Pipeline On-Bottom Stability Software Version 4.0

USER MANUAL

Project: SPDA-1-3 Industry High Value Objectives

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Prepared for the

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PRCI public reports are available on http://www.prci.org

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Nomenclature and Abbreviation

Abbreviations

AGA	American Gas Association
ASM	Absolute Stability Method
BUP	Build-up Parameter
DNV	Det Norske Veritas
DOF	Degree of Freedom
FOS	Factor of Safety
JONSWAP	Joint North Sea Wave Project
MWL	Mean Water Level
OBS	On-Bottom Stability
PRCI	Pipeline Research Council International
PSI	Pipe-Soil Interaction
SDO	Single Design Oscillation
SI	The International System of Units
UF	Utilization Factor
UI	User Interface
V&L	Verley & Lund Clay model
V&S	Verley and Sotberg Sand model

Notations

Δt	Time step increment

a	Wave amplitude when referring to wave physical properties Mixing constant when referring to bi-modal directional spectra
b	Buoyancy force
c	Wave propagation speed
D or OD	Outer Diameter
$D(\Theta)$	Directional spreading function
d_{50}	Seabed mean grain size
deg	Degrees
D_r	Soil relative density
e, e_{max}, e_{min}	Cohesion-less soil void ratios
EPS	Tolerance parameter
f	Wave frequency
f_0	Peak frequency (frequency of spectral function maximum)
f_{cutoff}	Highest frequency cutoff
F_D	Drag force
F_H	History-dependent soil resistance
F_I	Inertia force
F_L	Lift force
F_R	Soil passive resistance
ft	Feet
F_Y^*	Peak horizontal load
F_Z^*	Peak vertical load
$G^k(I)$	Convergence parameter at the k^{th} iteration
GPa	Gigapascal
H	Wave height

h	Water depth
in	Inch
k	Wave number when referring to wave properties Solve loop iteration number when referring to time domain dynamic simulation solving
k	Pipe surface roughness
K^*	Keulegan-Carpenter number for a single design oscillation (usage in ASM)
KC	Keulegan-Carpenter number
kPa	Kilopascal
L	Wave length
lbf	Pound force
m	meters
M^*	Steady to oscillatory velocity ratio for single design oscillation (usage in ASM)
min	Minutes
mm	Millimeters
M_x	x^{th} spectral moment of the wave spectrum
N	Newtons
NC	Number of nodes
$n_{time\ steps}$	Number of time steps
Pa	Pascal
pcf	Pounds per cubic feet
psf	Pounds per square foot
psi	Pounds per square inch
$r_{perm,I}$, $r_{pen,I}$, $r_{tr,I}$	Reduction factor for hydrodynamic peak load in direction I, for the components of permeable seabed, pipe penetration, and pipe trenching (usage in ASM)
$r_{tot,I}$	Reduction factor for hydrodynamic peak load in direction I (usage in ASM)

s	Wave steepness
$S(f)$	Sea surface frequency spectral density
$S(f,\Theta)$	Directional wave (sea surface) spectral density
sec or s	Seconds
T	Wave period
t	Time
T^*	Period associated with single design oscillation (usage in ASM)
T_p	Wave peak period
$t_{simulation}$	Simulation time
T_u	Wave zero up-crossing period
T_z	Wave zero crossing period
$U(z)$	Steady current as a function of height above seabed (sometimes V(z) in DNV nomenclature)
U^*	Oscillatory velocity amplitude for single design oscillation, perpendicular to pipeline (usage in ASM)
$U_{1/x}$	Wave velocity calculated from the mean height of the highest $1/x^{th}$ of the waves
$U^k(I,J)$	Deflection of node J in DOF I
U^k_{max}	Maximum deflection at iteration k in DOF I
U_r	Steady current velocity at reference height
U_s, U_{SIG}	Significant wave velocity
U_{UD}	User defined steady current velocity
V^*	Steady current velocity associated with design oscillation, perpendicular to pipeline (usage in ASM)
W_s, w_s	Submerged pipe weight
Y_x	Pipe oscillation amplitude
z_0	Seabed roughness
z_p, z_{pi}, z_{pm}	Total pipe penetration, initial pipe penetration, and penetration due to pipe movement

z_r	Steady current reference height
z_t	Trench depth
α	Ratio of steady current to oscillatory current
$\Gamma(\lambda)$	Gamma function
γ_{SC}	Safety factor for absolute lateral stability
γ_w	Safety factor for buoyancy
η	Surface elevation from MWL
θ_c	Steady current attack angle
λ	Spectral density function width parameter
μ	Coefficient of friction
ρ_w	Seawater density
σ	standard deviation of water surface elevation (when referring to statistics)
ω	Wave angular frequency
ω_p	Wave angular spectral peak frequency

1 Welcome

This manual presents the functionalities and the workflow of the upgraded PRCI On-Bottom Stability (OBS) software. The OBS software, also known as AGA software, has been upgraded by INTECSEA Over the last few years. This release is the first issue of the upgraded software to the public after the latest issue of Version 3.0. A summary of the main changes to the software include:

- General:
    - Complete rewrite on the graphical user interface
    - Storing projects models in a database format for easy archiving and handling
    - Changing the hard-coded parameters to user defined parameters
    - Addition of plotting features
    - Addition of the absolute lateral static stability code check module following DNV-RP-F109 (2011)
- Level 1:
    - Addition of the logarithmic boundary layer formulation
    - Addition of the marine growth specification option
- Absolute Stability Method:
    - This is a new module added based on the requests from users. The module conducts absolute stability check following methodology presented in the DNV-RP-F109 version 2011 [2].
- Level 2:
    - Addition of the logarithmic boundary layer formulation
    - Addition of the marine growth specification option
    - Addition of the JONSWAP spectrum
    - Addition of the Verley and Lund for Clay soils
    - Addition of the Verley and Sotberg Sand soils
    - Resolving the reported bug i.e. excessive embedment prediction in current dominated conditions
    - Addition of parametric run functionality for pipe wall thickness and water depth
- Level 3:
    - Addition of the logarithmic boundary layer formulation
    - Addition of the JONSWAP spectrum
    - Addition of running multiple wave seeds per run
    - Addition of plotting and reporting per wave seed for multiple seeds runs

The new graphical user interface was designed with the intent to maintain the overall layout and workflow of the previous version for the additional comfort of the active users to get familiarized with the new features as they begin to use the new software.

A significant series of verification tests were undertaken for the new additions especially for new developments of Level 2. A summary of finding was published in [18].

In production of this manual several previously generated reports for PRCI, including the works done by Kellogg Brown & Root (KBR) Inc. have been used. The usage includes direct use of texts and pictures that are still applicable to the upgraded version of the software. A list of reference reports is presented in the reference section of this manual.

The main components of the software include:

1.1 Level 1

Level 1 is the simplest of the three levels and is only used to get a feel of what has been done historically. The problem is considered to be static and the dynamic effects are not allowed. As a result, the pipeline is required to remain stationary on the seabed and the stability design criterion is that "no movement" occurs. The results of the analysis give a required submerged weight or coating thickness in order for the no movement criterion to be met. Note that this method uses a single wave with Morison's force equation, and may allow some movement if unconservative coefficients or a wave smaller than the maximum wave is used. It is anticipated that Level 1 analysis will be performed under the following circumstances.

- To obtain a simple, quick, reasonable estimate of historical concrete coating requirements
- To check Level 2 or Level 3 analysis against a more conservative yardstick, used in earlier designs.

1.2 Absolute Stability Method

The Absolute Stability Method (ASM) module performs a static stability analysis as per guidelines in DNV-RP-F109 [2]. The module incorporates various elements such as:

- Application of safety class information considering geographic location, operating / temporary conditions, and seabed type
- ‘Extreme horizontal’ and ‘extreme vertical’ forces applied together on pipeline
- Soil friction and passive resistance model

Among other informational outputs, this analysis calculates the lateral and horizontal utilization factors (UFs) for pipeline absolute stability.

1.3 Level 2

The Level 2 design tool is used to determine weight coating requirements based on the latest pipeline hydrodynamic and soil force formulations. It provides the designer a simplified method for estimating pipe embedment and the resulting soil resistance. This program should be used for all preliminary designs, and resulting concrete thicknesses should be adequate for most final designs.

1.4 Level 3

In a Level 3 analysis, a two-dimensional dynamic pipeline model is used to calculate stresses and deflections in the line during storm conditions. Input parameters are specified over a grid taking account of lengthwise variations along the pipeline route. A time history of the on-bottom current velocities and wave kinematics is simulated by the program to model the pipeline behavior in irregular seas. The pipeline model considers the impact of end restraints such as risers and anchor points by modeling them as a series of springs at the ends of the pipeline.

It is anticipated that this type of analysis will be used to check and/or calibrate designs produced using a Level 2 analysis, particularly where the Level 2 assumptions do not accurately represent the actual situation. The special features may be the ends restraints, other structural restraints, cases where the axial tension could develop, or if excessive pipe movements are allowed.

2 Getting Started

This section provides a quick overview of the user interface which shows all basic components of software and explain the general procedure of performing analysis.

2.1 Launching the Software

The software main page is opened through the shortcut to PRCI in the program files or on the desktop and appears as shown in Figure 2-1.

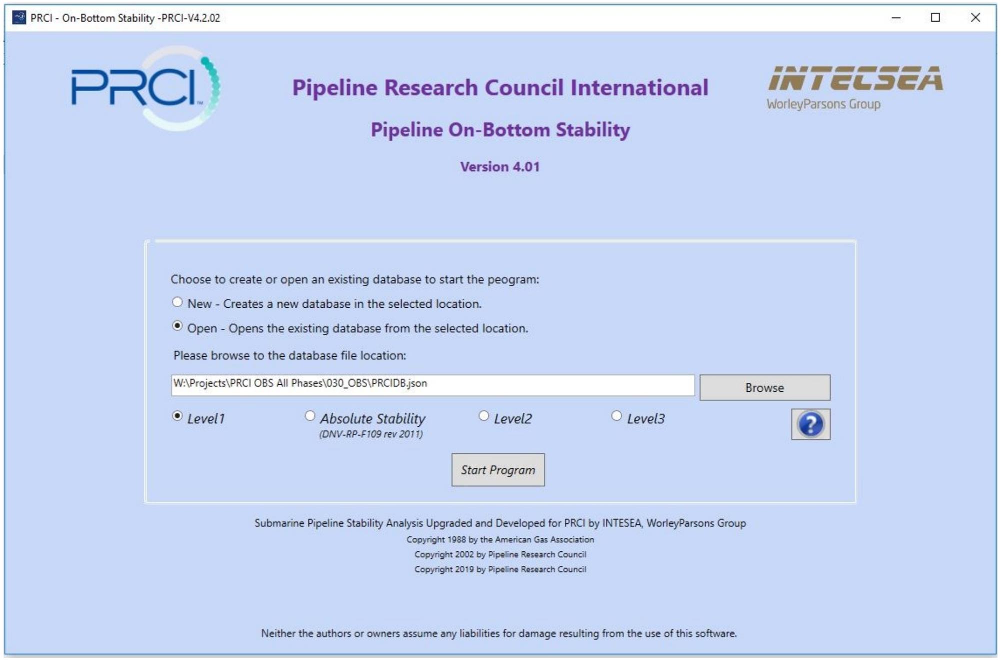


Figure 2-1: PRCI Pipeline On-Bottom Stability Software Start-Up Window

2.1.1 Creating a New Database

To create a new database for analysis, select the **New** radio button option. Then press the **Browse** button to open a separate window with a prompt to save the new analysis database (Figure 2-2**Error! Reference source not found.**).

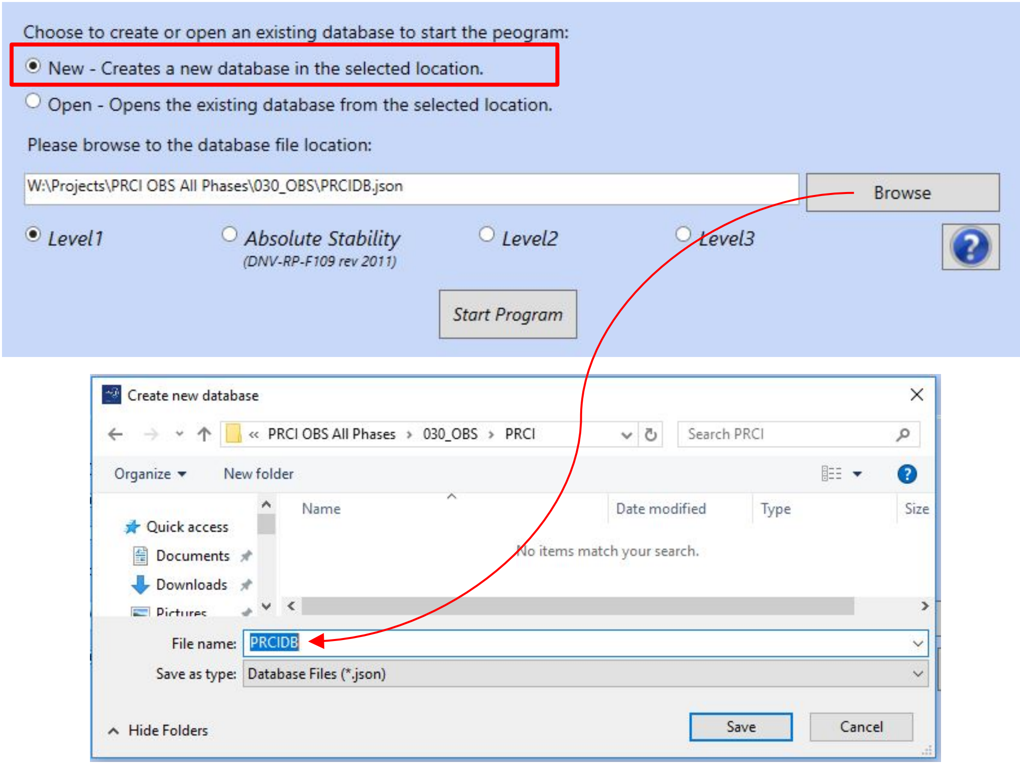


Figure 2-2: New Database Save Location

Browse to the desired directory and press the **Save** button to store the database in the selected location. Now that the database has been created in the required location, the main page radio button option will switch to **Open**. Select the analysis level and press the **Start Program** button.

2.1.2 Opening an Existing Analysis Database

Select the **Open** radio button option on the main page, navigate to the database location via **Browse** button and select the level of analysis. Then press the **Start Program** button to load the analysis tabs.

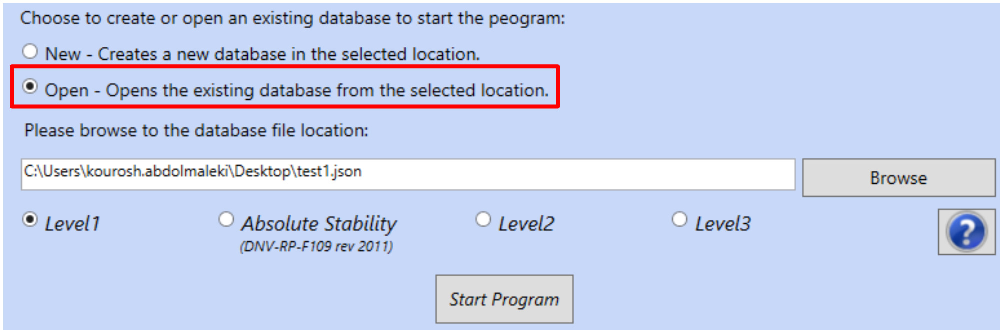


Figure 2-3: PRCI Pipeline On-Bottom Stability Software Start-Up Window ('Open' Option Selected)

2.2 Main Window

After launching the software and selecting the analysis, main window of the chosen analysis would appear. Main window is designed to cover all tools for managing cases, defining parameters, running, and generating reports and plots for different levels. All the operations are described throughout the manual, however, the more common items are presented here. These include navigation panel, toolbar, case navigation panel, input data tab, case definition, unit conversion, input data range, and status summary.

The Figure 2-4 illustrates an example of main window of PRCI software for a Level 1 analysis. This layout is more or less repeated in other levels of the software, albeit with different input options as detailed in the relevant sections provided for each analysis level.

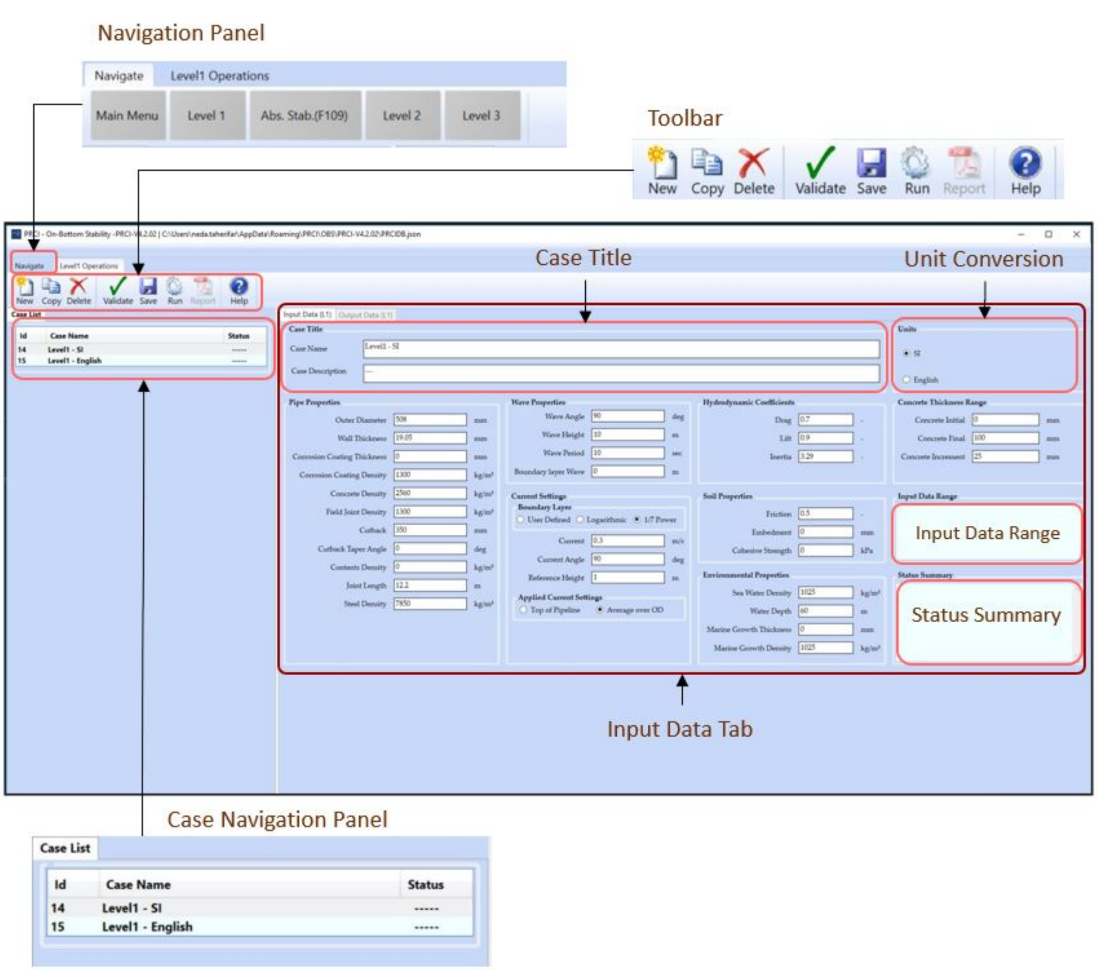


Figure 2-4: PRCI Pipeline On-Bottom Stability Software Main Page

2.2.1 Navigation Panel

The Navigate tab (Figure 2-5) provides a quick access to all levels of analysis as well as the software Main Menu. By clicking the Main Menu button, the software returns to Main Menu where users can load other projects or select other levels of analyses. Upon clicking other buttons in this tab, the software would switch directly to the corresponding analysis level.

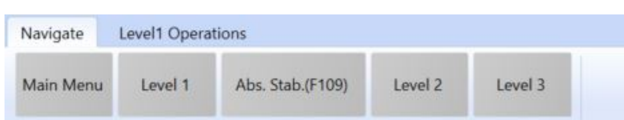


Figure 2-5: Navigation Panel

2.2.2 Toolbar Descriptions

The Toolbar (Figure 2-6) includes standard commands for case-based operations such as creating, copying, deleting, saving, validating, running, and generating reports and plots.

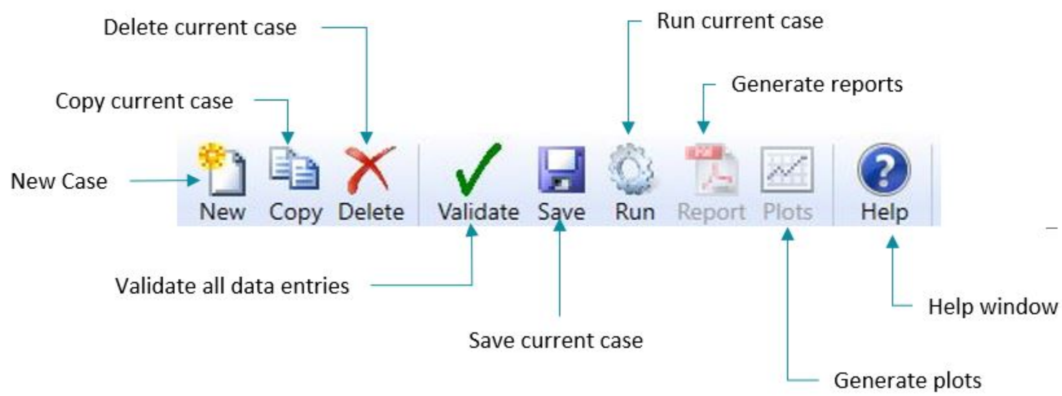


Figure 2-6:Toolbar Commands

Table 2-1 presents descriptions of the various tools available in the software ribbon and common area.

Table 2-1: Toolbar Descriptions

Item	Description
New	Creates a new file with default values for all fields. A default file name, “New…” is assigned to each new file. The Project Name in the “Project Title” field must be edited to change the file name. Project Name stands as the file name. Once Project Name is entered it shall be Added to the project list before it can be run.
Copy	Creates a copy of any chosen file. This option may be used to carry out parametric runs, for example.
Validate	Checks all data entries and raise errors or warning messages if it finds any issue in the input dataset. The message “All entries are validated” ensures the dataset is fine and user can safely proceed to Save or Run the case.
Save	Saves the changes made in the file. The message “Saved the Data Successfully” in the Status Summary field ensures the changes made have been updated in the database file.
Delete	Deletes the selected case together with its outputs.
Run	Runs the active case. When the button clicked, the data validation and saving takes place automatically. If there are warnings, the run will still proceed but if there is an error the run is aborted. Hence, to resolve the warnings before the run takes place, the user must use Validate button prior to running the case.
Report	Exports various outputs generated in PDF format.
Plot	Gives the graphical representation of the results which can be saved as PNG by user for reporting purposes
Help	Directs the user to help window

2.2.3 Case Navigation Panel

All available Cases are displayed in Case Navigation Panel (Figure 2-4**Error! Reference source not found.**). The user can select a Case from this field to work on. Associated parameters' values are displayed in Input fields once a selection is made.

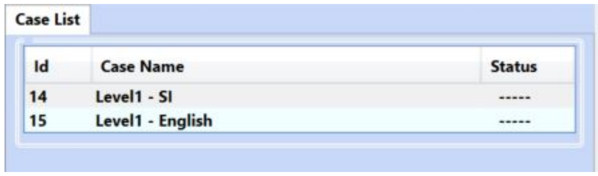


Figure 2-7:Case Navigation Panel

The Case List shows three main fields (**Figure 2-7Error! Reference source not found.**):

- Id: is a unique identifying number that database assigns to each individual case. The generated Input/output files are saved in a subdirectory identifiable by Id number as follows:

  <Project Folder>\Results-Filename\Level1\Id

  The Filename is the name of created database (e.g. Example in the present case). Hence, the output files of Example Case (Id = 14) is located in:

  <Project Folder>\Results-Example\Level1\14

- Case Name: is the name of created cases.
- Status: defines if the analysis for the case has been performed. It has two different states:

  '------': No analysis is performed yet.

  'Done': Analysis is completed.

The Case List is sortable as well. Users can sort the cases based on any of the three fields both in ascending and descending orders by clicking on the headers.

2.2.4 Input Data Tab

Input data tab, as shown in Figure 2-4, provides the entry data areas to define, modify, and display all input parameters of the selected case.

2.2.4.1 Case Title

- Case Name: This field can be used to enter/modify the Case Name. Up to 50 alphanumeric characters (including special characters) can be entered in this field.
- Case Description: A short description of the case can be entered, such as pipeline details and other crucial data. Up to 50 alphanumeric characters (including special characters) can be entered in this field (Figure 2-8).

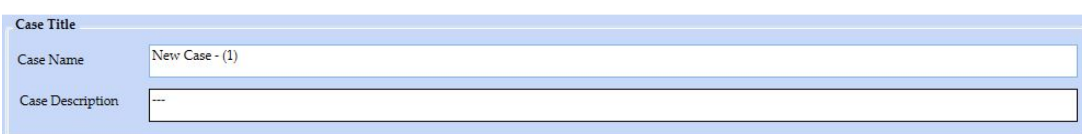


Figure 2-8: Case Title Information

2.2.4.2 Unit Conversion

The software allows specification of the following unit systems for display of the input and output fields (Figure 2-9):

- SI (kilograms, meters and millimeters)
- English (pounds, feet and inches)

Upon changing the selection of the unit system, all inputs are converted automatically.

Figure 2-9:Unit Conversion

2.2.4.3 Input Data Range

When an input field is selected, the area displays range and bound information for the minimum, maximum and default values of the current parameter selection. Figure 2-10 shows input data range for the Cohesive Strength field selection.

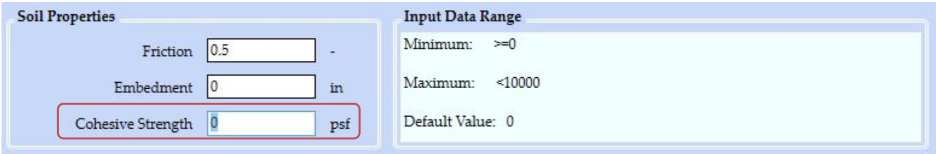


Figure 2-10: Input Field Selection and Input Data Range Information

2.2.4.4 Status Summary

This field displays the status of any action carried out in the module such as error, successful analysis runs, and etc. (Figure 2-11).

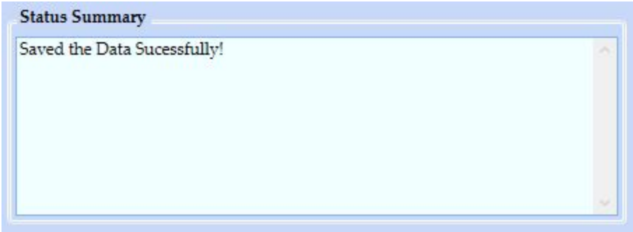


Figure 2-11: Status Summary

2.2.4.5 Data Entry

The input data can be specified, with the input fields selectable by mouse clicks, and able to be moved through by the standard TAB (forward) and SHIFT+TAB (backward) keyboard shortcuts.

The Input Data Range field will display the minimum, maximum and default value for each numerical input, as well as the inclusiveness of the upper and lower bounds (Figure 2-10).

2.3 Procedure of Setting up a Case for Analysis

This section will briefly run through an example analysis, covering generic aspects such as the creation, setup, parameter definition, running, and report generation. The example is given for a Level 1 analysis to serve as a simple introduction to the PRCI software (as mention in 2.2).

2.3.1 Creating new Case

For a blank database file, the Case Navigation area is initially filled with two default cases (one in English unit and the other in SI unit). Users can directly run these default cases, or they can create a copy of these cases in order to create a new case.

Alternatively, to create a fresh new case within the database (and for later adding more cases within the same database), press the **New** button at the very left of the toolbar (Figure 2-6), which will open the **Unit Settings** dialog (Figure 2-12).

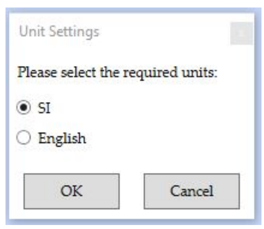


Figure 2-12: Specify Unit Settings

Select the desired system of units (this example has selected SI units). By clicking **OK** button, a new case would be created in the database with default entry values (Figure 2-13) and a default name of "New Case – (1)". The Case Description field remains empty. These two fields can be changed and saved, as shown in Figure 2-8.

The new case would be added to the Case List Table.

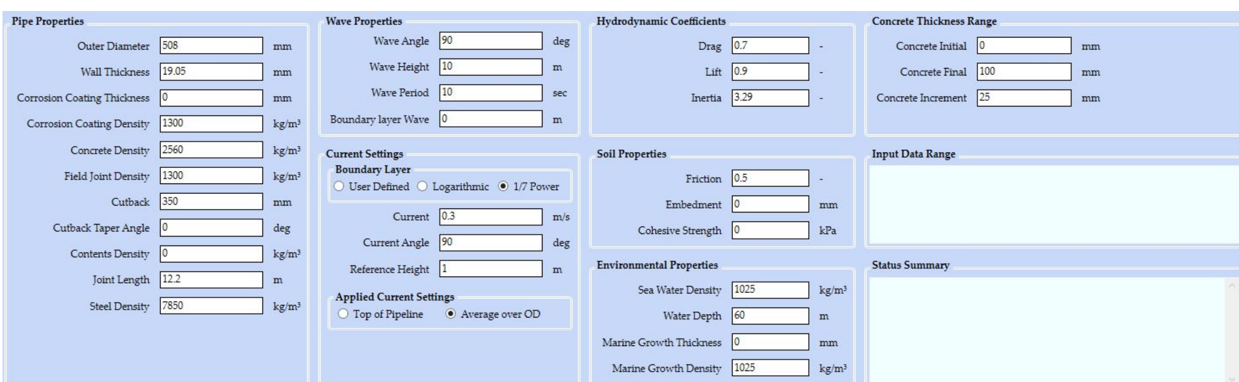


Figure 2-13: New Case with default values

2.3.2 Date Entry

If a value is entered outside the allowable bounds (or in a different format than required, e.g. text when a number is requested) as indicated in the Input Data Range field, once the Validate button is clicked

(Figure 2-6), a corresponding error message would appear in the Status Summary field (Figure 2-14). Validate button can be used regularly to perform a basic check on correctness of data entries. It is also recommended to use this button prior to saving and/or running the case. As shown in Figure 2-14, the error message in Status Summary, specifically declares which field(s) is problematic.

However, the validation check mostly performs a single entry check and does not always guarantee a smooth run for a set of input data. This is because, depending on selected analysis, a successful run depends on the interactions of many parameters and iterative solutions of some equations.

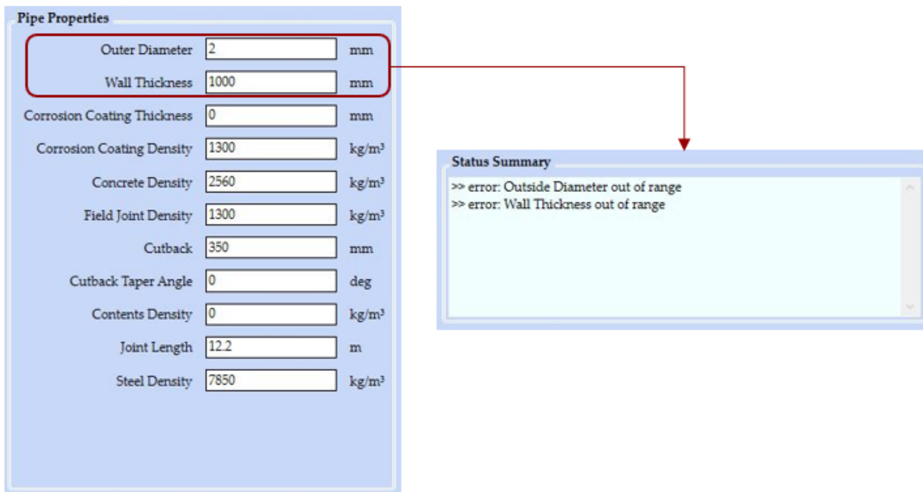


Figure 2-14: Use Validate button to check correctness of data entries

Some of the input data are optional where the user can choose via selecting a radio button. Depending on the selection, additional fields may appear in the input tab. For example, see choices in the **Current Settings** box of **Input Tab** as presented in Figure 2-15. The **User Defined** option displays only two required entries (**Current** and **Current Angle**). By selecting **1/7 Power**, additional entry fields would appear, while selecting the **Logarithmic Boundary Layer** formulation, would add an extra field to specify **Seabed Roughness**.

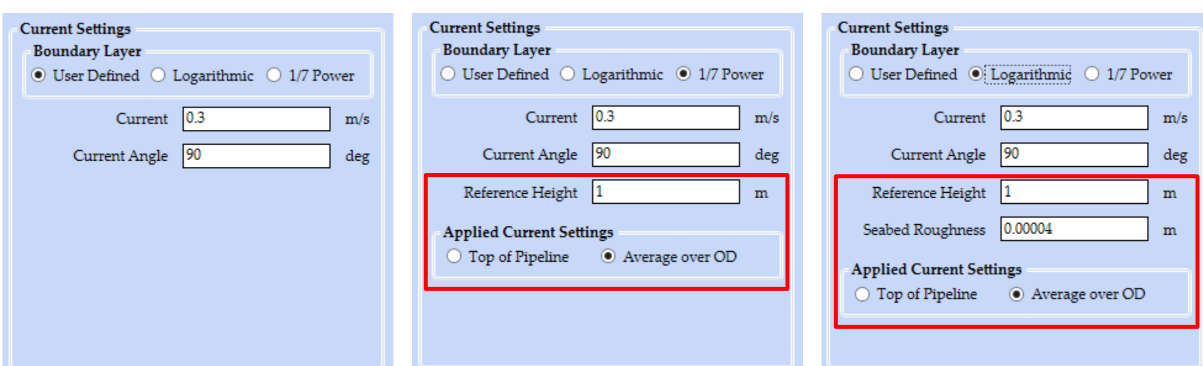


Figure 2-15: Example Current Setting for additional input data requirement depending on selection of options provided in the radio buttons. (Left: User Defined, requires minimum inputs, Middle: 1/7 Power Boundary Layer, Right: Logarithmic Boundary Layer)

2.3.3 Running the Analysis and Creating Reports

Now that all the input data is specified, and the project is validated and saved, press the **Run** button to run the analysis (Figure 2-6).

The software will compute the results, and the **Output Data (L1)** tab is displayed when the run has completed (Figure 2-16). Accordingly, the status of the case in **Case List** would turn to "**Done**" as shown in Figure 2-16.

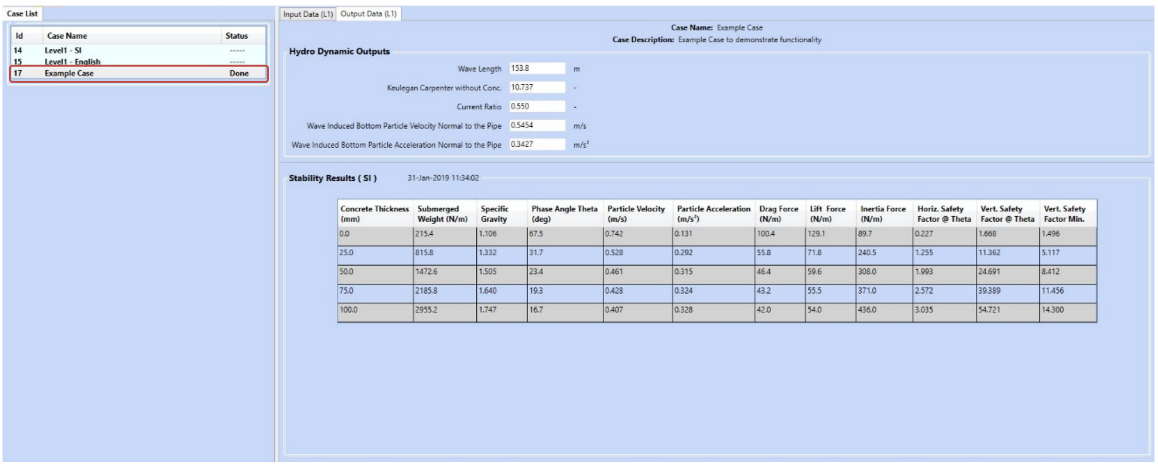


Figure 2-16: Output Data (L1) Tab for the Completed Analysis

As the Run completes successfully, a PDF report file would also be generated automatically. The PDF file could be opened through the **Report** button (Figure 2-6).

