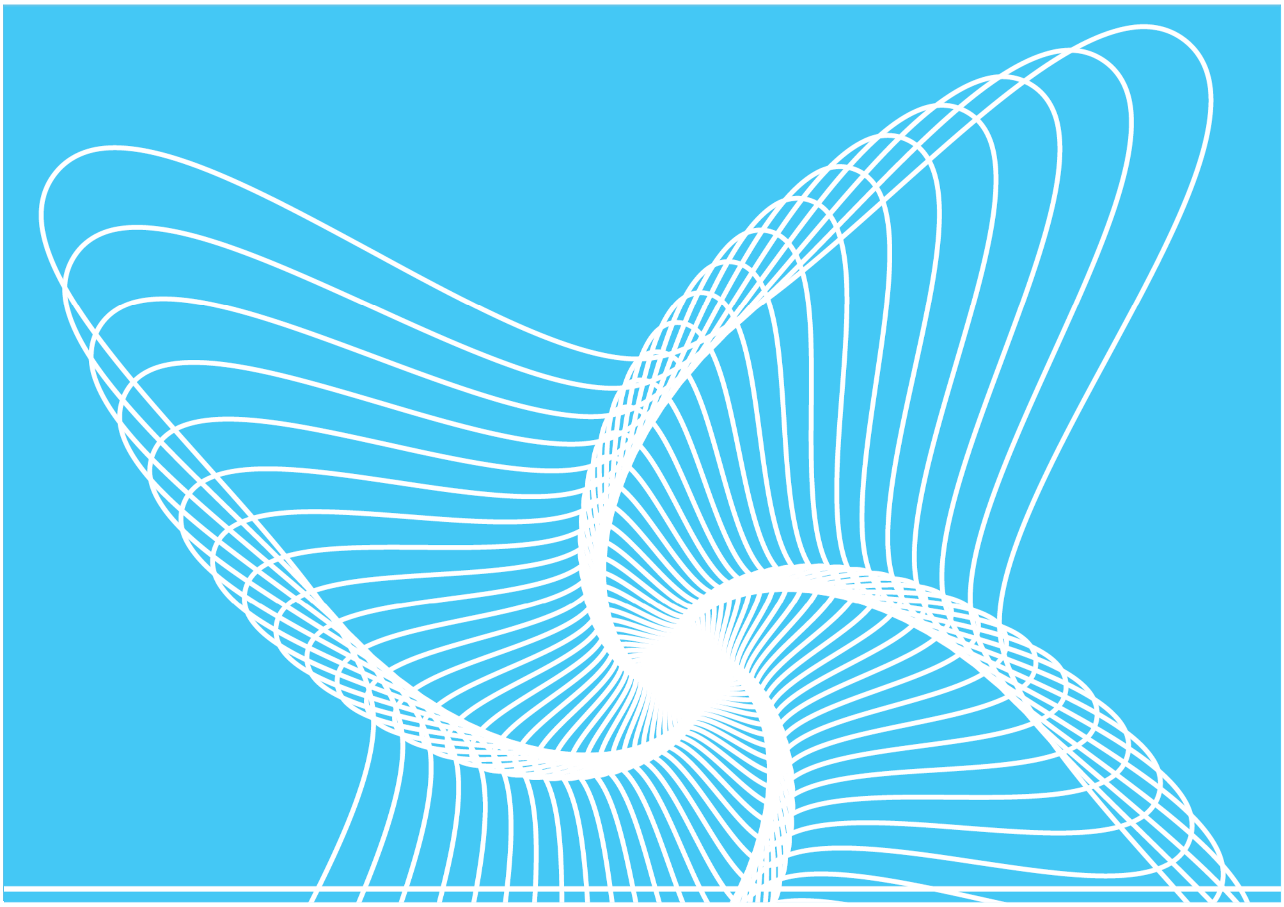
DNV·GL

SESAM USER MANUAL

FatFree

Pipeline Tools application for pipeline free span fatigue analysis according to DNVGL-RP-F105

Program version 13.0



SAFER, SMARTER, GREENER

Sesam User Manual

FatFree

Date: January 2020

Valid from FatFree Version 13.0

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1 INTRODUCTION

1.1 FatFree – Fatigue analysis of free spanning pipelines

FatFree is a Microsoft Excel spreadsheet which runs DNV GL developed code for design and (re-) assessment of submarine pipeline spans in compliance with DNVGL-RP-F105 "Free Spanning Pipelines", issued June 2017. FatFree calculates the fatigue life due to**:**

- Combined direct wave action and in-line vortex induced vibrations (VIV).
- Cross-Flow VIV based on environmental description, i.e., directional long term distribution for current and wave (in terms of height and period).
- Cross-Flow vibrations induced by waves in low KC regimes

FatFree calculations are performed considering

- Free span scenario (water depth, span geometry, soil conditions, etc.).
- Pipe characteristics (material, geometry, SN-curve, etc.).
- Natural frequency and mode shape from FE-analyses or simplified beam theory expressions.
- Environmental description, i.e., directional long term distribution for current and wave (in terms of height and period).

In addition, simplified ultimate limit state (ULS) design checks in terms of peak stress and equivalent stress due to combined static and dynamic actions are provided.

1.2 How to read the Manual

- Read section 2 *Fatfree Overview* to get a quick introduction to FatFree features (what you can do) and the changes introduced in version 13.0.
- Read Section 3 *Getting Started* to get up and running FatFree after a quick introduction.
- Read Section 4 *The "MAIN" sheet* for a description of the main user interface. This section describes how to provide the main inputs and the main results.
- Read section 5 *Environmental data* to learn how to provide current and wave date to FatFree.
- Read Section 6 *Multi-mode analysis* for a expanded description on multi-mode analysis in FatFree ant its additional inputs and results.
- Read Section 7 *Assessment of several span cases* for more advanced excecution of FatFree.
- Read Section 8 *The "plots" sheet* to learn about additional information available in FatFree.

1.3 Status List

In addition to this User Manual you may find additional information in the Status List (as for any other SESAM PIPELINE program). Such information may be:

- Reasons for update (new version)
- New features
- Errors found and corrected

Access this information by clicking the customer login link on our website www.dnvgl.com/software.

1.4 Acronyms frequently used in the Manual

VIV	Vortex induced vibrations
RM	Response model
FM	Force model
FE	Finite element
ULS	Ultimate limit state

2 FATFREE OVERVIEW

2.1 Features of FatFree

FatFree will let you:

- Calculate free span fatigue life due VIV, direct wave action and cross-flow vibrations induced by wave according to DNVGL-RP-F105 *June 2017*.
- Account for higher modes modes and interacting free spans.
- Consider fatigue damage distribution along a free span area.
- Consider response quantities from FE.
- Obtain allowable free span length and perform other sensitivity analyses.
- Calculate the loads in a free span due VIV and direct wave action for Combined Loading checks (ULS).

2.2 FatFree version 13.0 changes

The following significant changes were introduced in FatFree v. 13.0 when compared to its previous version, FatFree 12.0. For a more comprehensive list of changes, please refer to the Release Notes, ref. /2/.

NB: Users of previous versions of FatFree should examine this list carefully as significant changes in the FatFree user interface have been introduced.

