-	φ'_{seab} [deg]	-
$\mu_{seab,\,r}$ [-]	-	H_{TOP} [m]	-
μ_{fill} [-]	-	R_{ax} [N/m]	3,500

Figure 6 Format and typical values for "Geotechnical Parameters – Inside Rock Cover" section based on selected input method

3.2.7 Horizontal Imperfection Data

The horizontal imperfection data comprises three parameters, summarised below and illustrated in Figure 7.

R_1^{LB} The minimum, i.e. lower bound, radius of curvature in the horizontal direction for the first, i.e. primary, buckle due to, e.g. laying operations. This parameter is used for pre-buckling assessment based on Section 6.3.3 of DNV-RP-F110.

R_2^{m} The mean, i.e. best estimate, estimate of the radius of curvature in the horizontal direction for the second, i.e. adjacent, buckle due to, e.g. laying operations. This parameter is used for sharing criterion analysis based on Section 6.5.2 of DNV-RP-F110.

R_2^{UB} The upper bound estimate of the radius of curvature in the horizontal direction for the second, i.e. adjacent, buckle due to, e.g. laying operations. This parameter is used for sharing criterion analysis based on Section 6.5.2 of DNV-RP-F110.

Horizontal Imperfect.	
R_1^{LB} [m]	1500
R_2^{m} [m]	1750
R_2^{UB} [m]	2000

Figure 7 Format and typical values for "Horizontal Imperf." section

3.2.8 Hobbs Buckling Mode

The Hobbs buckling Mode corresponds to the different geometric geometries and boundary conditions that may apply to a pipeline section susceptible to global buckling. Detailed explanation of such can be found in /4/. An illustrative diagram showing the geometric appearance of each Hobbs Buckling mode has been reproduced from /4/ in Figure 8.

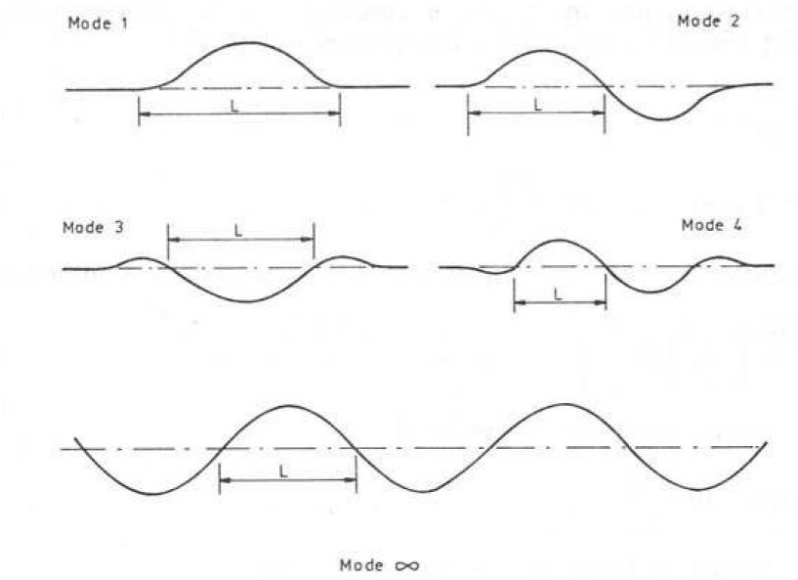


Figure 8 Illustration on Hobbs buckling mode (reproduced from /4/)

3.3 Viewing Results Output

3.3.1 Derived Parameters

These are intermediate results calculated automatically by **SIMBUCK** that govern the pipeline's global buckling response, as illustrated in Figure 9. These results are not editable and can be summarised as:

I	Second moment of area about the pipe's diameter of the pipeline's steel layer. Contribution from coating and concrete layers towards I is ignored. Error message-box will be prompted if this value turns out negative.
A_s	Cross-sectional area of the pipeline's steel layer. Error message-box will be prompted if this value turns out negative.
q_{sub}	Submerged unit weight of the pipeline per unit pipeline length. Error message-box will be prompted if this value turns out negative.
S_0	Effective axial force for a restrained pipeline (see /1/ for detailed calculation procedure). Error message-box will be prompted if this value turns out positive, i.e. pipeline under tension.

Derived Parameters	
I [m^4]	4.920E-04
A_s [m^2]	0.027356
q_{sub} [N/m]	1016
S_0 [N]	-4,583,254

Figure 9 Sample numerical results given in the "Main" sheet for derived parameters.

3.3.2 Pre buckle Assessment according to DNV-RP-F110

Results displayed in this section correspond to the pre-buckling assessment based on provisions in DNV-RP-F110 /1/. Analyses of the pipeline's buckling potential are based on Hobbs infinite mode solution /4/ assuming very high axial resistance. Lower bound lateral soil resistance is also assumed. Global buckling potential result is shown as either "Yes" or "No" based on **SIMBUCK**'s pre-buckling assessment modules as illustrated in Figure 10. If the result is "Yes", a message will be displayed underneath reading "Post buckle assessment performed", and **SIMBUCK** will continue with the post-buckling analyses modules. If the result is "No", the message will be "Post buckle assessment not relevant", and analyses will be terminated. Other relevant outputs in this section include:

S_∞	Minimum value of the axial force (compression as negative) away from the buckle based on Hobbs infinite mode, assuming very high axial friction and lower bound lateral soil resistance.
$S_{min,curve}$	Axial force (compression as negative) that triggers lateral slipping of the pipeline based on lower bound lateral soil resistance and lower bound imperfection radius of the first (i.e. primary) buckle.
$R_{min,eq}$	The imperfection radius corresponding to S_∞ /4/

Results					
1. Pre buckle assessment according to DNV-RP-F110					
S_{∞} [N]	-1,477,346		$S_{min,curve}$[N]	-822,875	
Buckling potential:		Yes	$R_{min,eq}$ [m]	1010	
Post buckle assessment performed.					

Figure 10 Sample numerical results given in the "Main" sheet for pre buckle assessment according to DNV-RP-F110.