2.3.4 Copying and Deleting Case

Upon completion of a run and returning to the **Input Data** tab (by clicking on the tab list or by using the standard CTRL+TAB and CTRL+SHIFT+TAB keyboard shortcuts) it is noticed that the **Input Data** entries has turned to **Read-Only** (Figure 2-17). This occurs in order to ensure that the input data cannot be changed accidently and remain in consistent with the output data. The only fields that can be altered and saved are the **Case Name** and **Case Description**. If users want to alter some entries of the case and see the outputs, they need to create a **Copy** of the case and alter the entries and re-Run the case. This approach might improve in the future upgrades of the software.

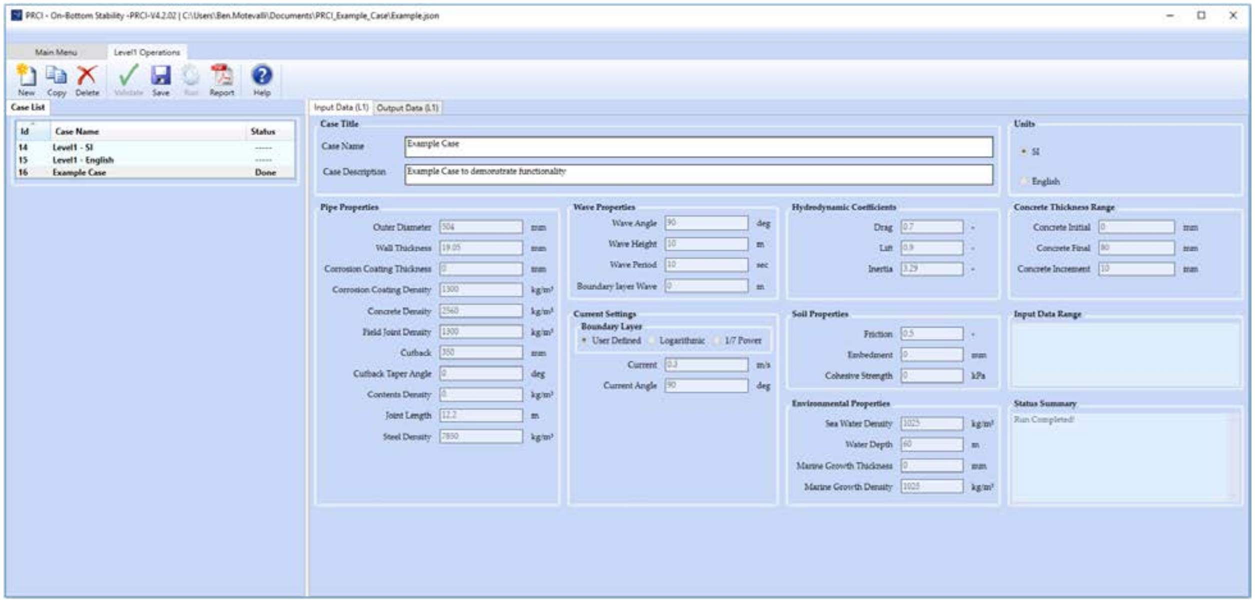


Figure 2-17: Input Data turns to Read-Only after Run

Creating a copy of selected case in the **List Case** field is accomplished by clicking the **Copy** button (Figure 2-6). This may be particularly useful for running sensitivity cases on single parameters, or for keeping a backup of a working project when attempting to determine other viable input options. The copied case will, by default, carry the parent case name with "-Copy1)" appended.

A Case may also be removed from the database by selecting them in the **List Case** field and pressing the **Delete** button, which prompts a confirmation message before case deletion (Figure 2-18**Error! Reference source not found.**).

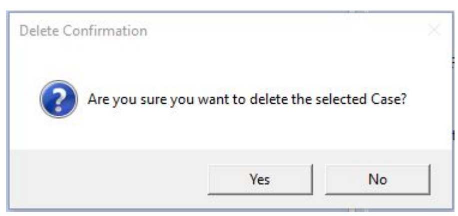


Figure 2-18: Deleting a case

2.3.5 Generating Plots

The generation of plots is performed in a similar manner to the generation of the output reports shown in Section 2.3.3. Once all the input values for the analysis are specified and the analysis has been run, the **Plots** button in the ribbon can be selected (Figure 2-6). The plotting features depend on the selected analysis and will be detailed in the relevant section of this manual.

3 Level 1 Analysis

3.1 Introduction

The Level 1 analysis tool is intended for simple pipeline stability analyses. It calculates the static stability of an un-trenched pipeline against lateral and vertical displacement under wave and current loading. Drag, lift and inertia forces are considered along with the restraining effect of either cohesive or non-cohesive soils. This restraining effect is dependent on the soil friction factor and pipe submerged weight for non-cohesive soils, and on the cohesive shear strength and pipe embedment depth for cohesive soils. Any assumed embedment will also reduce the exposed drag area.

The Level 1 analysis is based on static conditions and a single frequency regular wave. Linear wave theory is used to transform wave parameters to near seabed water particle velocities. Wave induced water particle velocities are added to the bottom current, and forces on the pipe are calculated using Morison's equation along with input force coefficients.

Assumptions associated with the Level 1 analysis include the following:

1. Waves are assumed to be regular and unidirectional.
2. Airy linear wave theory is used to describe wave kinematics.
3. Hydrodynamic drag, lift, and inertial forces are calculated assuming a stationary pipe and a Morison type force formulation.
4. The restraining force from a cohesive soil is independent from the pipe-seabed contact force

Level 1 analysis may typically be performed under the following circumstances:

- To obtain a simple, quick, reasonable estimate of historical concrete coating requirements.
- To check Level 2 or Level 3 analysis against a more conservative baseline, used in earlier designs.

3.2 Level 1 Input Data Tab

The **Input Data** tab allows the user to enter all the required parameter values for calculation, as presented in Figure 3-1.

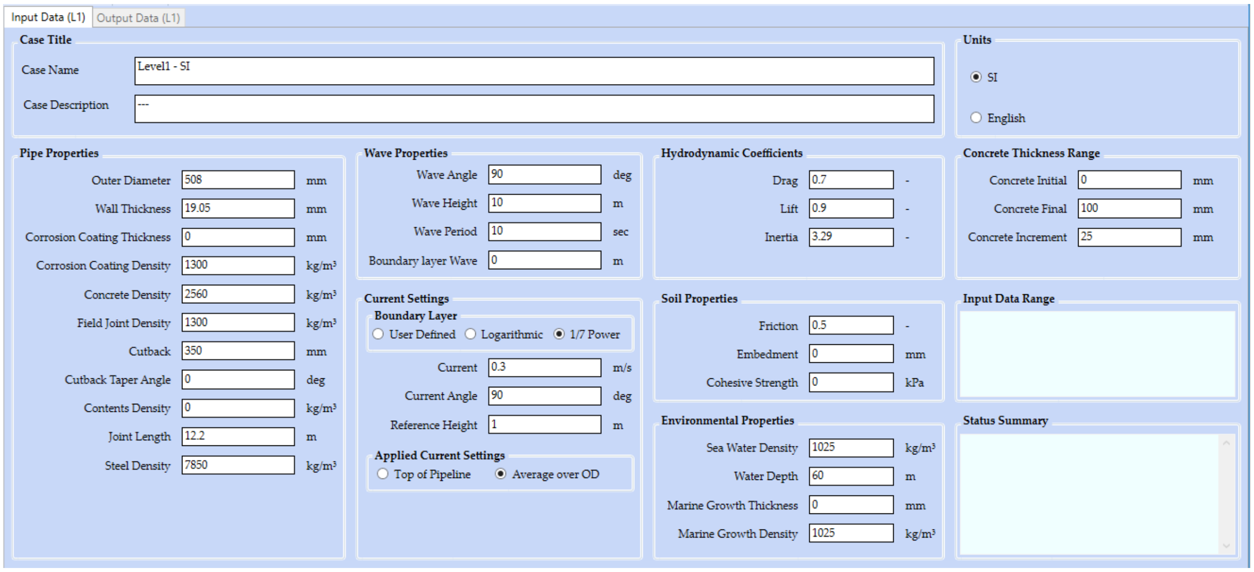


Figure 3-1: Level 1 Input Data Tab

3.2.1 Pipe Properties

3.2.1.1 Outer Diameter

The outer diameter of the steel pipe.

3.2.1.2 Wall Thickness

The wall thickness of the steel pipe.

3.2.1.3 Corrosion Coating Thickness

Thickness of the external corrosion (or insulation) coating.

3.2.1.4 Corrosion Coating Density

Density of the external corrosion (or insulation) coating.

3.2.1.5 Concrete Density

Density of the external concrete weight coating.

3.2.1.6 Field Joint Density

Density of the field joint coating and infill.

3.2.1.7 Cutback

Cutback in the concrete coating at each end of the pipe joint, as presented in Figure 3-2.

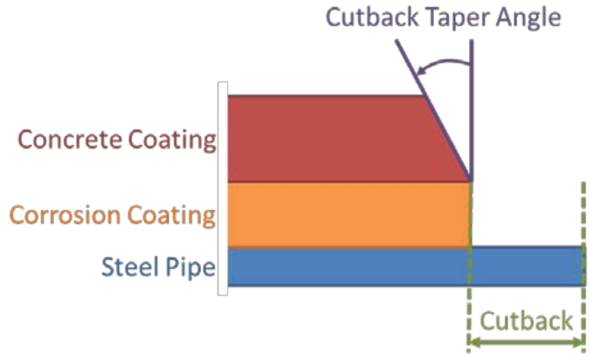


Figure 3-2: Concrete Cutback Layout

3.2.1.8 Cutback Taper Angle

Taper angle of concrete coating, referenced from the radial direction, as presented in Figure 3-2.

3.2.1.9 Product Density

Density of the product/contents inside the pipeline.

3.2.1.10 Joint Length

The nominal length of one pipe joint.

3.2.1.11 Steel Density

Density of the steel pipe.

3.2.2 Wave Properties

Various parameters defining the wave are inputted in this area, with the basic definitions connected to a single regular wave presented in Figure 3-3.

It should be noted that for situations where the wave induced velocity becomes very small, results are not outputted. The user can overcome this issue by setting a combination of small wave height and large water depth to create a negligible but non-zero wave induced velocity. The use of unrealistically small peak period with this intent is not recommended.

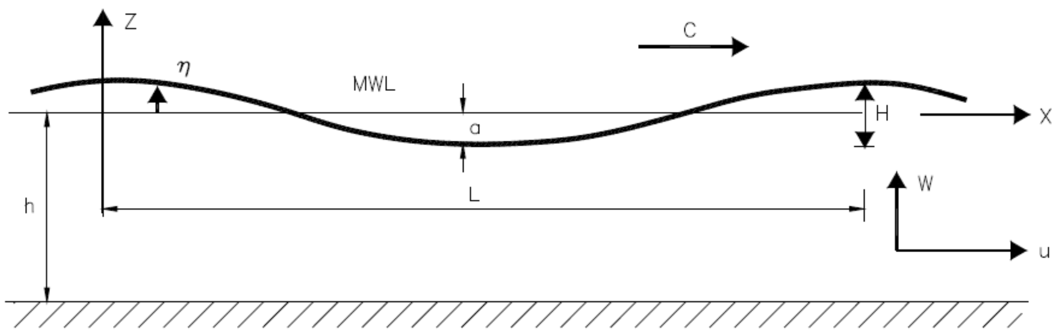


Figure 3-3: Single Regular Wave Parameters [16]

Where:

- a is the wave amplitude, the difference in surface elevation between crest/trough and mean water level (MWL)
- H is the wave height, the difference in surface elevation between the wave crest and trough (H = 2a in the case of a sinusoidal wave)
- η is the surface elevation from MWL
- L is the wave length, the horizontal distance between two successive crests
- T is the period, the time interval between passage of two successive crests at a fixed point
- h is the water depth
- k is the wave number (k = 2π/L)
- ω is the angular frequency (ω = 2π/T)
- f is the wave frequency (f = 1/T = ω/2π)
- s is the steepness, the ratio between wave height and length (s = H/L)
- c is the wave propagation speed

3.2.2.1 Wave Angle

The angle of wave propagation relative to the pipeline (perpendicular to the pipe is 90°).

3.2.2.2 Wave Height

The vertical distance from wave trough to crest, as presented in Figure 3-3.

3.2.2.3 Wave Period

The time interval between successive wave crests passing a particular point.

3.2.2.4 Boundary Wave

The height of the boundary layer for waves, measured upwards from seabed. A diameter-averaged seventh power law formulation, the base formula of which is described in Section 3.2.3.1, is used to calculate the wave velocity at the pipe.

3.2.3 Current Settings

3.2.3.1 Boundary Layer

Figure 3-4 presents a typical scenario where a pipeline diameter lies within the steady current boundary layer. Inclusion of current reduction due to its boundary layer can reduce the conservativeness in using free-stream current value.

The following options are provided in the software for the steady current boundary layer calculation (with the formulations below presented for a perpendicular current, for simplicity):

- User Defined: Uses the user defined current velocity as a constant value at the current angle for calculating current load.

$$U(z) = U_{UD}$$

- Logarithmic: Calculates the current load using a logarithmic relationship, given the current velocity, current angle, current reference height and seabed roughness.

$$\frac{U(z)}{U(z_r)} = \frac{ln(z + z_0) - ln(z_0)}{ln(z_r + z_0) - ln(z_0)}$$

- 1/7th Power: Calculates the current load using the 1/7th power law, given the current velocity, current angle and current reference height.

$$\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\frac{1}{7}}$$

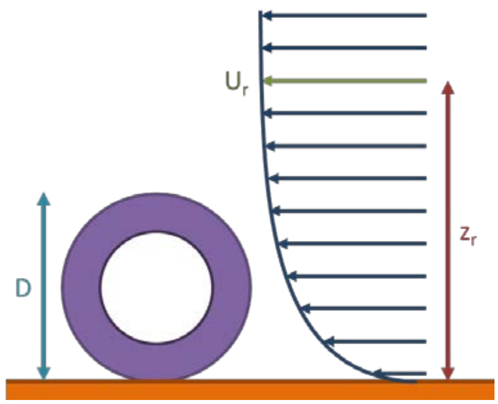


Figure 3-4: Boundary Layer

3.2.3.2 Current

The speed of the current, which acts at the reference height in the direction specified by the current angle.

3.2.3.3 Current Angle

The angle of attack at which the current acts on pipeline (perpendicular to the pipe is 90°).

3.2.3.4 Reference Height

The height above the seabed at which the current value is known (taken as the top of the boundary layer).

3.2.3.5 Seabed Roughness

Based on the seabed type Seabed roughness value can be input in this field. Reference can made from Table 3-1, as given in DNV-RP-F109 [2].

Table 3-1: Reference Seabed Roughness Values [2]

Seabed	Grain Size d_{50} [mm]	Roughness z_0 [m]
Silt and Clay	0.0625	$\approx 5 \cdot 10^{-6}$
Fine Sand	0.25	$\approx 1 \cdot 10^{-5}$
Medium Sand	0.5	$\approx 4 \cdot 10^{-5}$
Coarse Sand	1.0	$\approx 1 \cdot 10^{-4}$
Gravel	4.0	$\approx 3 \cdot 10^{-4}$
Pebble	25	$\approx 2 \cdot 10^{-3}$
Cobble	125	$\approx 1 \cdot 10^{-2}$
Boulder	500	$\approx 4 \cdot 10^{-2}$

3.2.3.6 Applied Current Settings

Selectable from the following options:

- Top of Pipeline: The applied current velocity is taken as the value calculated at the top of the pipe total diameter (being the pipe OD including all coatings and marine growth).
- Average over OD: The applied current velocity is taken as the average value experienced across the total OD.

3.2.4 Hydrodynamic Settings

3.2.4.1 Drag

Coefficient of drag force for the pipe.

3.2.4.2 Lift

Coefficient of lift force for the pipe.

3.2.4.3 Inertia

Coefficient of inertia force for the pipe.

3.2.5 Soil Properties

3.2.5.1 Friction

The lateral friction factor between the soil and the external surface of the pipe.

3.2.5.2 Pipe Embedment (Level 1)

Value of vertical embedment of the pipe into the soil.

3.2.5.3 Cohesive Strength (Level 1)

This shear strength value may be used in conjunction with friction for a cohesive soil, or simply specified as zero to represent a cohesion-less soil.

3.2.6 Environmental Properties

3.2.6.1 Seawater Density

Density of the seawater at the pipe location.

3.2.6.2 Water Depth

Depth of the sea from free surface to the seabed at the pipe location.

3.2.6.3 Marine Growth Thickness (Level 1)

Thickness of the marine growth on the outermost surface of the pipe. This parameter is denoted here as t_{MG} and illustrated in Figure 3-5 without embedment. Due to the various considerations of this parameter in the calculations, this value is treated slightly differently.

- Drag and Lift forces: these calculations include consideration of $1 \cdot t_{MG}$ at the top of the pipe, as the dimensional consideration for these parameters is relevant to the exposed vertical pipe profile, with marine growth not being present on the underside of the pipe.
- Inertia force and submerged weight: these calculations consider a volume that includes $1 \cdot t_{MG}$ circumferentially around the pipe, as the dimensional consideration for this parameter is relevant to the total volume, with the marine growth providing a volume almost equal to a full circumferential layer.
- KC number: Level 1 calculates this value without the presence of marine growth or concrete coating.

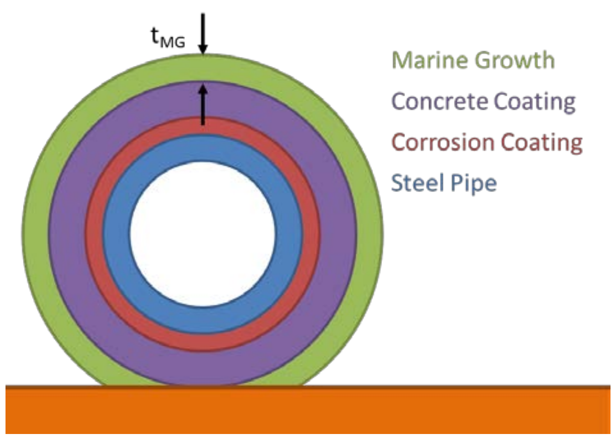


Figure 3-5: Marine Growth Diagram – Level 1 Module (No Embedment)

3.2.6.4 Marine Growth Density

Density of the marine growth on the external surface of the pipe.

3.2.7 Concrete Thickness Range

3.2.7.1 Concrete Initial

The starting value of concrete thickness for the parameter incrementing, which represents its minimum value.

3.2.7.2 Concrete Final

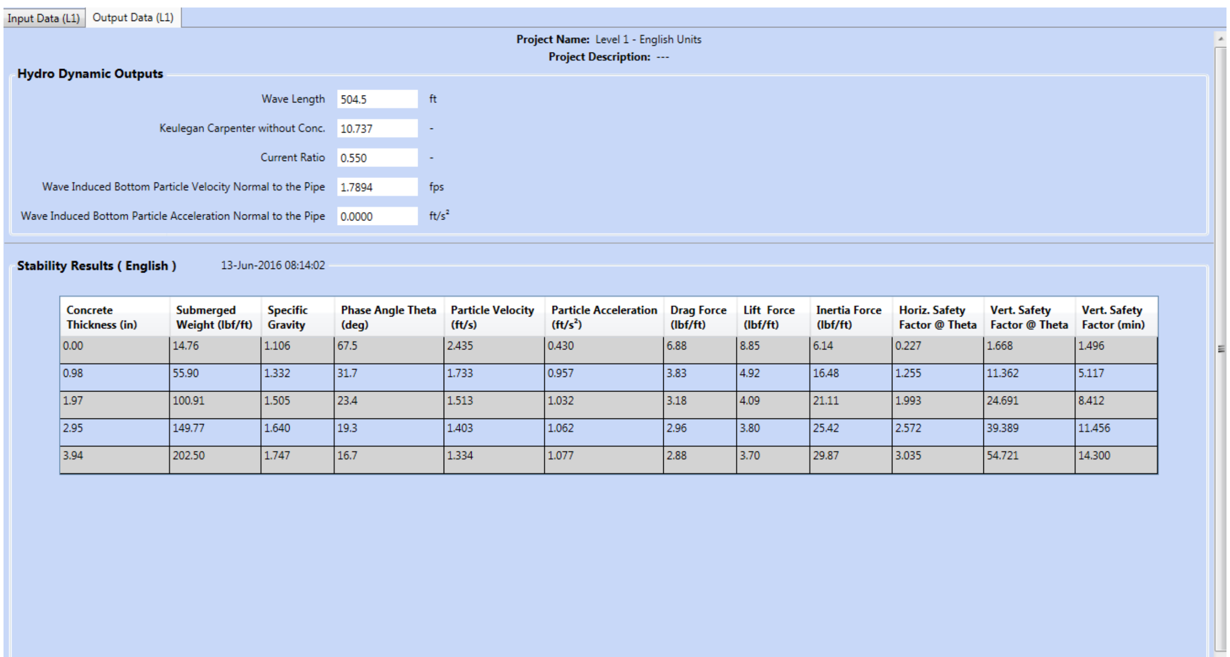
The final value of concrete thickness for the parameter incrementing, which represents its maximum value.

3.2.7.3 Concrete Increment

The value at which the concrete thickness is incremented, from Initial value to Final value. The incremented values appear as separate entries in the outputs.

3.3 Level 1 Output Data Tab

The output can be viewed by clicking the **Output Data (L1)** tab, which displays the results outlined in this section in the chosen unit system, as presented in Figure 3-6. The outputs are also exported in PDF format. The PDF file can be opened by clicking on the **Report** button option in the ribbon menu.



Concrete Thickness (in)	Submerged Weight (lbf/ft)	Specific Gravity	Phase Angle Theta (deg)	Particle Velocity (ft/s)	Particle Acceleration (ft/s^2)	Drag Force (lbf/ft)	Lift Force (lbf/ft)	Inertia Force (lbf/ft)	Horiz. Safety Factor @ Theta	Vert. Safety Factor @ Theta	Vert. Safety Factor (min)
0.00	14.76	1.106	67.5	2.435	0.430	6.88	8.85	6.14	0.227	1.668	1.496
0.98	55.90	1.332	31.7	1.733	0.957	3.83	4.92	16.48	1.255	11.362	5.117
1.97	100.91	1.505	23.4	1.513	1.032	3.18	4.09	21.11	1.993	24.691	8.412
2.95	149.77	1.640	19.3	1.403	1.062	2.96	3.80	25.42	2.572	39.389	11.456
3.94	202.50	1.747	16.7	1.334	1.077	2.88	3.70	29.87	3.035	54.721	14.300

Figure 3-6: Level 1 Output Data Tab

3.3.1 Hydrodynamic Outputs

3.3.1.1 Wave Length

The wave length is calculated based on the input wave properties, and describes the distance between successive wave crests.

3.3.1.2 Keulegan-Carpenter (without Concrete)

The Keulegan-Carpenter (KC) number calculated without considering a concrete coating on the pipe, which describes the relative importance in oscillatory flow of the drag forces over the inertia forces. The general form for the KC number is given by:

$$KC = \frac{U_{oscillatory} \cdot T}{D}$$

Where:

- $U_{oscillatory}$ is the oscillatory velocity
- T is the period
- D is the outermost diameter under consideration (which excludes the concrete coating in this output column)

3.3.1.3 Current Ratio

The ratio of steady current to oscillatory current, considering the mean current over one pipe diameter:

$$\alpha = \frac{U_{steady}}{U_{oscillatory}}$$

3.3.1.4 Wave Induced Bottom Particle Velocity Normal to the Pipe

This field displays the wave bottom velocity perpendicular to the pipe; calculated using Airy wave theory.

3.3.1.5 Wave Induced Bottom Particle Acceleration Normal to the Pipe

This field displays the wave induced bottom acceleration perpendicular to the pipe; calculated using Airy wave theory.

3.3.2 Stability Results

3.3.2.1 Concrete Thickness

Displays the range of concrete thickness in the increments defined in the **Input Data** tab, with the first and last values in this column being the initial (minimum) and final (maximum) concrete thicknesses.

3.3.2.2 Submerged Weight

This column displays the submerged weight of the pipe, calculated for the respective concrete coating thickness in the leftmost column.

3.3.2.3 Specific Gravity

The ratio of the coated pipe density for the respective concrete coating thickness to the density of seawater.

3.3.2.4 Phase Angle Theta

The wave phase angle at which the minimum horizontal stability occurs.

3.3.2.5 Particle Velocity

The summation of the wave and current velocities acting at the pipe depth, for the phase angle.

3.3.2.6 Particle Acceleration

The normal particle acceleration acting at the pipe depth, for the phase angle.

3.3.2.7 Drag Force

The drag force corresponding to the particle velocity presented.

3.3.2.8 Lift Force

The lift force corresponding to the particle velocity presented.

3.3.2.9 Inertia Force

The inertia force corresponding to the particle acceleration presented.

3.3.2.10 Horizontal Safety Factor at Theta

The minimum horizontal safety factor encountered across the full sweep of wave phase angle (which corresponds to the phase angle presented). It is the quotient of the available soil resistance divided by the sum of the horizontal forces.

3.3.2.11 Vertical Safety Factor at Theta

The vertical safety factor corresponding to the phase angle presented. It is the quotient of the pipe weight divided by the lift force.

3.3.2.12 Vertical Safety Factor

The minimum vertical safety factor encountered across the full sweep of wave phase angle, often not at the phase angle presented previously for the minimum horizontal safety factor.

3.4 Level 1 Reports

A PDF file is generated once an analysis is completed which can be accessed through the **Report** toolbar button. To access the PDF file from a directory please see section **Error! Reference source not found.**. An instance of Level 1 report is shown in Figure 3-7.

PRCI OBS Level 1 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis

Case Name: Example Case — Case Description: Example Case to demonstrate functionality

Report Compiled on 31/01/2019

Pipe Properties

Pipe OD (mm):	508.00
Wall Thickness (mm):	19.05
Corrosion Coating (mm):	0.00
Corrosion Coating Density (kg/m^3):	1300.0
Concrete Density (kg/m^3):	2560.0
Field Joint Density (kg/m^3):	1300.0
Cutback (mm):	350.0
Taper Angle (deg):	0.0
Product Density (kg/m^3):	0.0
Length of Pipe Joint (m):	12.20
Steel Density (kg/m^3):	7850.0

Environmental Properties

Sea Water Density (kg/m^3):	1025.0
Water Depth (m):	60.0
Marine Growth Thickness (mm):	0.00
Marine Growth Density (kg/m^3):	1025.0

Hydrodynamic Settings

Drag (-):	0.700
Lift (-):	0.900
Inertia (-):	3.290

Soil Properties

Friction (-):	0.500
Embedment (mm):	0.0
Cohesive Strength (kPa):	0.00

Wave Properties

Wave Angle (deg):	90.0
Wave Height (m):	10.00
Wave Period (sec):	10.00
Boundary Wave (m):	0.00

Concrete Thickness Range

Concrete Initial (mm):	0.0
Concrete Final (mm):	100.0
Concrete Increment (mm):	25.0

Current Settings

Boundary Layer:	1/7 Power
Current (m/s):	0.30
Current Angle (deg):	90.0
Reference Height (m):	1.00

Applied Current Settings

1 - Average over OD

PRCI OBS Level 1 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis

Case Name: Example Case — Case Description: Example Case to demonstrate functionality

Report Compiled on 31/01/2019

Concrete Thickness	Submerged Weight	Specific Gravity	Phase Angle Theta	Particle Velocity	Particle Acceleration	Drag Force	Lift Force	Inertia Force	Horizontal Safety Factor at Theta	Vertical Safety Factor at Theta	Vertical Safety Factor Min
[mm]	[N/m]	[-]	[deg]	[m/s]	[m/s^2]	[N/m]	[N/m]	[N/m]	[-]	[-]	[-]
0.0	215.4	1.106	67.5	0.742	0.131	100.4	129.1	89.7	0.227	1.668	1.496
25.0	815.8	1.332	31.7	0.528	0.292	55.8	71.8	240.5	1.255	11.362	5.117
50.0	1472.6	1.505	23.4	0.461	0.315	46.4	59.6	308.0	1.993	24.691	8.412
75.0	2185.8	1.640	19.3	0.428	0.324	43.2	55.5	371.0	2.572	39.389	11.456
100.0	2955.2	1.747	16.7	0.407	0.328	42.0	54.0	436.0	3.035	54.721	14.300

Figure 3-7: Level 1 Report. Page 1 lists inputs and Page 2 shows the outputs.

4 Level 2 Analysis

4.1 Introduction

The Level 2 quasi-static analysis has been designed to utilize the results from the PRCI's hydrodynamic and pipe/soil interaction tests without a full dynamic simulation. Therefore, it can be used to determine weight coating requirements based on more detailed hydrodynamic and soil force formulations than those used in the Level 1 analysis, and in a more simplified manner compared to those used in the Level 3 analysis. It provides the user a simplified method for estimating pipe embedment and the resulting soil resistance. This analysis level is appropriate for preliminary designs, and the resulting concrete thicknesses should be adequate for most final designs.

4.2 Calculation Procedure

The Level 2 analysis calculation procedure is depicted in Figure 4-1.

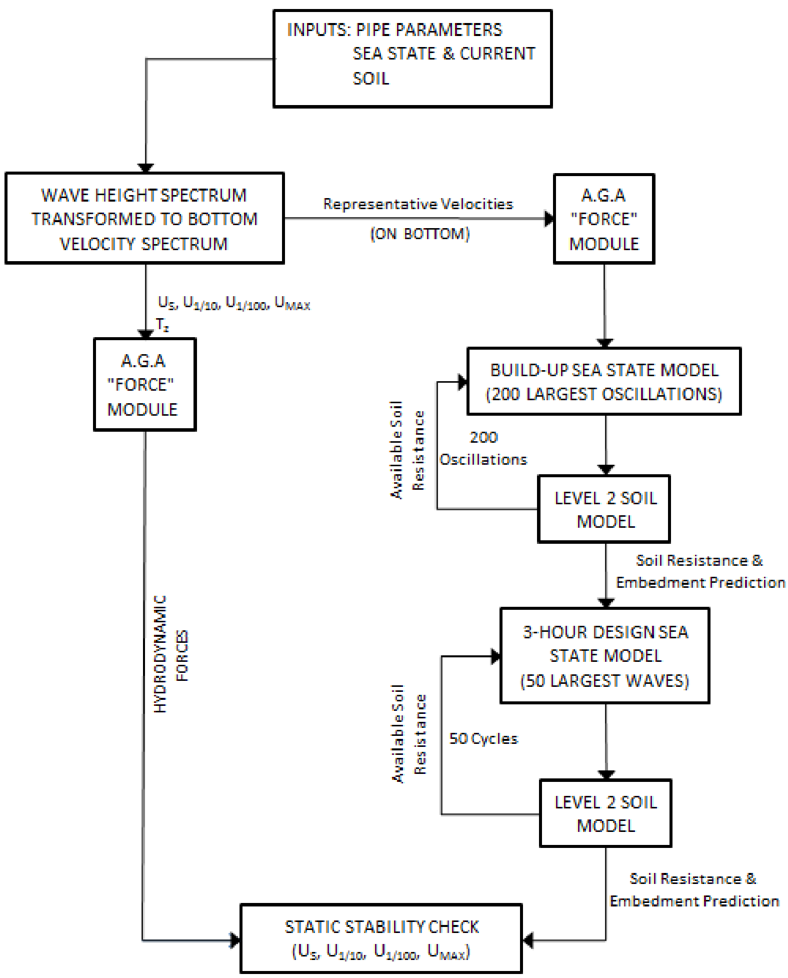


Figure 4-1: Level 2 Analysis Calculation Roadmap

The calculations occur via the following steps:

1. Based on user inputs, the software can calculate values for the design wave height spectral density function. The wave height spectral density function is then transformed to a bottom velocity spectral density function. The area under the bottom velocity spectrum is numerically integrated, and the significant bottom velocity is calculated. The peak frequency of the bottom velocity spectrum is determined.
2. Maximum and minimum in-line hydrodynamic forces for the largest 200 waves contained in an assumed 4-hour long build-up sea state are calculated (the 4-hour long build-up period is considered to start with a zero wave height and to linearly increase with time to the design sea state wave height, with the sea state model presented in **Error! Reference source not found.**). The 200 largest waves are characterized by the five wave heights illustrated in **Error! Reference source not found.**. Wave forces for each of the five wave heights are calculated using the PRCI hydrodynamic force calculation procedure and the associated database of force coefficients.
3. Maximum and minimum in-line forces for the largest 50 waves during a subsequent 3-hour long design sea state are calculated as in Step 2 above. These 50 waves are characterized by the four different wave heights illustrated in Figure 4-4.

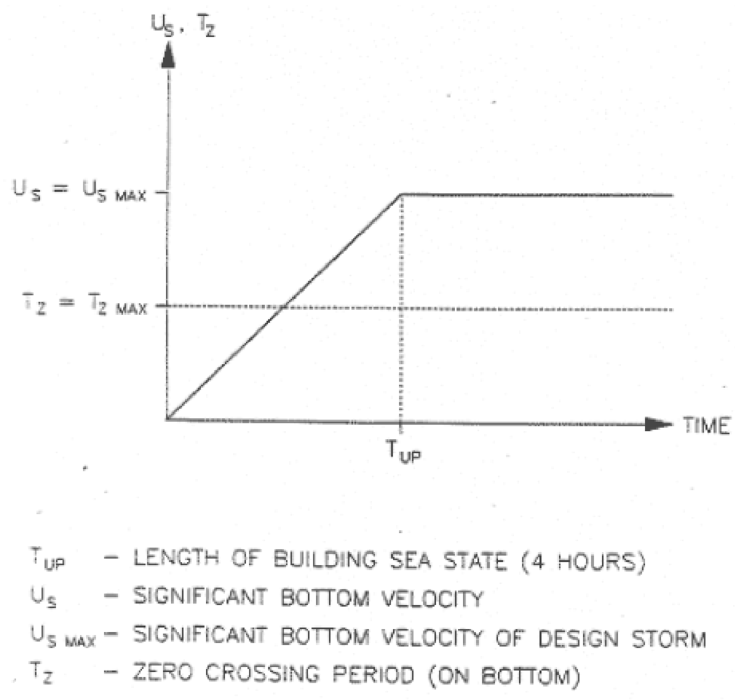


Figure 4-2: Level 2 Build-up Sea State Model Employed to Predict Pipe Embedment

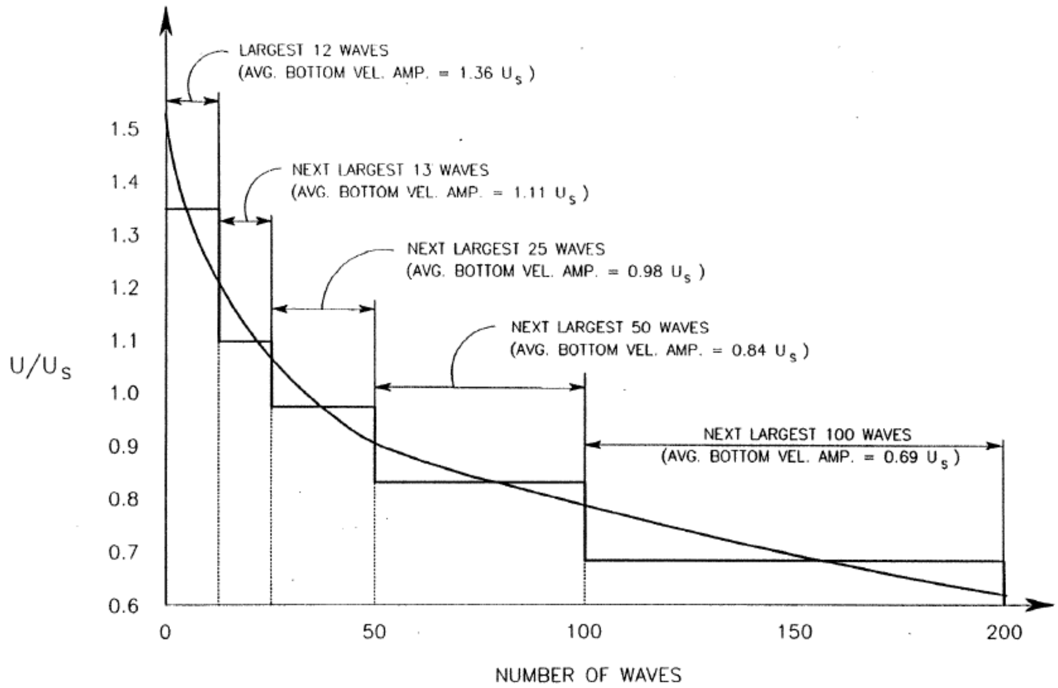


Figure 4-3: Bottom Velocity Amplitude Content during 4-hour Storm Build-up (Largest 200 Velocity Amplitudes used to Predict Embedment in Level 2 Analysis)

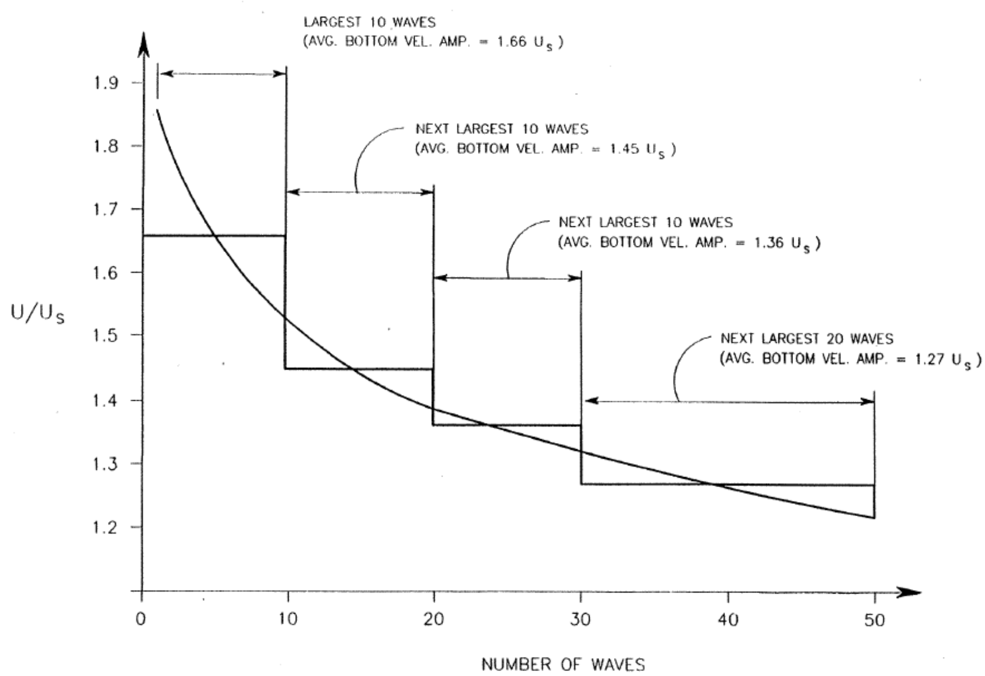


Figure 4-4: Bottom Velocity Amplitude Content during 3-hour Design Storm (Largest 50 Velocity Amplitudes used to Predict Embedment in Level 2 Analysis)

4. Based on the forces calculated in Step 2, a conservative estimate of pipe embedment at the end of the 4-hour storm build-up period is calculated. This estimate is obtained by subjecting the pipe to 200 small oscillations. The oscillations are limited in amplitude to be no larger than that which the wave forces can produce, or 0.07 times the pipe diameter, whichever is smaller. To simulate the build-up sea state, the smaller waves shown in **Error! Reference source not found.** are considered first. Not all of the 200 oscillations necessarily produce pipe embedment. Only the waves which produce in-line forces sufficient to overcome frictional resistance between the pipe and soil are considered to produce embedment.