- **New:** Multimode/multilocation force model formulation of *DNVGL-RP-F105 June 2017.*
- **New:** Low KC cross-flow vibration response model formulation of *DNVGL-RP-F105 June 2017.*
- **Modified:** The force model hydrodynamic damping formulation
- **Modified:** Enforced $\alpha = 1$ for $KC > 40$.
- **Modified:** For direct stress input, single or multi-locations, the input for force model has changed. Instead of the product of λ_1 and $A_{IL,MAX}$, the v. 13.0 input is the mode shape factor for the first mode, λ_1, which is then multiplied by the first mode modal stress during execution. Reference is made to Section 5 of *DNVGL-RP-F105 June 2017*. For direct mode shape input, FatFree will calculate the mode shape factor λ_j for each in-line mode.
- **Removed:** Single mode Calculations option. This may affect the calculation results associated with cross-flow induced in-line VIV. Single mode behaviour may be enforced by selecting *User Defined* response data and setting the number of in-line and cross-flow modes to 1.
- **Removed: O**mnidirectional Directionality option. The previous functionality may be reproduced by repeating the same probability distribution for each sector and having the sector probability equal as well, i.e. sector probability is 1 divided by the number of sectors considered. FatFree retains compatibility with previous Wave and Current input Template sheets which includes a omni specification, however the omni input will be ignored.
- **Removed:** User defined Return Period Values option for ULS calculations. The return perido values used for ULS are computed form actual wave and current distributions input and not given as direct input.

- **Bug Fix:** Sector scaling for Hs Histogram input and Discrete Current directionality option corrected and the fatigue life for this should improve as consequence. The larger the sector probability difference between wave and current for relevant wave sectors the larger the fatigue life improvement will be.

2.3 Migrating cases from v.12.0

A FatFree file is specific for the version it was created. This means that to perform calculations in FatFree files from older versions, that specific version needs to be installed, together with an active license.

Migration of old cases to v.13.0-00, the user must copy the information, i.e. cell values and drop-down selections, from the old file into a newer FatFree sheet. However, wave and Current sheets can be copied in their entirety by right-clicking the sheet tab and selecting "move or copy".

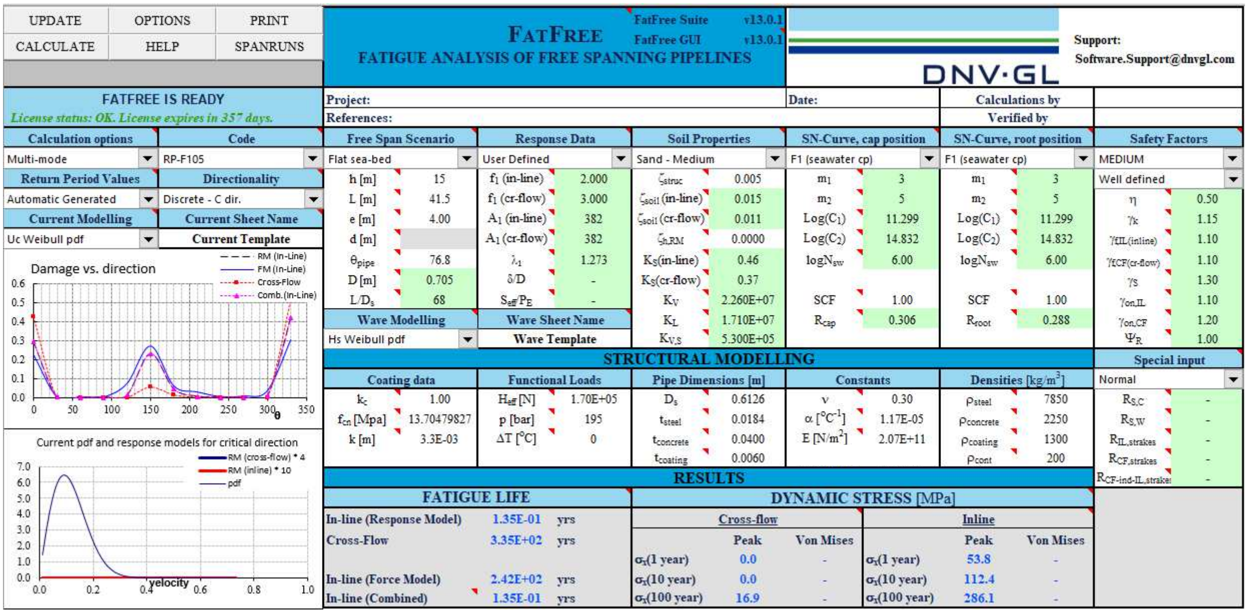
NB: Note that v.13 introduces changes to the input format in some sheets. This needs to be kept in mind when migrating data manually.

3 GETTING STARTED

3.1 User Interface

FatFree is a C# program that uses Microsoft Excel as Graphical User Interface (GUI). Hence, the user interface is the same as in a typical Excel spread-sheet with direct input cells, push buttons and pull-down menus and User has access to all standard Excel features such as creating plots.

When FatFree is started the **"MAIN"** sheet appears.



The program has been designed so that the majority of the input and results are located on the "MAIN" sheet, i.e., the user can see all the necessary information from this sheet without navigating between many windows.

In FatFree the following kinds of sheets are available:

- **"MAIN" sheet** — Contains all important input and output except environmental data. Provides link to environmental data.
- **"Current" sheets** — Contains the current data (several sheets can be used, one for each environmental zone).
- **"Wave" sheets** — Contains the wave data (several sheets can be used, one for each environmental zone).
- **"Plots" sheet** — Contains results for graphical presentation and additional information, such as control parameters and intermediate results.
- **"Multimode" sheet** — Contains information about potentially active higher order modes.
- **"Multimode Output" sheet** — Contains detailed results of multi-mode analyses.
- **"Span Runs" sheet** — Allows running several span cases at one time (these sheets are created when the "Span Runs" button on the "MAIN" sheet).

Several SpanRuns sheets can be made in the same workbook, and the user can copy/insert multiple environmental data sheets, but the program can only operate with a single "MAIN", "Multimode" and "Multimode Output" sheet.

The sheets have been designed so that the user can modify input cells only. This is to prevent corruption of the input data, formulae and the routines. Cells with input access are white, whereas cells that do not allow user access are coloured:

Some of the cells change access rights according to specific selections. This occurs when some of the User Options have been changed.

The "PLOTS" only contains output.

3.2 Running FatFree

All the calculation routines in the program are initiated using the two buttons on the "MAIN" sheet:

"UPDATE" updates the intermediate results in the MAIN sheet (e.g., all the pipe cross-sectional data at the bottom of the sheet, the structural response results, etc.), the "plots" sheet and the environmental-data sheets.

To update all results including fatigue and peak/von-Mises stresses, the "CALCULATE" button has to be pushed/clicked. Note that these calculations can be time consuming, since the fatigue damage for several sea-states may have to be calculated.

The "SpanRuns" sheets have their own "UPDATE" and "CALCULATE" buttons which has to be pushed/clicked.

3.3 Simple use of FatFree

The procedure to follow when assessing a single span under single mode vibration is briefly described below:

1. Define the environmental conditions in terms of long-term wave and current distributions on the wave and current sheets:
    a) Make properly named copies of the template sheets "Wave Template" and "Current Template" (optional but recommended).
    b) Delete the input tables not relevant in the wave and current sheets (optional).
    c) Enter the relevant wave and current data on the respective sheets.
    d) Specify the wave and current sheets under "Current Sheet Name" and "Wave Sheet Name", select the correct "Current Modelling", "Wave Modelling" and "Directionality" option.