3.3.3 Post buckle Assessment according to DNV-RP-F110

The post buckle assessment results are split into two parts: pipe integrity check and sharing criterion, as illustrated in Figure 11.

Pipe Integrity Check:

Global buckling is not a failure mode in itself, but can lead to other failure modes such as local buckling, fracture and fatigue. **SIMBUCK** outputs post-buckling analyses results so that other failure modes can be checked based on the provisions of DNV-OS-F101, DNV-RP-F111 and DNV-RP-F105. The output results can be summarised as:

Feed-in	The maximum allowable total feed-in length into the buckle /6/
L_{buckle}	"True", i.e. total, length of the buckle. This is not the same as Hobbs buckle length L /4/.
S_{post}	The post-buckling effective axial force (compression as negative) within the buckle
γ_c	An initial estimate on the load condition factor /1/. Please note that this is an indicative value only. Detailed evaluation of γ_c would require non-linear FE analyses /1/. An error message-box will be prompted if this value turns out greater than 1.0, i.e. design violates DNV-OS-F101 and DNV-RP-F110.
$L_{section}$	Maximum section length allowed between global buckles, i.e. the "pitch" length /6/. An error message-box will be prompted if this value turns out greater than 9999999 m, suggesting an infinite pitch length value. This is mostly likely due to either R_{ax} or M_{allow} being too high, or $p_i/\Delta T$ being too low.

Post-Buckling assessment					
2. Pipe Integrity Check			3. Sharing Criterion		
Feed-in [m]	44.55		$S_{r,1}$ [N]	-14,140	
L_{buckle} [m]	343		$S_{G,2}$ [N]	-72,695	
S_{post} [N]	-28,280		$\Delta S_{friction}$[N]	1,810,880	
γ_c [-]	0.86		Sharing criterion fulfilled.		
$L_{section}$ [m]	34875		L_{rock-c} [m]	-	
			$R_{2,req}^{m}$ [m]	7532	
			$R_{2,req}^{UB}$ [m]	9169	

Figure 11 Sample numerical results given in the "Main" sheet for pipe integrity check

Sharing Criterion:

Sharing of pipeline expansion into adjacent buckles is an effective way of releasing expansion potential into imperfections in the pipeline profile at various locations. If the benefit of sharing is taken into account, excessive feed-in to one of adjacent, pre-defined imperfection should be avoided. Two different input combinations are considered in this module: mean (i.e. best estimate) imperfection radius at second buckle with upper bound lateral soil resistance, and upper bound imperfection radius at second buckle with mean (i.e. best estimate) lateral soil resistance. Lower bound axial soil resistance is assumed in the calculation. **SIMBUCK** evaluates sharing criteria is based on Eq. 17 of DNV-RP-F110, and if violated, suggests a value for the required rock cover length and the required radius at adjacent buckles for sharing criteria to be fulfilled. A message "Sharing criterion violated" will also be displayed. If otherwise, the message will be "Sharing criterion fulfilled", and no required rock cover length value will be given. The output results in this section can be summarised as:

$S_{r,1}$	Post-buckle effective axial force in the first buckle, calculated assuming lower bound soil characteristics.
$S_{G,2}$	The upper bound value of the axial global buckling capacity force for the second buckle, calculated based on Eq. 18 in /1/.
$\Delta S_{friction}$	Axial friction force build up between the adjacent buckles calculated assuming lower bound soil characteristics
$L_{rock\text{-}c}$	Required rock cover length to ensure sharing of expansion
$R_{2,req}^{m}$	Required Best Estimate radius at second buckle to satisfy sharing criteria
$R_{2,req}^{UB}$	Required Upper Bound radius at second buckle to satisfy sharing criteria

3.3.4 Graphical Results

Two plots are also presented in the "Main" sheet, both updated automatically when the "*Calculate*" button is clicked. Illustrations of the two plots are shown in Figure 12 and Figure 13 respectively.

Figure 12 is to the left, underneath the numerical results. This graph shows how the Hobbs buckle length L varies with the axial force in the pipeline well away from the buckle P_0 depending on the selected Hobbs buckling mode. Detailed definition of L and P_0 can be found in /4/. L should not be confused with L_{buckle} or L_{pitch}, whereas P_0 is essentially the same as S_0 in **SIMBUCK** terminology.

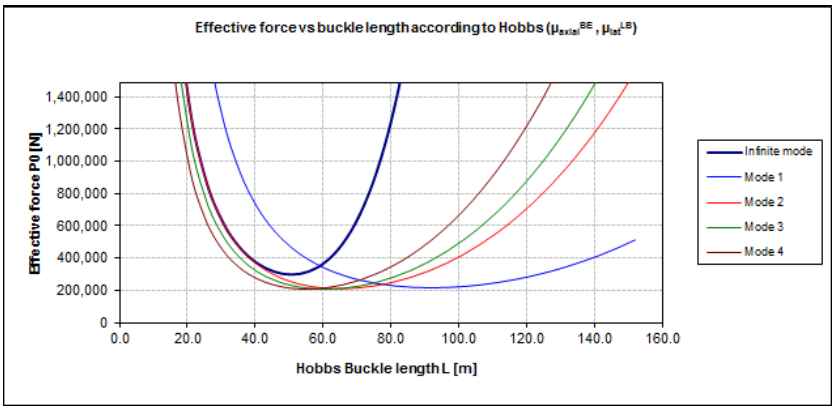


Figure 12 Sample plot given in the "Main" sheet showing the variation of effective force against buckle length based on Hobbs mode selection.

Figure 13 is to the right, underneath the numerical results. It illustrates how bending moment in the pipe changes with feed-in lengths. Allowable feed-in length is defined as when the dotted line ($M_{BE} \times \gamma_c \times \gamma_F$) crosses with the horizontal M_{Rd} line.