   For each of the 200 waves, the in-line hydrodynamic force is reduced to account for the pipe embedment just prior to its application. The estimated pipe embedment and the available soil resistance force at the end of the build-up period are then saved for further processing. Pipe embedment and history dependent soil resistance are calculated using the PRCI pipe/soil interaction model.

5. Based on the forces calculated in Step 3 and the pipe embedment calculated in Step 4, the amount of additional pipe embedment that can be produced by the 50 largest waves in the design sea state is calculated in a fashion similar to that described in Step 4 for the storm build-up period. This embedment and the associated soil resistance force are saved for further processing.

6. Hydrodynamic forces for a complete wave cycle are calculated for four statistically meaningful wave induced bottom velocities that are expected in a 3-hour long design sea state. These waves induced bottom velocities are typical of the largest 135 waves expected during the design event and have been selected to give users indicative information on how stable the pipeline designs are. Each statistical velocity has the possibility that some waves in the design event will exceed it. The four bottom velocities (and the most likely number of wave induced velocities exceeding each) are:

   - $U_{1/3} = 1.00\ U_s$; the significant wave velocity (135 exceedances)
   - $U_{1/10} = 1.27\ U_s$ (40 exceedances)
   - $U_{1/100} = 1.66\ U_s$ (4 exceedances)
   - $U_{1/1000} = 1.86\ U_s$ (0 exceedances)

7. Using the soil resistance values obtained in Steps 4 and 5 and the hydrodynamic forces calculated in Step 6, the minimum factor-of-safety against lateral sliding is calculated for the pipe embedment at the end of the 4-hour long build-up period, and at the end of the 3-hour long design sea state.
   The factor of safety is calculated at one-degree intervals of wave passage for a complete 360-degrees from:

$$Factor\ of\ Safety\ = \frac{\mu\left(W_s - F_L(t)\right) + F_H}{F_D(t) + F_I(t)}$$

   where:

   - t is time
   - μ is the pipe-soil friction coefficient
   - W_s is the submerged weight of the pipe
   - $F_L(t)$ is the hydrodynamic lift force (as a function of time)
   - $F_D(t)$ is the hydrodynamic drag force (as a function of time)
   - $F_I(t)$ is the hydrodynamic inertial force (as a function of time)
   - F_H is the history-dependent soil resistance

The minimum factor of safety is calculated for $U_{1/3}$, $U_{1/10}$, $U_{1/100}$ and $U_{1/1000}$ at the end of storm ramp-up and 3-hour developed storm conditions.

The above procedure was adopted after the results of typical analysis using the Level 3 dynamics software were used to calibrate and confirm that the results for pipe embedment are reasonable and that the results are conservative.

i. The pipe embedment developed by the "assumed recent wave history" in steps 2 through 4 above is computed using conservative assumptions which include the following:

ii. No initial pipe embedment is considered to have occurred until just prior to the design storm,

iii. A short, 4-hour storm build-up period is assumed to precede the design storm during which some pipe embedment is allowed to occur,

iv. The significant wave height during the build-up period starts at a zero-wave height and increases linearly with time to the significant wave height of the design storm (see Figure 4-2),

v. The pipe is considered to undergo only very small oscillations, and thus does not embed as far as it might otherwise.

Other assumptions specific to the Level 2 analysis tool are as follows:

a) Wave induced near seabed water particle velocities are assumed to have a Rayleigh distribution (i.e. similar to the wave height distribution).

b) Bottom velocity amplitudes are based on a 3-hour storm duration with input spectral parameters.

c) Soil resistance models are available for Sand and Clay soil types based on PRCI pipe/soil interaction model as well as the newly incorporated models for Sand (Verley and Sotberg) and Clay (Verley and Lund). These models include a frictional resistance (dependent on the normal force applied to the soil) and a passive soil resistance (dependent upon pipe embedment and independent of instantaneous pipe normal force).

d) Pipe embedment at the end of the storm build-up period is based on 200 small amplitude cyclic oscillations. The amplitude of the oscillations is limited by the hydrodynamic forces expected from a rapidly developing build-up sea state model.

e) Subsequent pipe embedment during the design storm is estimated using 50 small amplitude cyclic oscillations of the pipe. The amplitude of these oscillations is also limited by the hydrodynamic force contained in the storm.

These last two assumptions describe the basis for the soil resistance, and detail the conservative estimate of both number and magnitude of oscillations expected to embed the pipe just before the design sea state is encountered. Figure 4-5 shows the logic for determining pipe embedment at the end of the build-up sea state.

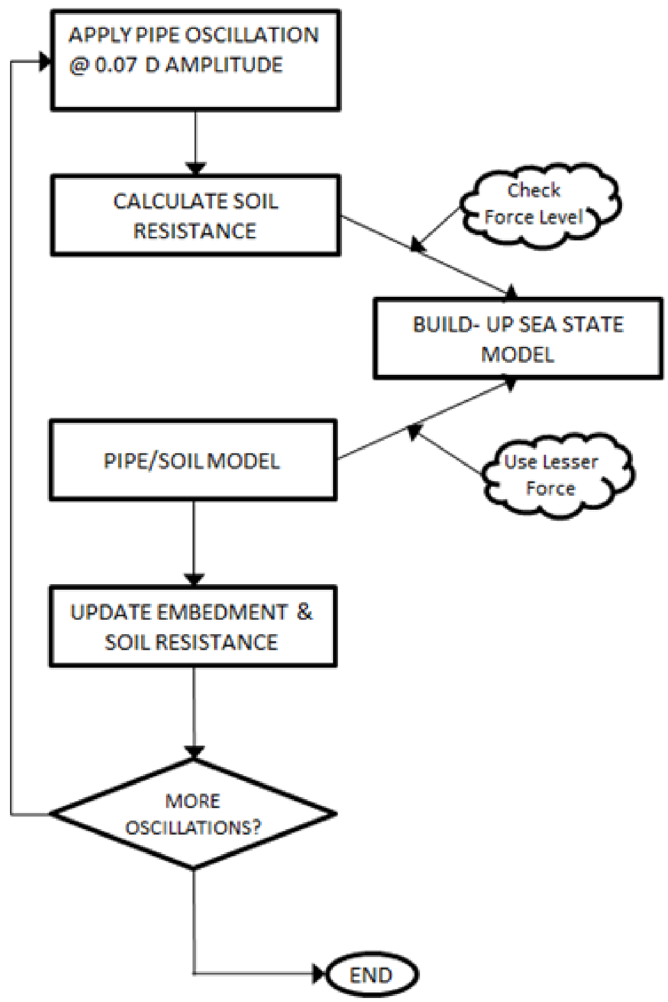


Figure 4-5: Level 2 Pipe Embedment Logic

4.3 Level 2 Input Data Tab

The **Input Data** tab allows the user to enter all the required parameter values for calculation, as presented in Figure 4-6.

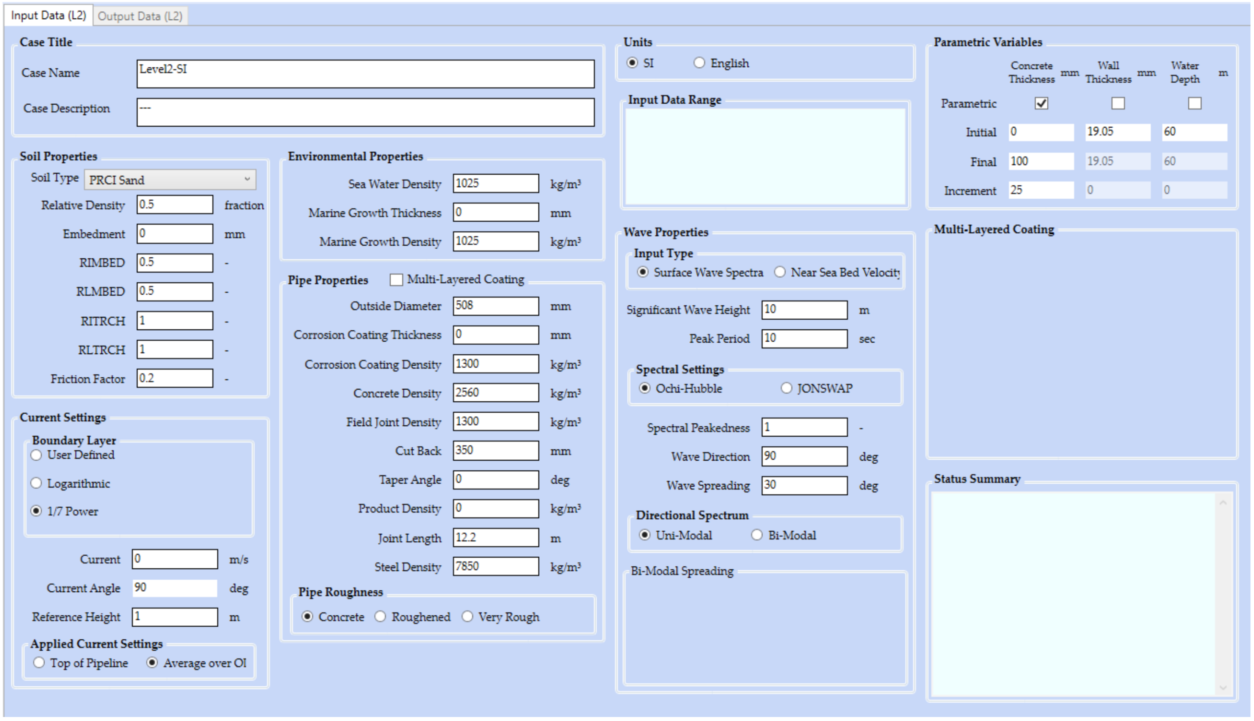


Figure 4-6: Level 2 Input Data Tab

4.3.1 Pipe Properties

4.3.1.1 Outer Diameter

Refer to Section 3.2.1.1.

4.3.1.2 Wall Thickness

Refer to Section 3.2.1.2.

4.3.1.3 Corrosion Coating Thickness

Refer to Section 3.2.1.3.

4.3.1.4 Corrosion Coating Density

Refer to Section 3.2.1.4.

4.3.1.5 Concrete Density

Refer to Section 3.2.1.5.

4.3.1.6 Field Joint Density

Refer to Section 3.2.1.6.

4.3.1.7 Cutback

Refer to Section 3.2.1.7.

4.3.1.8 Cutback Taper Angle

Refer to Section 3.2.1.8.

4.3.1.9 Product Density

Refer to Section 3.2.1.9.

4.3.1.10 Joint Length

Refer to Section 3.2.1.10.

4.3.1.11 Steel Density

Refer to Section 3.2.1.11.

4.3.1.12 Multi-Layered Coating

If this option is checked, an additional set of input fields appear on the input form under the heading of **Multi-Layered Coating**, as shown in Figure 4-7. The thickness and density of up to four coating layers can be specified to compute the equivalent coating thickness and density.

When using the multi-layered coating option, the standard inputs for the thickness and density of the corrosion coating are disabled, with the calculations using the computed equivalent values instead.

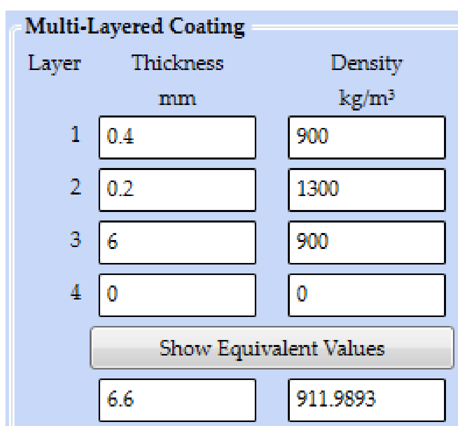


Figure 4-7: Multi-Layered Coating Input Fields

The multi-layered coating section includes the following:

- Layer: numerical index of the coating layer, numbered ascendingly from innermost to outermost layer.
- Thickness: the thickness of each corresponding coating layer.
- Density: the density of each corresponding coating layer.
- Show Equivalent Values: pressing this button calculates and displays the equivalent thickness and density for the coatings specified in the **Multi-Layered Coating** fields.

4.3.2 Soil Properties

4.3.2.1 Soil Type

The type of soil is selectable from three options listed under this heading, as presented in Figure 4-8:

- PRCI Sand (cohesion-less soil)
- V&S Sand (cohesion-less soil)
- PRCI Clay (cohesive soil)
- V&L Clay (cohesive soil with the pipe penetration calculated by the Verley and Lund method for clay soil [1])

By default, the selection is set to the first option (i.e. PRCI Sand soil).

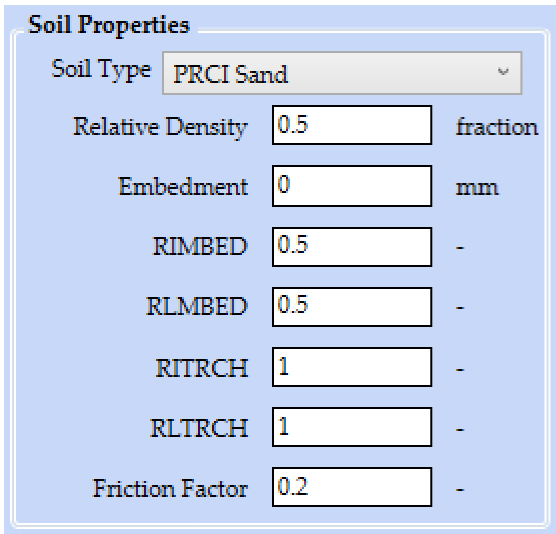


Figure 4-8: Level 2 Soil Property Input Fields

4.3.2.2 Relative Density

This field is available when the selected soil type is PRCI Sand, and characterizes the density of the soil; describing the ratio of the difference between the void ratios of a cohesion-less soil in its loosest state and in situ state to the difference between its void ratio in its loosest and densest states:

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

4.3.2.3 Submerged Weight (Level 2)

This field is available when the selected soil type is V&S Sand and is the submerged weight of the Sand.

4.3.2.4 Cohesive Strength (Level 2)

This field is available when the selected soil type is PRCI or V&L Clay, and describes the magnitude of shear stress the cohesive soil can sustain.

4.3.2.5 Embedment (Level 2)

Pipe embedment if pipe embedment is to be input rather than calculated.

- Embedment = 0 if software is to calculate embedment
- Embedment > 0 if input value is to be used

4.3.2.6 RIMBED (Level 2)

The in-line force reduction due to embedment is considered through the RIMBED factor. This factor is the maximum reduction of in-line force obtained at the embedment of 0.5 D or above, as presented in Figure 4-9. The force reduction factor is linearly interpolated between this value and 1 for an embedment less than 0.5 D.

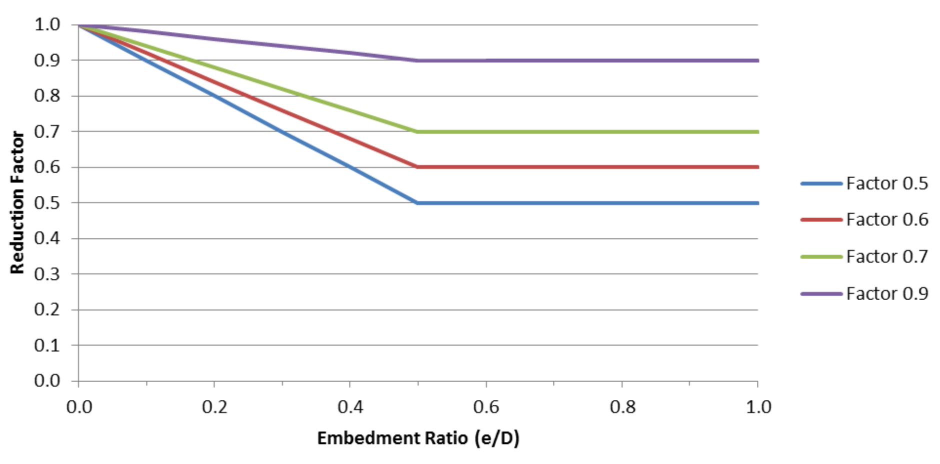


Figure 4-9: Modelling of Embedment Reduction Factors

4.3.2.7 RLMBED (Level 2)

The lift force reduction due to embedment is considered through the RLMBED factor. This factor is the maximum reduction of lift force obtained at the embedment of 0.5 D or above, as presented in Figure 4-9. The force reduction factor is linearly interpolated between this value and 1 for an embedment less than 0.5 D.

4.3.2.8 RITRCH (Level 2)

This factor reduces the in-line force due to the effect of a trench.

The multipliers for trench effects are combined with the multipliers for embedment, so for the example of a pipe at 0.5 D embedment in a trench, a RIMBED value of 0.5 and RITRCH value of 0.8 will reduce the in-line force to 40 % of its unreduced value.

4.3.2.9 RLTRCH (Level 2)

This factor reduces the lift force due to the effect of a trench.

The multipliers for trench effects are combined with the multipliers for embedment, so for the example of a pipe at 0.5 D embedment in a trench, a RLMBED value of 0.5 and RLTRCH value of 0.8 will reduce the lift force to 40 % of its unreduced value.

4.3.3 Current Settings

4.3.3.1 Boundary Layer

Refer to Section 3.2.3.1.

4.3.3.2 Current

Refer to Section 3.2.3.2.

4.3.3.3 Current Angle

Refer to Section 3.2.3.3.

4.3.3.4 Reference Height

Refer to Section 3.2.3.4.

4.3.3.5 Seabed Roughness

Refer to Section 3.2.3.5.

4.3.3.6 Applied Current Settings

Refer to Section 3.2.3.6.

4.3.4 Environmental Properties

4.3.4.1 Seawater Density

Refer to Section 3.2.6.1.

4.3.4.2 Water Depth

Refer to Section 3.2.6.2.

4.3.4.3 Marine Growth Thickness (Level 2)

Thickness of the marine growth on the outermost surface of the pipe. This parameter is denoted here as t_{MG} and illustrated in Figure 4-10 without embedment. Due to the various considerations of this parameter in the calculations, this value is treated slightly differently.

- Drag and lift forces: these calculations include consideration of $1 \cdot t_{MG}$ at the top of the pipe, as the dimensional consideration for these parameters is relevant to the vertical pipe profile, with marine growth not being present on the underside of the pipe. Embedment is accounted for by the use of force reduction factors for Level 2 drag and lift.
- Inertia force and submerged weight: these calculations consider a volume that includes $1 \cdot t_{MG}$ circumferentially around the pipe, as the dimensional consideration for this parameter is relevant to the total volume, with the marine growth providing a volume almost equal to a full circumferential layer.
- KC number: the calculation of this value considers a pipe diameter with $2 \cdot t_{MG}$, as the dimensional consideration for this parameter is relevant to the horizontal pipe profile (i.e. t_{MG} on each side of the pipe).

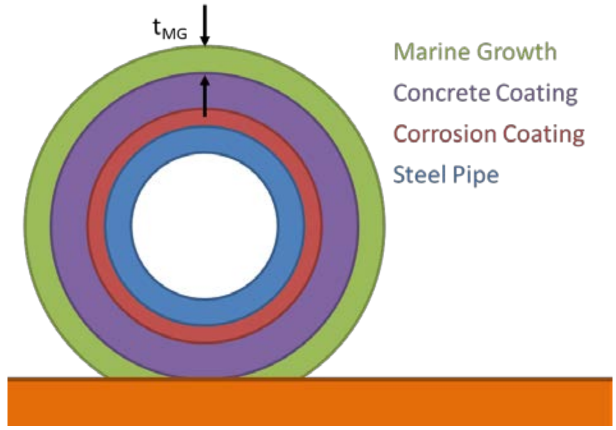


Figure 4-10: Marine Growth Diagram – Level 2 Module (No Embedment)

4.3.4.4 Marine Growth Density

Refer to Section 3.2.6.4.

4.3.5 Pipe Roughness

External roughness ratio of the outermost surface of the pipe, selectable from the following [6]:

- Concrete: smooth concrete coating; $k/D = 10^{-3}$
- Roughened: a roughened concrete coating (typically resulting from hard bio-fouling, such as barnacles); $k/D = 10^{-2}$
- Very Rough: further roughened pipe (typically resulting from soft bio-fouling); $k/D = 5 \cdot 10^{-2}$

4.3.6 Wave Properties Input Type

The wave type is specified from two options: **Surface Wave Spectra** and **Near Seabed Velocity**.

4.3.6.1 Surface Wave Spectra

The wave is defined by the surface wave parameters, which are used to calculate the wave loads near the seabed:

- Significant Wave Height: the vertical distance from trough to crest of the significant wave.
- Peak Period: the time interval between successive peak wave crests passing a particular point.

4.3.6.2 Near Seabed Velocity

The wave is defined by the near-seabed parameters:

- Significant Velocity: the velocity of the near seabed wave-induced current.
- Zero-Crossing Period: period of the near seabed wave-induced current.

4.3.7 Wave Properties Spectral Settings

The spectral settings are available for the wave input selection of **Surface Wave Spectra**.

4.3.7.1 Ochi-Hubble

This is a general spectrum formulated to describe seas as a combination of two different sea states, using a sum of two Gamma distributions [3]. The Ochi-Hubble spectrum is modelled in the software as a single peak spectrum, and is defined by the following parameters, as presented in Figure 4-11:

- Spectral Peakedness: the dimensionless peakedness parameter for the Ochi-Hubble spectrum.
- Wave Direction: the angle of wave propagation relative to the pipeline (perpendicular to the pipe is 90°).
- Wave Spreading: the standard deviation of wave spreading used in the wrapped normal spreading function.

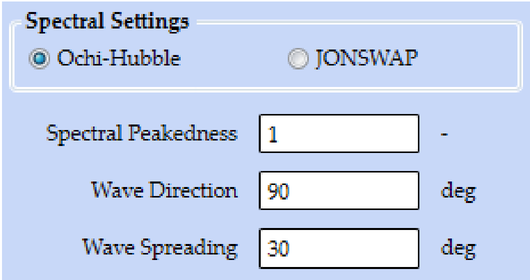


Figure 4-11: Ochi-Hubble Spectral Input

4.3.7.2 JONSWAP

This single peak spectrum was initially formulated as a modification of the Pierson-Moskowitz spectrum to describe a developing sea state in a fetch limited situation. It is often applied to on-bottom stability analyses, and is defined by the following parameters, as presented in Figure 4-12.

- Spectral Peakedness: the dimensionless peakedness parameter for the JONSWAP spectrum.
- Sigma A: JONSWAP spectral width parameter, applicable when $\omega \leq \omega_p$.
  Where:
  - ω is the wave angular frequency
  - ω_p is the wave angular spectral peak frequency
- Sigma B: JONSWAP spectral width parameter, applicable when $\omega > \omega_p$.
- Wave Direction: the angle of wave propagation relative to the pipeline (perpendicular to the pipe is 90°).
- Wave Spreading: the standard deviation of wave spreading used in the wrapped normal spreading function.

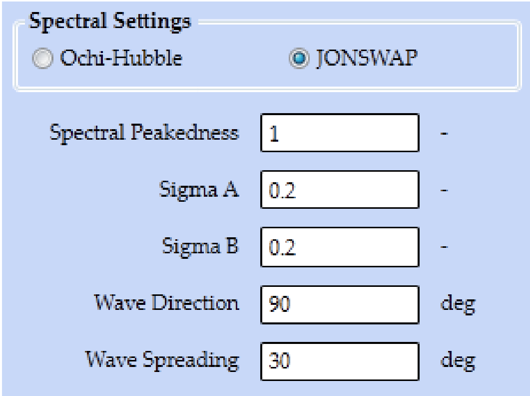


Figure 4-12: JONSWAP Spectral Input

4.3.8 Wave Properties Directional Spectrum

The directional spectrum settings are available for the wave input selection of **Surface Wave Spectra**. This area enables characterization of the wrapped normal function used for directional wave spreading, which can be set as either uni-modal or bi-modal.

This is further discussed in the additional technical description of Section 5.12.1.4.

4.3.8.1 Uni-Modal

A single directional spectrum is used for wave spreading, as defined by the parameters already assigned in the wave properties spectral settings.

4.3.8.2 Bi-Modal

Two directional spectra are used for determining wave spreading. The following additional inputs are required to define the bi-modal spreading, as presented in Figure 4-13:

- Secondary Direction: the secondary mean direction for wave spreading relative to the pipeline (perpendicular to the pipe is 90°).
- Secondary Spreading: the secondary standard deviation of wave spreading used in the bi-modal wrapped normal spreading function.
- Mixing Constant: the value used to combine the two components of the bi-modal directional spectrum, termed *a* in the following:

$$D(\Theta) = a\, D_1(\Theta) + (1 - a)\, D_2(\Theta)$$

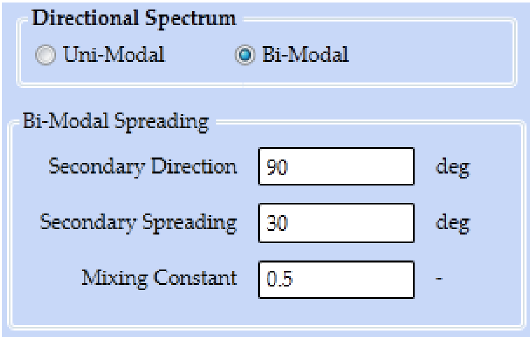


Figure 4-13: Bi-Modal Directional Spreading Input

4.3.9 Parametric Variables

This section facilitates parametric stability analyses that involve iteration over a single parameter, or over combinations of multiple parameters. The parametric analyses are available for concrete thickness, pipe wall thickness, and water depth.

The default configuration for this area is for all variables as single values, with the parametric analysis being opt-in for each, as shown in Figure 4-14. With the parametric study of a variable being disabled, the value input for the Initial field is used in the calculations as the single value for that variable, in the same manner as for the other variables on the **Input Data** tab.

The parametric analysis for a variable is enabled via the checkbox in its column, which enables the specification of the **Final** and **Increment** values, as shown in Figure 4-15. The inputs specified are then:

- Initial: the starting value for the parameter incrementing, which represents its minimum value.
- Final: the ending value for the parameter incrementing, which represents its maximum value.
- Increment: the value at which the parameter is incremented, from Initial value to Final value. The incremented values appear as separate entries in the outputs.

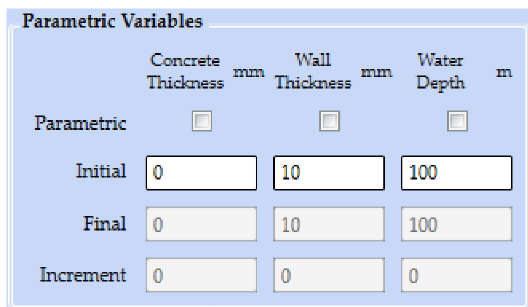


Figure 4-14: Parametric Variables Disabled

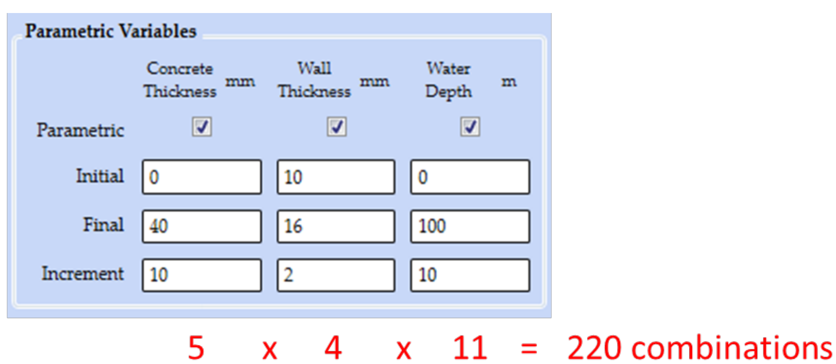
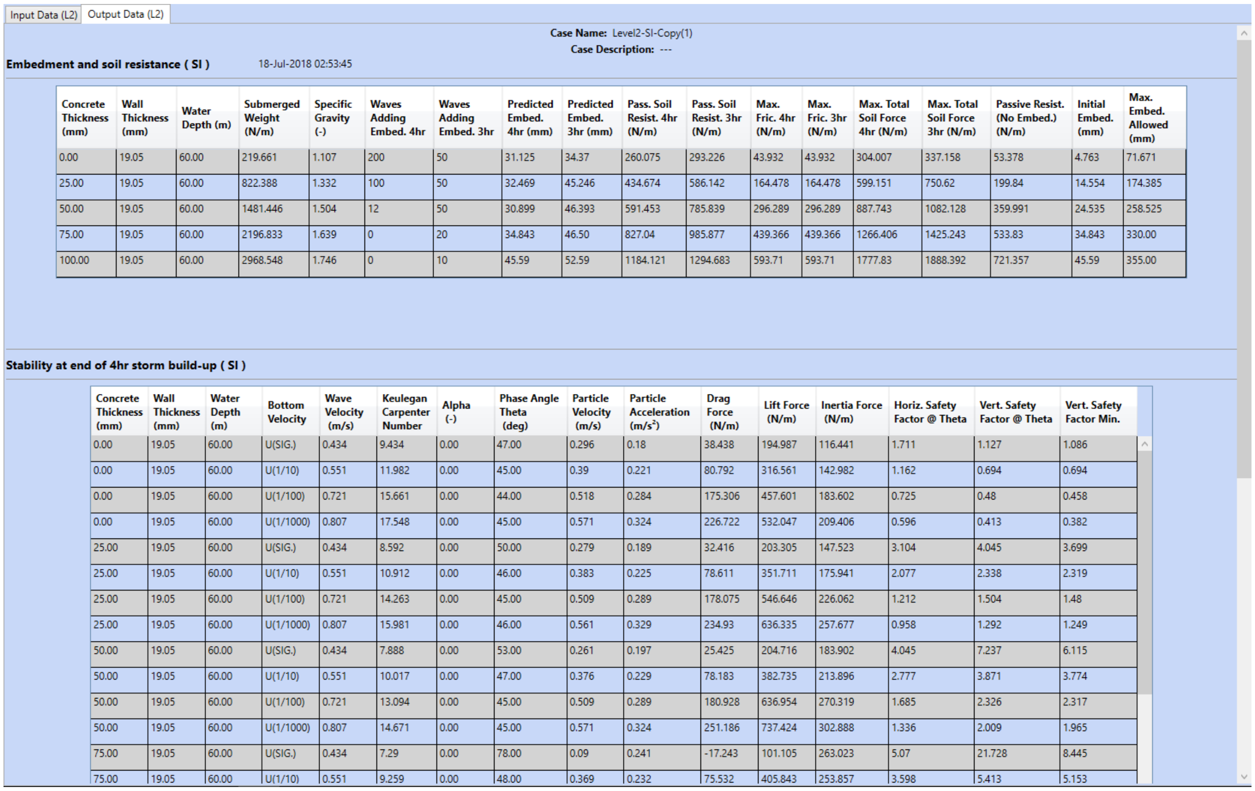


Figure 4-15: Parametric Variables Enabled

4.4 Level 2 Output Data Tab

The output can be viewed by clicking the **Output Data (L2)** tab, which displays the results outlined in this section in the chosen unit system, as presented in Figure 4-16.