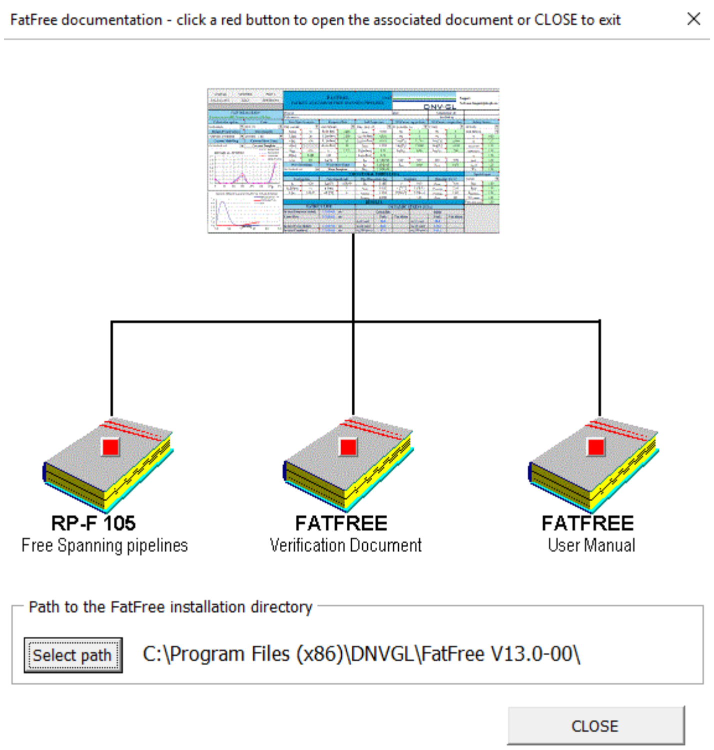
2. Click the "UPDATE" button to check the intermediate results on environmental conditions.
3. Perform “Structural Modelling”: provide pipe and operational data.
4. Describe “Free Span Scenario”: give the span length, water depth, etc.
5. Specify “Response Data”, damping (under “Soil Properties”), “SN-Curves” and “Safety Factors” by using pull-down menus and giving input values.
6. Click the "CALCULATE" button.

Once FatFree completes the calculations, results are presented in the “MAIN” sheet in terms of fatigue lives (for in-line and cross-flow directions) and extreme stresses due to functional and environmental loading.

3.4 Getting help

Comments are provided in many of the cells to give further guidance to the user. The comments give additional definitions and references to DNVGL-RP-F105. Comments are identified by a small red triangle in the top right-hand corner of the cell and are viewed by pointing at the cell.

The Help button opens a new window which provides additional sources for further information.



Clicking in the red buttons will trigger actions to provide the required documentation.

- RP-F105: FatFree will open a web browser to the downloading site of DNVGL-RP-F105, https://www.dnvgl.com/oilgas/download/dnvgl-rp-f105-free-spanning-pipelines.html. The recommended Practice contails all relevant information regarding the FatFree calculation methodology as well as relevant information regarding FatFree input and general free span design.

- Verification Document: FatFree will open the Verification Document from the installation folder. It contains the checks performed to document the correct implementation of FatFree.
- User Manual: FatFree will open the User Manual (current document) from the installation folder.

The text box displays the path in which Fatfree will look-up for its documentation. It shall be the FatFree installation folder and it can be adjusted by clicking in the “Select path” button.

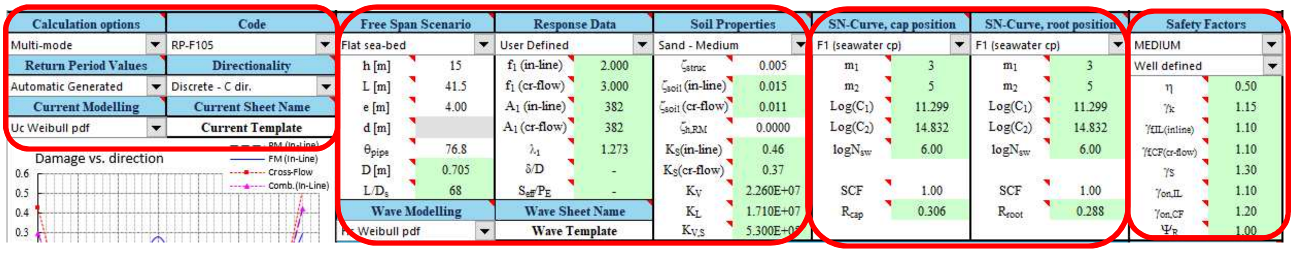
Additional support is available through Software.Support@dnvgl.com.

4 THE "MAIN" SHEET

4.1 Overview

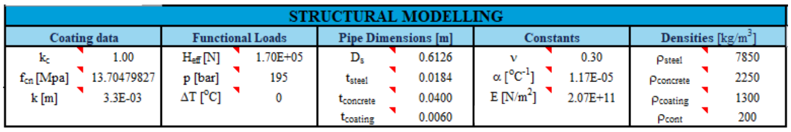
Header area

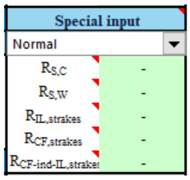
Calculations Options
Span & Soil Data
SN-curves
Safety factors



Structural modelling area

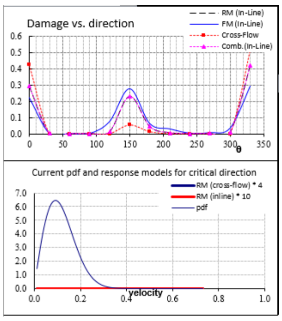
Shielding and Strake modelling (not in use)

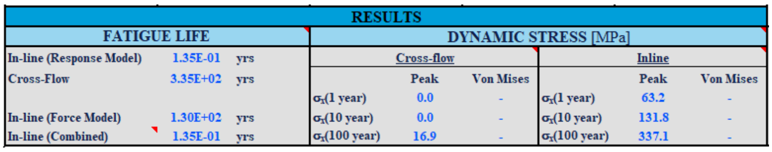




Graphical results area

Main Results area





4.2 License information

License status and expiry is displayed just below the FatFree status field. A failed license checkout will also trigger a message box with licensing information in case support is needed.

If, for some reason, the start-up configuration of FatFree should fail to run, the license status will be displayed as UNKNOWN. This may happen in cases where the Excel macros have been disabled due to anti-virus or security settings in Excel.

FATFREE IS RUNNING	FATFREE IS READY
License status: OK. License expires in 244 days.	*License status: LICENSE CHECKOUT FAILED.*

FATFREE IS READY
License status: UNKNOWN.

4.3 Structural modelling

The user should enter all the pipe details into the structural modelling area/section:

STRUCTURAL MODELLING									
Coating data		Functional Loads		Pipe Dimensions [m]		Constants		Densities [kg/m^3]	
k_c	0.25	H_{eff} [N]	9.00E+04	D_s	0.4000	ν	0.30	ρ_{steel}	7850
f_{cn} (MPa)	42	p [bar]	0	t_{steel}	0.0200	α [°C^{-1}]	1.17E-05	$\rho_{concrete}$	1800
k	3.3E-03	ΔT [°C]	0	$t_{concrete}$	0.0000	E [N/m^2]	2.07E+11	$\rho_{coating}$	940
				$t_{coating}$	0.0000			ρ_{cont}	0

The following input is to be given:

Coating data

k_c Concrete stiffness factor (empirical constant for concrete stiffening).

f_{cn} Construction strength of concrete coating [MPa].

k Surface roughness [m].

Functional Loads

H_{eff} Effective (residual) lay tension [N].

p Internal pressure at spanning pipe (normally the operational pressure) [bar].

ΔT Temperature change relative to ambient temperature during installation [ºC].

Pipe Dimensions

D_s Steel outer diameter [m].

t_{steel} Thickness of steel wall [m].

$t_{concrete}$ Thickness of concrete coating [m].

$t_{coating}$ Thickness of corrosion coating [m].

FatFree does not support modelling of inner coating or multilayer external coating.

If multilayer external coating is required, then the user shall input the total thickness.

If the pipeline has inner coating that does not contribute to structural resitance, then inner coating thickness is to be ignored. If the inner coating contributes to structural resistance, then a equivalent thickness of steel wall and inner coating is to be given under t_{steel}. It shall be noted that root position is assumed to be $\frac{D_s}{2} - t_{steel}$.

FatFree performs all calculations considering the t_{steel} as given as input. It does not consider separate values for load and response effects, such as corrosion allowance.

Constants

ν	Poisson's number.
α	Temperature expansion coefficient [ºC^{-1}].
E	Young's modulus [Pa].

If a equivalent wall thickness is given in t_{steel}, then a equivalent Young's modulus shall be given so that the correct bending stiffness of the pipeline is given.