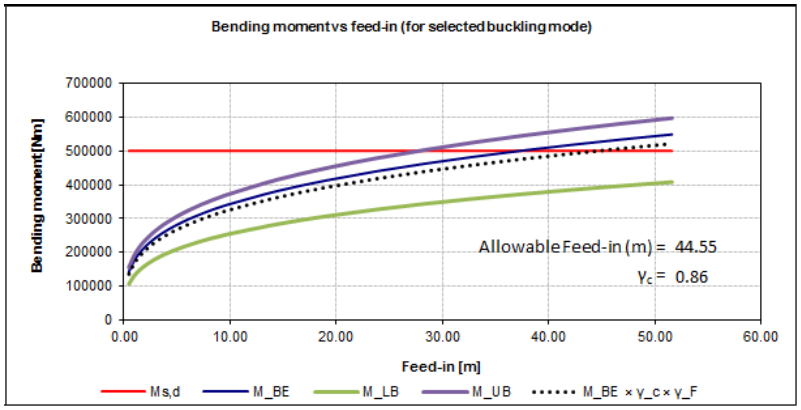


Figure 13 Sample plot given in the "Main" sheet showing the variation of bending moment versus feed-in length

3.3.5 Plots Sheet

When performing global buckling calculations, detailed numerical results are sometimes required to find out how feed-in lengths affect post-buckling analyses outputs. These results are displayed in the "Plots" sheet.

The "Plots" sheet contains two tables and three plots. The table on the top left, illustrated in Figure 14 below, displays the variation of bending moment, as well as pitch length, as a function of feed-in length. Only results corresponding to the user's selected Hobbs buckling mode are displayed ("Mode 1" in the case illustrated). The caption and contents of this table are updated automatically whenever the "*Calculate*" button is pressed on the "Main" sheet.

The table on the bottom left, illustrated in Figure 15, shows detailed analytical results based on Hobbs global buckling analyses /4/. All five Hobbs buckling mode, modes 1 to 4 plus the infinite mode, are considered simultaneously. Variation of the effective axial force away from the buckle, S_0, is displayed as a function of the Hobbs buckling length L for each mode. With this table available, the user can easily identify the value of L corresponding to the lowest S_0 for each Hobbs buckling mode and how $L_{section}$ is derived in **SIMBUCK**.

Three additional plots are also included in the "Plot" sheet. The plot at the top right is exactly the same as the one on the bottom right of the "Main" sheet, illustrating how bending moment varies with feed-in length. The one at the middle right shows the variation of section length as a function of feed-in length. The plot in the bottom right of the "plot" sheet displays section length as a function of bending moment. The last two plots are illustrated in Figure 16 and Figure 17 respectively.

Detailed numerical results

Detailed results for Hobbs' mode 3

Feed-in [m]	M^{BE} [Nm]	Section length [m]	M^{LB} [Nm]	M^{UB} [Nm]	$M^{BE} \times \gamma_c \times \gamma_F$ [Nm]
0.47	142965	370.25	106223	155540	135803
0.93	174276	736.66	129487	189606	165546
1.40	195682	1103.19	145391	212894	185879
1.86	212445	1470.38	157846	231132	201803
2.33	226431	1838.46	168238	246348	215088
2.79	238539	2207.57	177234	259521	226589
3.26	249280	2577.80	185214	271206	236792
3.72	258974	2949.22	192417	281753	246000
4.19	267837	3321.87	199002	291396	254420
4.65	276022	3695.81	205084	300301	262195
5.12	283642	4071.06	210745	308591	269433
5.58	290782	4447.67	216050	316359	276215
6.05	297509	4825.65	221048	323677	282605
6.51	303875	5205.04	225778	330604	288652
6.98	309925	5585.87	230273	337186	294399
7.44	315693	5968.16	234559	343461	299878
7.91	321208	6351.94	238657	349462	305117
8.37	326497	6737.23	242586	355216	310141
8.84	331580	7124.06	246363	360746	314969
9.30	336475	7512.44	250000	366071	319619
9.77	341198	7902.41	253509	371210	324106
14.42	381358	11894.62	283348	414903	362254
19.07	413072	16073.56	306911	449405	392378
23.72	439650	20470.10	326659	478322	417625
28.37	462726	25123.49	343804	503428	439546
33.03	483238	30085.81	359044	525743	459030
37.68	501778	35429.05	372819	545914	476641
42.33	518748	41258.09	385428	564377	492760
46.98	534433	47736.82	397082	581442	507660
51.63	549045	55148.89	407939	597339	521540

Figure 14 Sample numerical results given in the "Plot" sheet on the variation of bending moment and pitch length against feed-in length

Hobbs curves for effective axial force S_0

L	Infinite mode	Mode 1	Mode 2	Mode 3	Mode 4
5.1	22345941	45712522	22345941	19278957	15962025
10.1	5586490	11428132	5586494	4819750	3990524
15.2	2482937	5079187	2482979	2142226	1773748
20.3	1396926	2857130	1397111	1205544	998569
25.3	895001	1828838	895386	773094	641402
30.4	624196	1270657	624361	540094	450140
35.5	464803	934710	463143	402384	338779
40.6	368682	717520	361439	316712	271759
45.6	315461	569711	295425	262673	232458
50.7	297946	465338	252754	229774	212478
55.8	316635	389736	226615	212307	207404
60.8	377596	334144	213102	207079	214917
65.9	491756	293086	209933	212309	233882
71.0	674858	263027	215791	227054	263877
76.0	947763	241620	229957	250898	304925
81.1	1336964	227279	252101	283765	357348
86.2	1875244	218922	282152	325812	421670
91.2	2602419	215808	320223	377359	498567
96.3	3566182	217434	366554	438846	588824
101.4	4822999	223465	421486	510802	693312
106.5	6439087	233691	485429	593828	812973
111.5	8491438	247996	558856	688578	948806
116.6	11068912	266329	642283	795757	1101860
121.7	14273381	288696	736266	916104	1273226
126.7	18220926	315144	841395	1050396	1464035
131.8	23043101	345754	958285	1199439	1675452
136.9	28888237	380632	1087580	1364064	1908675
141.9	35922809	419906	1229942	1545129	2164933
147.0	44332859	463726	1386055	1743513	2445482
152.1	54325464	512253	1556623	1960118	2751606