Input Data (L2) | Output Data (L2)

Case Name: Level2-SI-Copy(1)

Case Description: ---

Embedment and soil resistance (SI) 18-Jul-2018 02:53:45

Concrete Thickness (mm)	Wall Thickness (mm)	Water Depth (m)	Submerged Weight (N/m)	Specific Gravity (-)	Waves Adding Embed. 4hr	Waves Adding Embed. 3hr	Predicted Embed. 4hr (mm)	Predicted Embed. 3hr (mm)	Pass. Soil Resist. 4hr (N/m)	Pass. Soil Resist. 3hr (N/m)	Max. Fric. 4hr (N/m)	Max. Fric. 3hr (N/m)	Max. Total Soil Force 4hr (N/m)	Max. Total Soil Force 3hr (N/m)	Passive Resist. (No Embed.) (N/m)	Initial Embed. (mm)	Max. Embed. Allowed (mm)
0.00	19.05	60.00	219.661	1.107	200	50	31.125	34.37	260.075	293.226	43.932	43.932	304.007	337.158	53.378	4.763	71.671
25.00	19.05	60.00	822.388	1.332	100	50	32.469	45.246	434.674	586.142	164.478	164.478	599.151	750.62	199.84	14.554	174.385
50.00	19.05	60.00	1481.446	1.504	12	50	30.899	46.393	591.453	785.839	296.289	296.289	887.743	1082.128	359.991	24.535	258.525
75.00	19.05	60.00	2196.833	1.639	0	20	34.843	46.50	827.04	985.877	439.366	439.366	1266.406	1425.243	533.83	34.843	330.00
100.00	19.05	60.00	2968.548	1.746	0	10	45.59	52.59	1184.121	1294.683	593.71	593.71	1777.83	1888.392	721.357	45.59	355.00

Stability at end of 4hr storm build-up (SI)

Concrete Thickness (mm)	Wall Thickness (mm)	Water Depth (m)	Bottom Velocity	Wave Velocity (m/s)	Keulegan Carpenter Number	Alpha (-)	Phase Angle Theta (deg)	Particle Velocity (m/s)	Particle Acceleration (m/s^2)	Drag Force (N/m)	Lift Force (N/m)	Inertia Force (N/m)	Horiz. Safety Factor @ Theta	Vert. Safety Factor @ Theta	Vert. Safety Factor Min.
0.00	19.05	60.00	U(SIG.)	0.434	9.434	0.00	47.00	0.296	0.18	38.438	194.987	116.441	1.711	1.127	1.086
0.00	19.05	60.00	U(1/10)	0.551	11.982	0.00	45.00	0.39	0.221	80.792	316.561	142.982	1.162	0.694	0.694
0.00	19.05	60.00	U(1/100)	0.721	15.661	0.00	44.00	0.518	0.284	175.306	457.601	183.602	0.725	0.48	0.458
0.00	19.05	60.00	U(1/1000)	0.807	17.548	0.00	45.00	0.571	0.324	226.722	532.047	209.406	0.596	0.413	0.382
25.00	19.05	60.00	U(SIG.)	0.434	8.592	0.00	50.00	0.279	0.189	32.416	203.305	147.523	3.104	4.045	3.699
25.00	19.05	60.00	U(1/10)	0.551	10.912	0.00	46.00	0.383	0.225	78.611	351.711	175.941	2.077	2.338	2.319
25.00	19.05	60.00	U(1/100)	0.721	14.263	0.00	45.00	0.509	0.289	178.075	546.646	226.062	1.212	1.504	1.48
25.00	19.05	60.00	U(1/1000)	0.807	15.981	0.00	46.00	0.561	0.329	234.93	636.335	257.677	0.958	1.292	1.249
50.00	19.05	60.00	U(SIG.)	0.434	7.888	0.00	53.00	0.261	0.197	25.425	204.716	183.902	4.045	7.237	6.115
50.00	19.05	60.00	U(1/10)	0.551	10.017	0.00	47.00	0.376	0.229	78.183	382.735	213.896	2.777	3.871	3.774
50.00	19.05	60.00	U(1/100)	0.721	13.094	0.00	45.00	0.509	0.289	180.928	636.954	270.319	1.685	2.326	2.317
50.00	19.05	60.00	U(1/1000)	0.807	14.671	0.00	45.00	0.571	0.324	251.186	737.424	302.888	1.336	2.009	1.965
75.00	19.05	60.00	U(SIG.)	0.434	7.29	0.00	78.00	0.09	0.241	-17.243	101.105	263.023	5.07	21.728	8.445
75.00	19.05	60.00	U(1/10)	0.551	9.259	0.00	48.00	0.369	0.232	75.532	405.843	253.857	3.598	5.413	5.153

Figure 4-16: Level 2 Output Data Tab

4.4.1 Embedment and Soil Resistance

4.4.1.1 Concrete Thickness

Refer to Section 3.3.2.1.

4.4.1.2 Submerged Weight

Refer to Section 3.3.2.2.

4.4.1.3 Specific Gravity

Refer to Section 3.3.2.3.

4.4.1.4 Waves Adding Embedment 4hr/3hr

The number of waves that contribute to pipe embedment when the pipe is subjected to 4-hour storm build-up and 3-hour design storm following the 4-hour build-up periods, respectively.

4.4.1.5 Predicted Embedment 4hr/3hr

The embedment predicted of the pipe into the soil after being subjected to 4-hour storm build-up and 3-hour design storm following the 4-hour build-up periods, respectively.

4.4.1.6 Passive Soil Resistance 4hr/3hr

The passive soil resistance that is generated after the pipe is subjected to 4-hour storm build-up and 3-hour design storm following the 4-hour build-up periods, respectively.

4.4.1.7 Maximum Friction 4hr/3hr

Maximum friction force generated after the pipe is subjected to 4-hour storm build-up and 3-hour design storm following the 4-hour build-up periods, respectively.

4.4.1.8 Maximum Total Soil Force 4hr/3hr

The maximum total horizontal soil force generated after the pipe is subjected to 4-hour storm build-up and 3-hour design storm following the 4-hour build-up periods, respectively. This value is the summation of the passive soil resistance and the friction force.

4.4.1.9 Passive Resistance (No Embedment)

The passive soil resistance without considering any pipe embedment.

4.4.1.10 Initial Embedment

The pipe embedment under initial conditions (i.e. before the application of any storm periods). The value is either calculated by the software or as input by the user; depending on the specification of the embedment inputs (refer to Section 4.3.2.5).

4.4.1.11 Maximum Embedment Allowed

Describes the upper limit that the embedment can reach. This value is dependent on parameters such as pipe dimensions and weight, and is calculated using different methods depending on the soil model.

4.4.2 Stability Results for 4hr Storm Build-up / Additional 3hr Storm

The results for the end of the 4-hour storm build-up and for the end of additional 3-hour storm are presented in separate tables, with outputs as described in this section.

4.4.2.1 Concrete Thickness

Refer to Section 3.3.2.1.

4.4.2.2 Bottom Velocity

The four different bottom velocity categories, for which all the calculations are carried out, are presented in separate rows in this column:

- $U_{SIG.}$: the velocity associated with the significant wave
- $U_{1/10}$: the velocity calculated from the mean height of the highest one-tenth of the waves; = 1.27 U_{SIG}
- $U_{1/100}$: the velocity calculated from the mean height of the highest one-hundredth of the waves; = 1.66 U_{SIG}
- $U_{1/1000}$: the velocity calculated from the mean height of the highest one-thousandth of the waves; = 1.86 U_{SIG}

4.4.2.3 Wave Velocity

Velocity of the near seabed wave including the effects of spreading.

4.4.2.4 Keulegan-Carpenter Number

The Keulegan-Carpenter number calculated for each respective wave velocity and concrete thickness, with the form as given in Section 3.3.1.2.

4.4.2.5 Alpha

The current to wave ratio calculated for each respective bottom velocity; refer to Section 3.3.1.3.

4.4.2.6 Phase Angle Theta

Refer to Section 3.3.2.4.

4.4.2.7 Particle Velocity

Refer to Section 3.3.2.5.

4.4.2.8 Particle Acceleration

Refer to Section 3.3.2.6.

4.4.2.9 Drag Force

Refer to Section 3.3.2.7.

4.4.2.10 Lift Force

Refer to Section 3.3.2.8.

4.4.2.11 Inertia Force

Refer to Section 3.3.2.9.

4.4.2.12 Horizontal Safety Factor at Theta

Refer to Section 3.3.2.10.

4.4.2.13 Vertical Safety Factor at Theta

Refer to Section 3.3.2.11.

4.4.2.14 Vertical Safety Factor

Refer to Section 3.3.2.12.

4.5 Level 2 Reports

Similar to Level 1, once the analysis is completed a PDF file report would also be created. This file can be accessed through the **Report** button option in the ribbon menu. To access the PDF file from a directory please see section **Error! Reference source not found.**. An instance of input and output pages of Level 2 report are shown in Figure 4-17 and Figure 4-18, respectively.

PRCI OBS Level 2 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis

Case Name: Level2-SI-Copy(1) Case Description: ---

Report Compiled on 18/07/2018

Soil Properties

Soil Type:	PRCI Sand
Relative Density (-):	0.500
Embedment (mm):	0.0
RIMBED (-):	0.500
RLMBED (-):	0.500
RITRCH (-):	1.000
RLTRCH (-):	1.000
Mu (-):	0.200

Environmental Properties

Sea Water Density (kg/m³):	1025.0
Marine Growth Thickness (mm):	0.0
Marine Growth Density (kg/m³):	1025.0

Pipe Properties

Pipe OD (mm):	508.00
Corrosion coating (Layer):	Multi
Densitiy coating (Layer):	Multi
Density concrete (kg/m³):	2560.0
Density field joint (kg/m³):	1300.0
Cutback (mm):	350.0
Taper angle (deg):	0.0
Product Density (kg/m³):	0.0
Length of pipe joint (m):	12.20
Density of steel pipe (kg/m³):	7850.0

Pipe Roughness

Pipe Roughness:	Concrete

Concrete Thickness Range

Concrete Initial (mm):	0.00
Concrete Final (mm):	100.00
Concrete Increment (mm):	25.00

Wall Thickness

Wall Thickness (mm):	19.05

Water Depth

Water Depth (m):	60.00

Current Settings

Boundary Layer:	1/7 Power
Current (m/s):	0.00
Current Angle (deg):	90.0
Reference Height (m):	1.00

Applied Current Settings

Current:	Average over OD

Wave Properties

Input Type:	Surface Wave Spectra
Significant Wave Height (m):	10.0
Peak Period (sec):	10.0

Spectral Settings

Spectrum:	Ochi-Hubble
Spectral Peakedness (-):	1.0
Wave Direction (deg):	90.0
Wave Spreading (deg):	30.0

Directional Spectrum

Selected:	Bi-Modal
Secondary Direction (deg):	90.0
Secondary Spreading (deg):	30.0
Mixing Constant (-):	0.5

Multi-Layered Coating

Layer	Thickness (mm)	Density (kg/m³)
1	1.00	1300.0
2	0.00	0.0
3	0.00	0.0

Page 1

Figure 4-17: Level 2 Report (list of inputs)

PRCI OBS Level 2 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis

Case Name: Level2-SI-Copy(1) Case Description: ---

Report Compiled on 18/07/2018

Concrete Thickness (mm): 0.00	Wall Thickness (mm): 19.05	Water Depth (m): 60.00
	Submerged Weight (N/m): 219.66	Specific Gravity (-): 1.11
Embedment & Soil Resistance	**After 4hr Storm Buildup**	**After additional 3hr Storm**
No. of Waves adding Embedment	200	50
Predicted Embedment (mm)	31.125	34.370
Passive Soil Resistance (N/m)	260.075	293.226
Max. Friction (No Lift) (N/m)	43.932	43.932
Total Soil Force (No Lift) (N/m)	304.007	337.158

Stability at end of 4hr storm build-up

Bottom Velocity	Wave Velocity	Keulegan Carpenter Number	Alpha	Phase Angle Theta	Particle Velocity	Particle Acceleration	Drag Force	Lift Force	Inertia Force	Horiz. Safety Factor at Theta	Vert. Safety Factor at Theta	Vert. Safety Factor Min.
[-]	[m/s]	[-]	[-]	[deg]	[m/s]	[m/s²]	[N/m]	[N/m]	[N/m]	[-]	[-]	[-]
SIG	0.434	9.434	0.000	47.000	0.296	0.180	38.438	194.987	116.441	1.711	1.127	1.086
1/10	0.551	11.982	0.000	45.000	0.390	0.221	80.792	316.561	142.982	1.162	0.694	0.694
1/100	0.721	15.661	0.000	44.000	0.518	0.284	175.306	457.601	183.602	0.725	0.480	0.458
1/1000	0.807	17.548	0.000	45.000	0.571	0.324	226.722	532.047	209.406	0.596	0.413	0.382

Potential for stability at end of additional 3hr storm

SIG	0.434	9.434	0.000	47.000	0.296	0.180	38.177	193.665	115.652	1.940	1.134	1.094
1/10	0.551	11.982	0.000	45.000	0.390	0.221	80.245	314.416	142.013	1.319	0.699	0.699
1/100	0.721	15.661	0.000	44.000	0.518	0.284	174.118	454.501	182.358	0.823	0.483	0.461
1/1000	0.807	17.548	0.000	45.000	0.571	0.324	225.186	528.441	207.987	0.677	0.416	0.385

Page 3

Figure 4-18: Level 2 Report (an instant of output page)

4.6 Level 2 Plots

Control of the generation, viewing and printing of output data plots for the Level 2 analyses is facilitated by the options in the **Plots** drop down list, as presented in Figure 4-19. Each of the plot menu items opens a window to display the selected plot, with various view options.

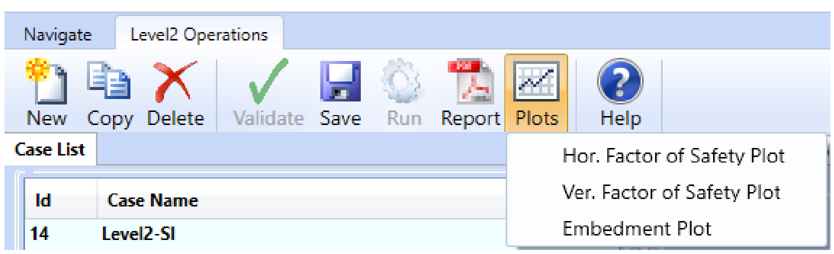


Figure 4-19: Level 2 Plot Selection List

4.6.1 Hor. Factor of Safety Plot

This plot displays the Horizontal stability factor of safety as a function of the various parametric input ranges, as presented in Figure 4-20. The plot shows various lines that present the Horizontal safety factor values, based on the selection of options for bottom velocity, primary variable selection (which sets the parameter of focus, plotted on the x-axis), and secondary variables (where curves can be restricted to specific combinations of inputs only).

The plot window has options to **Close** the plot window, **Save as PNG** the plot, and show/hide grid lines.

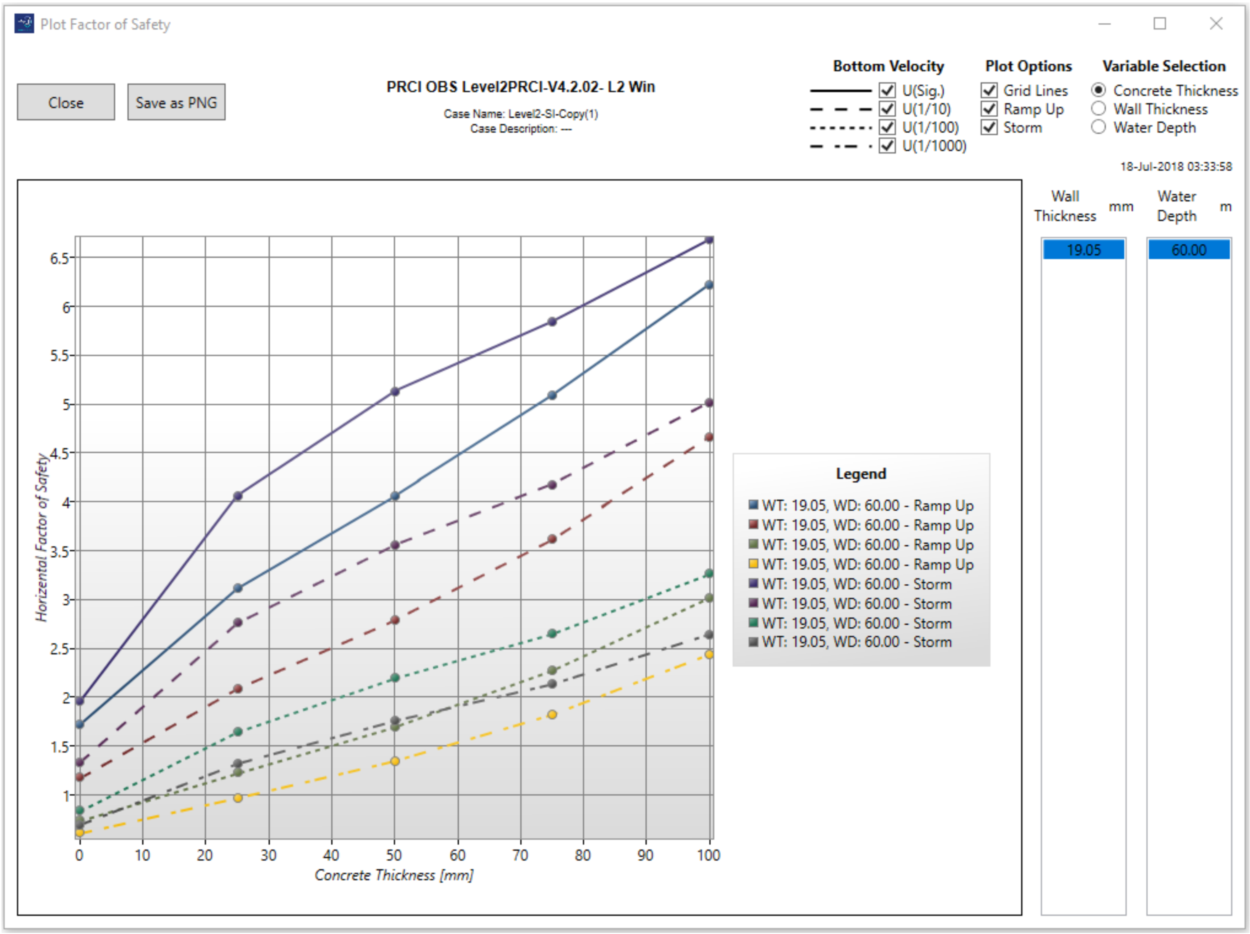


Figure 4-20: Level 2 Horizontal Stability Factor of Safety Plot

4.6.2 Ver. Factor of Safety Plot

This plot displays **Vertical Stability Factor of Safety** as a function of the various parametric input ranges, as presented in Figure 4-21. The plot window has similar features as **Hor. Factor of Safety**.

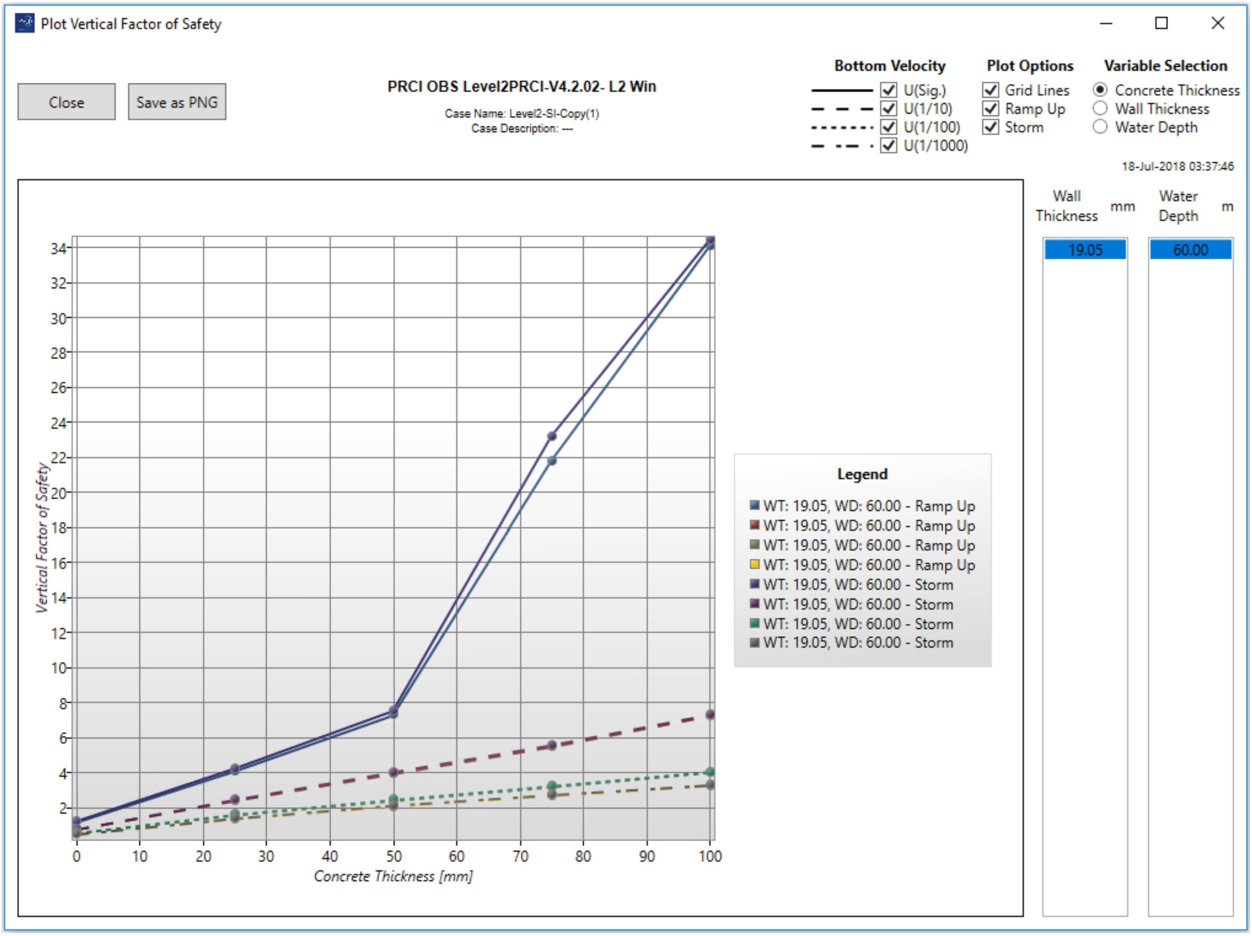


Figure 4-21: Level 2 Stability Vertical Factor of Safety Plot

4.6.3 Embedment Plot

This plot displays the pipe embedment as a function of the various parametric input ranges, as presented in Figure 4-22. The plot shows various lines that present the embedment values based on the selection of options for bottom velocity, primary variable selection (which sets the parameter of focus, plotted on the x-axis), and secondary variables (where curves can be restricted to specific combinations of inputs only).

The plot window has options to **Close** the plot window, **Save as PNG** the plot, and show/hide grid lines.

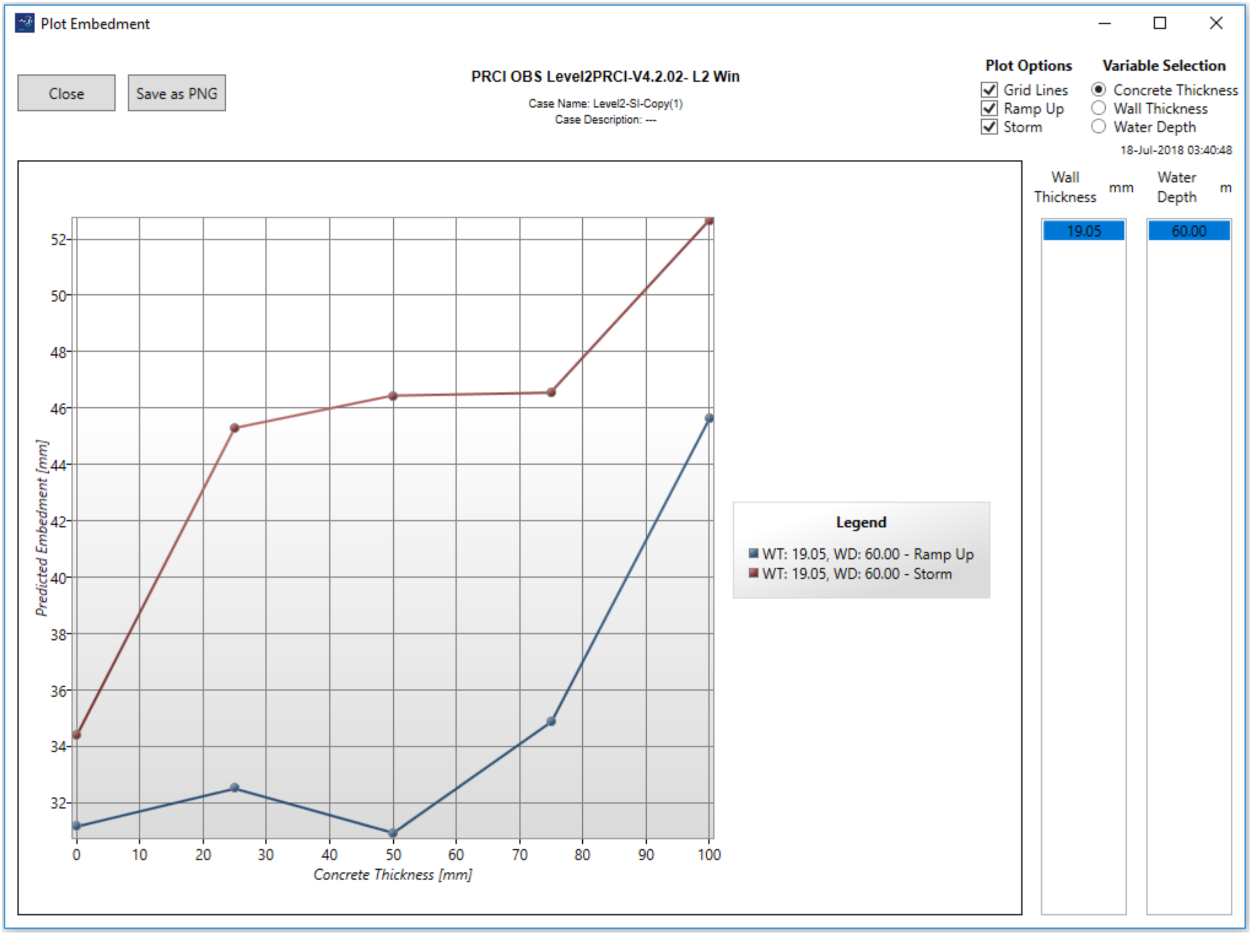


Figure 4-22: Level 2 Embedment Plot

5 Level 3 Analysis

5.1 Introduction

In a Level 3 analysis, a two-dimensional dynamic pipeline model is used to calculate stresses and deflections in the line during storm conditions. Input parameters are specified over a grid, taking account of lengthwise variations along the pipeline route. A time history of the on-bottom current velocities and wave kinematics is simulated by the software module to model the pipeline behavior in irregular seas. The pipeline model considers the effect of end restraints such as risers and anchor points by modeling them as a series of springs on the end of the pipeline.

It is anticipated that this type of analysis will be used to establish a refined design, or to check and/or calibrate designs produced using a Level 2 analysis, particularly where the Level 2 assumptions do not accurately represent the actual situation. This may occur close to end restraints or other structural restraints, if axial tension could develop, or if excessive pipe movements are allowed.

The Level 3 software module consists of multiple tabs for specification of inputs, controls for the viewing and plotting of results, and three core calculation submodules: WINWAVE, the Random Wave Generation module; WINFORCE, the Hydrodynamic Force module; and WINDYNA, the dynamic simulation module.

The Random Wave Generation module WINWAVE simulates water-particle velocity time series that result from wave motion at the sea surface. The time series are simulated at grid points on the sea floor that correspond to the pipeline route. The geometric layout of the pipeline and nodes is shown in Figure 5-1. The velocity time series simulated at each pipe node is passed to the hydrodynamic force module. Plot output of the velocities is available and can be referenced to check the simulation output.

The main assumption of the Level 3 analysis tool is that the Fourier expansion of the measured drag and lift forces in regular waves (as determined during the PRCI model tests, project PR-170-185 [6]) can be used to calculate the forces associated with the individual waves in irregular waves when taking into account the effect of the flow history; the so-called “wake effect”.

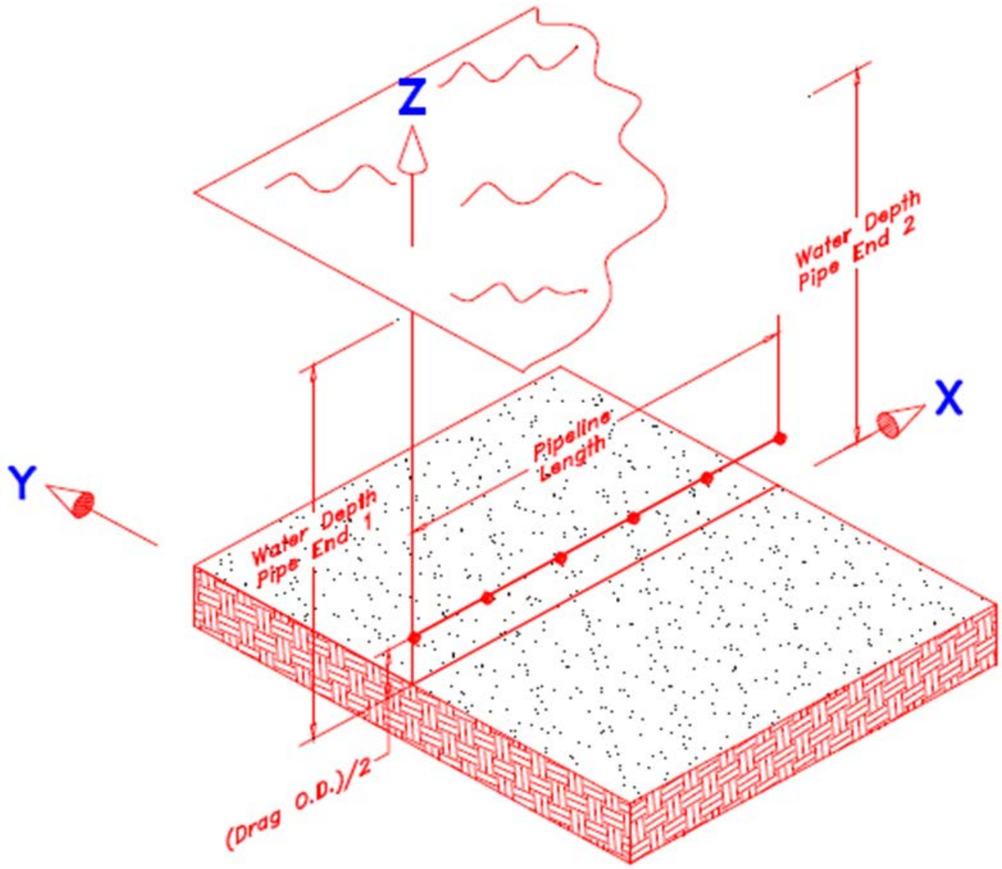


Figure 5-1: Level 3 Geometric Layout of Pipeline and Nodes

5.2 Calculation Procedure

The Level 3 suite consists of a top level input and post processing module and an integrated time domain dynamic simulation routine that incorporates random wave generation and hydrodynamic forces based on Fourier decomposition of results from numerous model tests and soil models which include lateral earth pressure soil resistance as well as frictional soil resistance. Three core subroutines of the Level 3 module are WINWAVE, WINFORCE and WINDYNA.

The random wave generation routine (WINWAVE) calculates bottom water particle velocities based on Airy wave theory and a set of randomly phased waves that are assigned different wave frequencies and directions. Wave energy is directionally spread using a wrapped normal distribution. Each component wave is assigned a direction based on a normal distribution in which the mean direction and standard deviation from the mean direction are specified by the user.

The hydrodynamic force generation routine (WINFORCE) uses the generated bottom particle velocities and a state-of-the-art force formulation to calculate hydrodynamic drag and lift forces on a stationary pipeline. The calculation uses a Fourier summation to determine the wave forces. The coefficients for the Fourier summation are taken from a database developed from the model test results. The three database files of force coefficients (AGAWCU, AGAWCX, and AGAWU) that were developed for PRCI are incorporated in the Level 3 module.

The on-bottom pipeline dynamics simulation routine (WINDYNA) models the pipeline as two-dimensional finite beam elements. The module uses the hydrodynamic forces and a history dependent soil resistance model (developed for the PRCI in project PR-194-719 [14]) to dynamically model the wave/soil interaction. All elements are in a straight line and of equal length, but soil parameters, pipe parameters, boundary conditions, and applied loads can be varied along the pipe length.

Pipeline displacements, embedment, instantaneous factors of safety and stresses are the main outputs. These can be obtained for several nodes as a function of time, or for the entire pipeline at specified time steps.

The processes within the Level 3 module are illustrated in Figure 5-2, Figure 5-3, and Figure 5-4.

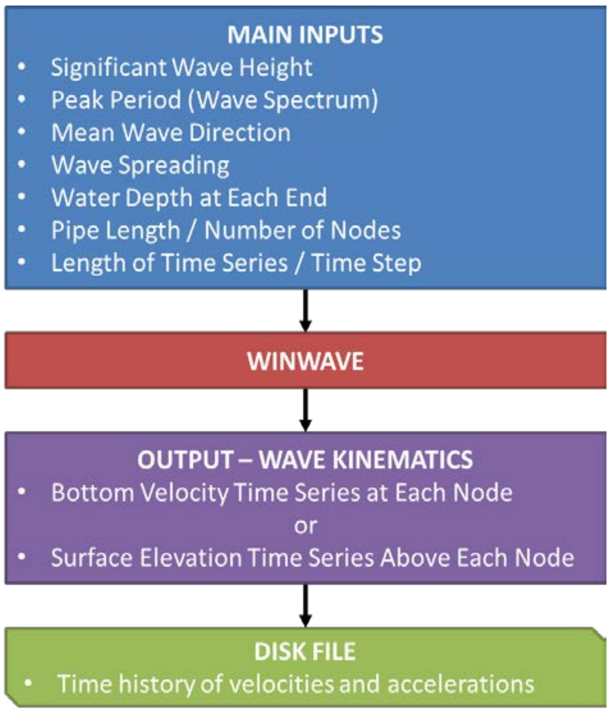


Figure 5-2: Input/Output for WINWAVE

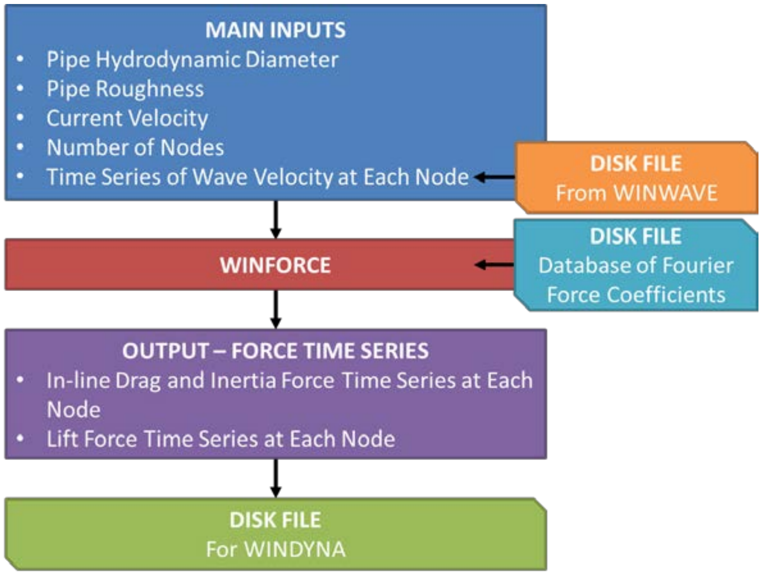


Figure 5-3: Input/Output for WINFORCE

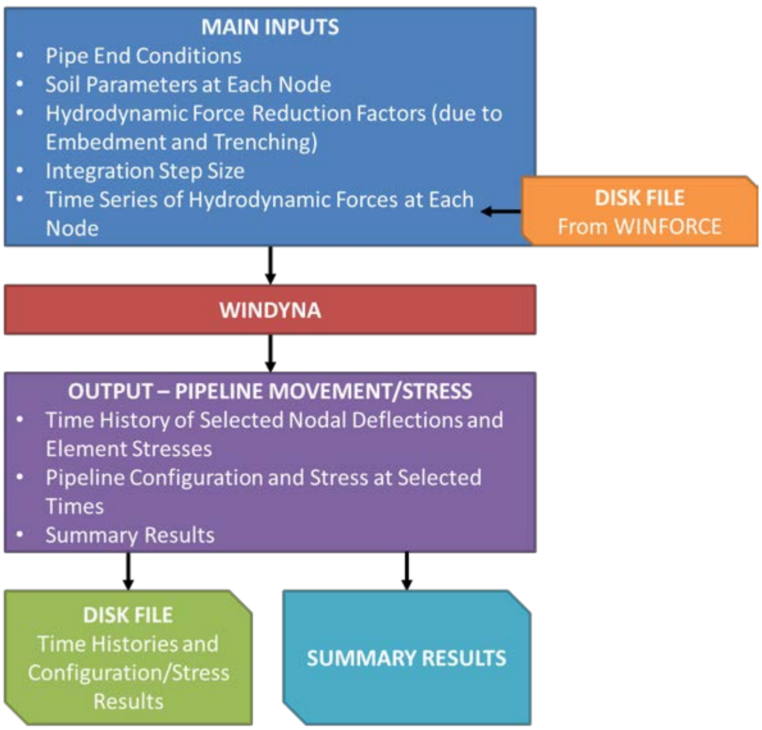


Figure 5-4: Input/Output for WINDYNA

5.3 Guidance Notes

5.3.1 General

Whereas the Level 2 and ASM modules may be used for routine determination of pipeline stability and selection of concrete thickness, Level 3 is not as well suited to those tasks. Instead, it does offer the potential for optimizing pipeline stability with respect to concrete weight coating, using a more refined but complex analysis than that used by the other levels. Before embarking on a stability analysis using the Level 3 module, the detailed internal procedures should be well understood, including some of the following points:

- Preliminary stability analyses should be completed using Level 2 or the ASM module, so as to have a good starting point for a Level 3 stability analysis.
- For each pipe outer diameter and weight, sufficient runs need to be made with different "seeds". Random seeds are numbers used as internal input to generate random irregular sea states, with two different seed values resulting in two different sea states. Performing the analysis with a sufficient number of storm simulation seeds provides a reliable indication of the range of results which may be obtained for the specified wave spectrum parameters.
    - Note: this may need to be repeated at other water depths and wave conditions along the pipeline route.
- Once a satisfactory pipe weight and outer diameter have been determined for one condition, say the maximum significant wave height (H_s) case, other wave conditions need to be checked e.g. storms with lower H_s but greater peak period and/or different peakedness. Add some additional cases to check the effects of currents. These all need to be run with sufficient different seeds.
    - Note: this may need to be repeated at other water depths and wave conditions along the pipeline route.
- Instead, the criteria for pipeline stability need to be established. With Level 3 the instantaneous factors of safety computed are not meaningful. The following questions need to be answered:
    - What displacement is acceptable?
    - If a single 3-hour storm produces displacements greater than a minor fraction of the pipeline diameter, what will be the total displacement (and resulting stresses) of the pipeline during a lifetime of storms and how can that be determined?
- Level 3 reflects many kinds of nonlinear behavior as discussed further below. It is not rare for this to produce unexpected results which then require further evaluation and time.
- Due to Level 3's greater complexity, there is a larger potential for errors in the usage of Level 3 as compared to the other levels, as well as greater difficulty in identifying the errors.