Densities

ρ_{steel}	Densities of pipe steel [kg/m^3].
$\rho_{concrete}$	Density of concrete [kg/m^3].
$\rho_{coating}$	Density of corrosion coating [kg/m^3].
$\rho_{content}$	Density of content [kg/m^3].

FatFree does not support modelling of inner coating or multilayer external coating.

If multilayer external coating is required, then density of the coating, $\rho_{coating}$, shall be adjusted (equivalent density) to give the correct mass of the pipeline.

If the pipeline has inner coating, then one of the densities shall be adjusted (equivalent density) to give the correct mass of the pipeline. It is recommended that the pipe steel density, ρ_{steel}, is used.

By clicking the "UPDATE " or "CALCULATE" button, or changing a drop-down menu choice (except current/wave model dropdowns) all structural modelling results are updated.

The following should be noted:

- Different phases of the pipeline design/operational life may be simulated by changing the density of the content, the internal pressure or the temperature in the pipeline.
- The effective axial force is a very important parameter in the free span fatigue assessment. The assumption of a fully axially restrained pipeline can lead to over-conservative results. Based on experience and engineering judgement the effective axial force may be partly released, e.g., by increasing the lay tension or reducing the temperature.

  The effective axial force is not relevant for the when the “Response Data” is set as “User Defined”, where both the natural frequencies and the associated stress ranges are determined by FE analysis and directly given as input. However appropriate input of pressure and effective axial force are required for FatFree return meaningful von Mises results.

4.4 Free-span scenario, response data, soil properties and damping

The free-span configuration (span length, gap height, etc.), response quantities, soil properties and damping values are given in the following areas:

Free Span Scenario		Response Data		Soil Properties	
Flat sea-bed		User Defined		Sand - Medium	
h [m]	15	f_1 (in-line)		ζ_{struc}	0.005
L [m]	41.5	f_1 (cr-flow)		ζ_{soil} (in-line)	0.015
e [m]	4.00	A_1 (in-line)		ζ_{soil} (cr-flow)	0.011
d [m]		A_1 (cr-flow)		$\zeta_{h,RM}$	0.0000
θ_{pipe}	76.8	λ_1	1.290	K_S(in-line)	0.46
D [m]	0.705	δ/D	-	K_S(cr-flow)	0.37
L/D_s	68	S_{eff}/P_E	-	K_V	2.260E+07
				K_L	1.710E+07
				$K_{V,S}$	5.300E+05

As can be seen, the span and soil data is divided into three areas:

- **Free Span Scenario** — Describing the actual free span.
- **Response Data** — Characterising the natural frequencies and stresses for the span.
- **Soil Properties** — Describing the damping characteristics and the soil stiffness for various types of soil.

<u>Free Span Scenario</u>

A pull down menu allows the choice between:

- **Pipe in trench** — Typical for spans caused by scouring with some sort of trench underneath the pipeline
- **Flat sea-bed** — No trench underneath pipeline. Nomenclature is not in contrast to an uneven seabed.

The following parameters are to be given:

h	Water depth [m].
L	Span length [m].
e	Gap between pipeline and seabed [m].
d	Depth of trench taken three outer pipe diameters away from pipe centreline [m].
θ_{pipe}	Direction of pipeline relative to geographic North [º].

In addition, the outer diameter, D, and the span length over outer steel pipe diameter ratio, L/Ds, are calculated and listed.

NB: It is important that pipeline direction, wave direction and current direction follows the same convention. If this is the case, the analyses are insensitive to actual definition of pipeline direction.

Response Data

A pull down menu allows the user to choose the following boundary conditions:

- **User Defined** All values specified by user
- **RP-F105 Span** Approximate response quantities according to DNVGL-RP-F105
- **Pinned-pinned** Euler-Bernoulli beam with pinned-pinned boundary conditions
- **Pinned-fixed** Euler-Bernoulli beam with pinned-fixed boundary conditions
- **Fixed-fixed** Euler-Bernoulli beam with fixed-fixed boundary conditions

When the response data is set as "RP-F105 Span", the fatigue criterion is based on definition of the free span scenario with beam theory based estimates of frequencies and mode shapes. No input is required except for the "User Defined" case.

The option "User Defined" implies that the response data is provided by finite element analysis or similar methods or measurements. For discussion and details see Refs. /4/, /5/.

If the "Calculation Options" is set as "Multi-mode", the "User Defined" data needs to be input from the "Multimode" worksheet. More information on the "Multimode" option is presented in chapter 6.

The parameters in the "Response Data" section are described below:

f_1(in-line)	First natural frequency in the in-line direction [Hz].
f_1(cr-flow)	First natural frequency in the cross-flow direction [Hz].
A_1(in-line)	Maximum stress amplitude associated with the in-line mode shape given a maximum deflection of one pipe outer diameter, 1D, and calculated and mid-wall (i.e. distance from the neutal line of $\frac{D_s - t}{2}$) [MPa].
A_1(cr-flow)	Maximum stress amplitude associated with the cross-flow mode shape given a maximum deflection of one pipe outer diameter, 1D, and calculated and mid-wall (i.e. distance from the neutal line of $\frac{D_s - t}{2}$) [MPa].
λ_1	Mode shape weighting factor for 1st in-line mode for Force Model.
δ/D	Normalised static deflection of pipe at mid-span.
S_{eff}/P_E	Normalised effective axial force (with Euler buckling load).

The applicability limits for the approximate response quantity model from DNVGL-RP-F105, shown below, cannot be changed. Pressing the Calculate button when case is outside the validity limit will generate a warning, but will not stop the calculations.

- Limit value for effective axial force $C_2 \cdot S_{eff}/P_E$ (-0.5).
- Limit value for L/D for approximate response quantities (140).
- Limit value for static pipe deflection δ/D (2.5)

Soil Properties

A pull down menu allows user to choose between different soil models, those are preset models based on the general description presented in Section 7 of DNVGL-RP-F114, /7/. The following choices are available:

- **User Defined**
- **Clay - Very soft**
- **Clay - Soft**
- **Clay - Firm**
- **Clay – Stiff**
- **Clay - Very stiff**
- **Clay - Hard**
- **Sand - Loose**
- **Sand – Medium**
- **Sand – Dense**

For all options but "User Defined", soil damping parameters and soil stiffness are automatically updated.

Damping

The soil damping parameters are defined according to the soil type and the length/diameter ratio, see DNVGL-RP-F114 for further information. The hydrodynamic damping due VIV is computed automatically as part of the Response Model, but additional damping might be included by the user. The structural damping is always set by the user.

The following parameters are to be set:

ζ_{struc}	Structural damping.
ζ_{soil} (in-line)	Soil damping, in-line (input required only for "User Defined" case).
ζ_{soil} (cr-flow)	Soil damping, cross-flow (input required only for "User Defined" case)
$\zeta_{h,RM}$	Hydrodynamic damping (normally taken as zero), as this should not be included in the VIV response.

Soil stiffness

The following parameters are set based on the choice of the soil stiffness type:

K_V	Vertical dynamic soil stiffness per unit length [kN/m/m].
K_L	Lateral (horizontal) dynamic soil stiffness per unit length [kN/m/m].
$K_{V,S}$	Vertical static soil stiffness per unit length [kN/m/m].

4.5 SN-curves and safety factors

The utilised SN-curves and safety factors are defined in the following areas of the Main sheet:

SN-Curve, cap position		SN-Curve, root position		Safety Factors	
F1 (seawater cp)		F1 (seawater cp)		MEDIUM	
m_1	3	m_1	3	Well defined	
m_2	5	m_2	5	η	0.50
$Log(C_1)$	11.299	$Log(C_1)$	11.299	γ_k	1.15
$Log(C_2)$	14.832	$Log(C_2)$	14.832	$\gamma_{fIL(inline)}$	1.10
$logN_{sw}$	6.00	$logN_{sw}$	6.00	$\gamma_{fCF(cr\text{-}flow)}$	1.10
				γ_S	1.30
SCF	1.00	SCF	1.00	$\gamma_{on,IL}$	1.10
R_{cap}	0.306	R_{root}	0.288	$\gamma_{on,CF}$	1.20
				Ψ_R	1.00

SN-Curves

Two sets of SN-curves are available, for the weld root and weld cap. FatFree automatically presents the lowest fatigue life between the two sets. Each set is identified by where fatigue damage is calculated:

R_{cap} Radial distance from pipe centre to damage location, in [m], at weld cap, defined as $\frac{D_s}{2}$.