Figure 15 Sample numerical results given in the "Plot" sheet on the variation of effective axial force against Hobbs buckling length

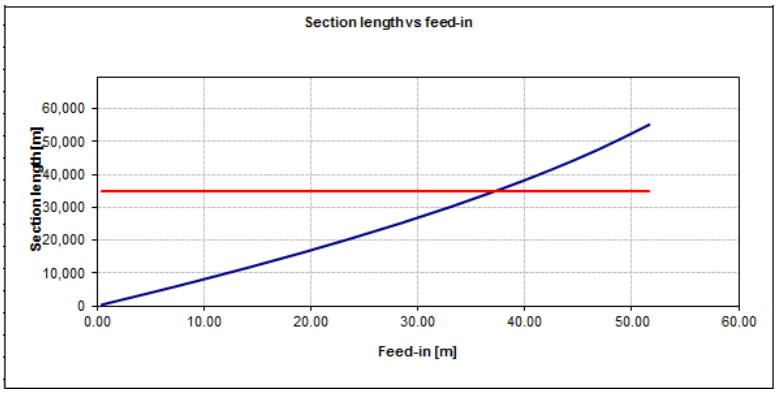


Figure 16 Sample plot given in the "Plot" sheet on the variation of section length as a function of feed-in length

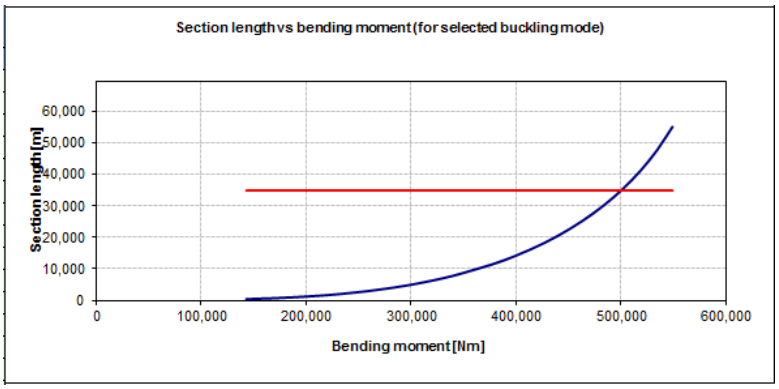


Figure 17 Sample plot given in the "Plot" sheet on the variation of section length as a function of bending moment

3.4 "Parametric runs" Sheet

3.4.1 General

SIMBUCK includes a powerful tool named "Parametric runs" that is capable of performing a large number of lateral buckling cases in one run, ideal for screening, performing sensitivity analyses, or simply analysing many separate cases and keeping all the input and output results together on a single data sheet, e.g. lateral buckling scenarios at different KP's along a pipeline with varying input such as section geometry, soil interaction and imperfection radii.

3.4.2 Functionality

To utilise the "Parametric runs" sheet, the "Parametric runs" on the "Main" sheet must first be clicked. **SIMBUCK** will issue a message-box stating that existing data on the "Parametric runs" sheet will be overwritten, i.e. the "Parametric runs" sheet will be cleared of all previous analyses results. The user should consider saving the previous data to a different Excel sheet to avoid losing results.

If the user selects "OK" to the message-box prompt, **SIMBUCK** will automatically jump to the "Parametric runs" sheet with all previous data cleared. The user should then copy-and-paste the data from the "Main" sheet into corresponding cells in the "Parametric runs" sheet, or input data into these cells directly. Input parameters can be found to the right of the row, starting with pipe's cross-sectional data and ending with Hobbs buckling mode.

Once all the data related to all the design cases to be considered have been entered, the user should then press the "*Calculate*" button on the "Parametric runs" sheet. **SIMBUCK** will then perform all the global buckling analyses, including pre-buckling assessment, post-buckling pipe integrity check and post-buckling sharing criterion, for all the cases inputted. Results are automatically presented to the left on the row.

All input parameters could be changed in the Parametric runs sheet. Therefore, the user is advised to press the "*Calculate*" button once more to avoid unintentional modification of the results before copying-and-pasting the data to a different Excel sheet.

A detailed example on how to work with the "Parametric runs" sheet is shown in Appendix A.

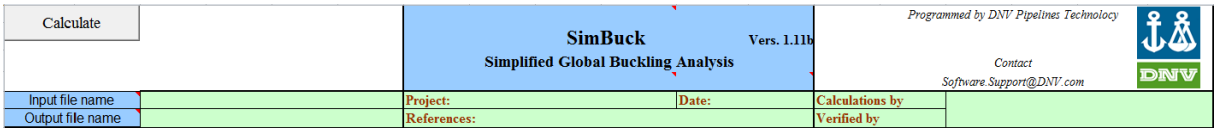


Figure 18 "Parametric runs" sheet heading area

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 clicked. This button does not affect the displayed results on other sheets, i.e. the "Main" sheet and the "Plot" sheet.

3.5 UHB sheet

3.5.1 General

SIMBUCK v1.12 features analytical upheaval buckling pre-design check functionality based on DNV-RP-F110 /1/ and DNV-RP-F109 /7/. The interface of this additional sheet is very similar to "Main", the structure of which is illustrated below.