In summary, the stability analysis using Level 3 will require additional time and effort compared to that using Levels 1, 2 or ASM. Additionally, Level 3 assessment is more suitable for experienced users who are able to provide at least engineering judgement on the results. However, this may be beneficial depending on the case considered, with the decision of design approach left up to the designer.

5.3.2 Simulations with Unit Length

One way to minimize the complexity of a Level 3 analysis whilst still claiming the benefits of the more advanced stability analysis is to simulate a single pipe segment of unit length. This allows one to determine if a unit length of pipe would remain in place using all of the hydrodynamics, force estimation, and soil embedment resistance of the dynamic simulation without the additional output and runtime burden of multiple segments. Importantly, simulations with unit length can provide a very good source of information on the physical behavior of the considering design case.

5.3.3 Non-Linearities

The Level 3 module has a great number of the non-linearities that reflect corresponding physical non-linearities. The software module evaluates pipeline stability every few degrees during wave cycles. Unexpected results almost always are associated with shifts in the relationship between drag and lift forces, i.e. the phase in the wave cycle at which the critical conditions occur changes due the non-linearities. Consequently, small changes in parameters can shift the relationship between drag and lift forces in such a way that the general trends one expects do not apply. This is especially true for relatively shallow water cases, say less than 200 ft. It is always good to study variations around the design parameters. Unfortunately, the design parameter space for pipeline stability is large enough that to do this systematically is considerable work that is difficult to justify (and may produce results that are even more difficult to explain!).

5.3.4 Simulation Duration

In order for the results of a particular Level 3 simulation to be representative, it is necessary to simulate a sufficient length of time. Typically, this means that Level 3 simulations should be made to represent on the order of three hours of time. If shorter periods of time are simulated, the likelihood that the extreme waves are included in the analysis is reduced. Moreover, since the pipe/soil interaction is history dependent, a single 3-hour simulation may not be representative of the “average” result determined from a large number of simulations, where each simulation represents a different realization of the design sea state. This is most likely to be the case in weaker soils, where the history dependent portion of the soil resistance can become very large in relation to the history independent portion. If the pipe breaks out of the soil during such a simulation, a large change in total soil resistance capability would occur, since the history dependent portion is reset to zero. For this type problem, the timing of the breakout (early or late in the simulation) could significantly change the total net movement of the pipe.

5.3.5 Further Comments on Displacement

The resulting pipe displacements obtained from a Level 3 analysis should be used with caution. The pipeline-soil interaction tests that the calculation routines are based on (see Chapter 1 of [16]) were conducted by oscillating a short length of pipe back and forth on a prepared bed so that it would become embedded, and then determining the force required to pull it out of the trench it had created. The focus of these test programs was not to determine how far the pipe would move. The amount of movement calculated by the software is a function of how many times the wave force exceeds the force to move the pipe from the embedment trench that develops after each movement. The Level 3 analysis has not been validated as to the amount of pipeline displacement produced by specified wave and soil conditions, i.e. as to the accuracy of the displacement prediction. These test programs and the resulting calculation routines such as those used by the Level 3 module were developed to determine the weight of pipeline needed to remain stable as-laid. Any estimate they produce as to the amount of displacement to be experienced needs to be treated with caution.

5.4 Case Definition Tab

This input tab defines the case title, simulation duration, unit system, pipe properties and water depths, as presented in Figure 5-5.

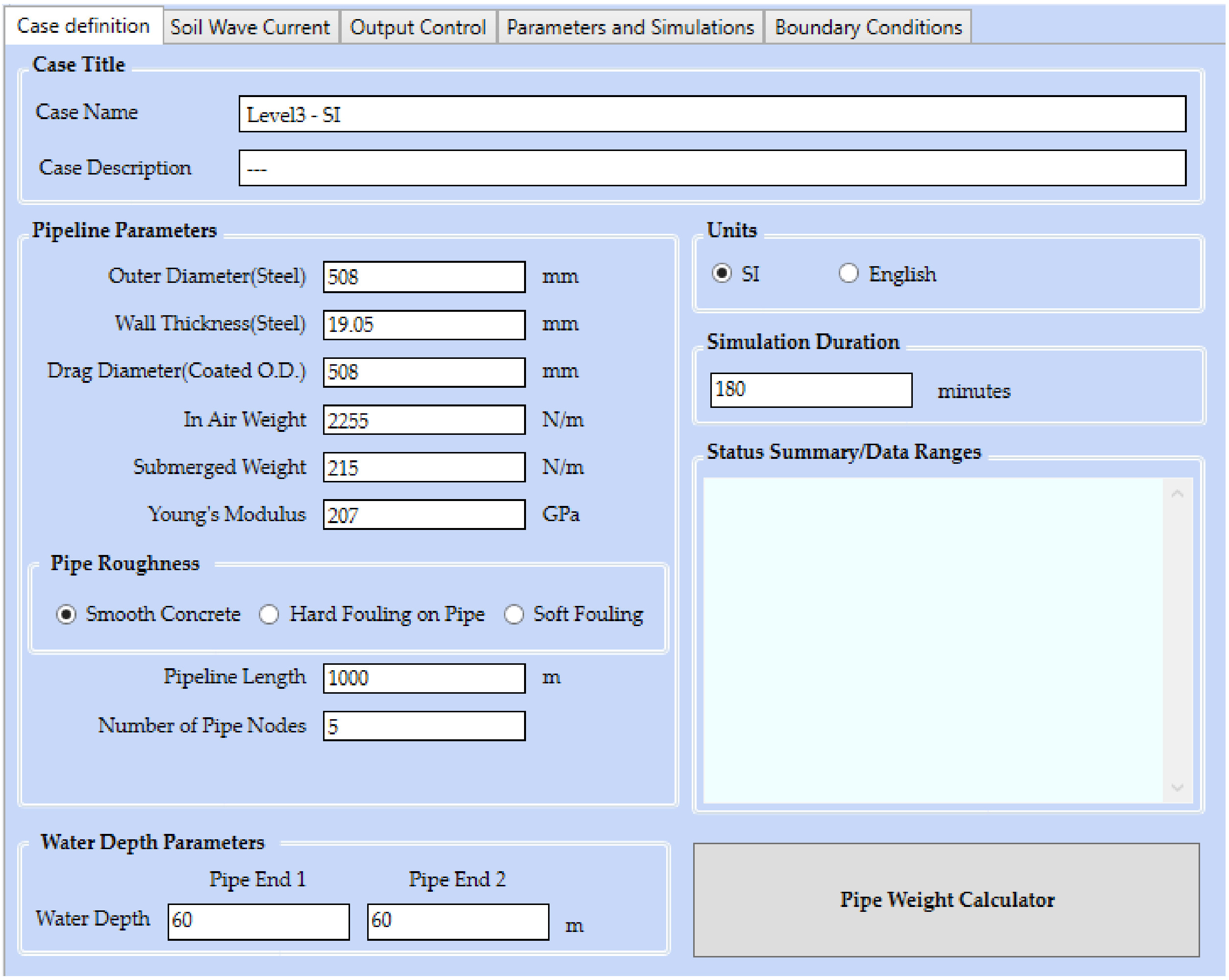


Figure 5-5: Level 3 Input – Case Definition Tab

5.4.1 Pipe Parameters

5.4.1.1 Outer Diameter

Refer to Section 3.2.1.1.

5.4.1.2 Wall Thickness

Refer to Section 3.2.1.2.

5.4.1.3 Drag Diameter (Coated OD)

Total pipe hydrodynamic diameter, including all coatings, that is not embedded in the soil (refer to Figure 5-6). This may also be input using the **Pipe Weight Calculator** option (refer to Section 5.5).

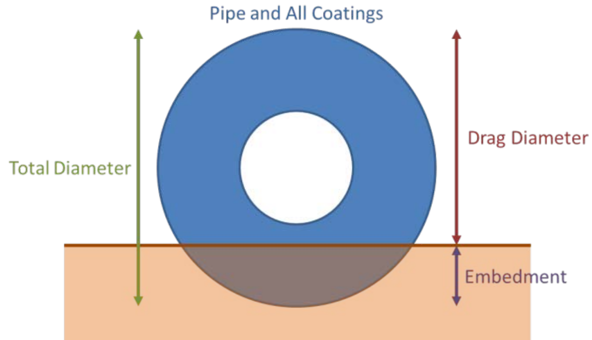


Figure 5-6: Pipe Drag Diameter

5.4.1.4 In-Air Weight

Average total weight of the pipeline, including all coatings and contents, in air per unit length of pipe. This may also be input using the **Pipe Weight Calculator** option (refer to Section 5.5).

5.4.1.5 Submerged Weight

Average total submerged weight of the pipeline, including all coatings and contents, per unit length of pipeline. This value is equal to the in-air weight minus the buoyant force of displaced water. This may also be input using the **Pipe Weight Calculator** option (refer to Section 5.5).

5.4.1.6 Young's Modulus

Young's Modulus for the steel pipe.

5.4.1.7 Pipe Roughness

Refer to Section 4.3.5.

5.4.1.8 Pipeline Length

The total length of pipeline to be analyzed. If only a section of pipe is to be analyzed for stability (similar to a Level 2 analysis), a unit length of pipeline (a one foot or one meter segment of pipe) is sufficient.

5.4.1.9 Number of Pipe Nodes

The number of nodal points to include in the finite element model. If only a section of pipe is to be analyzed for stability (similar to a Level 2 analysis), a two-node model (which corresponds to a single element model) is sufficient.

5.4.2 Water Depth Parameters

The water depth at the first end and the second end of the pipeline.

5.4.3 Simulation Duration

The simulated duration (not to be confused with the computing runtime) is the total duration for the dynamic simulation of the design storm. Based on limitations of the Random Wave Generation module, durations must be no greater than 1000 cycles (based on the peak period). In order for the results of a particular simulation to be representative, it is necessary to simulate a sufficient length of time.

5.5 Pipe Weight Calculator

This dialog box enables calculation of pipe weight parameters such as the in-air weight, the submerged weight and the specific gravity of the pipe with product contents, with the following operation buttons, as presented in Figure 5-7:

- **Calc** Button
    - Performs the calculation of the following parameters based on the input values.
- **Paste** Button
    - Results from the **Pipe Weight Calculator** may be pasted into the **Pipe Properties** section of the input by using the **Paste** button.
- **Cancel** Button
    - The calculation may be canceled without pasting the information into the **Pipeline Parameters** section of the input by selecting the **Cancel** button.

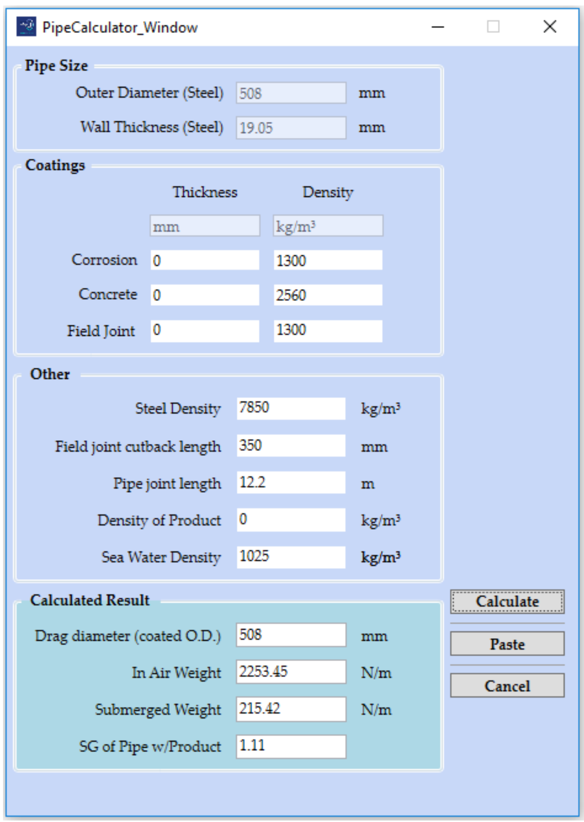


Figure 5-7: Pipe Weight Calculator

5.5.1 Pipe Size

5.5.1.1 Outer Diameter

Refer to Section 3.2.1.1.

5.5.1.2 Wall Thickness

Refer to Section 3.2.1.2.

5.5.2 Coatings

5.5.2.1 Corrosion Coating Thickness

Refer to Section 3.2.1.3.

5.5.2.2 Corrosion Coating Density

Refer to Section 3.2.1.4.

5.5.2.3 Concrete Coating Thickness

The thickness of the external layer of concrete coating to be considered.

5.5.2.4 Concrete Coating Density

Refer to Section 3.2.1.5.

5.5.2.5 Field Joint Coating Thickness

The thickness of the field joint coating to be considered.

5.5.2.6 Field Joint Coating Density

Refer to Section 3.2.1.6.

5.5.3 Other

5.5.3.1 Steel Density

Refer to Section 3.2.1.11.

5.5.3.2 Field Joint Cutback Length

Refer to Section 3.2.1.7. The **Pipe Weight Calculator** assumes a taper angle of 0° from the radial direction of the pipe.

5.5.3.3 Pipe Joint Length

Refer to Section 3.2.1.10.

5.5.3.4 Density of Product

Refer to Section 3.2.1.9.

5.5.3.5 Seawater Density

Refer to Section 3.2.6.1.

5.5.4 Calculated Result

5.5.4.1 Drag Diameter (Coated OD)

The total outer diameter of the pipe with all coatings, as described in Section 5.4.1.3.

5.5.4.2 In-Air Weight

The total of the pipe weight, concrete and corrosion coating weight without field joint coating weight and the internal contents (product weight), as an average per unit length. The ratio of field joints and concrete/corrosion coating is specified with the cutback length and pipe joint length.

5.5.4.3 Submerged Weight

The in-air weight minus the buoyancy force from the displaced seawater on the coated pipe (drag OD).

5.5.4.4 Specific Gravity of Pipe with Product

The specific gravity is presented for information purposes only, calculated as the ratio of the in-air weight of the pipe to the buoyancy force.

5.6 Soil Wave Current Tab

This input tab defines the soil conditions, current and wave parameters, as presented in Figure 5-8.

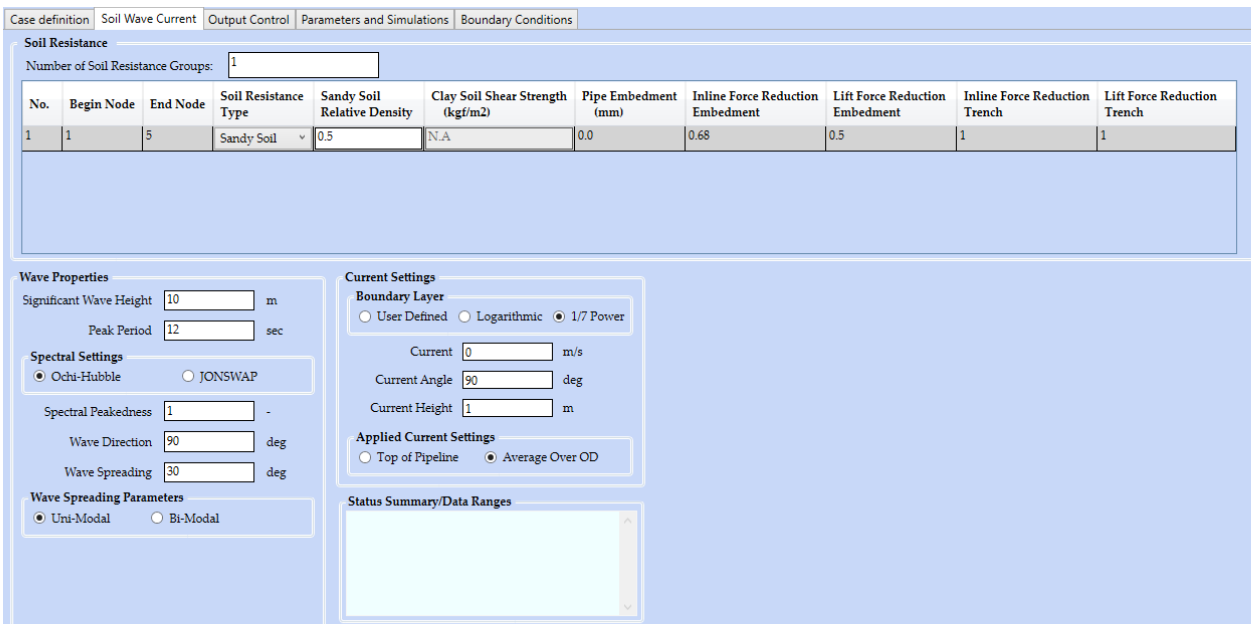


Figure 5-8: Level 3 Input – Soil Wave Current Tab

5.6.1 Soil Resistance

5.6.1.1 Number of Soil Resistance Groups

The soil conditions can be varied over the length of the pipeline. The user may input up to a maximum of ten different soil groups.

5.6.1.2 Begin Node

Beginning node number for the soil group.

5.6.1.3 End Node

Ending node number for the soil group.

5.6.1.4 Soil Resistance Type

The model for determination of lateral earth pressure soil resistance and frictional soil resistance using the PRCI pipe/soil interaction model **Error! Reference source not found.** is selectable from the options of sandy soil and clay soil. The user should note that the V&S and V&L models have not been implemented in the Level 3 and the existing soil models are still the original PRCI models. This is crucial when it is planned to compare the results of Level 2 and Level 3.

5.6.1.5 Sandy Soil Relative Density

Refer to Section 4.3.2.2. This field will be inactive when clay soil is chosen.

5.6.1.6 Clay Soil Shear Strength

Refer to Section 4.3.2.3. This field will be inactive when sandy soil is chosen.

5.6.1.7 Pipe Embedment

If this value is positive, it represents the limiting pipe embedment into the soil. If this value is negative (or zero), it represents the actual pipe embedment at the start of the run.

5.6.1.8 In-Line Force Reduction due to Embedment (Level 3)

Maximum in-line force reduction multiplier due to pipe embedment. Considering the reduction factor data presented in Figure 5-9 and Figure 5-10, the following values may be generally suggested for the available soils at an embedment ratio of 0.5:

- 0.313 for clay
- 0.680 for sand

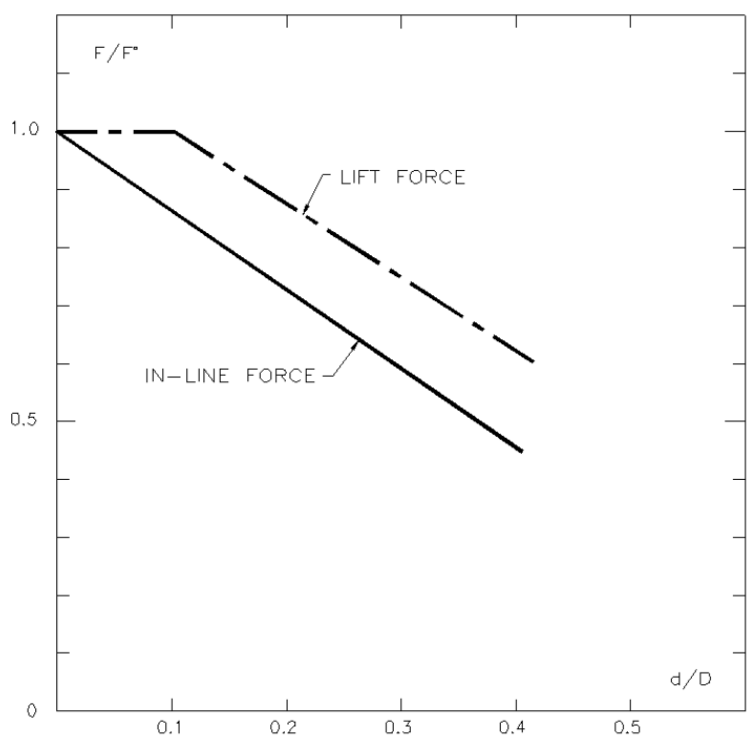


Figure 5-9: Force Reduction Factors vs Embedment Ratio for Impermeable Soils [6], [19]

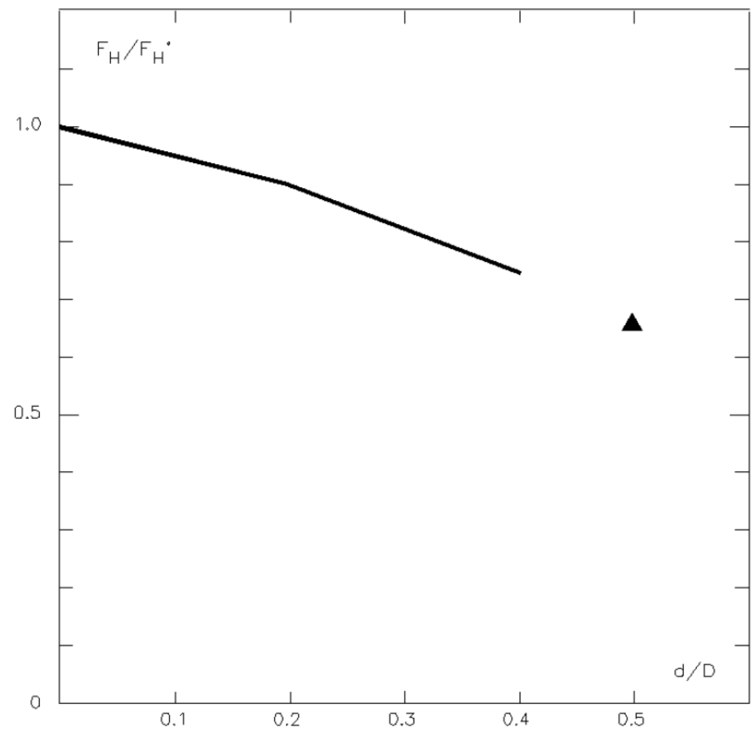


Figure 5-10: In-Line Force Reduction Factor vs Embedment Ratio for Fully Permeable Soils [6], [19]

5.6.1.9 Lift Force Reduction due to Embedment (Level 3)

Maximum lift force reduction multiplier due to pipe embedment. Considering the reduction factor data presented in Figure 5-9, the following values may be generally suggested for the available soils at an embedment ratio of 0.5, as per [6]:

- 0.5 for clay
- 0.5 for sand

5.6.1.10 In-Line Force Reduction due to Trench (Level 3)

Maximum in-line force reduction multiplier due to trench geometry. This value may be obtained using the reduction factor data presented in Figure 5-11. The reduction factor is plotted against the trench slope measured with respect to the flat seabed. The dotted lines represent extrapolations to the actual conducted model tests.

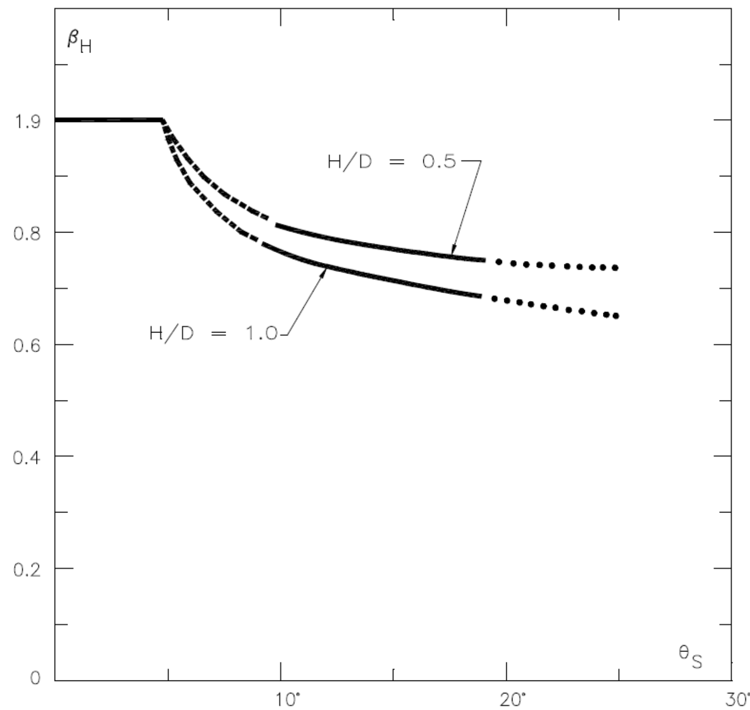


Figure 5-11: In-Line Force Reduction Factor vs Trench Slope Angle [7], [16]

5.6.1.11 Lift Force Reduction due to Trench (Level 3)

Maximum lift force reduction multiplier due to trench geometry. This value may be obtained using the reduction factor data presented in Figure 5-12. The reduction factor is plotted against the trench slope measured with respect to the flat seabed. The dotted lines represent extrapolations to the actual conducted model tests.

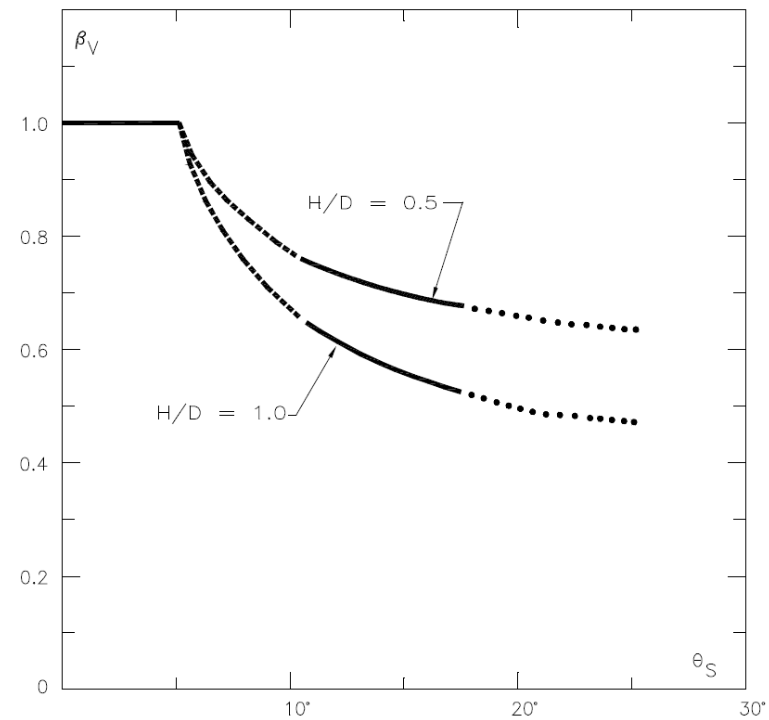


Figure 5-12: Vertical Force Reduction Factor vs Trench Slope Angle [7], [16]

5.6.2 Wave Properties Input Type

Refer to Section 4.3.6.

5.6.3 Wave Properties Spectral Settings

Refer to Section 4.3.7.

5.6.4 Wave Properties Directional Spectrum

Refer to Section 4.3.8.

In addition, the Level 3 calculations permit the user-specification of the number of angle divisions for wrapped normal directional spreading discretization (up to a maximum of 24), for both single and bi-modal spreading.

5.6.5 Current Settings

5.6.5.1 Boundary Layer

Refer to Section 3.2.3.1.

5.6.5.2 Current

Refer to Section 3.2.3.2.

5.6.5.3 Current Angle

Refer to Section 3.2.3.3.

5.6.5.4 Reference Height

Refer to Section 3.2.3.4.

5.6.5.5 Seabed Roughness

Refer to Section 3.2.3.5.

5.6.5.6 Applied Current Settings

Refer to Section 3.2.3.6.

5.7 Output Control Tab

This input tab controls the aspects of the printing and plotting outputs, as presented in Figure 5-13.

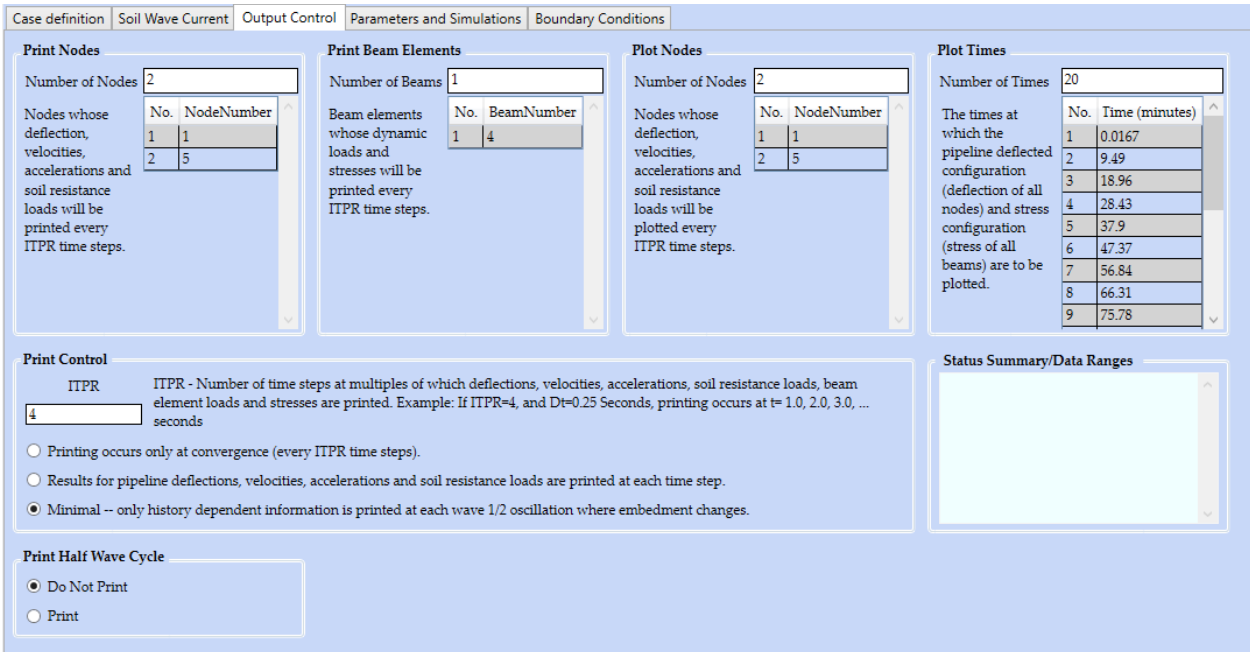


Figure 5-13: Level 3 Output Control Tab

5.7.1 Print Nodes

5.7.1.1 What is ITPR?

A print control integer. **ITPR** is the number of time steps at multiples of which the deflections, velocities, accelerations, soil-resistance loads, beam element loads, and stresses are printed. Example: If **ITPR** = 4, and the time step interval, DT = 0.25 sec, printing occurs at t = 1.0 sec, 2.0 sec, 3.0 sec, etc.

5.7.1.2 Number of Nodes

The total number of nodes whose deflections, velocities, accelerations, and soil-resistance loads will be printed to the output file, which occurs every **ITPR** (a print control integer) time steps. This part of the output can be large for many time steps. For long simulation runs, it may be useful to set this value to zero to suppress this part of the output and expedite the process.

5.7.1.3 Node List

List containing the nodes numbers whose deflections, velocities, accelerations, and soil-resistance loads are to be printed to the output file, every **ITPR** time steps.

5.7.2 Print Beam Elements

5.7.2.1 Number of Beams

The total number of beam elements whose dynamic loads and stresses will be printed to the output file every **ITPR** time steps. This part of the output can be large for many time steps. For long simulation runs, it may be useful to set this value to zero to suppress this part of the output and expedite the process.

5.7.2.2 Beam List

List containing the beam element numbers whose dynamic loads and stresses are to be printed to the output file, every **ITPR** time steps.

5.7.3 Plot Nodes

5.7.3.1 Number of Nodes

The total number of nodes whose deflections, embedment, forces, stresses, tension and factors of safety will be written to a file every **ITPR** time steps, for use in plotting. This part of the output is recommended to be set greater than zero for long simulation runs whether or not plotting is planned.

5.7.3.2 Node List

List containing the nodes whose deflections, etc. will be written to a file every **ITPR** time steps, for use in plotting.

5.7.4 Plot Times

5.7.4.1 Number of Times

The total number of times at which the deflected configuration and stress configuration of the pipeline will be written to the plot file. This provides a series of instantaneous ‘snapshots’ of the pipe condition.

5.7.4.2 Time List

List containing the times at which the pipeline deflected configuration (deflection of all nodes) and stress configuration (stress of all beams) are to be written to the plot file.

5.7.5 Print Control

5.7.5.1 ITPR Parameter

A print control integer. **ITPR** is the number of time steps at multiples of which the deflections, velocities, accelerations, soil-resistance loads, beam element loads, and stresses are printed. Example: If **ITPR** = 4, and the time step interval, DT = 0.25 sec, printing occurs at t = 1.0 sec, 2.0 sec, 3.0 sec, etc.

5.7.5.2 Print Options

Three options are available for print output:

- Printing occurs only at convergence (every **ITPR** time steps).

- Results for pipeline deflections, velocities, accelerations, and soil-resistance loads are printed at each time step iteration.
- Minimal print detail (which is the default) where only history dependent information is printed at each applicable wave 1/2 oscillation where embedment changes.

5.7.6 Print Half Wave Cycle

Two options for print output:

- Printing is suppressed for 1/2 wave cycles.
- History dependent information is printed at each wave 1/2 oscillation.

5.8 Parameters and Simulations Tab

This input tab contains advanced options to control the simulation times and time steps for each analysis module, and various pipe dynamic simulation parameters, as presented in Figure 5-14.

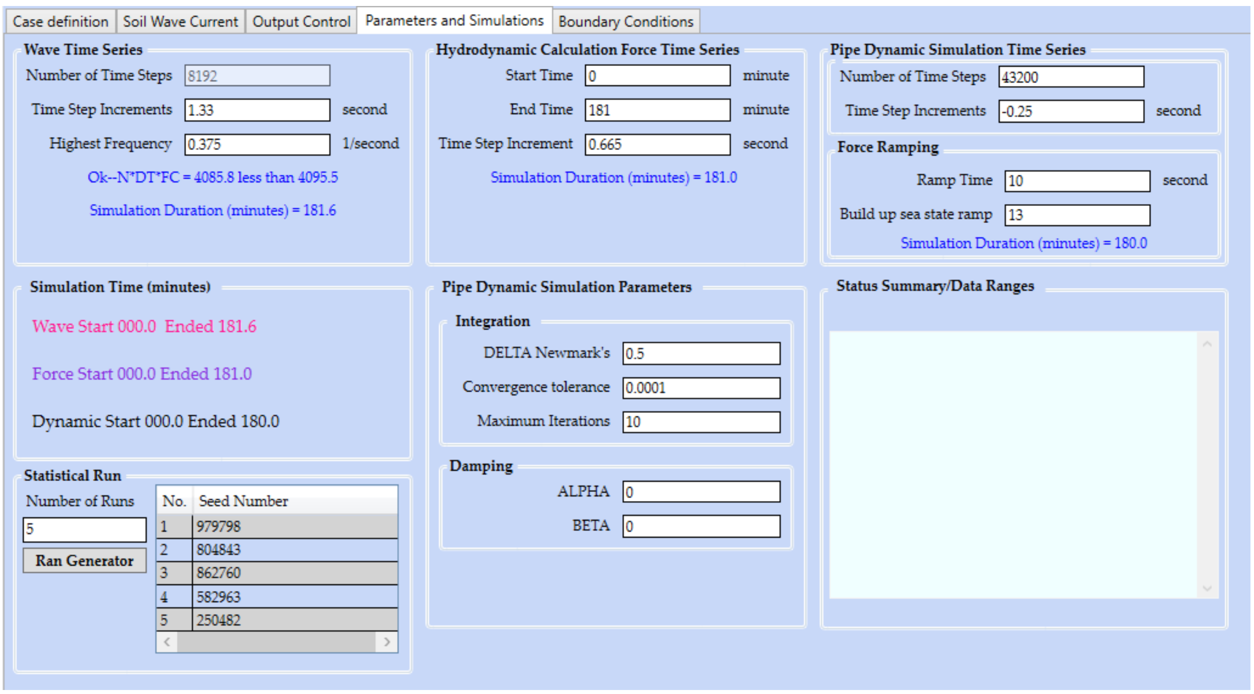


Figure 5-14: Level 3 Input – Parameters and Simulations Tab

5.8.1 Wave Time Series

This area defines the number of times steps ($n_{time\ steps}$), the time step increments (Δt), and the highest frequency cutoff (f_{cutoff}). The values of these parameters must satisfy the inequality:

$$n_{time\ steps} \cdot \Delta t \cdot f_{cutoff} < 4095.5$$

5.8.1.1 Number of Time Steps

The number of time steps for the Random Wave Generation module, which due to the computational format should be 2 raised to a power, with 2^{18} (= 8192) as the maximum.