R_{root} Radial distance from pipe centre to damage location, in [m], at weld root, defined as $\frac{D_s}{2} - t_{steel}$.

The pull-down menu allows the choice between pre-implemented SN-curves and user specified linear or bilinear log-log SN-curve:

- **User Defined**
- **D (air)**
- **E (air)**
- **F (air)**
- **F1 (air)**
- **F3 (air)**
- **D (seawater cp)**
- **E (seawater cp)**
- **F1 (seawater cp)**
- **F3 (seawater cp)**
- **D (free corrosion)**
- **E (free corrosion)**
- **F1 (free corrosion)**

- **F3 (free corrosion)**
- **DIN 2413**
- **F2 (CN 30.4)**

The following parameters can be given for the weld root and cap:

m_1	Negative inverse slope of SN curve for $N < N_{sw}$.
m_2	Negative inverse slope of SN curve for $N > N_{sw}$.
$Log(C_1)$	Intercept between SN-curve and stress axis for $N < N_{sw}$.
$Log(C_2)$	Intercept between SN-curve and stress axis for $N > N_{sw}$.
$LogN_{sw}$	Point at logN axis where the SN-curves intersect (point of slope change). Equals = 6 for seawater with cathodic protection, 7 for air. A default value of $LogN_{sw}$ = 8 is used for single slope curves.
SCF	Stress concentration factors. All relevant factors contributing to SCF must be included in a single input (e.g. due to weld misalignment and due to thickness effect)

In case the fatigue calculations are to be performed in hot-spots different than location than the weld root and cap, then the SCF may be used to adjust the calculation location. Then a equivalent SCF, equal to the relation between the desired hot spot distance from the neutral line and R_{cap} or R_{root}, shall be included in the SCF composition.

Safety Factors

Safety factors are specified according to the pipeline class. A pull-down menu allows the choice between:

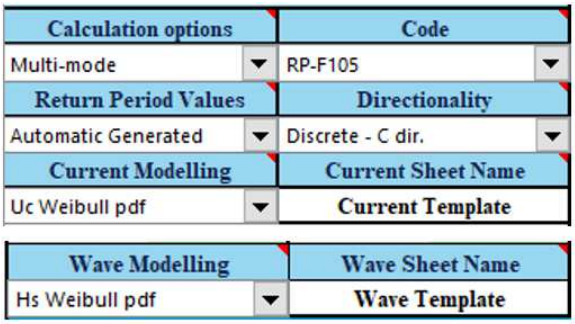
- **LOW**
- **MEDIUM**
- **HIGH**

The safety factor for the natural frequencies is set by the free-span type. Another pull-down menu allows the following choices for the free-span type:

- **Very well defined**
- **Well to very well defined**
- **Well defined**
- **Not well defined**

4.6 Calculation options and environmental modelling

Several calculation options and possibilities for specifying the environmental conditions exist in FatFree via the following dropdown menus:



The specific choices in the pull-down menus are described below.

<u>Calculation options:</u>

FatFree offers one possibility to perform free span analysis:

- **Multi-mode** Multi-mode analysis accounts for higher modes and mode competition in accordance with DNVGL-RP-F105, /1/. The active and contributing modes are selected automatically from the list of input modes, which shall include all relevant modes.

If required, single mode behaviour, i.e. no possibility of higher modes, can be enforced by using User Defined response data and selecting 1 in-line and 1 cross-flow modes.

<u>Code:</u>

FatFree only permits the use of “RP-F105” as choice of design code which complies fully with DNVGL-RP-F105, Ref. /1/.

<u>Return Period Values:</u>

A pull down menu allows the choice on how extreme values for ULS check are defined.

- **Automatic Generated** Return period values (1, 10 and 100 year) are generated automatically from the specified wave and current distributions.

<u>Current Modelling:</u>

A pull down menu allows the current distribution to be defined as:

- **Uc Weibull pdf** Weibull distribution defined by 3 parameters.
- **Uc pdf - RPV** 3-parameter Weibull distribution estimated from 1, 10 and 100 year return period values.
- **Uc histogram** A series of discrete values/measurements and associated probabilities.

Note that it is not recommended to use the return period values "Uc pdf - RPV" option as the distribution is fitted to extreme values located in the tail of the distribution. Hence, the fitted distribution may not give a good representation of the actual distribution. Use of this option must be based on experience and engineering judgement.

The histogram option allows user to include a probability distribution function other than Weibull.

Current Sheet Name:

Different current sheets can be defined within the same workbook. Thus, all free span assessments for a whole pipeline may be made within the same workbook. E.g., let us consider that there 5 different current zones for which environmental data is available. Each of them is specified in a separate current sheet and given an appropriate name. The applicable current zone worksheet name is specified in the "Current Sheet Name" field, in the "Main" sheet.

The environmental modelling is described in the section 4.6.

Wave Modelling:

A pull down menu allows the wave distribution to be defined as:

- **No Wave** — No waves.
- **Hs Weibull pdf** — Weibull distribution defined by 3 parameters.
- **Hs pdf - RPV** — 3-parameter Weibull distribution estimated from 1, 10 and 100 year return period values.
- **Hs histogram** — A series of discrete values/measurements and associated probabilities.
- **Scatter Hs - Tp** — A scatter diagram giving joint probability of discrete H_s, T_p values.

Note that it is not recommended to use the return period values "Hs pdf - RPV" option as the distribution is fitted to extreme values located in the tail of the distribution. Hence, the fitted distribution may not give a good representation of the actual distribution. Use of this option must be based on experience and engineering judgement.

The histogram and scatter options enables the use of discrete probability distributions.

Wave Sheet Name:

Different wave sheets can be defined within the same workbook. Thus, all free span assessments for a whole pipeline may be made within the same workbook. E.g., let us consider that there 5 different wave zone for which environmental data is available. Each of them is specified in a separate wave sheet and given an appropriate name. The applicable wave zone worksheet name is specified in the "Wave Sheet Name" field, in the "MAIN" sheet.

The environmental modelling is described in the section 5.

Directionality:

A basic assumption made in FatFree is that wave-induced flow and current flow are co-linear, i.e., they act in the same direction and with the same sector probability. If the sector probability of wave and current differs, then FatFree scales one of them to match the other. A pull down menu allows the choice between the reference sector probability:

- **Discrete - W dir.** Given as the discrete occurrence data for waves (scales current data).
- **Discrete - C dir.** Given as the discrete occurrence data for current (scales wave data).

The number of discrete directions for wave/current is specified in the "Wave Template"/ "Current Template" sheets respectively. Consider a case, when "Uc Weibull pdf" is used for current modelling in conjunction with the "Discrete-C dir" option in "Directionality". Let the number of discrete directions be 2 and this is to be specified in "Current Template" sheet. In this case, the data specified in the 2 rows following the identification header "Uc Weibull pdf" in "Current Template" are used in the calculations. Similarly, consider a case when "Hs Histogram" is used in wave modelling and "Discrete -W dir" option is used in "Directionality". Let the number of discrete directions be 3, then the data specified in the 3 columns adjacent to the identification header "Hs Histogram" of "Wave Template" are used in calculations.

If the "No Wave" option is selected from the Wave Model dropdown, the Directionality option is automatically set to "Discrete – C dir.".