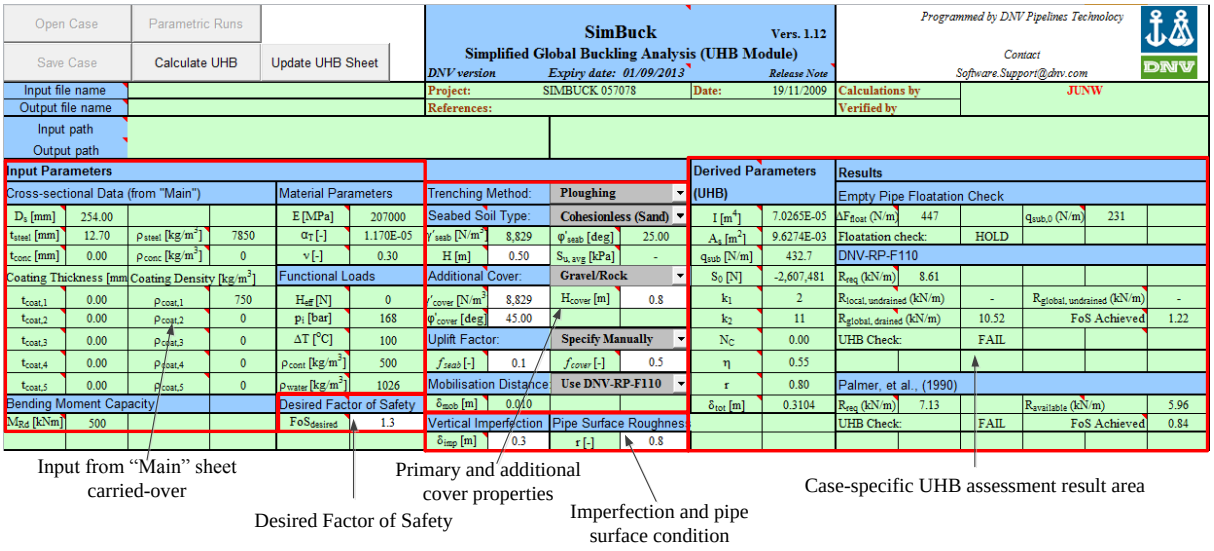


Figure 19 Interface for UHB extension module

3.5.2 Additional required inputs for UHB sheet

A few additional input parameters are required for the UHB sheets:

$FoS_{desired}$	The desired factor of safety. Factor of safety is defined as the ratio between available net downward soil resistance to the required downward resistance
Trenching Method	Method used in trenching which can be either "Jetting" or "Ploughing"
Seabed Soil Type	Backfilled seabed soil type (primary backfill) which can be "Cohesionless (Sand)", "Cohesionless (Rock)", or "Cohesive"
H	Primary backfill cover height (after consolidation) measured to pipe crown
$s_{u,\,avg}$	Average undrained shear strength across primary cover, activated when "Seabed Soil Type" is selected as "Cohesive"
Additional Cover	Additional cover placed on top of primary backfill, which can be either "Sand/Sand-Gravel Mix" or "Rock/Gravel"
γ'_{cover}	Submerged unit weight of additional cover material
H_{cover}	Height of additional cover
φ'_{cover}	Peak friction angle of cover
Uplift Factor	Specify options for inputting uplift factors, i.e. either "Use DNV-RP-F110" or "Specify Manually"
f_{seab}	Uplift factor for primary backfill, automatically calculated if "Use DNV-RP-F110" option is selected for "Uplift Factor"
f_{seab}	Uplift factor for additional cover, automatically calculated if "Use DNV-RP-F110" option is selected for "Uplift Factor"

Mobilisation Distance	Specify options for inputting mobilisation distance, i.e. either "Use DNV-RP-F110" or "Specify Manually"
δ_{mob}	Mobilisation distance at peak uplift resistance, automatically calculated if "Use DNV-RP-F110" option is selected for "Mobilisation Distance"
δ_{imp}	Equivalent prop-type imperfection height of as-laid pipe
Pipe surface Roughness	Surface roughness of the pipe's external surface, ranging from 0 for a perfectly smooth pipe to 1 for a perfectly rough pipe

3.5.3 Additional derived parameters for UHB sheet

A few additional derived parameters are automatically specified for the UHB sheets:

k_1, k_2	Fitting coefficients for calculating required downward resistance (DNV-RP-F110, sec. 5.3.3)
N_c	Bearing capacity coefficient for local undrained failure mode
η	Empirical correlation coefficient
r	Pipe surface roughness factor
δ_{tot}	Total mobilisation distance, i.e. sum of δ_{mob} and δ_{imp}

Like in the "Main" sheet, these derived parameters are automatically calculated.

3.5.4 UHB Results

Results from UHB check is split into three sections:

- Pipe floatation check against DNV-RP-F109
- UHB check against simplified deterministic solutions based on DNV-RP-F110
- UHB check against simplified deterministic solutions based on Palmer, et al., (1990) /8/.

3.5.4.1 Pipe floatation check against DNV-RP-F109

The floatation potential of the pipe is determined by its submerged unit weight in seawater and, if the seabed soil is subject to liquefaction, liquefied primary cover soil. Two calculated parameters are given in this section:

ΔF_{float}	Additional floatation force in liquefied seabed soil compared with in seawater
$q_{sub,0}$	Submerged unit weight of pipe in seawater when air-filled, e.g. during installation

If $q_{sub,0}$ is less than 0, the pipe floats in seawater, and the "Floatation check" returns a "FAIL" value. If $q_{sub,0}$ is less than ΔF_{float}, the pipe floats in liquefied seabed soil, and the "Floatation check" returns a "HOLD" value. If otherwise, "Floatation check" returns a "PASS" value.

3.5.4.2 UHB check against DNV-RP-F110

UHB potential of the pipe based on DNV-RP-F110 is determined by the following calculated parameters:

R_{req}	Required downward soil resistance based on DNV-RP-F110
$R_{local,undrained}$	Undrained peak soil resistance based on local undrained failure mode ("Cohesive" primary backfill only)
$R_{global,undrained}$	Undrained peak soil resistance based on global undrained failure

	mode ("Cohesive" primary backfill only)
$R_{global,\ drained}$	Drained peak soil resistance based on global drained failure mode (not applicable for "Cohesive" primary backfill trenched by "Jetting")
FoS Achieved	Achieved Factor of Safety based on DNV-RP-F110 and input parameters

If "FoS Achieved" is less than $FoS_{desired}$, then "UHB Check" returns a "FAIL" value, and vice versa.