5.8.1.2 Time Step Increments

The value of the time step size for the Random Wave Generation module. Value is related to the simulation time and the number of times steps by:

$$(Number\ of\ Time\ Steps) \cdot (Time\ Step\ Increments) = (Simulation\ Time)$$

$$n_{time\ steps} \cdot \Delta t = t_{simulation}$$

5.8.1.3 Highest Frequency

The high frequency cutoff (f_{cutoff} below) is the highest frequency to be considered with non-negligible energy. For numerical stability, the following limit is imposed:

$$n_{time\ steps} \cdot \Delta t \cdot f_{cutoff} < 4095.5$$

5.8.2 Hydrodynamic Calculation Force Time Series

5.8.2.1 Start Time

Starting time for the Hydrodynamic Force module time series.

5.8.2.2 End Time

Ending time for the Hydrodynamic Force module time series.

5.8.2.3 Time Step Increment

Time step value for Hydrodynamic Force module.

5.8.3 Pipe Dynamic Simulation Time Series

5.8.3.1 Number of Time Steps

Number of time steps for the Pipe Dynamic module.

5.8.3.2 Time Step Increments

Time step value (sec) used in the numerical integration (Newmark) method. If the value is specified as less than or equal to zero or left the software will select an appropriate value of 0.25 sec.

5.8.4 Force Ramping

5.8.4.1 Ramp Time

This is rather a numerical setup parameter The length of time over which forces are increased to their full value, in order to avoid transient effects. This ramp value is typically specified around the value of the peak wave period.

5.8.4.2 Build-up Sea State Ramp

This parameter should be specified as greater than 12 if no ramping is desired (default). Otherwise, BUP divided by 12 is the wave height ratio by which hydrodynamic forces are scaled to simulate a building sea-state. Each 20-minute BUP is incremented by 1 until BUP equals 12.

5.8.5 Simulation Time

This area displays the simulation duration of wave time series, hydrodynamic force calculation time series and pipe dynamic simulation time series, in minutes.

5.8.6 Statistical Run and Seed Numbers

In this field users can setup multiple wave seed numbers. This can be done through the **Number of Runs** entry (Figure 5-15). For each run, users can set specific **Seed Numbers**. The seed numbers can either be generated randomly by the **Ran Generator** button or can directly be inputted into the table by modifying the values in the relevant cells.

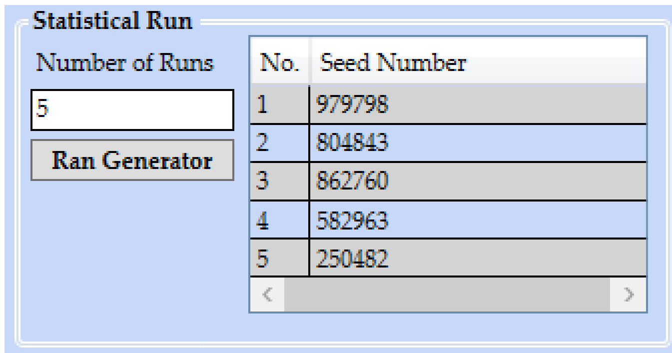


Figure 5-15: Level 3 Random Seed Input

The generated Input/output files are also saved in a subdirectory identifiable by Id number and Seed Number as follows:

<Project Folder>\Results-Filename\Level1\Id\Seed Number

5.8.7 Pipe Dynamic Simulation Parameters

5.8.7.1 DELTA Newmark's

The δ parameter of the Newmark numerical integration method. The default value is 0.5.

5.8.7.2 Convergence Tolerance

The tolerance parameter EPS, is used to check for convergence. The default value is 0.0001.

Convergence is assumed at the kth iteration when:

$$G^k(I) \leq EPS; \; I = 1, 2$$

These parameters and functions are defined in Section 5.12.3.2.

5.8.7.3 Maximum Iterations

Maximum number of iterations to achieve convergence at a given time step. The default value is 10. This may be increased for complex systems that fail to converge under the default number of iterations.

5.8.8 Damping

5.8.8.1 ALPHA

The mass-proportional damping coefficient.

5.8.8.2 BETA

The stiffness-proportional damping coefficient.

ALPHA and **BETA** are the proportionality factors defining proportional, or classical, damping according to:

$$[C] = ALPHA\,[M] + BETA\,[K]$$

This damping may be introduced to account for structural damping.

5.9 Boundary Conditions Tab

This input tab contains advanced options to control the boundary conditions: tension, fixity, external springs and the effects of external pressure, as presented in Figure 5-16.

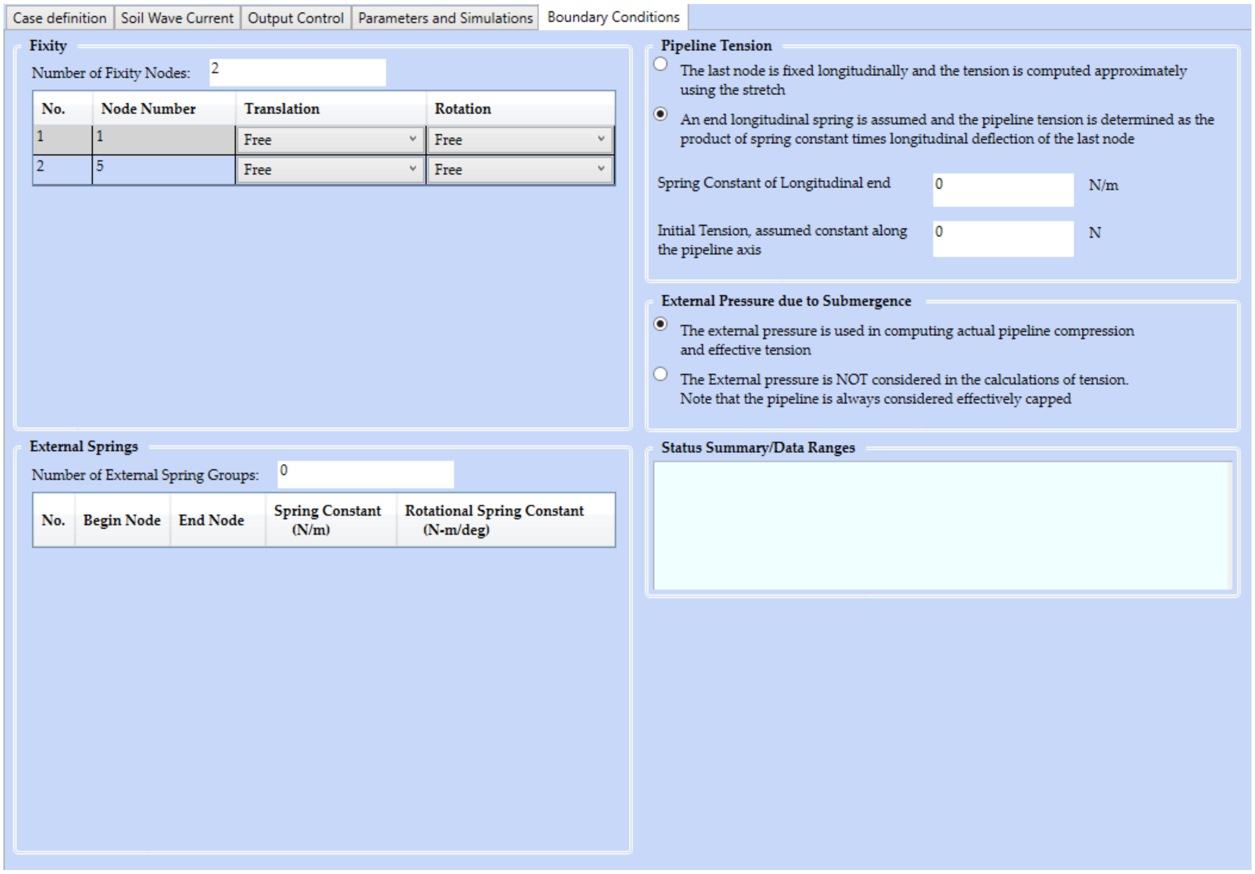


Figure 5-16: Level 3 Input – Boundary Conditions Tab

5.9.1 Fixity

5.9.1.1 Number of Fixity Nodes

Number of nodes at which to specify restraints.

5.9.1.2 Node Number

The node number at which to specify restraint.

5.9.1.3 Translation

Translational fixity in the lateral and longitudinal directions, which can be set as either **Free** or **Fixed** at the specified node number.

5.9.1.4 Rotation

Rotational fixity in the horizontal plane (about the vertical Z-axis), which can be set as either **Free** or **Fixed** at the specified node number.

5.9.2 External Springs

5.9.2.1 Number of External Springs Groups

The specification of external springs can be varied over the length of the pipeline, up to a maximum of ten external spring groups.

5.9.2.2 Begin Node

Starting node for the external spring group.

5.9.2.3 End Node

Ending node for the external spring group.

Note: If the ending node number is zero or blank, springs are added at the beginning node number only. The nodal increment from beginning node to ending node is 1.

5.9.2.4 Spring Constant

Translational spring constant of the springs applied to nodes of the current external spring group, applicable in degree of freedom 1 (lateral direction).

5.9.2.5 Rotational Spring Constant

Rotational spring constant of the springs applied to nodes of the current external spring group, applicable in the rotational degree of freedom in the horizontal plane (about the vertical Z-axis).

5.9.3 Pipeline Tension

5.9.3.1 Pipeline Tension Option

Two options are selectable for the calculation of pipeline tension:

- The last node is fixed longitudinally and the tension is computed approximately using the stretch.
- A longitudinal spring is assumed to act at the end (refer to Section 5.9.3.2), and the pipeline tension is determined as the product of spring constant multiplied by the longitudinal deflection of the last node.

5.9.3.2 Spring Constant of Longitudinal End

The spring constant of the optional longitudinal spring at the last node of the pipeline.

5.9.3.3 Initial Tension

Initial pipeline tension, which is assumed constant along the pipe longitudinal axis.

5.9.4 External Pressure due to Submergence

These options allow the software to either consider or ignore the effect of external hydrostatic pressure:

- The external pressure is used in computing actual pipeline compression and effective tension (default).
- The external pressure is not considered in the calculations of tension.

Note that the pipeline is always considered as effectively capped.

5.10 Level 3 Reports

The primary outputs of the Level 3 time-domain analysis are presented through various reports and plots. Generation of reports for the Level 3 analysis is facilitated by the **Reports** drop down menu, as presented in Figure 5-17. Due to the size of the output data, the PDF reports are not generated automatically after the analysis is completed. Instead, each report is generated whenever the user chooses an item in the menu.

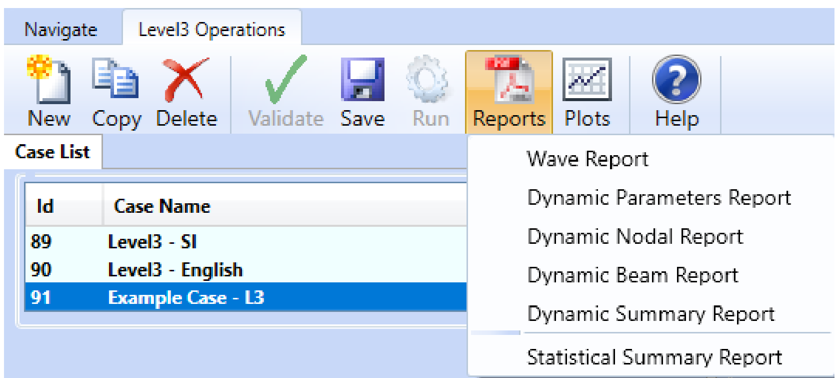


Figure 5-17: Level 3 Report Selection Menu List

By clicking on each of report options, the user can select which seed number to report through a secondary dropdown list as illustrated in Figure 5-18.

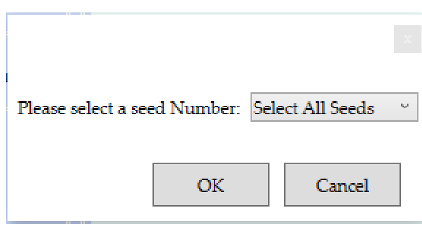


Figure 5-18: Level 3 Choosing Random Seed Number for Plotting

5.10.1 Wave Report

This report displays the wave related parameters calculated by the software, along with some key user input values, as presented in Figure 5-19. The report can be found as L3_Wave_Report.pdf in <Project Folder>\Results-Filename\Level3\Id\Seed Number.

PRCI OBS Level3 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis - Wave Report

Case Name: Example Case - L3 | Case Description: ---

Report Compiled on 18/07/2018

Wave Spectral Parameters	
Significant Wave Height	10 m
Peak Period	12 sec
RLAMDA (Peakedness)	1
VMULT (Velocity Multiplier)	1
CTH (Wave Direction)	90 deg
CSIG (Spreading S.D.)	30 deg
Control Parameters	
IOPT	0 (Uni-Modal Spreading)
ICHECK	0 (Velocity)
ISEED	285427
ISPEC	1 (Statistics Only)
ISPECT	1 (Ochi-Hubble)
Simulation Parameters	
N (Number of time steps)	8192
DTIME (TimeStep Increment)	1.33 sec
DF (Frequency Increment)	9.18E-05 Hz
FC (Cut-Off Frequency)	0.375 Hz
NF (Number of Frequency Divisions)	4086
DT (Spread Angle Division Increment)	15 deg
NT (Number of Angle Divisions)	24
Input Current	0 m/s

Figure 5-19: 1st page of Level 3 Wave Report

5.10.2 Dynamic Parameters Report

This report displays soil resistance parameters and other data calculated by the software, as presented in Figure 5-20. The report can be found as L3_DynParams_Report.pdf in <Project Folder>\Results-Filename\Level3\Id\Seed Number.

PRCI OBS Level3 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis - Dynamic Parameter Report

Case Name: Example Case - L3 Case Description: ---

Report Compiled on 18/07/2018

Pipeline Parameters and Environmental Data	
Pipeline Segment Length	1000 m
Steel Diameter	508 mm
Weight per Unit Length	2255 N/m
Pipe Wall Thickness	19.05 mm
Submerged Weight per Unit Length	215 N/m
Drag Diameter	508 mm
Cross-Sectional Area	2.926E+04 mm^2
Moment of Inertia	8.758E+08 mm^4
Young's Modulus	207 GPa
Axial End Spring	0 N/m

Inital Soil Resistance Parameters

Node	ISOIL	Epsilon1 (m)	Epsilon2 (m)	Epsilon3 (m)	MU	FR1 (N/m)	FR2 (Begin) (N/m)	Dr or Su (N/m^2)
1	1	0.0101	0.0509	0.954	0.6	52.2	0	0.5
2	1	0.0101	0.0509	0.954	0.6	52.2	0	0.5
3	1	0.0101	0.0509	0.954	0.6	52.2	0	0.5
4	1	0.0101	0.0509	0.954	0.6	52.2	0	0.5
5	1	0.0101	0.0509	0.954	0.6	52.2	0	0.5

Nodal Properties

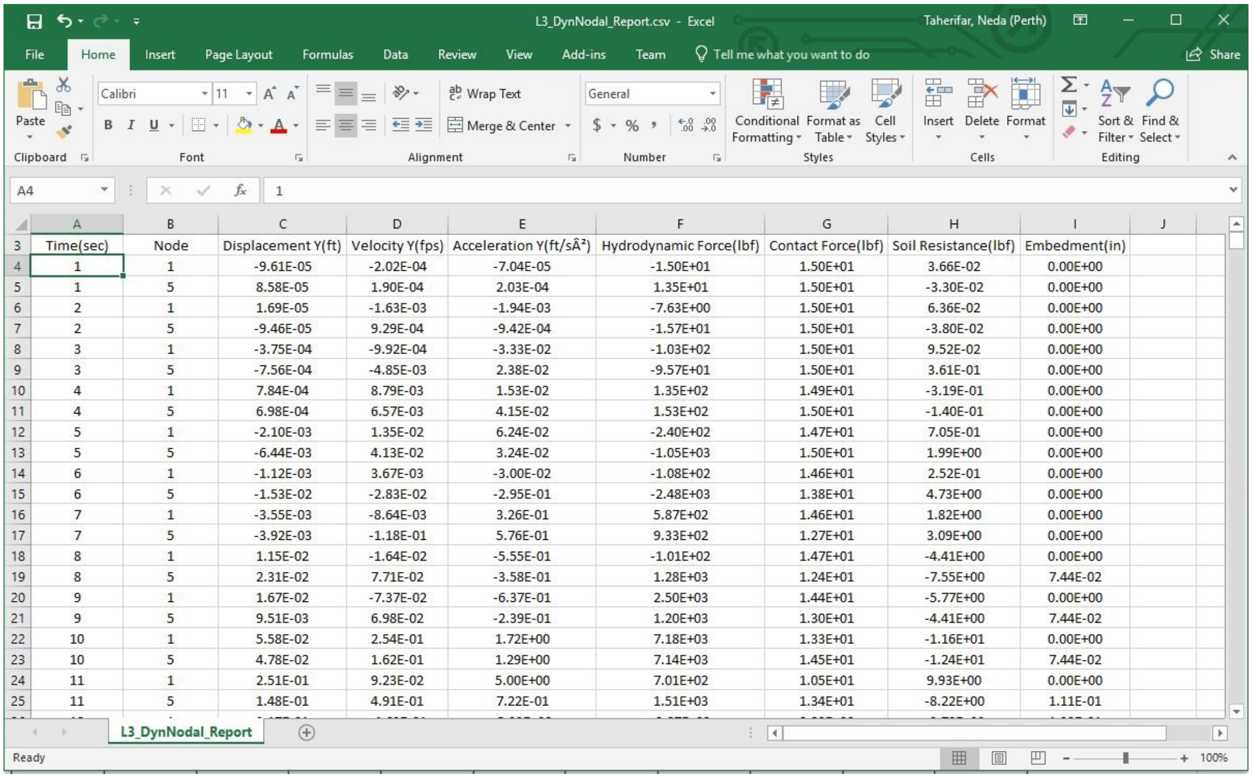
Node	Coordinates		Nodal Restraints		Spring Additions	
	X (m)	Y (m)	Y	RZ	KY (N/m)	KRZ (N/m/deg)
1	0	0	Free	Free	0	0
2	250	0	Free	Free	0	0
3	500	0	Free	Free	0	0
4	750	0	Free	Free	0	0
5	1E+03	0	Free	Free	0	0

Maximum Soil Force = 25.1 N
Maximum Available Soil Force = 30 N
Number of Half Oscillations = 1.04E+04

Figure 5-20: Level 3 Dynamic Parameters Report

5.10.3 Dynamic Nodal Report

This report displays nodal deflections, velocities, accelerations and seabed loads calculated by the software. The report is generated in the CSV form, named as L3_DynNodal_Report.csv and saved in <Project Folder>\Results-Filename\Level3\Id\Seed Number.

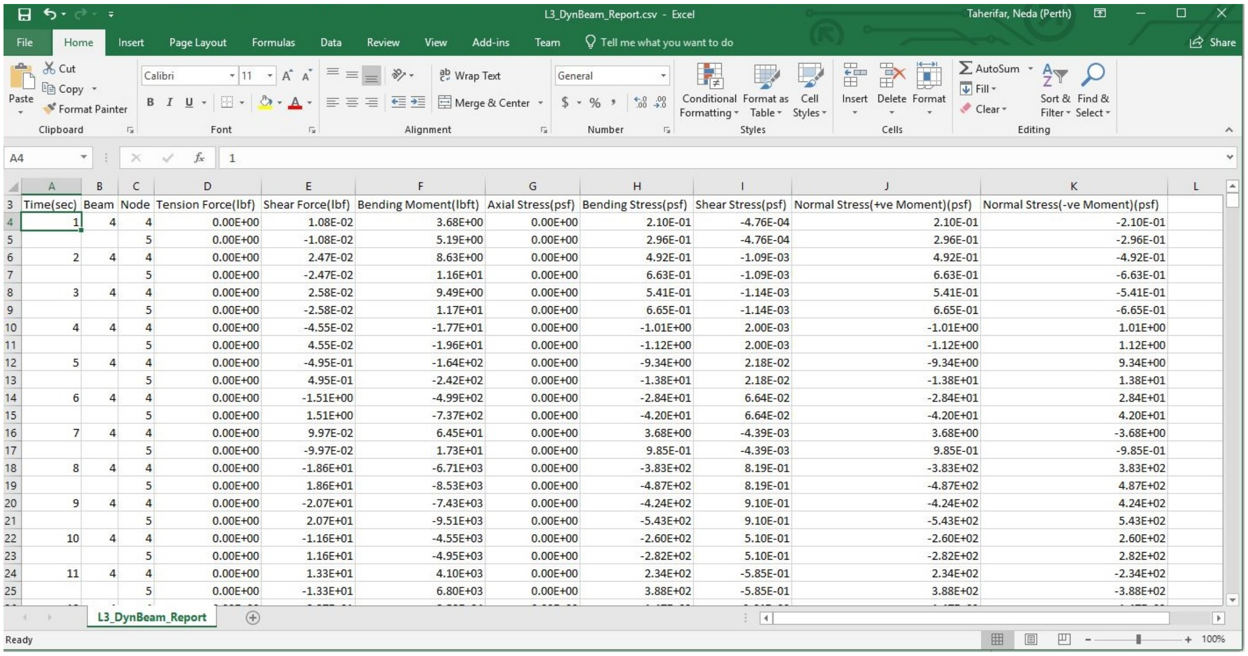


Time(sec)	Node	Displacement Y(ft)	Velocity Y(fps)	Acceleration Y(ft/sÂ²)	Hydrodynamic Force(lbf)	Contact Force(lbf)	Soil Resistance(lbf)	Embedment(in)
1	1	-9.61E-05	-2.02E-04	-7.04E-05	-1.50E+01	1.50E+01	3.66E-02	0.00E+00
1	5	8.58E-05	1.90E-04	2.03E-04	1.35E+01	1.50E+01	-3.30E-02	0.00E+00
2	1	1.69E-05	-1.63E-03	-1.94E-03	-7.63E+00	1.50E+01	6.36E-02	0.00E+00
2	5	-9.46E-05	9.29E-04	-9.42E-04	-1.57E+01	1.50E+01	-3.80E-02	0.00E+00
3	1	-3.75E-04	-9.92E-04	-3.33E-02	-1.03E+02	1.50E+01	9.52E-02	0.00E+00
3	5	-7.56E-04	-4.85E-03	2.38E-02	-9.57E+01	1.50E+01	3.61E-01	0.00E+00
4	1	7.84E-04	8.79E-03	1.53E-02	1.35E+02	1.49E+01	-3.19E-01	0.00E+00
4	5	6.98E-04	6.57E-03	4.15E-02	1.53E+02	1.50E+01	-1.40E-01	0.00E+00
5	1	-2.10E-03	1.35E-02	6.24E-02	-2.40E+02	1.47E+01	7.05E-01	0.00E+00
5	5	-6.44E-03	4.13E-02	3.24E-02	-1.05E+03	1.50E+01	1.99E+00	0.00E+00
6	1	-1.12E-03	3.67E-03	-3.00E-02	-1.08E+02	1.46E+01	2.52E-01	0.00E+00
6	5	-1.53E-02	-2.83E-02	-2.95E-01	-2.48E+03	1.38E+01	4.73E+00	0.00E+00
7	1	-3.55E-03	-8.64E-03	3.26E-01	5.87E+02	1.46E+01	1.82E+00	0.00E+00
7	5	-3.92E-03	-1.18E-01	5.76E-01	9.33E+02	1.27E+01	3.09E+00	0.00E+00
8	1	1.15E-02	-1.64E-02	-5.55E-01	-1.01E+02	1.47E+01	-4.41E+00	0.00E+00
8	5	2.31E-02	7.71E-02	-3.58E-01	1.28E+03	1.24E+01	-7.55E+00	7.44E-02
9	1	1.67E-02	-7.37E-02	-6.37E-01	2.50E+03	1.44E+01	-5.77E+00	0.00E+00
9	5	9.51E-03	6.98E-02	-2.39E-01	1.20E+03	1.30E+01	-4.41E+00	7.44E-02
10	1	5.58E-02	2.54E-01	1.72E+00	7.18E+03	1.33E+01	-1.16E+01	0.00E+00
10	5	4.78E-02	1.62E-01	1.29E+00	7.14E+03	1.45E+01	-1.24E+01	7.44E-02
11	1	2.51E-01	9.23E-02	5.00E+00	7.01E+02	1.05E+01	9.93E+00	0.00E+00
11	5	1.48E-01	4.91E-01	7.22E-01	1.51E+03	1.34E+01	-8.22E+00	1.11E-01

Figure 5-21: Level 3 Dynamic Nodal Report

5.10.4 Dynamic Beam Report

This report displays the loads and stresses calculated by the software, on the specified beam elements, as presented in Figure 5-22. The report is generated in the CSV form, named as L3_DynBeam_Report.csv and saved in <Project Folder>\Results-Filename\Level3\Id\Seed Number.

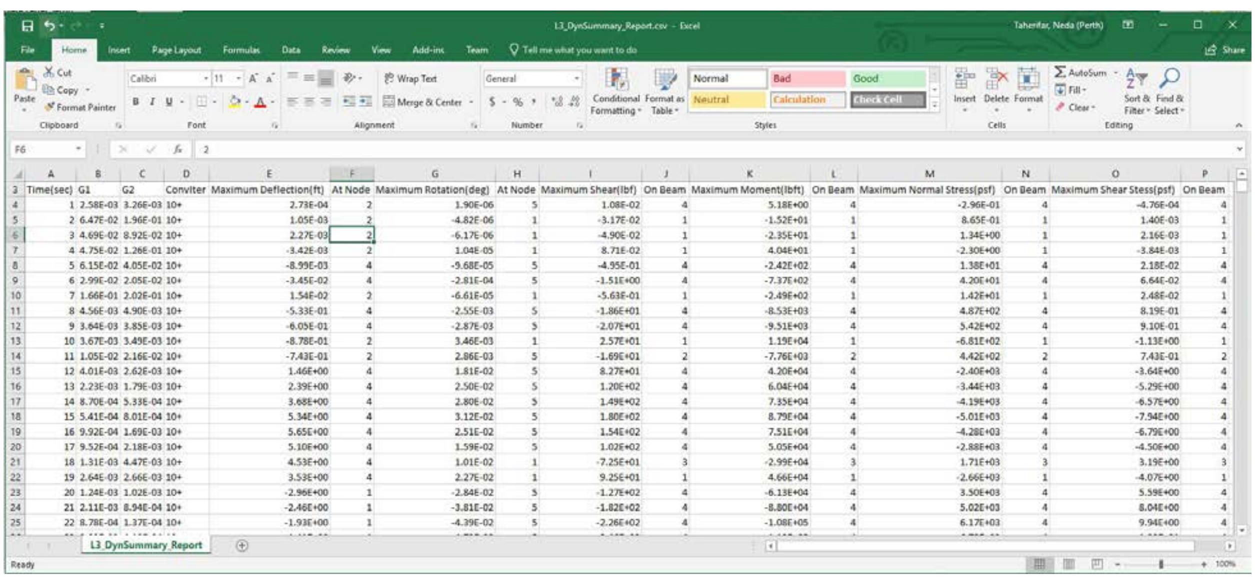


Time(sec)	Beam	Node	Tension Force(lbf)	Shear Force(lbf)	Bending Moment(lbft)	Axial Stress(psf)	Bending Stress(psf)	Shear Stress(psf)	Normal Stress(+ve Moment)(psf)	Normal Stress(-ve Moment)(psf)
1	4	4	0.00E+00	1.08E-02	3.68E+00	0.00E+00	2.10E-01	-4.76E-04	2.10E-01	-2.10E-01
		5	0.00E+00	-1.08E-02	5.19E+00	0.00E+00	2.96E-01	-4.76E-04	2.96E-01	-2.96E-01
2	4	4	0.00E+00	2.47E-02	8.63E+00	0.00E+00	4.92E-01	-1.09E-03	4.92E-01	-4.92E-01
		5	0.00E+00	-2.47E-02	1.16E+01	0.00E+00	6.63E-01	-1.09E-03	6.63E-01	-6.63E-01
3	4	4	0.00E+00	2.58E-02	9.49E+00	0.00E+00	5.41E-01	-1.14E-03	5.41E-01	-5.41E-01
		5	0.00E+00	-2.58E-02	1.17E+01	0.00E+00	6.65E-01	-1.14E-03	6.65E-01	-6.65E-01
4	4	4	0.00E+00	-4.55E-02	-1.77E+01	0.00E+00	-1.01E+00	2.00E-03	-1.01E+00	1.01E+00
		5	0.00E+00	4.55E-02	-1.96E+01	0.00E+00	-1.12E+00	2.00E-03	-1.12E+00	1.12E+00
5	4	4	0.00E+00	-4.95E-01	-1.64E+02	0.00E+00	-9.34E+00	2.18E-02	-9.34E+00	9.34E+00
		5	0.00E+00	4.95E-01	-2.42E+02	0.00E+00	-1.38E+01	2.18E-02	-1.38E+01	1.38E+01
6	4	4	0.00E+00	-1.51E+00	-4.99E+02	0.00E+00	-2.84E+01	6.64E-02	-2.84E+01	2.84E+01
		5	0.00E+00	1.51E+00	-7.37E+02	0.00E+00	-4.20E+01	6.64E-02	-4.20E+01	4.20E+01
7	4	4	0.00E+00	9.97E-02	6.45E+01	0.00E+00	3.68E+00	-4.39E-03	3.68E+00	-3.68E+00
		5	0.00E+00	-9.97E-02	1.73E+01	0.00E+00	9.85E-01	-4.39E-03	9.85E-01	-9.85E-01
8	4	4	0.00E+00	-1.86E+01	-6.71E+03	0.00E+00	-3.83E+02	8.19E-01	-3.83E+02	3.83E+02
		5	0.00E+00	1.86E+01	-8.53E+03	0.00E+00	-4.87E+02	8.19E-01	-4.87E+02	4.87E+02
9	4	4	0.00E+00	-2.07E+01	-7.43E+03	0.00E+00	-4.24E+02	9.10E-01	-4.24E+02	4.24E+02
		5	0.00E+00	2.07E+01	-9.51E+03	0.00E+00	-5.43E+02	9.10E-01	-5.43E+02	5.43E+02
10	4	4	0.00E+00	-1.16E+01	-4.55E+03	0.00E+00	-2.60E+02	5.10E-01	-2.60E+02	2.60E+02
		5	0.00E+00	1.16E+01	-4.95E+03	0.00E+00	-2.82E+02	5.10E-01	-2.82E+02	2.82E+02
11	4	4	0.00E+00	1.33E+01	4.10E+03	0.00E+00	2.34E+02	-5.85E-01	2.34E+02	-2.34E+02
		5	0.00E+00	-1.33E+01	6.80E+03	0.00E+00	3.88E+02	-5.85E-01	3.88E+02	-3.88E+02

Figure 5-22: Level 3 Dynamic Beam Report

5.10.5 Dynamic Summary Report

This report displays the summary of convergence and maximum values of the dynamic analysis, as presented in Figure 5-23. The report is generated in the CSV form, named as L3_DynSummary_Report.csv and saved in <Project Folder>\Results-Filename\Level3\Id\Seed Number folder.



Time(sec)	G1	G2	Conviter	Maximum Deflection(ft)	At Node	Maximum Rotation(deg)	At Node	Maximum Shear(lbf)	On Beam	Maximum Moment(lbft)	On Beam	Maximum Normal Stress(psf)	On Beam	Maximum Shear Stess(psf)	On Beam
1	2.58E-03	3.26E-03	10+	2.73E-04	2	1.90E-06	5	1.08E-02	4	5.18E+00	4	-2.96E-01	4	-4.76E-04	4
2	6.47E-02	1.96E-01	10+	1.05E-03	2	-4.82E-06	1	-3.17E-02	1	-1.52E+01	1	8.65E-01	1	1.40E-03	1
3	4.69E-02	8.92E-02	10+	2.27E-03	2	-6.17E-06	1	-4.90E-02	1	-2.35E+01	1	1.34E+00	1	2.16E-03	1
4	4.75E-02	1.26E-01	10+	-3.42E-03	2	1.04E-05	1	8.71E-02	1	4.04E+01	1	-2.30E+00	1	-3.84E-03	1
5	6.15E-02	4.05E-02	10+	-8.99E-03	4	-9.68E-05	5	-4.95E-01	4	-2.42E+02	4	1.38E+01	4	2.18E-02	4
6	2.99E-02	2.05E-02	10+	-3.45E-02	4	-2.81E-04	5	-1.51E+00	4	-7.37E+02	4	4.20E+01	4	6.64E-02	4
7	1.66E-01	2.02E-01	10+	1.54E-02	2	-6.61E-05	1	-5.63E-01	1	-2.49E+02	1	1.42E+01	1	2.48E-02	1
8	4.56E-03	4.90E-03	10+	-5.33E-01	4	-2.55E-03	5	-1.86E+01	4	-8.53E+03	4	4.87E+02	4	8.19E-01	4
9	3.64E-03	3.85E-03	10+	-6.05E-01	4	-2.87E-03	5	-2.07E+01	4	-9.51E+03	4	5.42E+02	4	9.10E-01	4
10	3.67E-03	3.49E-03	10+	-8.78E-01	2	3.46E-03	1	2.57E+01	1	1.19E+04	1	-6.81E+02	1	-1.13E+00	1
11	1.05E-02	2.16E-02	10+	-7.43E-01	2	2.86E-03	5	-1.69E+01	2	-7.76E+03	2	4.42E+02	2	7.43E-01	2
12	4.01E-03	2.62E-03	10+	1.46E+00	4	1.81E-02	5	8.27E+01	4	4.20E+04	4	-2.40E+03	4	-3.64E+00	4
13	2.23E-03	1.79E-03	10+	2.39E+00	4	2.50E-02	5	1.20E+02	4	6.04E+04	4	-3.44E+03	4	-5.29E+00	4
14	8.70E-04	5.33E-04	10+	3.68E+00	4	2.80E-02	5	1.49E+02	4	7.35E+04	4	-4.19E+03	4	-6.57E+00	4
15	5.41E-04	8.01E-04	10+	5.34E+00	4	3.12E-02	5	1.80E+02	4	8.79E+04	4	-5.01E+03	4	-7.94E+00	4
16	9.92E-04	1.69E-03	10+	5.65E+00	4	2.51E-02	5	1.54E+02	4	7.51E+04	4	-4.28E+03	4	-6.79E+00	4
17	9.52E-04	2.18E-03	10+	5.10E+00	4	1.59E-02	5	1.02E+02	4	5.05E+04	4	-2.88E+03	4	-4.50E+00	4
18	1.31E-03	4.47E-03	10+	4.53E+00	4	1.01E-02	1	-7.25E+01	3	-2.99E+04	3	1.71E+03	3	3.19E+00	3
19	2.64E-03	2.66E-03	10+	3.53E+00	4	2.27E-02	1	9.25E+01	1	4.66E+04	1	-2.66E+03	1	-4.07E+00	1
20	1.24E-03	1.02E-03	10+	-2.96E+00	1	-2.84E-02	5	-1.27E+02	4	-6.13E+04	4	3.50E+03	4	5.59E+00	4
21	2.11E-03	8.94E-04	10+	-2.46E+00	1	-3.81E-02	5	-1.82E+02	4	-8.80E+04	4	5.02E+03	4	8.04E+00	4
22	8.78E-04	1.37E-04	10+	-1.93E+00	1	-4.39E-02	5	-2.26E+02	4	-1.08E+05	4	6.17E+03	4	9.94E+00	4

Figure 5-23: Level 3 Dynamic Summary Report

5.10.6 Statistical Summary Report

This report displays the summary of the multiple time domain analysis runs and statistical information on the output parameters, as presented in Figure 5-24 and Figure 5-25. The report can be found as L3_Stats Summay_Report.pdf in <Project Folder>\Results-Filename\Level3\Id.