4.7 Buttons

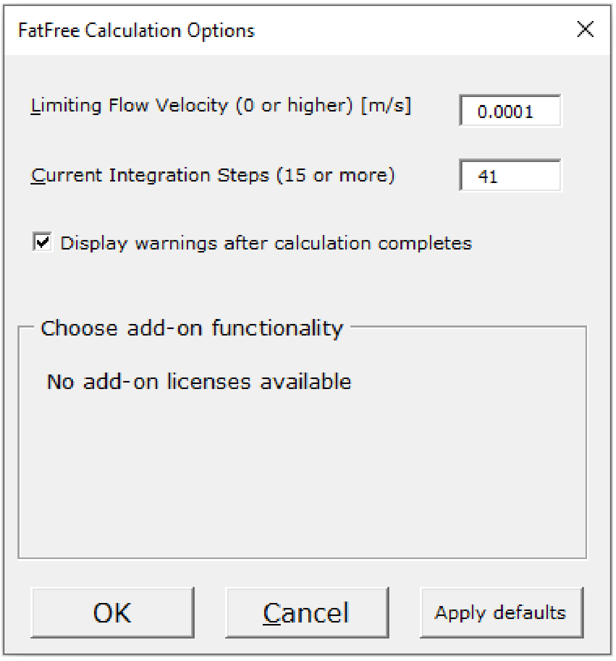
UPDATE	OPTIONS	PRINT
CALCULATE	HELP	SPANRUNS

The following buttons are available in "MAIN" sheet:

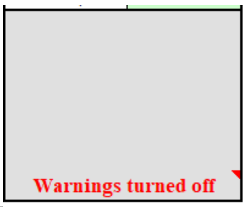
- **Update** Performs preliminary calculations to check the intermediate results.
- **Calculate** Performs the calculations defined in "MAIN" sheet.
- **Options** Allows modifying some FatFree settings. Additional information given bellow.
- **Help** Provides quick access to FatFree documentation. Additional information given bellow.
- **Print** Generates a print of the "MAIN" sheet.
- **SpanRuns** Generates a new "SpanRuns" sheet. Sheet is populated with data provided in "MAIN" sheet.

Options:

The user can chose to modify some of the calculation control parameters, however this is not recommended. Clicking on the "OPTIONS" button in the "MAIN" sheet will display the form shown below:



The following options are available:

	•	Limiting wave flow velocity: if the wave velocity is below this value then the wave effect is ignored completely (pure current applied, with this value added to the current velocity obtained from current input data).
	•	Current integration steps: specifies the number of divisions between minimum (either in-line onset or 0 m/s in case of low KC) and maximum (1.5·100-year RPV) current values for calcualtions. This presents a trade-off between precision and run time. Suggested value is 41. This control is not available for the wave (H_s) discretization.
	•	Display warnings after calculation completes: if unchecked, then warnings are not displayed. The user is notified of this through a message in the bottom right corner of the **Main** sheet (see below picture). Fatal errors, i.e. issues that prevent FatFree excecution, are still displayed. 
	•	Chose add-on functionality: This is a placeholder for controls enabling licensed add-on functionality. Currently, no such functionality is commercially available.

The recommended default values can be restored by the “Apply defaults” button. The option values can no longer be edited directly in the “PLOTS” sheet.

4.8 Shielding and Strake modelling

Special input	
Normal	
$R_{S,C}$	-
$R_{S,W}$	-
$R_{IL,strakes}$	-
$R_{CF,strakes}$	-
$R_{CF\text{-}ind\text{-}IL,strakes}$	-

These input are part of a beta implementation and are deactivated in FatFree 13.0.

4.9 Results

FatFree presents the results in two different ways:

<u>Numerical results:</u>

The fatigue damage is calculated and integrated over all sea-states and the current distribution. Fatigue life (including all the safety factors displayed in the "MAIN" sheet) is shown for the in-line response model, in-line force model and the cross-flow response model:

FATIGUE LIFE		
In-line (Response Model)	1.35E-01	yrs
Cross-Flow	3.35E+02	yrs
In-line (Force Model)	1.30E+02	yrs
In-line (Combined)	1.35E-01	yrs

The design fatigue life for the in-line mode is a combination of the response model and the force model fatigue lives. FatFree has an upper limit of a million years for fatigue life, i.e. maximum reported life is 1.00e+6 years.

Peak dynamic stresses are found from the extreme wave and current conditions and are displayed for cross-flow and in-line response:

DYNAMIC STRESS [MPa]					
Cross-flow			Inline		
	Peak	Von Mises		Peak	Von Mises
σ_x(1 year)	0.0	-	σ_x(1 year)	63.2	-
σ_x(10 year)	0.0	-	σ_x(10 year)	131.8	-
σ_x(100 year)	16.9	-	σ_x(100 year)	337.1	-

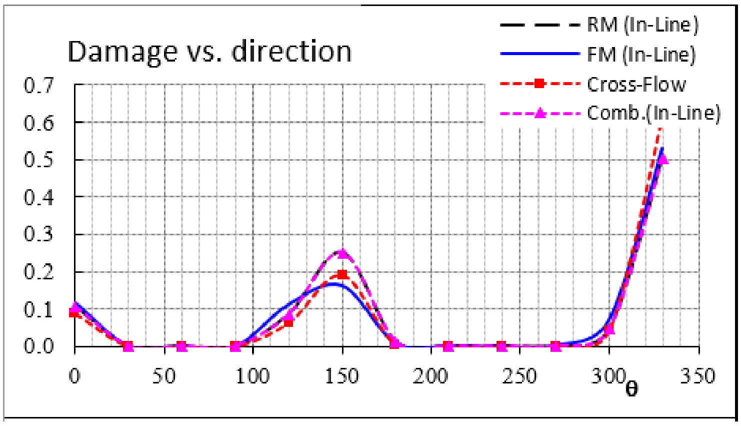
These values can be used to check against the ultimate stress limits for the pipeline. Note that the stresses do not contain any safety factors or stress concentration factors, i.e. all calculations that lead to those values assume all safey factors and stress concentration factors (SCF) equal to 1.

Dynamic stresses are calculated at the weld cap radius ($D_s/2$). A linear relation between stress and location can be considered if stress at another point in cross-section is required.

Graphical results:

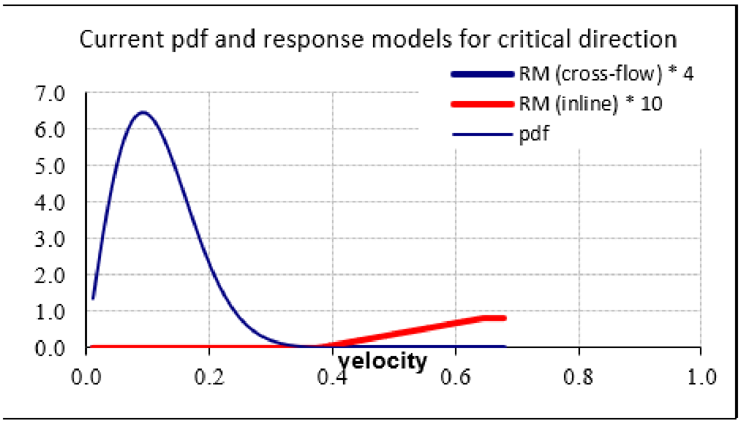
Two plot windows are included in the main sheet:

- Damage distribution vs. direction



The “Damage distribution vs. direction” chart shows the normalized contribution each direction relative to geographic North has to the individual fatigue components, i.e., in-line response model, in-line force model, combined in-line fatigue life and cross-flow fatigue life.

- Current pdf and response models for critical direction



The pdf graph indicates the likelihood of cross-flow or in-line motion occurring from the critical direction current flow alone. The effect of waves can be evaluated by adding the wave induced flow velocities to the long-term current probability density function in the figure. Safety factors are included.

The response model amplitude graphs for in-line and cross-flow VIV are adjusted for better visualization. A scaling factor of 10 is included for the in-line, while a scaling factor of 4 times is applied for cross-flow.

5 ENVIRONMENTAL DATA

5.1 General

The environmental information is defined in the form of long term probability distributions for the current and the waves. The information is given as directional data with associated sector probability.