3.5.4.3 UHB check against Palmer, et al., (1990) /8/

UHB potential of the pipe based on Palmer, et al., (1990) /8/ is determined by the following calculated parameters:

R_{req}	Required downward soil resistance based on Palmer, et al., (1990) /8/
$R_{available}$	Maximum available soil resistance interpreted from Palmer, et al., (1990)
$R_{global,undrained}$	Undrained peak soil resistance based on global undrained failure mode ("Cohesive" primary backfill only)
$R_{global,\ drained}$	Drained peak soil resistance based on global drained failure mode (not applicable for "Cohesive" primary backfill trenched by "Jetting")
FoS Achieved	Achieved Factor of Safety based on Palmer, et al., (1990) /8/ and input parameters

If "FoS Achieved" is less than "$FoS_{desired}$", then "UHB Check" returns a "FAIL" value, and vice versa.

3.5.5 Limitations on usage of the UHB extension module

Usage of the UHB extension module is subject to the following limitations:

- The implemented analytical method assumes linear elastic material behaviour
- The assumed imperfection is of the "prop" type, which may be inappropriate for some arbitrary imperfection shapes, esp. those featuring flat plateaus;
- The same soil upheaval resistance is assumed along the entire imperfection wavelength. This is not the case in sag bend regions, where the pipeline will have a tendency to move downwards, resulting in no soil contribution to uplift resistance;
- The implemented analytical method does not take the vertical soil resistance force-displacement curve into account, but bases the calculation on the available peak resistance. It is possible that the required mobilisation distance to maximum uplift resistance may exceed the maximum allowable vertical displacement to cause other failure modes, in which case the implemented analytical method is no longer governing;
- The implemented analytical method cannot account for cyclic loading and possible creep;
- The implemented analytical method does not consider axial movement, hence it is possible that buckles may not fail when considered individually using the implemented force-based approach, but can fail in a collective manner when axial movement and sharing is allowed.

Generally, the UHB extension module should be used only for pre-design checks. Detailed analyses involving FEA are recommended in detailed design.

4 LIST OF WARNING AND ERROR MESSAGES

A list of system messages and their possible causes are shown below. Unless explicitly stated, calculation resumes after the "OK" button is pressed.

- "The cell or chart that you are typing to change is protected and therefore read-only"
  - The cell value that you want to edit is not an input parameter and hence is not editable
- "The value you entered is not valid"
  - The cell value that you entered is outside the allowable boundary values of that particular cell
- "The friction coefficients must be greater than zero"
  - The friction coefficients you have entered contains negative or none-numeric values on the "Main" sheet
- "Please specify all required soil parameters."
  - Some friction coefficients are missing from the "Main" sheet
- "Please specify Htop."
  - The value of H_{top} is missing from the "Main" sheet
- "Hobbs mode shall be input as number less than 5. Calculations terminated"
  - SimBuck only considers Hobbs modes 1 to 4 plus the infinite mode. Higher order modes needs to be checked separately
- "Hobbs mode shall be input as number less than 5. Calculations terminated"
  - SimBuck only considers Hobbs modes 1 to 4 plus the infinite mode. Higher order modes needs to be checked separately
- "Warning: H/D range greater than 4. Suggested mobilisation distance value of 30 mm for rocky seabed may not be applicable."
  - The total cover:diameter ratio is greater than 4.0 for rocky backfill on the "UHB" sheet. The suggested 30mm mobilisation distance as in DNV-RP-F110 may not be applicable. It is recommended that you specify δ_{mob} directly in this case.
- "Please enter soil undrained shear strength value"
  - Value of $S_{u,avg}$ is missing from the "UHB" sheet for "Cohesive" "Seabed Soil Type"
- "Warning: Su is outside the recommended range of DNV-RP-F110."
  - The value of $S_{u,avg}$ is outside common boundaries for "Jetting" or "Ploughing" method for "Cohesive" "Seabed Soil Type"
- "Warning: H/D ratio is outside the recommended range of DNV-RP-F110. Results may not be conservative!"
  - The total cover:diameter ratio is outside the applicable range of the suggestions in DNV-RP-F110. More detailed check is needed.
- "Pipe floats in seawater when air filled. Please revise cross-sectional dimensions, e.g. concrete coating thickness."
  - "Floatation Check" returns "FAIL" as pipe floats in seawater.
- "Warning: Pipe may float if soil is liquifiable. Please consider revising cross-sectional dimensions, e.g. concrete coating thickness."

  - "Floatation Check" returns "HOLD" as pipe floats in liquefied seabed soil if liquefaction can happen.

- "Local undrained failure occurs. Mobilisation distance updated in accordance with DNV-RP-F110."
  - $R_{local,undrained}$ is less than R_{req} for "Cohesive" "Seabed Soil Type" based on DNV-RP-F110. The pipe is expected to penetrate through the soil cover, hence mobilisation distance and associated derived and calculated results have been updated to reflect such.
- "DNV-RP-F110 suggests that the required downward soil resistance is negative. UHB check PASSED based on DNV-RP-F110"
  - Pipe will be safe from UHB from its submerged weight based on DNV-RP-F110, hence no UHB check is necessary
- "Achieved Factor of Safety is lower than the desired Factor of Safety based on DNV-RP-F110. UHB check FAILED."
  - UHB check based on DNV-RP-F110 is not satisfied as $FoS_{desired}$ is not achieved.
- "Palmer et al., (1990) suggests that the required downward soil resistance is negative. UHB check PASSED based on Palmer, et al., (1990)"
  - Pipe will be safe from UHB from its submerged weight based on Palmer, et al., (1990), hence no UHB check is necessary
- "Achieved Factor of Safety is lower than the desired Factor of Safety based on Palmer, et al., (1990). UHB check FAILED."
  - UHB check based on Palmer, et al., (1990) is not satisfied as $FoS_{desired}$ is not achieved.
- "Total cover less than mobilisation distance. UHB check failed based on DNV-RP-F110."
  - Required mobilisation distance to peak uplift resistance is greater than the available cover.
- "The license period has expired. Please contact the DNV Software. Calculation function has been disabled."
  - Please contact DNV Software for updated license
- "The password check has failed. The calculation option in SimBuck has been deactivated"
  - Password you have entered is not correct.
- "Existing sheet Parametric runs will be over-written - consider renaming!"
  - Warning message as "Parametric Runs" sheet will be cleared of pre-existing contents
- "Parametric runs sheet does not exist. Procedure terminated."
  - Please check if "Parametric Runs" sheet is present in the software. If not, please contact DNV Software.