PRCI OBS Level3 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis - Statistical Summary Report

Case Name: Example - L3 Case Description: ---

Report Compiled on 18/07/2018

Case Number & Random Seed	Node Number	Lateral FOS		Vertical FOS		Position (m)		Maximum Stress (kPa)	Final Embedment (mm)
		Minimum	Time (mm:ss)	Minimum	Time (mm:ss)	Minimum	Time (mm:ss)		
Case 1 879191	1	0.072	58:36	0.152	53:54	15.582	142:17	142994.378	5.856
	2	0.052	45:28	0.140	68:00	8.090	68:01	131033.891	22.104
	3	0.051	20:49	0.156	20:49	7.207	142:35	109329.772	11.968
	4	0.052	170:32	0.149	46:33	5.339	107:50	136013.437	24.775
	5	0.080	69:56	0.159	175:30	9.958	132:37	0.000	8.671
Case 2 574742	1	0.076	24:00	0.155	157:33	6.820	157:54	135189.897	15.449
	2	0.048	179:54	0.137	179:53	6.385	173:25	113792.211	0.000
	3	0.049	129:11	0.139	129:11	5.247	25:10	96607.988	15.320
	4	0.046	75:53	0.138	75:53	4.456	39:41	116837.396	7.578
	5	0.076	157:58	0.148	20:55	5.790	27:19	0.000	5.160
Case 3 793816	1	0.073	168:43	0.159	140:28	7.062	52:34	144081.260	8.112
	2	0.051	57:10	0.139	129:18	5.396	66:12	125331.353	10.505
	3	0.053	102:42	0.150	102:42	5.441	161:03	107740.147	23.610
	4	0.048	131:14	0.138	131:14	5.723	67:10	123066.617	15.186
	5	0.074	8:08	0.152	25:04	11.224	167:39	0.000	16.673
Case 4 919689	1	0.071	9:43	0.141	54:24	10.396	67:05	149295.420	10.733
	2	0.047	8:48	0.145	106:22	5.965	177:47	121079.586	0.000
	3	0.056	28:03	0.169	136:43	8.227	136:36	116372.957	5.211
	4	0.048	72:27	0.128	72:27	5.099	86:25	132072.892	15.593
	5	0.075	119:13	0.141	128:13	11.886	91:23	0.000	20.781
Case 5 423885	1	0.072	37:58	0.154	120:31	9.940	155:53	158105.386	14.894
	2	0.051	150:34	0.136	14:42	7.288	66:07	144938.317	8.759
	3	0.048	89:19	0.153	163:35	8.720	142:55	136372.539	13.797
	4	0.048	7:07	0.136	7:07	8.188	166:45	129607.059	2.927
	5	0.078	69:16	0.142	90:08	8.687	115:19	0.000	21.652

Figure 5-24: Level 3 Statistical Summary Report: Analysis Summary

PRCI OBS Level3 PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis - Statistical Summary Report

Case Name: Example - L3 Case Description: ---

Report Compiled on 18/07/2018

Minimum Lateral Factor of Safety

Case Number & Random Seed	Node Number					Mean	Std. Dev.	Minimum
	1	2	3	4	5			
Case 1	0.072	0.052	0.051	0.052	0.080	0.062	0.012	0.051
Case 2	0.076	0.048	0.049	0.046	0.076	0.059	0.014	0.046
Case 3	0.073	0.051	0.053	0.048	0.074	0.060	0.012	0.048
Case 4	0.071	0.047	0.056	0.048	0.075	0.059	0.012	0.047
Case 5	0.072	0.051	0.048	0.048	0.078	0.059	0.013	0.048
Case 6	0.078	0.055	0.050	0.048	0.083	0.063	0.015	0.048
Case 7	0.080	0.051	0.055	0.053	0.078	0.063	0.013	0.051
Case 8	0.070	0.050	0.054	0.047	0.074	0.059	0.011	0.047
Case 9	0.073	0.051	0.052	0.052	0.072	0.060	0.010	0.051
Case 10	0.076	0.046	0.051	0.050	0.080	0.061	0.015	0.046
Mean	0.074	0.050	0.052	0.049	0.077			
Std. Dev.	0.003	0.003	0.003	0.003	0.003			
Minimum	0.070	0.046	0.048	0.046	0.072			

Figure 5-25: Level 3 Statistical Summary Report: Parameter Statistics

5.11 Level 3 Plots

Control of the generation, viewing and printing of output data plots for the Level 3 analyses is facilitated by the options in the **Plots** drop down list, as presented in Figure 5-26. Each of the plot menu items opens a window to display the selected plot, with various view options.

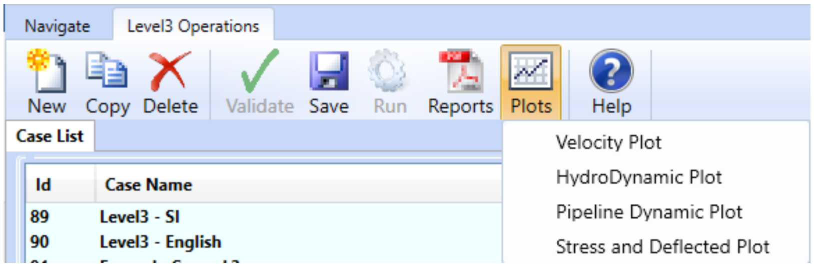


Figure 5-26: Level 3 Plot Selection List

5.11.1 Velocity Plot

Displays the velocity time series output from the random wave generation module, as presented in Figure 5-27. The line in the middle of the plot indicates the magnitude of the contribution of the steady current velocity. The plot window will automatically scale and break the plot up into a number of pages to ensure adequate resolution of the time series (note if resolution is not desirable the same data may be plotted through the **Pipeline Dynamic Plot** menu item, as per Section 5.11.3).

The plot window has button options to **Close** the plot window, view the **Previous** and **Next** page of the time series plot, and **Save as PNG** the current page of the time series plot.

The user can choose the node number as well as the seed number at which the data to be displayed.

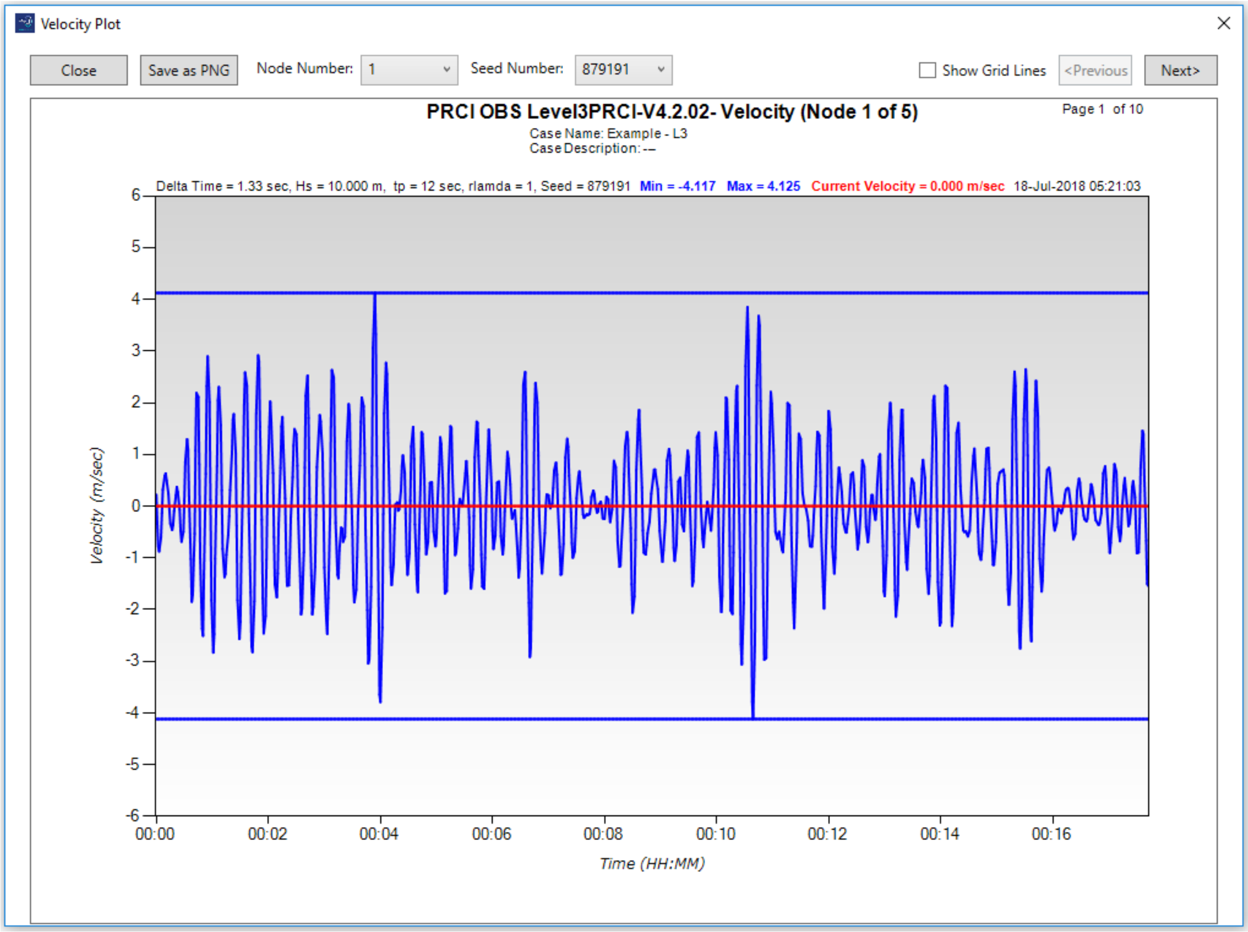


Figure 5-27: Level 3 Velocity Plot

5.11.2 Hydrodynamic Plot

Displays the raw (static pipe) lift and drag forces output from the hydrodynamic force module at top half of the page and a velocity time series plot at the bottom half of the page, as presented in Figure 5-28. This plot is useful to illustrate the velocities and the resultant hydrodynamic forces. The plot window will automatically scale and break the plot up into a number of pages to ensure adequate resolution of the time series (note if resolution is not desirable the same data may be plotted through the **Pipeline Dynamic Plot** menu item, as per Section 5.11.3).

The plot window has button options to **Close** the plot window, view the **Previous** and **Next** page of the time series plot, and **Save as PNG** the current page of the time series plot.

The user can choose the node number as well as the seed number at which the data to be displayed.

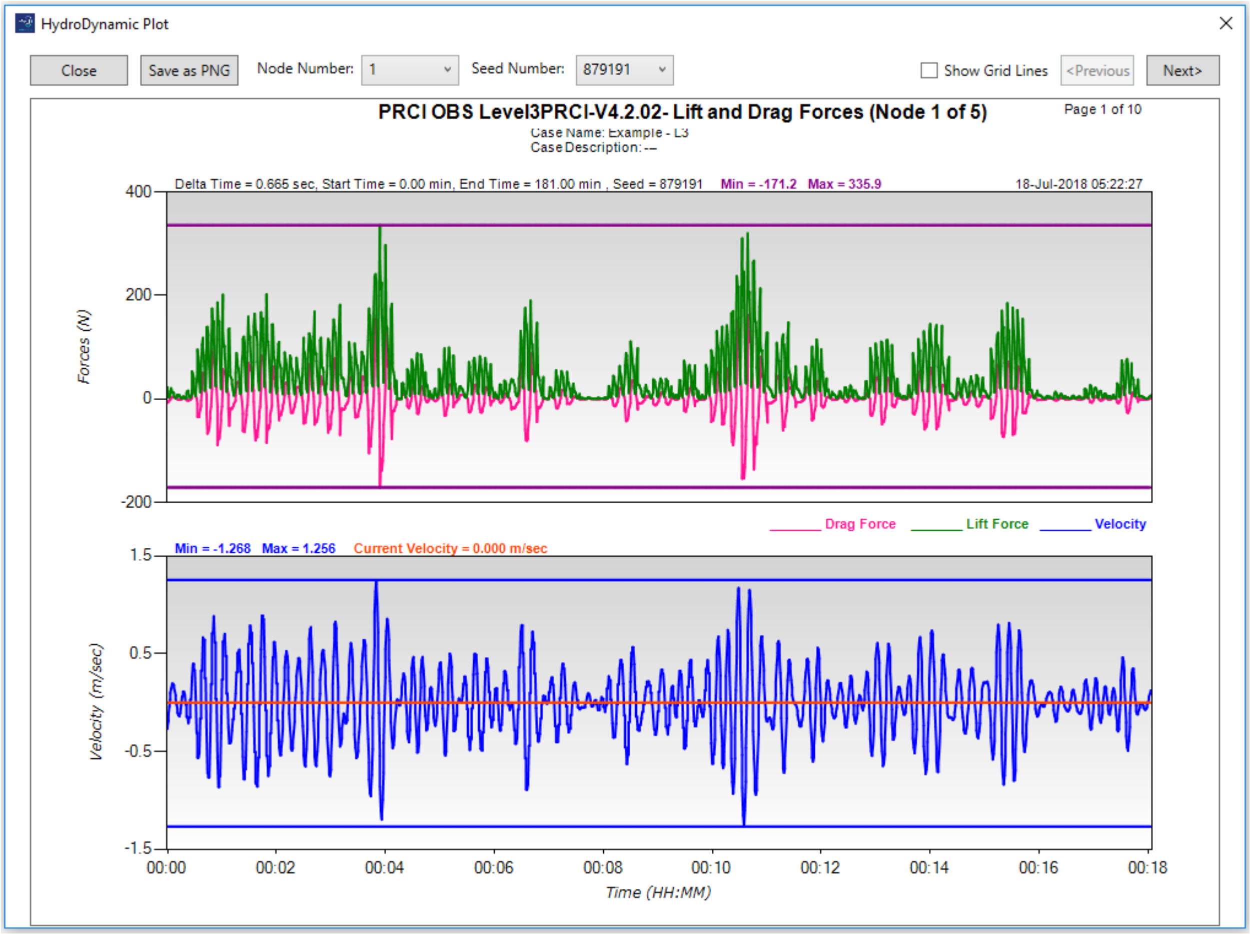


Figure 5-28: Level 3 Hydrodynamic Plot

5.11.3 Pipeline Dynamic Plot

Displays a dynamic plot selection window that enables more detailed customization of plot generation, as presented in Figure 5-29. The available controls include the selection of the data curves to be plotted, the scope (time series) and scaling (magnitude) of the plot, the desired number of pages for splitting of the plot, the node and the seed number for which the data is to be plotted, and a factor of safety cap.

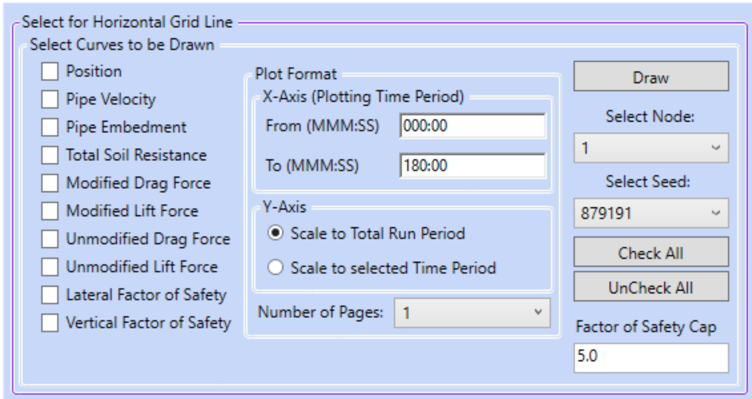


Figure 5-29: Level 3 Pipeline Dynamic Plot

5.11.3.1 Select Curves to be Drawn

This area contains a menu to select which data time series are to be drawn including **Position**, **Fluid Velocity**, **Pipe Embedment**, **Total Soil Resistance**, **Modified** (with pipe moving) **Drag and Lift Forces**, **Unmodified** (static pipe) **Drag and Lift Forces**, and the **Lateral and Vertical Factors of Safety**. The checkboxes allow one or more curves to be drawn simultaneously on the same plot.

5.11.3.2 Plot Format

This area includes the following inputs:

- X-Axis (Plotting Time Period): Specifies the start and end times for the plot (in MMM:SS format). These values default to the entire time series.
- Y-Axis: Controls the automatic y-axis scaling to either the maximum and minimum of the entire time series or the maximum and minimum of the selected time interval.
- Number of Pages: Sets the number of pages the selected time series plot is split over.

5.11.3.3 DRAW Button

Generates the plot and opens the dynamic plot window to view and print the resulting plot selection.

5.11.3.4 Select Node

Allows specification of the number of the node at which to display the time series.

5.11.3.5 Select Seed

Allows specification of the seed at which to display the time series.

5.11.3.6 Check All and Uncheck All Buttons

Selects and de-selects (respectively) all data time series to be plotted.

5.11.3.7 Factor of Safety Cap

Factors of safety get large as the lift and drag forces reverse (and when force is zero, the instantaneous factor of safety goes to infinity). Thus, the user can specify a cap on the maximum value of factor of safety to be displayed to obtain the desired resolution of the data.

The factors of safety are defined as:

$$FOS_{lateral} = \frac{Soil\ Resistance}{Modified\ Drag\ Force}$$

$$FOS_{vertical} = \frac{Submerged\ Weight}{Modified\ Lift\ Force}$$

5.11.4 Stress and Deflected Plot

This plot displays normal stress (bending + axial) and deflected configuration output data, as presented in Figure 5-30. These data series are snapshots of the instantaneous stress and deflected position of the entire model length at a selected time. These times are specified in the **Output Control** input tab, under the **Plot Times** selection (refer to Section 5.7.4).

These configurations can be either displayed as an animated series (where the display increments through the plots to create a "movie"), or as individual snapshots. The options for animation and static display times are selectable in an input form at the top of the page.

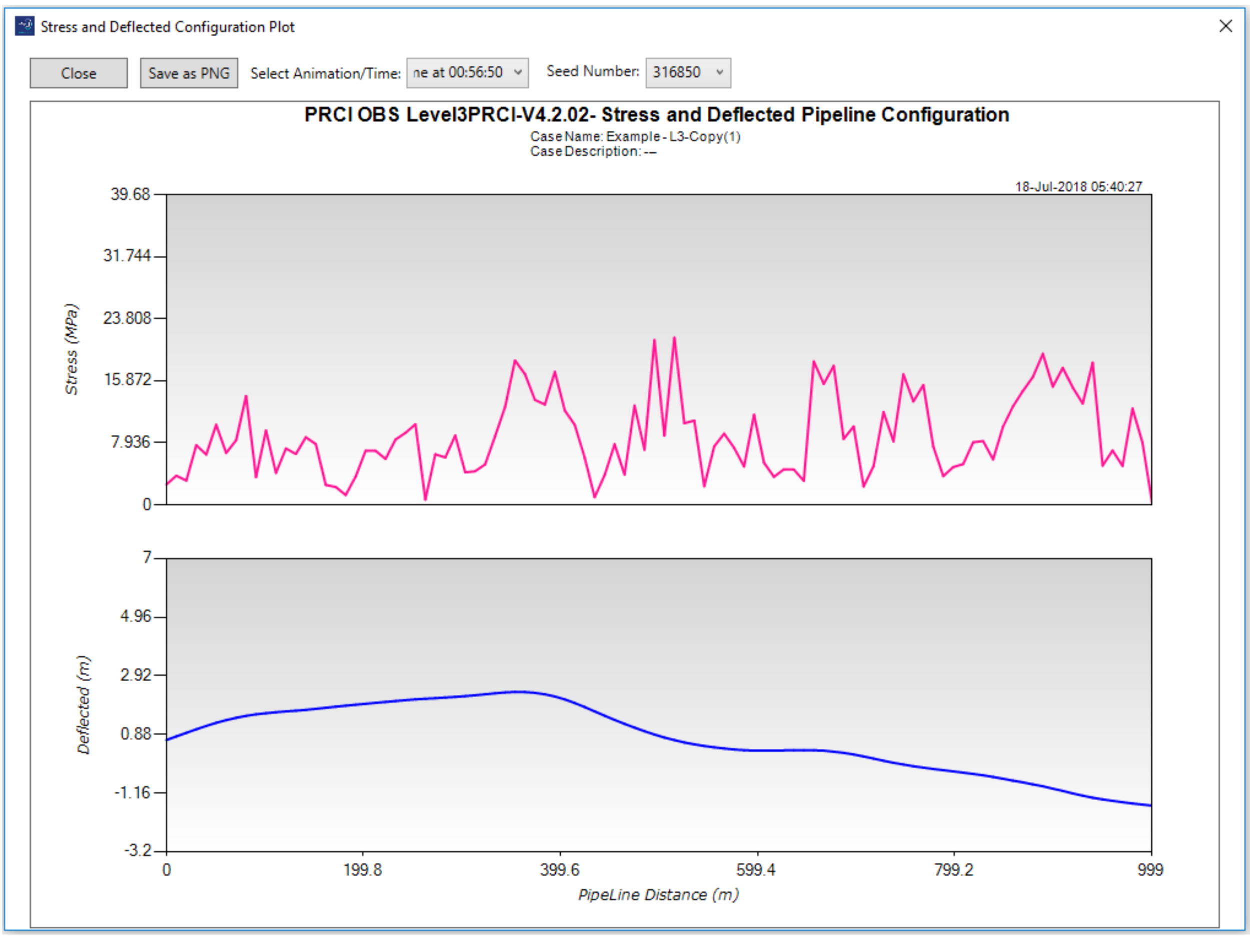


Figure 5-30: Level 3 Stress and Deflected Plot

5.11.4.1 Select Animation or a Time Period (HH:MM:SS)

This dropdown list enables selection of either **Animation** or of one of the specific time snapshots. If animation is chosen then by clicking on **Start Animation** button, the stress and deflected animation loop can be seen. For the specific time snapshots, the window will display the static plots for the chosen time period, which can be saved as PNG using the **Save as PNG** button.

5.11.4.2 Seed Number

Through the dropdown list a **Seed Number** can be selected in order to observe the corresponding results.

5.11.4.3 Start Animation

This button will begin the animation if the **Animation** option is selected.

5.11.4.4 Animation Delay (ms)

The rate of the animation can be controlled from 25 (very fast) to 3200 (slower).

5.12 Level 3 Additional Technical Description

5.12.1 Random Wave Generation

5.12.1.1 Directional Wave Spectra Model

The directional wave (sea surface) spectral density, S(f,Θ) is a function of frequency, f, and direction, Θ; and is expressed as the product of two parametric quantities, frequency spectral density, S(f), and D(Θ), the directional spreading function:

$$S(f,\Theta) = S(f) \cdot D(\Theta)$$

Where:

- S(f) is the sea surface frequency spectral density
- D(Θ) is the spreading function at frequency, f
- $\int_0^{2\pi} D(\Theta)d\Theta = 1.0$, by definition

This involves a substantial simplification because S(f,Θ) is taken as separable (i.e. the spreading function, D(Θ), is actually only a function of Θ and not of f) over the frequencies where substantial wave energy is present. This assumption is reasonable for wave periods affecting submarine pipelines.

5.12.1.2 Frequency Spectral Density

A three parameter generalization of the Pierson-Moskowitz-Bretschneider formula [8] is used for S(f), and the wrapped-normal directional density ([8], [9]) is used for D(Θ). This characterizes the sea surface with five input parameters. The original Ochi-Hubble formulation contains six parameters. However, the high frequency component contributes little to the pipeline motion and has, therefore, been deleted, eliminating three terms.

The formulation of the three-parameter spectral density developed by Ochi and Hubble is expressed as a one-sided function of radian frequency. This formula may be modified to the two-sided function of cycles-per-second frequency, for -∞ < f < ∞, to obtain:

$$S(f) = \frac{2\left(\frac{(4\lambda+1)f_0^4}{4}\right)^{\lambda} \sigma^2 e^{\frac{-(4\lambda+1)\left(\frac{f_0}{f}\right)^4}{4}}}{\Gamma(\lambda)|f|^{4\lambda+1}}$$

Where Γ(λ) is the complete gamma function. By the definition of a two-sided spectral density, the variance of the sea surface elevations is given by:

$$\sigma^2 = \int_{-\infty}^{\infty} S(f)df = 2\int_{0}^{\infty} S(f)df$$

The spectral function has a maximum (denoted by S) at f = f_0. This may be verified by differentiating the spectra and setting the derivative equal to zero. Consequently, an expression for S may be obtained by setting f equal to f_0:

$$S = \frac{2\left(\frac{4\lambda+1}{4}\right)^{\lambda}}{\Gamma(\lambda)|f_0|}\sigma^2 e^{\frac{-(4\lambda+1)}{4}}$$

This formula depends on three parameters, f_0, σ^2, and λ. The parameters f_0 and σ^2 have direct geometric interpretations. The parameter f_0 is the frequency at which the spectrum reaches its maxima. The variance, σ^2, is the area under the spectral density in (-∞, ∞) or twice the area under S(f) in (0, ∞). This leaves λ as a fitting parameter to force the function to have maximum height of S.

Lambda, λ, is a mathematical parameter which measures the width of the spectral density function, S(f), and is a function of another more intuitive (or geometric) parameter called the effective width of the spectrum. Consider the diagram in Figure 5-31. The area under the spectral density from (0, ∞) is $\sigma^2/2$. The height of the spectra at f=f_0 is S(f_0). The effective width is defined to be the width of the rectangle which is S(f_0) tall and which equals the area under S(f).

The Ochi-Hubble function can represent fairly well many spectral shapes. Very narrow spectra (small δ) give large values of λ. Very broad spectra (large δ) give small values of λ. If λ = 1, the function becomes a form of the Pierson-Moskowitz-Bretschneider spectral density. If λ = 1.664, the function becomes a form of the JONSWAP spectrum.

5.12.1.3 Ochi-Hubble Wave Spectrum in Level 3 Module (Double Sided)

The Ochi-Hubble spectral function is plotted in Figure 5-31 and given by:

$$S_\eta(f) = \frac{2\left(\frac{(4\lambda+1)f_0^4}{4}\right)^{\lambda}\sigma^2 e^{\frac{-(4\lambda+1)\left(\frac{f_0}{f}\right)^4}{4}}}{\Gamma(\lambda)|f|^{4\lambda+1}}$$

Where:

- Γ(λ) is the Gamma Function
- $\sigma^2 = 2\int_0^{\infty} S_\eta(f)df$ is the variance of sea surface elevation
- σ is the standard deviation of water surface elevation
- $H_s = 4\sigma$ is the significant wave height
- f_0 is the peak frequency
- $T_p = 1/f_0$ is the peak period

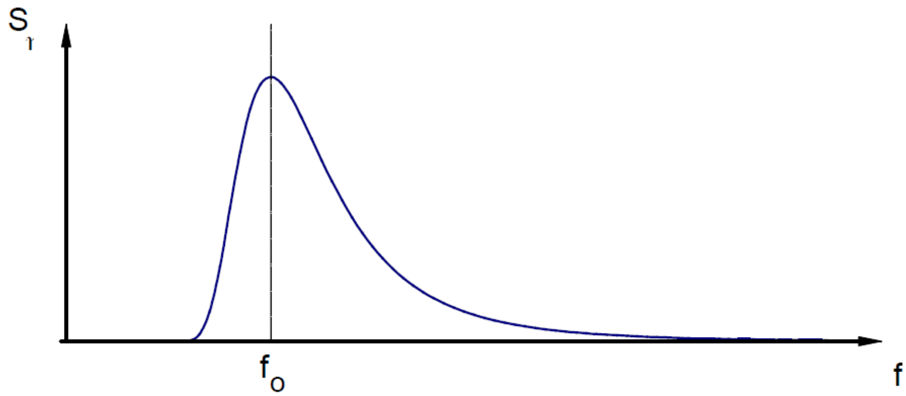


Figure 5-31: Ochi-Hubble Wave Spectrum

5.12.1.4 Directional Spreading Function

Various spreading function formulas such as the von Mises, the generalized cosine-squared [11], and the wrapped-normal function can all represent, with about the same accuracy, the spreading function for waves where the function is unimodal and roughly symmetric. Thus, it appears reasonable to use the formula which is most tractable mathematically. The wrapped-normal matches this criterion and is used in the current version of the Level 3 module.

The wrapped-normal formula may be expressed in two mathematically equivalent forms:

$$D(\Theta) = \frac{1}{2\pi} + \sum_{n=1}^{\infty} e^{\frac{-n^2\sigma_D^2}{2}} \cos(\theta - \theta_0)$$

$$= \sum_{n=1}^{\infty} \frac{\exp\left(\frac{\left(-\frac{1}{2}(\theta - \theta_0) - 2\pi k\right)^2}{\sigma_D^2}\right)}{\sqrt{2\pi} \cdot \sigma_D}$$

If $\sigma_D < \pi/3$, as is usually the case for storm waves, the second formula (in the exponential form) will have only one term in the summation which is not essentially zero. Thus, the spreading function would then become:

$$D(\Theta) = \frac{e^{-\frac{1}{2}\left(\frac{\Theta - \Theta_0}{\sigma_D}\right)^2}}{\sqrt{2\pi\sigma_D}}$$

This is providing Θ is restricted to the interval (Θ_0-π, Θ_0+π). The wave energy is being spread over the various angles by what is functionally equivalent to a normal probability density with standard deviation, σ_D.

In the unimodal option (default), the wrapped normal spreading function is used for D(Θ). The vector of directional spreading values are computed from parametric input based on a central direction, H_0, (direction toward which the waves are traveling) and a directional standard deviation, σ_D. The standard deviation can be directly compared with the corresponding parameter in the usual normal probability density. That is about 2/3 of the energy is contained between Θ_0-σ_D and Θ_0+σ_D.

The bi-modal option (an advanced feature) is very similar to the unimodal option, except that two wrapped normal spreading functions at each frequency are used.

$$D(\Theta) = a\, D_1(\Theta) + (1 - a)\, D_2(\Theta)$$

Here "a" is a selected constant, 0 < a < 1, and $D_j(\Theta)$ are each wrapped normal spreading functions with their own sets of Θ_0 and σ_D values.

5.12.1.5 Input Parameters

The values of S(f) and D(Θ) are developed in the software as two vectors NF and NT long, respectively. Here NF denotes number of frequencies and NT is the number of theta values. Frequency is expressed in cycles per second, or Hertz, and Θ is in degrees. The frequency increment is DF, representing Δf, and the angle increment is DR, standing for ΔΘ.

The number of terms in the simulated wave time sequence is N. As an advanced option, this value can input directly (rather than generated by the pre-processor) and must be an integer power of 2, (i.e. $N=2^K$). If not, the value is rounded down to the next lowest integer power of 2.

The time increment, DT, can also be directly input, and since DT=1.0/(N*DF); this also fixes the frequency internal, DF. The aforementioned relation is required by the fast Fourier transform algorithm used in the simulation.

The cut-off frequency, FC, can also be input. Given the cut-off frequency, FC, and the frequency interval, DF, the number of frequencies, NF is defined.

$$NF = DF \cdot FC$$

The value of NF must satisfy two requirements. The values of NF and DF must be selected so that:

1. S(F,Θ) is negligible (close to zero) for f > NF*DF, and
2. NF must be less than half of N, where N is the length, or number of terms, in the time series of wave properties being simulated.

For stability of the fast Fourier transform applied in the wave generation module, the product of M, DT and FC must be less than 4095.5 to ensure convergence. This is satisfied automatically with values chosen by the pre-processor, but must be enforced if the values are input.

As an advanced option, the number of theta values, DT, can be directly input. The values of DT and NT are chosen so that NT*DT is a full circle, 360°. The default option sets DT to the maximum value allowed by the software, 24. Other input parameters are covered in sufficient detail in the input instructions.

5.12.2 Hydrodynamic Force Calculation

5.12.2.1 Decomposition of Irregular Waves

By decomposing a time series of bottom wave velocities in irregular waves into zero-upcrossing and zero-downcrossing half-wave cycles it is possible to define local wave parameters, such as the KC-number and the current ratio, a, see Figure 5-32. The half-wave cycle is by no means sinusoidal. It is, however, treated as a regular wave with an amplitude equal to the maximum absolute value of the observed velocity during the corresponding upcrossing or downcrossing half-wave cycle, and with a wave period equal to twice the half-wave period.

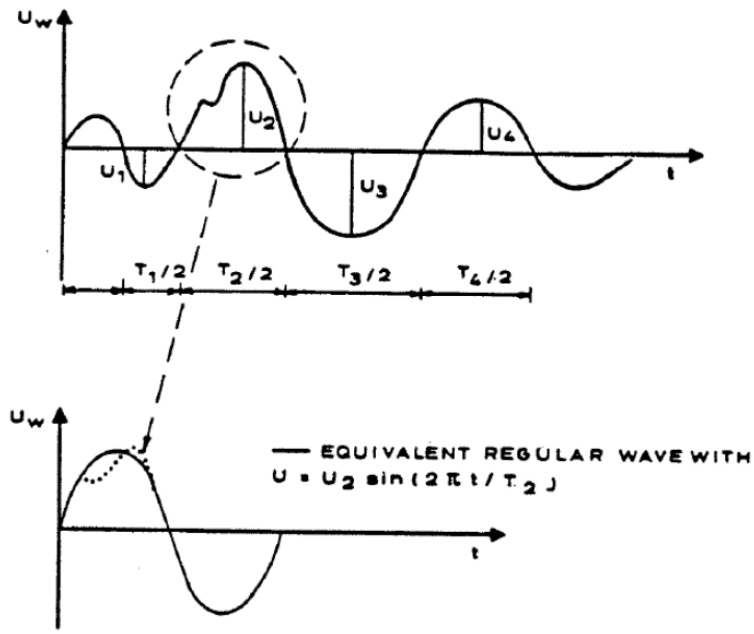


Figure 5-32: Decomposition of Irregular Waves into Single Regular Waves

The non-dimensional wave parameters are thus calculated as:

$$KC_1 = \frac{2 \cdot |U_{w1}| \cdot \frac{T_1}{2}}{D}, \quad \alpha_1 = \frac{U_c}{|U_{w1}|}$$

$$KC_2 = \frac{2 \cdot |U_{w2}| \cdot \frac{T_2}{2}}{D}, \quad \alpha_2 = \frac{U_c}{|U_{w2}|}$$

$$\cdots$$

$$KC_n = \frac{2 \cdot |U_{wn}| \cdot \frac{T_n}{2}}{D}, \quad \alpha_n = \frac{U_c}{|U_{wn}|}$$

Where n is the total number of half-wave cycles, U_w the maximum wave velocity, T/2 the half-wave period, and U_c is the steady current, which is assumed constant for all n. The steady current, U_c applied when calculating the local current ratio, α, is the mean current over one pipe diameter. This value may either be given directly (default) or it may be calculated based on an assumed logarithmic velocity profile. In the present version a procedure is included which is based on the calculations performed by the Current Complex Model (PRCI PR-169-186 [12]). In this case the bottom friction must be given as input in terms of a drag coefficient in addition to the steady current at a reference level 1 m above the sea bed.

5.12.2.2 Force Calculation

The hydrodynamic forces during the first part of half period No. 2 are mainly determined by the reversal of the wake created in the previous half period, No. 1.

The properties of this wake are determined by the parameters associated with half period No. 1, and the forces in the first part of half period No. 2 are then those associated with a regular wave corresponding to half wave No. 1. For the remainder of half period No. 2, the flow (and hence the forces) correspond to those associated with the regular wave defined by the parameters of half period No. 2, i.e.:

$$KC_2 = U_2 \cdot \frac{T_2}{D} \; and \; \alpha_2 = \frac{U_c}{U_2}$$

In PR-170-185 [6] it was found that the Fourier decomposition method was superior in predicting the hydrodynamic forces associated with regular waves (with or without steady current). This method is therefore applied to calculate the forces corresponding to the single half regular waves. The force model reads in analytical format:

$$t' < t < t' + 0.25\frac{T_2}{2}: \qquad F = \frac{1}{2} \cdot \rho \cdot D \cdot U_1^2 \cdot \left(C_{01} + \sum_1^5 C_{n1} \cdot \cos(n(\omega_2 t + \phi_{n1}) \right)$$

$$t' + 0.25\frac{T_2}{2} < t < t' + \frac{T_2}{2}: \qquad F = \frac{1}{2} \cdot \rho \cdot D \cdot U_2^2 \cdot \left(C_{02} + \sum_1^5 C_{n2} \cdot \cos(n(\omega_2 t + \phi_{n2}) \right)$$

Here t' is the time for the zero-crossing at the start of half period No. 2. C_{01}, C_{11} ... C_{51}, and Φ_{01}, Φ_{11} ... Φ_{51} are the Fourier coefficients and phases related to the force associated with the regular wave defined by KC_1 and α_1. Similarly, C_{02}, C_{12} ... C_{52} and Φ_{12}, Φ_{22} ... Φ_{52} are those associated with the force determined by the second half wave. ω_2 is the cyclic frequency of the half period No. 2, i.e. $\omega_2 = 2\pi/T_2$.