Note that the sum of sector probability must add up to 1.00 (100%). A tolerance of 1% is applied, and FatFree will give you a warning if this limit is exceeded.

The is taken from the wave and current sheets specified by the user in the fields "Current Sheet Name" and "Wave Sheet Name" in the "MAIN" sheet. This allows several wave and current sheets to be defined in the same Excel book, however, only one pair of wave and current sheets are active.

Also note that only one set of current and wave is specified in each calculation. If different sets are to be used, the user should either save/print the "MAIN" sheet results in between each selection/calculation.

In order to generate a new environment, it is recommended to copy an existing environmental data sheet (e.g., "Wave Template" or "Current-Template") and amend the values accordingly.

NB: It is important that pipeline direction, wave direction and current direction follows the same convention. If this is the case, the analyses are insensitive to actual definition of pipeline direction. It is recommended to use the "relative to geographic North" convention as this the most widespread, but other conventions may be applied as long as they are used consistently.

FatFree assumes that the pipeline cross-section is symmetric and only accounts for linear waves. Therefore coming and going conventions are not enforced.

A basic assumption made in FatFree is that wave-induced flow and current are co-linear, i.e., they act in the same direction. This means that the directional information in wave and current data must match in number, value and order given. It is recommended that environmental data is given only in a 180º total sector relative to the free span, so the cross-section symmetry can be correctly accouted for.

Another consequence of the co-linear assumption is that directional sector probability is equal for both current and wave. So, if the sector probability of wave and current differs, than FatFree scales one of them to match the other based on the selection made in the MAIN sheet.

Even though the omni direction option has been removed in FatFree v. 13.0, FatFree retains compatibility with the legacy Wave and Current input Template sheets. The omni input in these sheets will however be ignored. The previous omni-directional functionality may be replicated by repeating the same probability distribution for each sector and having the sector probability equal as well, i.e. sector probability is 1 divided by the number of sectors considered.

5.2 Current data

5.2.1 Overview

Common Data

Turbulence intensity; I_c	0.04
Measurement ref. Height; $z_{r\,[m]}$	3.0
On-bottom roughness, $z_{0\,[m]}$	4.0E-06
Number of discrete directions	8
Number of discrete current measurements (max 20)	16
Time between independent current events [hour]	1
Reduction factor R_c	0.88

Return period values for ULS design Check		
1	10	100
(m/s)	(m/s)	(m/s)
0.501	0.558	0.604

Weibull distribution input

Uc Weibull pdf	Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)		
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)
0	2.91E-01	2.1590	0.1428	0.0000	0.13	0.49	0.36	0.41	0.45
30	2.01E-01	1.8190	0.1196	0.0000	0.11	0.57	0.35	0.41	0.46
60	1.14E-01	1.3500	0.0748	0.0103	0.08	0.65	0.31	0.39	0.46
90	9.27E-02	1.3000	0.0675	0.0079	0.07	0.69	0.28	0.36	0.43
120	1.16E-01	1.5000	0.0894	0.0000	0.08	0.68	0.31	0.38	0.44
150	1.85E-01	1.3970	0.0858	0.0123	0.09	0.63	0.34	0.42	0.50

RPV input for fitted Weibull distribution

Uc pdf - RPV	Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)			Calculated 100 year RPV
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)	
0	2.91E-01	1.418	0.080	0.163	0.24	0.22	0.47	0.54	0.61	
30	2.01E-01	3.125	0.320	-0.089	0.20	0.51	0.49	0.55	0.60	
60	1.14E-01	1.389	0.135	0.172	0.29	0.30	0.65	0.78	0.90	
90	9.27E-02	4.082	0.745	-0.657	0.02	9.48	0.48	0.58	0.66	
120	1.16E-01	1.000	0.026	0.228	0.25	0.10	0.38	0.44	0.50	
150	1.85E-01	1.606	0.134	0.000	0.12	0.64	0.42	0.51	0.63	

Current Histogram input

Uc Histogram	Identification header: do not change name or location to subsequent data

Current velocity	Direction relative to geographic North											
	0	22.5	45	67.5	90	112.5	135	157.5				
0.025	2.73E-02	2.80E-02	2.52E-02	2.02E-02	1.36E-02	2.88E-02	4.16E-02	3.01E-02				
0.075	2.08E-02	2.84E-02	4.33E-02	4.44E-02	3.33E-02	2.61E-02	2.07E-02	1.36E-02				
0.125	1.39E-02	2.66E-02	5.34E-02	6.39E-02	3.81E-02	1.51E-02	1.07E-02	9.84E-03				
0.175	8.74E-03	1.64E-02	4.08E-02	5.10E-02	3.01E-02	7.76E-03	3.61E-03	4.58E-03				
0.225	2.91E-03	7.63E-03	2.27E-02	3.20E-02	2.37E-02	4.99E-03	9.71E-04	9.71E-04				
0.275	1.11E-03	2.50E-03	1.29E-02	1.39E-02	7.90E-03	9.71E-04	9.71E-04	9.71E-04				
0.325	2.77E-04	1.11E-03	3.47E-03	7.21E-03	2.91E-03	0.00E+00	4.16E-04	9.71E-04				
0.375	1.39E-04	0.00E+00	4.16E-04	1.94E-03	2.08E-03	0.00E+00	0.00E+00	0.00E+00				
0.425	0.00E+00	0.00E+00	4.16E-04	6.93E-04	1.39E-04	0.00E+00	0.00E+00	0.00E+00				
0.475	1.39E-04	0.00E+00	2.77E-04	4.16E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
probability	0.075	0.111	0.203	0.236	0.152	0.084	0.079	0.061				
mean value	0.089	0.107	0.138	0.150	0.146	0.087	0.066	0.075				
1 year	0.35	0.35	0.45	0.5	0.4	0.3	0.35	0.35				
10 year	0.5	0.35	0.5	0.5	0.45	0.3	0.35	0.35				
100 year	0.5	0.35	0.5	0.5	0.45	0.3	0.35	0.35				

5.2.2 Common Data

Some general current data have to be specified at the top of the current sheet:

Turbulence intensity; I_c	0.04
Measurement ref. Height; $z_{r\,[m]}$	3.0
On-bottom roughness, $z_{0\,[m]}$	4.0E-06
Number of discrete directions	8
Number of discrete current measurements (max 20)	16
Time between independent current events [hour]	1
Reduction factor R_c	0.88

Return period values for ULS design Check		
1	10	100
(m/s)	(m/s)	(m/s)
0.501	0.558	0.604

The values to be specified are:

Turbulence intensity, I_c	Factor as specified in DNVGL-RP-F105.
Measurement reference height, z_r [m]	Height above seabed where the current measurements were made.
On-bottom roughness, z_0 [m]	Factor depending on the type of seabed, see DNVGL-RP-F105.
Number of discrete directions	Number of directions in case current distributions for different directions is specified.
Number of discrete current measurements	Number of measurements in case a discrete current measurement is used, i.e. Uc Histogram. It is recommended to keep at maximum 20 different values.
Time between independent current events [hour]	This correlates to the number of events considered for the extreme value calculations. All calculations related to extreme events are based on 1 independent event occurring in 1, 10 or 100 years.

5.2.3 Uc Weibull pdf

Uc Weibull pdf ← Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)		
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)
0	2.91E-01	2.1590	0.1428	0.0000	0.13	0.49	0.36	0.41	0.45
30	2.01E-01	1.8190	0.1196	0.0000	0.11	0.57	0.35	0.41	0.46
60	1.14E-01	1.3500	0.0748	0.0103	0.08	0.65	0.31	0.39	0.46
90	9.27E-02	1.3000	0.0675	0.0079	0.07	0.69	0.28	0.36	0.43
120	1.16E-01	1.5000	0.0894	0.0000	0.08	0.68	0.31	0.38	0.44
150	1.85E-01	1.3970	0.0858	0.0123	0.09	0.63	0.34	0.42	0.50

Here, the three Weibull parameters are given together with the sector probability of occurrence for different directions. Dimensionful parameters, α and γ, are defined in [m/s].