5 REFERENCES

/1/ DNV-RP-F110, *Global buckling of submarine pipelines – structural design due to high temperature / high pressure*, October 2007

/2/ SimBuck verification – Theory, report number 2013-1083, rev.02, 2013-08-20

/3/ Simbuck verification, report number 2013-1082, rev.02, 2013-08-20

/4/ R.E. Hobbs, *In-Service buckling of heated ppelines*, J. Transp. Engrg. Volume 110, Issue 2, pp. 175-189 (March/April 1984)

/5/ DNV-OS-F101, *Submarine pipeline systems*, August 2012

/6/ Røneid & Collberg, *Global buckling design of submarine pipelines – design performed based on DNV-RP-F110*, Proc. ASME 27th International Conference on Offshore Mechanics and Arctic Engineering, Estoril, Portugal, June 15-20, 2008

/7/ DNV-RP-F109, *On-Bottom Stability Design of Submarine Pipelines*, October 2010

/8/ Palmer, A.C., Ellinas, C.P., Richards, D.M., & Guijt, J. (1990). *Design of submarine pipelines against upheaval buckling*. 22nd Offshore Technology Conference, Houston, Texas, May 7-10, 1990: OTC 6335.

APPENDIX A
PARAMETRIC RUNS EXAMPLE CASE

This example is set up to illustrate a typical "Parametric runs" sheet usage. A pipeline section is to be analysed for global buckling potential. Along the pipeline profile, ΔT vary between 100 bar and 200 bar, whereas p_i varies between 10°C and 30°C. The pipeline geometric and material data are to be assumed constant along the section of interest, and have already been input into the **SIMBUCK** "Main" sheet, as shown in Figure 1 below. Only Hobbs buckling mode 1 is considered in this example, although it is advised that all 4 Hobbs buckling modes are checked for each case.

Input parameters									
Cross section data				Material Parameters		Geotechnical Parameters			
D_s [m]	0.4016			E [Pa]	2.07E+11	Exposed on seabed			
t_{steel} [m]	0.0230	ρ_{steel} [kg/m^3]	7850	α_T [-]	1.170E-05		LB	BE	UB
t_{conc} [m]	0.0000	ρ_{conc} [kg/m^3]	2250	ν [-]	0.30	μ_{axial} [-]	0.32	0.44	0.58
Coating Thickness [m]		Coating Density [kg/m^3]		Functional Loads		$\mu_{lateral}$ [-]	0.54	0.88	1.00
$t_{coat,1}$	0.0003	$\rho_{coat,1}$	1450	H_{eff} [N]	140,000	Inside Rock Cover		Typical clay	
$t_{coat,2}$	0.0077	$\rho_{coat,2}$	900	p_i [bar]		γ'_{seab} [N/m^3]	9,000	φ'_{seab} [deg]	30.0
$t_{coat,3}$	0.0000	$\rho_{coat,3}$	0	ΔT [°C]		$\mu_{seab,\,r}$ [-]	0.07	H_{TOP} [m]	1.50
$t_{coat,4}$	0.0000	$\rho_{coat,4}$	0	ρ_{cont} [kg/m^3]	200	μ_{fill} [-]	0.40	R_{ax} [N/m]	2,856
$t_{coat,5}$	0.0000	$\rho_{coat,5}$	0	ρ_{water} [kg/m^3]	1026	Horizontal Imperfect.		Hobbs Buckling Mode	
Bending moment capacity						R_1^{LB} [m]	1500	Mode 1	
M_{allow} [Nm]	1,043,000					R_2^{m} [m]	1750		
						R_2^{UB} [m]	2000		

Figure 1 Input parameters used in this design example

Step 1:

Confirm that all previous data on the "Parametric runs" sheet have been saved to another Excel sheet and can be overwritten. If so, press the "Parametric Runs" button on the "Main" sheet. A warning message box will be prompted, shown in Figure 2. Press "OK" to proceed.

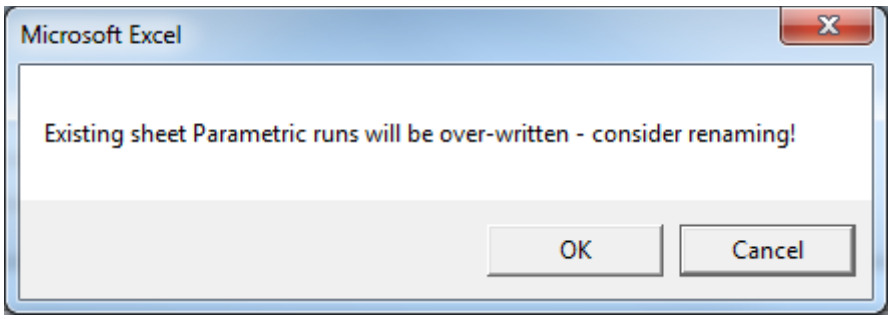


Figure 2 Warning message-box prompted when the "Parametric Runs" button on "Main" sheet is pressed

Step 2:

SIMBUCK then automatically directs the user to the "Parametric runs" sheet. Another message-box will also be prompted, suggesting to the user to insert or copy the values into the "Parametric runs" sheet, as shown in Figure 3. Press "OK" to continue.