In summary, the forces in the half period No. 2 are in the first 25 percent of the time found as those associated with a regular wave flow defined by the parameters of the previous half period (No. 1) and for the latter 75 percent of the time by the forces associated with the present half wave (No. 2).

The equations given above apply to the in-line drag force and the lift force components, with different sets of coefficients and phases. The total in-line force is found by adding the inertia term,

$$F_I = \frac{\pi}{4} \cdot \rho \cdot D^2 \cdot C_M \cdot a(t), \text{ taking } C_M = 3.29$$

In the PR-170-185 [6] project it was demonstrated that this force prediction model yields accurate time series for in-line as well as lift forces.

5.12.2.3 Data Base

In the present version, the data base contains Fourier coefficients for relative pipe roughness, $k/d = 10^{-3}$, 10^{-2} and $5 \cdot 10^{-2}$ and for test conditions as outlined in Table 5-1.

Table 5-1: Fourier Coefficients for Regular Waves and Regular Waves with Steady Current

KC	Current Ratio: α_u								
Number	0.10	0.16	0.32	0.48	0.64	0.80	0.96	1.20	1.60
2.5	1								
4.5	1								
5.0	1								
10	1	1	1	1	1	1	1	1	1
12	1								
15	1	1	1	1	1	1	1	1	1
17	1								
20	1	1	1	1	1	1	1	1	1
25	1								
30	1	1	1	1	1	1	1	1	1
40	1	1	1	1	1	1	1	1	
50	1	1	1	1	1	1	1		
55	1								
60	1	1	1	1	1	1			
65	1								
70	1	1	1	1	1				
75	1								
80	1								
100	1								
120	1								
140	1								
160	1								

The content of the data base is illustrated in Figure 5-33 below, showing a plot of the Fourier coefficients and phases.

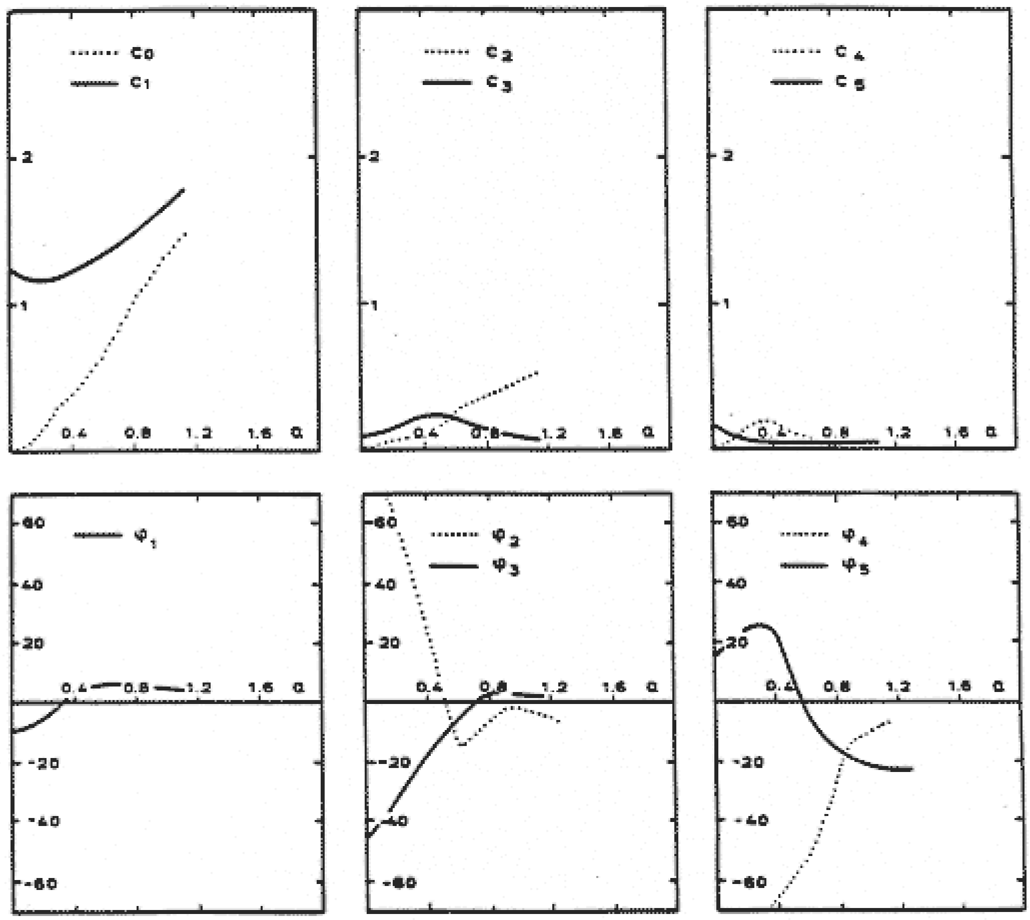


Figure 5-33: Plot of Data Base Content, Amplitudes and Phases of Drag Force as a Function of the Current Ratio, α for KC = 40

Within the ranges listed in Table 5-1, linear interpolation has been applied. For local KC-numbers and current ratios beyond these ranges various extrapolation routines have been adopted as follows:

a. Extrapolation beyond max. KC for $\alpha = 0$

Drag:
for KC > 160
C_{Di}, ϕ_{Di} = C_{Di}, ϕ_{Di} for KC = 160

Lift:
for KC > 160
C_{Li}, ϕ_{Li} = C_{Li}, ϕ_{Li} for KC = 160

b. Extrapolation beyond min. KC for $\alpha = 0$

Drag:
for KC = 0
C_{Di}, $\phi_{Di} = 0$

Linear interpolation is used between C_{Di}, ϕ_{Di} at KC = 2.5 and C_{Di}, ϕ_{Di} at KC = 0.
Lift:
for KC < 2.5
C_{Li}, ϕ_{Li} = C_{Li}, ϕ_{Li} for KC = 2.5

c. Extrapolation beyond max. KC for $\alpha > 0$

Drag:
Estimates have been made on C_{Di}, ϕ_{Di} for KC = 100 and 160 based on results for $\alpha = 0$. Linear interpolation is then performed between KC = 70, 100 and 160.
for KC > 160
C_{Di}, ϕ_{Di} = C_{Di}, ϕ_{Di} for KC = 160

Lift:
A similar approach is made for C_{Li}, ϕ_{Li}

d. Extrapolation beyond min. KC for $\alpha > 0$

Estimates have been made on C_{Di}, ϕ_{Di} for KC = 2.5 and 5 based on results for $\alpha = 0$
for KC = 0
C_{Di}, $\phi_{Di} = 0$
Linear interpolation is then used between C_{Di}, ϕ_{Di} at KC = 2.5 and C_{Di}, ϕ_{Di} at KC = 0
For 2.5 \ KC \ 10 linear interpolation is used.

Lift:
Estimates have been made on C_{Li}, ϕ_{Li} for KC = 2.5 and 5 based on results for $\alpha = 0$
for KC < 2.5
C_{Li}, ϕ_{Li} = C_{Li}, ϕ_{Li} FOR KC = 2.5
For 2.5 \ KC \ 10 linear interpolation is used.

e. Extrapolation beyond max. α > for given KC

Drag:
$C_{DO} = C_D\,(1/2 + \alpha^2)$ for $\alpha \geq 2.0$
$C_{D1} = C_D\,(2\alpha)$ for $\alpha \geq 3.0$

C_{D2} = 1/2 C_D for $\alpha \geq 3.0$
$C_{D3} = C_{D4} = C_{D5}$ = 0for $\alpha \geq 3.0$

Where C_D is the drag coefficient found from the least-squares-fit analysis of the model tests at α = max. α.

Linear interpolation is used between max. α given in Table E-1 and α = 2 and 3, respectively, as given above.

For α > max. α in Table E-1
$\phi_{Di} = \phi_{Di}$ at max. α.

Lift:
A similar approach is made for C_{Li}, ϕ_{Li}, i.e.:
$C_{L0} = C_L (1/2 + \alpha^2)$ for $\alpha \geq 2.0$
$C_{Li} = C_L (2\alpha)$ for $\alpha \geq 3.0$
C_{L2} = 1/2 C_L for $\alpha \geq 3.0$
$C_{L3} = C_{L4} = C_{L5} = 0$ for $\alpha \geq 3.0$

Where C_L is the lift coefficient found from the least-squares-fit analysis of the model tests at α = max. α.

For α > max. α in Table E-1
$\phi_{Li} = \phi_{Li}$ at max. α.

5.12.3 Pipe Dynamics Simulation

5.12.3.1 General

Basically, WINDYNA solves the Euler-Bernoulli equation for bending of a uniform beam under tension. Finite beam elements (with cubic shape functions) are used to model the pipeline, and the Newmark numerical integration scheme is use to integrate the non-linear equations of motion. At each time step an iterative procedure is used to satisfy dynamic equilibrium.

Specifically, the Euler-Bernoulli equation:

$$EIu'' - T_e u' + C\dot{u} + \ddot{m} = q_a(x,t) + q_s(s,t) + q_h(x,t)$$

is reduced to:

$$[M]\{U\} + [C]\{U\} + [K]\{U\} = \{R\}$$

Where:

- [M] is the inertia matrix
- [C] is the proportional damping matrix
- [K] is the stiffness matrix
- {U} is the vector of nodal deflections
- {R} is the resultant load vector

And solved at each incremented time step using the Newmark method:

$$[K]\{U_{t+Dt}\} = \{R_{t+Dt}\}$$

Where:

- $[K_e]$ is the effective stiffness matrix = [K] + a_1 [M] + a_2 [C]
- $\{U_{t+Dt}\}$ is the vector of nodal deflections at time t+Dt
- $\{R_{t+Dt}\}$ is the resultant load vector at time t+Dt
- a_1, a_2 are integration constants

An iterative procedure known as "Successive substitution" is used at each time step until convergence is reached at each time step.

$$[K_e^i]\{U^{i+1}\} = \{R^i\}$$

Where the superscript i denotes the "i"th iteration.

The software module was originally developed during project PR-175-420 [13], and the details of the module can be found in the final report for that project. The basic programming is the same; however, many modifications regarding the hydrodynamic and soil models have been incorporated.

5.12.3.2 Convergence Criteria

The convergence parameter at the k^{th} iteration, $G^k(I)$, is defined as:

$$G^k(I) = \sqrt{\frac{\sum_{J=1}^{NC}(U^k(I,J) - U^{k-1}(I,J))^2}{NC \cdot |U_{max}(I)|}}$$

Where:

- I is the degree of freedom (DOF)
- NC is the number of nodes
- U^k_{max} is the maximum deflection at iteration k in DOF I
- $U^k(I,J)$ is the deflection of node J in DOF I

Convergence is assumed when:

$$G^k(I) \leq EPS;\ I = 1, 2$$

Where:

- EPS is a very small number to determine if G(I) can be considered as small enough to be insignificant, refer to Section 5.8.7.2.

6 ASM Analysis

6.1 Introduction

In the ASM analysis, the pipeline is checked for absolute lateral stability based on DNV-RP-F109, On-Bottom Stability Design of Submarine Pipelines [2].

Absolute static requirement for lateral on-bottom stability is based on a static equilibrium of forces that ensures that the resistance of the pipe against motion is sufficient to withstand maximum hydrodynamic loads during a sea state, i.e. the pipe will experience no lateral displacement under the design extreme conditions in the sea state considered.

"Extreme horizontal" and "extreme vertical" forces are applied together on pipeline, whereas the phase angles of drag, lift and inertia forces are ignored in this calculation.

Furthermore, this criterion of zero displacement often leads to the requirement for heavy pipes. This is because, with zero displacement, one cannot take advantage of the increased passive resistance built up due to the penetration caused by the pipe being rugged back and forth by the wave induced flow.

The following two criteria are to be met to satisfy the absolute lateral static stability requirement:

$$\gamma_{SC} \cdot \frac{F_Y{}^* + \mu . F_Z{}^*}{\mu . w_s + F_R} \leq 1.0$$

and

$$\gamma_{SC} \cdot \frac{F_Z{}^*}{w_s} \leq 1.0$$

Where:

- F_Y^* is the peak horizontal load
- F_Z^* is the peak vertical load
- γ_{SC} is the safety factor for absolute lateral stability
- F_R is the soil passive resistance
- μ is the coefficient of friction between the pipe outer surface and the soil
- w_s is the submerged weight of pipe

The following assumptions are applicable:

- The spectral wave is calculated based on a 3-hour storm.
- The calculation methodology considers monotonic loading only; the cyclical movements of the pipe are not taken into account.
- The friction coefficient is based on the values for concrete coated pipe as given in DNV-RP-F109 [2].
- For non-permeable seabed, the load reduction due to seabed penetration is taken as equal to 1.0 (i.e. no load reduction).
- When the vertical contact force between the pipe and soil is less than or equal to zero, the passive soil resistance is taken as zero.
- No piggy backed lines are considered in the calculations.
- No reduction due to piping of sand layers is taken into account.
- Soil properties are taken as constant with depth.

6.2 ASM Input Data Tab

The **Input Data** tab allows the user to enter all the required parameter values for calculation, as presented in Figure 6-1.

Figure 6-1: Absolute Stability Method Input Data Tab

6.2.1 Pipe Properties

6.2.1.1 Outer Diameter

Refer to Section 3.2.1.1.

6.2.1.2 Wall Thickness

Refer to Section 3.2.1.2.

6.2.1.3 Corrosion Coating Thickness

Refer to Section 3.2.1.3.

6.2.1.4 Corrosion Coating Density

Refer to Section 3.2.1.4.

6.2.1.5 Concrete Density

Refer to Section 3.2.1.5.

6.2.1.6 Field Joint Density

Refer to Section 3.2.1.6.

6.2.1.7 Cutback

Refer to Section 3.2.1.7. The ASM calculations assume a taper angle of 0° from the radial direction of the pipe.

6.2.1.8 Product Density

Refer to Section 3.2.1.9.

6.2.1.9 Joint Length

Refer to Section 3.2.1.10.

6.2.1.10 Steel Density

Refer to Section 3.2.1.11.

6.2.1.11 Multi-Layered Coating

Refer to Section 4.3.1.12.

6.2.2 Soil Properties

6.2.2.1 Soil Type

The type of soil is selectable from two options listed under this heading and covered by DNV-RP-F109 [2], which are defined by different parameters:

- Sand
  - Internal angle of friction
  - Unit submerged weight of sand soil
- Clay
  - Undrained shear strength
  - Dry unit weight of clay soil

6.2.2.2 Soil Friction Coefficient

The value of friction coefficient between the soil and the external surface of the pipe. DNV-RP-F109 [2] suggests a value of 0.2 for a concrete-coated pipe on clay and 0.6 for a concrete-coated pipe on sand.

6.2.2.3 Reduction Factor Permeable Seabed

The permeable seabed reduction factor can be applied to take consideration of flow in the seabed underneath the pipe, reducing the vertical load. DNV-RP-F109 [2] suggests a reduction factor value of 0.7 for a permeable seabed, such as sand.

6.2.3 Embedment

6.2.3.1 Penetration due to Pipe Movement

Pipe penetration due to pipe movement can be entered in this fiel. This value can typically be obtained from installation analysis.

6.2.4 Safety Factors

6.2.4.1 Safety Class

Safety class level for the pipeline in accordance with DNV-OS-F101 [4], selectable from the options of Low, Medium and High.

The safety classes are broadly defined such that a failure under each corresponds to:

- Low: insignificant risk of human injury and minor environmental and economic consequences.
- Medium: low risk of human injury, minor environmental pollution or high economic or political consequences.
- High: risk of human injury, significant environmental pollution or very high economic or political consequences.

6.2.4.2 Geographical Area

This refers to the geographical location of the laid pipeline. The selection of this value, the soil type, and the safety class results in the determination of an applicable absolute stability safety factor to use in the analysis, in accordance with DNV-RP-F109 [2] Sec. 3.6.3.

6.2.4.3 User Defined Safety Factor

This field allows the overwriting of the code absolute stability safety factor, as described in Section 6.2.4.2, with a user defined value. This may be applicable if the laid pipeline is located in a different area from the DNV-RP-F109 [2] geographical locations available in the list (Section 6.2.4.2) or if more project-relevant safety factor information is available.

6.2.4.4 Safety Factor on Submerged Weight

This numerical value (γ_w in the equation below) defines the safety factor to be applied to the vertical stability check (as distinct from the absolute stability check), which assesses the potential of flotation of the pipe:

$$\gamma_w \cdot \frac{b}{w_s + b} \leq 1.0$$

6.2.5 Trench Properties

6.2.5.1 Depth of Trench

This defines the depth of any trench the pipe sits in (z_t in Figure 6-2), referenced from the bottom of the trench to the general seabed level at a width not greater than three pipe diameters away from the pipe, as presented in Figure 6-2.

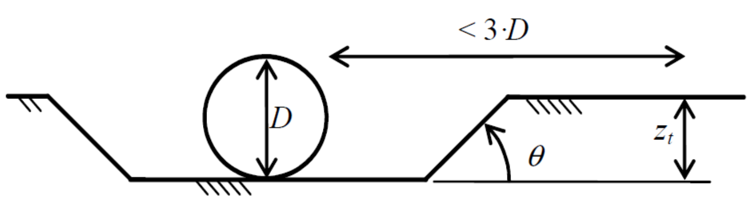


Figure 6-2: Definition of Trench Parameters [2]

6.2.5.2 Angle of Trench

This defines the angle of the pipe trench with respect to the horizontal, as presented in Figure 6-2 as θ.

6.2.6 Environmental Properties

6.2.6.1 Seawater Density

Refer to Section 3.2.6.1.

6.2.6.2 Water Depth

Refer to Section 3.2.6.2.

6.2.6.3 Marine Growth Thickness (ASM)

Thickness of the marine growth, taken as a full circumferential layer on the outermost surface of the pipe, illustrated in Figure 6-3 without embedment, as denoted t_{MG}.

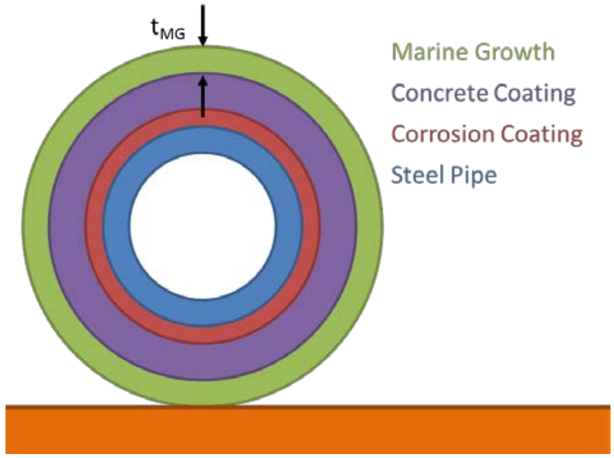


Figure 6-3: Marine Growth Diagram – ASM Module (No Embedment)

6.2.6.4 Marine Growth Density

Refer to Section 3.2.6.4.

6.2.7 Wave Properties

6.2.7.1 Surface Wave Properties

Refer to Section 4.3.6.1.

6.2.7.2 JONSWAP Parameters

Refer to Section 4.3.7.2.

6.2.8 Current Settings

The values describing the steady current are input in this area.

The type of boundary layer calculation applied by the software in the ASM analysis is that given in DNV-RP-F109 [2]; described as:

$$V(z) = V(z_r) \cdot \frac{\ln(z + z_0) - \ln(z_0)}{\ln(z_r + z_0) - \ln(z_0)} \cdot \sin(\theta_c)$$

Where:

- $V(z)$ is the current speed at elevation above seabed z
- z_r is the current reference height
- z_0 is the seabed roughness
- θ_c is the angle of the current, with respect to the pipeline

6.2.8.1 Current

Refer to Section 3.2.3.2.

6.2.8.2 Current Angle

Refer to Section 3.2.3.3.

6.2.8.3 Reference Height

Refer to Section 3.2.3.4.

6.2.8.4 Seabed Roughness

Refer to Section 3.2.3.5.

6.2.9 Concrete Thickness Range

Refer to Section 3.2.7.

6.2.10 Include Deepwater Calculations

Checking this option will consider the horizontal peak load formula as given below and described in the DNV On-Bottom Stability in Deep Waters note [5]. This modified load formula accounts for calculation behavior that can occur for deepwater scenarios when the Keulegan-Carpenter number is low and the hydrodynamics are dominated by steady current.

This option may typically be selected when the on-bottom stability check is performed for a pipeline laid in deep waters (where current action is more than wave action). The option may be unselected for a shallow water analysis (where wave action is more than current action), however this is not required, as for non-small KC numbers, the modified load formula matches the DNV-RP-F109 [2] formulation.

$$K^* \geq 2.5: \quad F_Y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot C_Y^* \cdot (U^* + V^*)^2$$

$$K^* < 2.5: \quad F_Y^* = r_{tot,y} \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot \left(C_Y^* \cdot (U^* + V^*)^2 + \frac{C_M \cdot \pi^2}{K^*} \cdot U^{*2} \right), \qquad C_Y^* = 1.00,\ C_M = 3.29$$

6.2.11 Initial Penetration

This area presents three condition options for the consideration of the pipe self-weight to use to determine the initial penetration: Empty, Contents Filled and Water Filled. The software will automatically calculate the initial pipe penetration value for the chosen pipe condition in accordance with DNV-RP-F109 [2].

The condition of the pipe in its initial configuration at the beginning of the stability analysis should be considered, and not necessarily the contents of the analyzed condition itself. For example, if analyzing the stability of a pipeline in operation, although the contents during operation would correspond to Contents Filled, for an operating condition subsequent to hydrotest of the line, it may be more appropriate to select Water Filled, given that the maximum embedment will have already been achieved for the pipe full of water, prior to operation.

However, the consideration of an Empty pipe may also be a valid choice for the same scenario, if it is desired to reduce the beneficial effects of initial embedment for the stability analysis.

6.3 ASM Output Data Tab

The output can be viewed by clicking the **Output Data** tab, which displays the results outlined in this section in the chosen unit system, as presented in Figure 6-4. The output can also be exported in PDF format by clicking on the **Report** button option in the ribbon menu.

Input Data | Output Data

Case Name: Example Case
Case Description: ---

Ouput Parameters (SI) 18-Jul-2018 05:54:34

Concrete Thickness (mm)	Pipeline Outside Diameter (mm)	Mean Perpendicular Current Velocity (m/s)	Significant Flow Velocity Amplitude (m/s)	Mean Zero Up-crossing Period (sec)	Perpendicular Wave Velocity for SDO (m/s)	Period Associated with SDO (sec)	Wave Spreading Reduction Factor (-)	KC Number for SDO (-)	Steady to Oscillatory Velocity Ratio for SDO (-)	Empty Weight of Pipe In Air (N/m)	Submerged Weight - Empty (N/m)	Submerged Weight - with Product (N/m)	Submerged Weight - with Water (N/m)
0.0	508.0	0.250	0.462	11.09	0.892	11.09	0.949	19.47	0.281	2252.7	215.3	215.3	1958.5
25.0	558.0	0.253	0.462	11.09	0.892	11.09	0.949	17.73	0.284	3273.9	815.8	815.8	2559.0
50.0	608.0	0.256	0.462	11.09	0.892	11.09	0.949	16.27	0.287	4391.0	1472.6	1472.6	3215.8
75.0	658.0	0.258	0.462	11.09	0.892	11.09	0.949	15.03	0.289	5603.9	2185.8	2185.8	3929.0
100.0	708.0	0.260	0.462	11.09	0.892	11.09	0.949	13.97	0.292	6912.5	2955.2	2955.2	4698.4

Concrete Thickness (mm)	Total Pipe Penetration (mm)	Vertical Load Reduction Factor (-)	Horizontal Load Reduction Factor (-)	Peak Vertical Load Coefficient (-)	Peak Horizontal Load Coefficient (-)	Peak Vertical Hydrodynamic Load (N/m)	Peak Horizontal Hydrodynamic Load (N/m)	Floating Check UF (-)	Sinking Check UF (-)	Passive Resistance Parameter (-)	Passive Resistance Force (FR) (N/m)	Lateral Absolute Stability UF (-)	Vertical Absolute Stability UF (-)
0.0	4.9	1.000	0.986	2.300	2.108	781.8	706.7	0.995	0.011	2540.00	30.42	16.443	5.082
25.0	12.7	1.000	0.968	2.522	2.237	946.1	812.5	0.826	0.016	2790.00	105.52	5.219	1.623
50.0	19.5	1.000	0.955	2.709	2.344	1111.9	919.0	0.731	0.021	8.43	186.21	3.324	1.057
75.0	26.1	1.000	0.944	2.867	2.433	1279.2	1024.9	0.671	0.027	3.63	275.64	2.515	0.819
100.0	32.9	1.000	0.935	3.005	2.508	1447.6	1129.8	0.630	0.034	2.35	375.67	2.055	0.686

Figure 6-4: Absolute Stability Method Output Data Tab

6.3.1 General

6.3.1.1 Concrete Thickness

Refer to Section 3.3.2.1.

6.3.1.2 Pipeline Outside Diameter

Pipe total outside diameter, including corrosion coating, concrete coating, and marine growth.

6.3.1.3 Mean Perpendicular Current Velocity

The velocity of the current perpendicular to the pipe, averaged over the pipe diameter.

6.3.1.4 Significant Flow Velocity Amplitude

The spectrally-derived oscillatory velocity (significant amplitude) for the design spectrum, with the wave spreading and directionality reduction factor (Section 6.3.1.8) applied.

6.3.1.5 Mean Zero Up-crossing Period

Average period of the zero up-crossing waves, calculated using the zeroth and second moments of the wave spectrum (M_0 and M_2 below, respectively):

$$T_u = 2\pi \sqrt{\frac{M_0}{M_2}}$$

6.3.1.6 Perpendicular Wave Velocity for Single Design Oscillation

The wave velocity perpendicular to the pipe calculated for a single design oscillation (SDO); derived using the JONSWAP spectral equations, U^*.

6.3.1.7 Period Associated with Single Design Oscillation

Period of the wave associated with a single design oscillation, T^*.

6.3.1.8 Wave Spreading Reduction Factor

The reduction factor applied to the significant flow velocity to account for the effect of main wave directionality and wave spreading. This incorporates projection onto the velocity normal to the pipe and the wave energy spreading directional function.

6.3.1.9 KC Number for Single Design Oscillation

The Keulegan-Carpenter number for a single design oscillation; calculated using wave velocity of single design oscillation and the period associated with it.

$$K^* = \frac{U^* \cdot T^*}{D}$$

6.3.1.10 Steady to Oscillatory Velocity Ratio for Single Design Oscillation

The ratio of steady current to oscillatory perpendicular wave velocity for a single design oscillation.

$$M^* = \frac{V^*}{U^*}$$

6.3.1.11 Pipe Weight Columns

These columns display the weight of the pipe calculated under various conditions, for the respective concrete coating thicknesses in the leftmost column:

- In-air weight of empty pipe
- Submerged weight of empty pipe
- Submerged weight of product-filled pipe (with product density as defined in the **Input Data** tab)
- Submerged weight of water-filled pipe (with the density of seawater as defined in the **Input Data** tab)

6.3.1.12 Total Pipe Penetration

Calculated total pipe penetration for the respective concrete thickness and chosen pipe condition, taken as the summation of the initial penetration and the penetration due to pipe movement:

$$z_p = z_{pi} + z_{pm}$$

6.3.1.13 Vertical Load Reduction Factor

The reduction factor applied to the vertical force is the product of vertical reduction components for seabed permeability, pipe penetration, and pipe trenching:

$$r_{tot,z} = r_{perm,z} \cdot r_{pen,z} \cdot r_{tr,z}$$

6.3.1.14 Horizontal Load Reduction Factor

The reduction factor applied to the horizontal force is the product of horizontal reduction components for pipe penetration and pipe trenching:

$$r_{tot,y} = r_{pen,y} \cdot r_{tr,y}$$

6.3.1.15 Peak Vertical Load Coefficient

The peak vertical load coefficient is the load coefficient to be multiplied with the peak vertical load, C_Z^*.

6.3.1.16 Peak Horizontal Load Coefficient

The peak horizontal load coefficient is the load coefficient to be multiplied with the peak horizontal load, C_Y^*.

6.3.1.17 Peak Vertical Hydrodynamic Load

The peak vertical hydrodynamic load for a single design oscillation, F_Z^*.

6.3.1.18 Peak Horizontal Hydrodynamic Load

The peak horizontal hydrodynamic load for a single design oscillation, F_Y^*.

6.3.1.19 Floating Check UF

The utilization factor (UF) for the pipe floating check; for the pipe to be safe against flotation this value should be less than 1, in accordance with DNV-RP-F109 [2] Sec. 3.2.

6.3.1.20 Sinking Check UF

The UF for the pipe sinking check; for the pipe to be safe against sinking into the soil this value should be less than 1, in accordance with DNV-RP-F109 [2] Sec. 3.3.

6.3.1.21 Passive Resistance Parameter

Soil passive resistance parameter calculated for the pipe product-filled submerged weight and maximum lift force (i.e. F_Z^* due to a single design oscillation).

6.3.1.22 Passive Resistance Force

Passive resistance force exerted by the soil on the pipe, calculated based on the passive resistance parameter with condition weight and maximum lift force.

6.3.1.23 Absolute Static Stability UFs

These are the design criterion utilization factors for absolute lateral static stability, as given in DNV-RP-F109 [2] Sec. 3.6.2. For the pipe to satisfy the absolute stability zero displacement criteria, these values should both be less than or equal to 1:

$$UF_1 = \gamma_{SC} . \frac{F_Y{}^* + \mu . F_Z{}^*}{\mu . w_s + F_R} \leq 1.0$$

$$UF_2 = \gamma_{SC} . \frac{F_Z{}^*}{w_s} \leq 1.0$$

6.4 ASM Reports

Generation of reports for the DNV-RP-F109 ASM analysis is facilitated by the **Report** toolbar button, and produces a pdf report for saving, as presented in Figure 6-5.

PRCI OBS Absolute Stability to DNV-RP-F109 (2011) PRCI-V4.2.02 - On-Bottom Pipeline Stability Analysis

Case Name: Example Case　　Case Description: ---

Report Compiled on 18/07/2018

Soil Properties		**Pipe Properties**		**Wave Properties**		**Environmental Properties**	
Soil Type:	Clay	Pipe OD (mm):	508.00	Significant Wave Height (m):	10.00	Sea Water Density (kg/m³):	1025.00
Shear Strength Undrained (kPa):	5.00	Wall Thickness (mm):	19.05	Peak Period (sec):	10.00	Water Depth (m):	60.00
Unit Soil Weight Dry (kN/m³):	18.00	Corrosion coating (mm):	0.00	**JONSWAP Wave Properties**		Marine Growth Thickness (mm):	0.00
Unit Soil Weight Submerged (kN/m³):	8.00	Densitiy coating (kg/m³):	1300.00	Spectral Peakedness (-):	1.00	Marine Growth Density (kg/m³):	1025.00
Soil Friction Coefficient (-):	0.20	Density concrete (kg/m³):	2560.00	Sigma A (-):	0.07	**Concrete Thickness Range**	
Reduction Factor Permeable Seabed (-):	1.00	Density field joint (kg/m³):	1300.00	Sigma B (-):	0.09	Concrete Initial (mm):	0.00
Embedment		Cutback (mm):	350.00	Wave Direction (deg):	90.00	Concrete Final (mm):	100.00
Penetration due to Pipe movement (mm):	0.00	Product Density (kg/m³):	0.00	Wave Spreading (deg):	8.00	Concrete Increment (mm):	25.00
Safety Factors		Length of pipe joint (m):	12.200	**Current Settings**		**Trench Properties**	
Safety Class:	Medium	Density of steel pipe (kg/m³):	7850.00	Current (m/s):	0.30	Depth of Trench (m):	0.00
Geographical Area:	North sea winter storms	**DeepWater Calculations**		Current Angle (deg):	90.00	Angle of Trench (deg):	90.00
Safety Factor on Absolute Stability (-):	1.4	Not Included		Reference Height (m):	1.00	**Pipe Condition**	
Safety Factor on Submerged Weight (-):	1.1			Seabed Roughness (m):	0.000040	Initial Penetration:	Empty

Figure 6-5: 1st page of DNV-RP-F109 ASM Report

6.5 ASM Plots

Generation of graphical information for the DNV-RP-F109 ASM analysis is facilitated by the **Plot** toolbar button, and produces a graph of the lateral and vertical stability UFs, as presented in Figure 6-6.

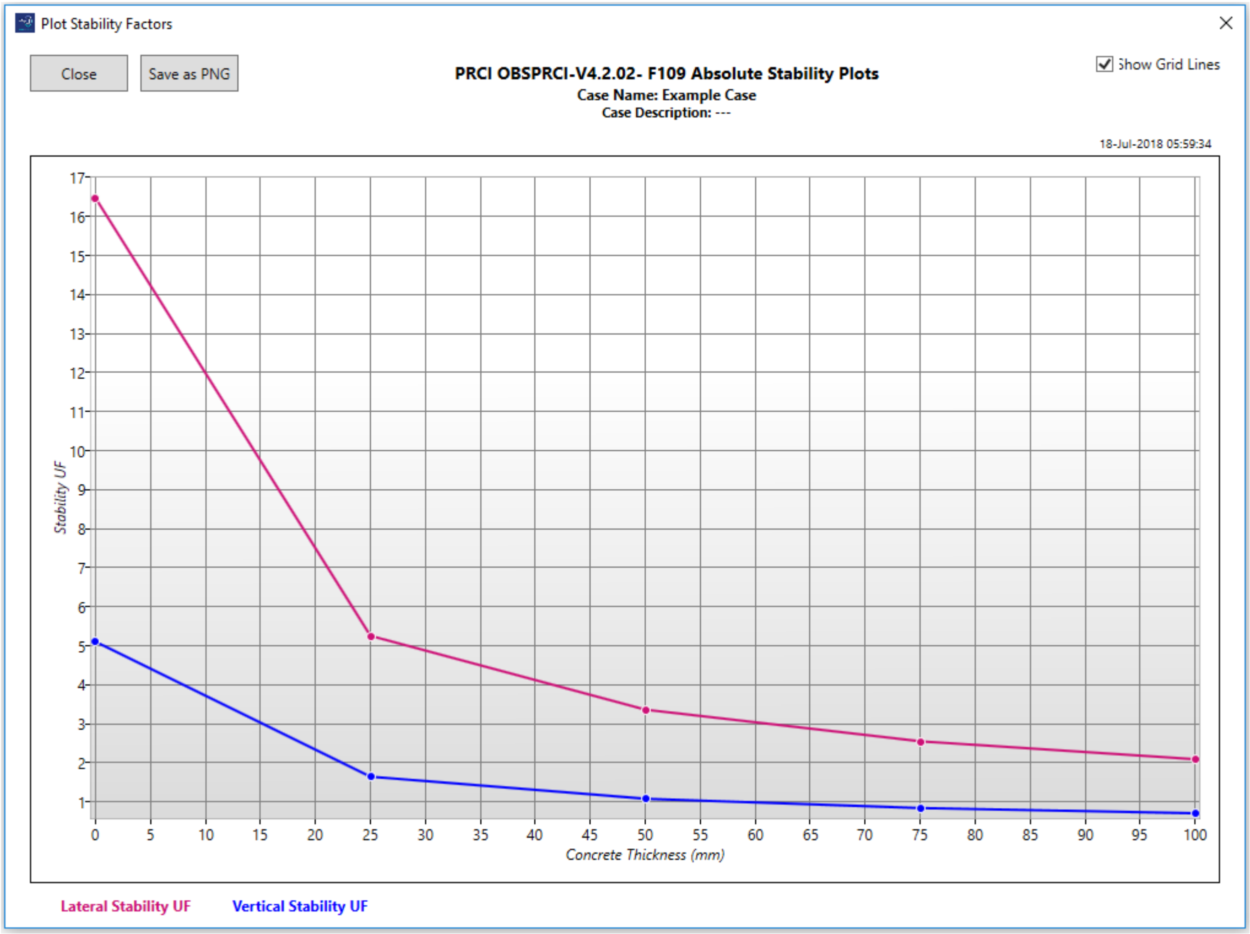


Figure 6-6: DNV-RP-F109 ASM Stability UF Plot

7 References

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