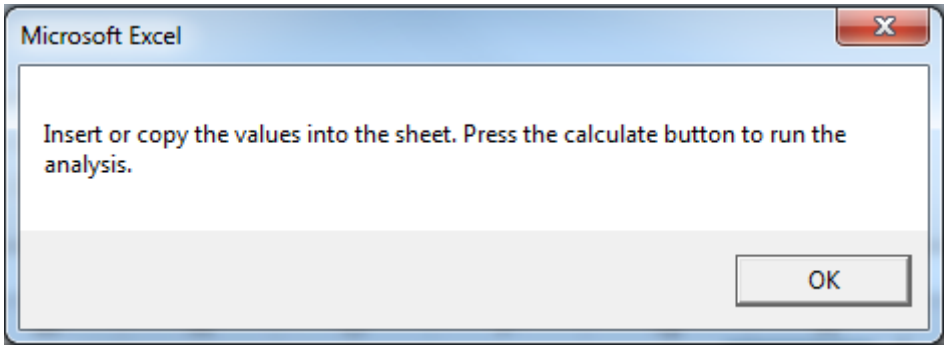


Figure 3 Message-box prompted when the user is directed automatically to the "Parametric runs" sheet

Step 3:

Scroll to the right of the "Parametric runs" sheet. It is evident that **SIMBUCK** has already copied-and-pasted the data from the "Main" sheet into corresponding cells in the "Parametric sheet", as shown in Figure 4. In this design example, 4 combinations of p_i (100 bar or 200 bar) and ΔT (10°C or 30°C) are to be considered. For easy inputting, copy the first row and paste it to the three blank rows underneath. Do not leave any blank rows in between. Then input the p_i and ΔT data for each row, i.e. design case, as shown in Figure 5.

Input parameters																							
Cross section data					Coating Thickness [m]					Coating Density [kg/m^3]					Bending r	Material Parameters			Functional Loads			
D_s [m]	t_{steel} [m]	t_{conc} [m]	ρ_{steel} [kg/m^3]	ρ_{conc} [kg/m^3]	$t_{coat,1}$	$t_{coat,2}$	$t_{coat,3}$	$t_{coat,4}$	$t_{coat,5}$	$\rho_{coat,1}$	$\rho_{coat,2}$	$\rho_{coat,3}$	$\rho_{coat,4}$	$\rho_{coat,5}$	M_{allow} [Nm]	E [Pa]	α_T [-]	ν [-]	H_{eff} [N]	p_i [bar]	ΔT [°C]	ρ_{con}
0.4016	0.0230	0.0000	7850	2250	0.0003	0.0077	0.0000	0.0000	0.0000	1450	900	0	0	0	1,043,000	2.07E+11	1.170E-05	0.30	140,000			

Figure 4 Automatically copied-and-pasted data (part) from "Main" sheet to "Parametric runs" sheet

Input parameters																							
Cross section data					Coating Thickness [m]					Coating Density [kg/m^3]					Bending r	Material Parameters			Functional Loads			
D_s [m]	t_{steel} [m]	t_{conc} [m]	ρ_{steel} [kg/m^3]	ρ_{conc} [kg/m^3]	$t_{coat,1}$	$t_{coat,2}$	$t_{coat,3}$	$t_{coat,4}$	$t_{coat,5}$	$\rho_{coat,1}$	$\rho_{coat,2}$	$\rho_{coat,3}$	$\rho_{coat,4}$	$\rho_{coat,5}$	M_{allow} [Nm]	E [Pa]	α_T [-]	ν [-]	H_{eff} [N]	p_i [bar]	ΔT [°C]	ρ_{con}
0.4016	0.0230	0.0000	7850	2250	0.0003	0.0077	0.0000	0.0000	0.0000	1450	900	0	0	0	1,043,000	2.07E+11	1.170E-05	0.30	140,000	100	10	
0.4016	0.0230	0.0000	7850	2250	0.0003	0.0077	0.0000	0.0000	0.0000	1450	900	0	0	0	1,043,000	2.07E+11	1.170E-05	0.30	140,000	100	30	
0.4016	0.0230	0.0000	7850	2250	0.0003	0.0077	0.0000	0.0000	0.0000	1450	900	0	0	0	1,043,000	2.07E+11	1.170E-05	0.30	140,000	200	10	
0.4016	0.0230	0.0000	7850	2250	0.0003	0.0077	0.0000	0.0000	0.0000	1450	900	0	0	0	1,043,000	2.07E+11	1.170E-05	0.30	140,000	200	30	

Figure 5 Generate input data for additional cases

Step 4:

Check that all data have been entered correctly, and if so, press the "*Calculate*" button on the "Parametric runs" sheet. Analyses results will be displayed for all four cases, as shown in Figure 6. As illustrated above, the "Parametric runs" sheet is a very illustrative and useful tool. **SIMBUCK** provides the possibility of performing several global buckling calculations at the same time, reducing the time for analyses by a significant factor.

Results													Derived Parameters			
1. Pre buckle assessment				2. Pipe integrity check					3. Sharing criterion							
S_{ie} [N]	Buckling po	$S_{min,curve}$[N]	$R_{min,eq}$ [m]	Feed-in [m]	L_{buckle} [m]	S_{buckle} [N]	γ_c [-]	L_{pitch} [m]	$S_{r,1}$ [N]	$S_{G,2}$ [N]	$\Delta S_{friction}$[N]	Lrock-c [m]	I [m^4]	A_s [m^2]	q_{sub} [N/m]	S_0 [N]
-1477346	No	-822875	1009.894	0	0	0	0	0	0	0	0	0	0.000492	0.027356	1015.895	-919802.3
-1477346	Yes	-822875	1009.894	0.759254	129.6759	-489078	0.8339	2815.678	-300115.76	-1777817	915338.8	196.9203	0.000492	0.027356	1015.895	-2244890
-1477346	No	-822875	1009.894	0	0	0	0	0	0	0	0	0	0.000492	0.027356	1015.895	-1317061
-1477346	Yes	-822875	1009.894	0.759254	129.6759	-489078	0.8339	2175.563	-300115.76	-1777817	707246.2	269.7873	0.000492	0.027356	1015.895	-2642148

Figure 6 Output results for all four design cases