Some key statistical data and the extreme values are presented in order to check the specified data.

5.2.4 Uc pdf - RPV

Uc pdf - RPV ← Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)			Calculated 100 year RPV
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)	
0	2.91E-01	1.418	0.080	0.163	0.24	0.22	0.47	0.54	0.61	
30	2.01E-01	3.125	0.320	-0.089	0.20	0.51	0.49	0.55	0.60	
60	1.14E-01	1.389	0.135	0.172	0.29	0.30	0.65	0.78	0.90	
90	9.27E-02	4.082	0.745	-0.657	0.02	9.48	0.48	0.58	0.66	
120	1.16E-01	1.000	0.026	0.228	0.25	0.10	0.38	0.44	0.50	
150	1.85E-01	1.606	0.134	0.000	0.12	0.64	0.42	0.51	0.63	

Here the three extreme values for 1, 10 and 100 year return periods are given in [m/s] together with the sector probability of occurrence for different directions.

In order to check the specified data, mean value, coefficient of variation (CoV) and the fitted Weibull parameters are listed. In some cases a fit using all three extreme values is not possible. Then the 1 and 10 year values are used, and the estimated 100 year value is listed (in the right column) to check the deviation from the specified one. Normally all three extreme values are used, and no information given in the right column.

Note that care should be observed when using this way of specifying the long-term current distribution. A fitting procedure based on tail distribution values is considered, which could lead to a poor representation of the actual current distributions and erroneous fatigue results.

5.2.5 Uc histogram

Uc Histogram ← Identification header: do not change name or location to subsequent data

Current velocity	Direction relative to geographic North											
	0	22.5	45	67.5	90	112.5	135	157.5				
0.025	2.73E-02	2.80E-02	2.52E-02	2.02E-02	1.36E-02	2.88E-02	4.16E-02	3.01E-02				
0.075	2.08E-02	2.84E-02	4.33E-02	4.44E-02	3.33E-02	2.61E-02	2.07E-02	1.36E-02				
0.125	1.39E-02	2.66E-02	5.34E-02	6.39E-02	3.81E-02	1.51E-02	1.07E-02	9.84E-03				
0.175	8.74E-03	1.64E-02	4.08E-02	5.10E-02	3.01E-02	7.76E-03	3.61E-03	4.58E-03				
0.225	2.91E-03	7.63E-03	2.27E-02	3.20E-02	2.37E-02	4.99E-03	9.71E-04	9.71E-04				
0.275	1.11E-03	2.50E-03	1.29E-02	1.39E-02	7.90E-03	9.71E-04	9.71E-04	9.71E-04				
0.325	2.77E-04	1.11E-03	3.47E-03	7.21E-03	2.91E-03	0.00E+00	4.16E-04	9.71E-04				
0.375	1.39E-04	0.00E+00	4.16E-04	1.94E-03	2.08E-03	0.00E+00	0.00E+00	0.00E+00				
0.425	0.00E+00	0.00E+00	4.16E-04	6.93E-04	1.39E-04	0.00E+00	0.00E+00	0.00E+00				
0.475	1.39E-04	0.00E+00	2.77E-04	4.16E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
probability	0.075	0.111	0.203	0.236	0.152	0.084	0.079	0.061				
mean value	0.089	0.107	0.138	0.150	0.146	0.087	0.066	0.075				
1 year	0.35	0.35	0.45	0.5	0.4	0.3	0.35	0.35				
10 year	0.5	0.35	0.5	0.5	0.45	0.3	0.35	0.35				
100 year	0.5	0.35	0.5	0.5	0.45	0.3	0.35	0.35				

Here the probability of occurrence for different directions and current velocities in are given. The discrete measurements are sorted into sample bins. Bin reference values in [m/s] are given in leftmost column, with one row per value from lowest to highest, and those are used in FatFree calculations. Appropriate histograms shall include extreme events.

The sectors are given in the uppermost row and the sector probability is the sum of a given column. The probability of occurrence over all velocities and directions shall sum up to 1.00 (100 %). In order to check the specified data, some key statistical data and the extreme values are presented.

Histograms shall be used if current distribution does not follow a Weibull distribution, but may be used for Weibull distributions as well.

Due to the process to obtain the extreme event values, inputs should be zero or greater than 1 event in 100 years or a numerical error may occur.

It is recommended that at least two U_c values are given as input.

5.3 Wave data

5.3.1 Overview

Common Data

Peakedness parameter i Wave Spectrum γ,	0.00
Wave Speading Constant	8.0
Number of discrete directions	8
Number of discrete H_s values (<20)	15
Number of discrete T_p values (<20)	17
Time between independent sea-states [hour]	3
Reduction factor R_D	0.95

Return period values for ULS design Check			
	1	10	100
H_S	7.16	9.44	11.60
T_p	13.54	14.71	15.64
U_w	0.24	0.40	0.57

Peak Period Model

$T_p = c\,H_s^n$	
factor, c (default = 7.5)	7.5
exponent, n (default=0.3)	0.3

Weibull distribution input

Hs Weibull pdf — Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)		
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)
0	2.63E-01	1.1720	1.4950	0.8500	2.27	0.53	8.37	10.55	12.64
30	1.04E-01	1.0830	0.7380	0.8100	1.53	0.43	4.50	5.86	7.18
60	9.46E-02	1.0760	0.7790	0.8400	1.60	0.44	4.72	6.17	7.60
90	1.48E-01	1.1630	1.0610	0.6500	1.66	0.52	5.65	7.24	8.77
120	1.91E-01	1.6110	2.8980	0.2900	2.89	0.57	9.39	11.33	13.08
150	2.00E-01	1.7710	2.8620	0.9100	3.46	0.43	9.05	10.60	11.98

RPV input for fitted Weibull distribution

Hs pdf - RPV — Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)			Calculated 100 year RPV
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)	
0	2.63E-01	1.170	1.477	1.272	2.67	0.45	8.06	10.25	12.35	
30	1.04E-01	1.099	0.777	0.135	0.89	0.77	3.51	4.89	6.24	
60	9.46E-02	1.105	0.854	-0.338	0.48	1.54	3.28	4.78	6.23	
90	1.48E-01	1.220	1.248	-0.991	0.18	5.42	3.96	5.65	7.24	
120	1.91E-01	1.639	3.037	-0.091	2.63	0.65	8.62	10.65	12.46	
150	2.00E-01	1.852	3.210	0.083	2.93	0.54	8.28	9.93	11.38	

H_s Histogram input

Hs Histogram	← Identification header: do not change name or location to subsequent data

H_s (m)	Direction relative to Geographic North					
	0	30	60	90	120	150
0.7	5.50E-04	4.13E-04	1.38E-04	1.83E-04	4.58E-04	4.58E-04
1.4	5.12E-02	3.84E-02	1.28E-02	1.71E-02	4.26E-02	4.26E-02
2.1	6.84E-02	5.13E-02	1.71E-02	2.28E-02	5.70E-02	5.70E-02
2.8	4.89E-02	3.66E-02	1.22E-02	1.63E-02	4.07E-02	4.07E-02
3.5	3.21E-02	2.41E-02	8.02E-03	1.07E-02	2.67E-02	2.67E-02
4.2	2.04E-02	1.53E-02	5.09E-03	6.79E-03	1.70E-02	1.70E-02
4.9	1.27E-02	9.53E-03	3.18E-03	4.23E-03	1.06E-02	1.06E-02
5.6	7.08E-03	5.31E-03	1.77E-03	2.36E-03	5.90E-03	5.90E-03
6.3	3.80E-03	2.85E-03	9.50E-04	1.27E-03	3.17E-03	3.17E-03
7	1.93E-03	1.44E-03	4.81E-04	6.42E-04	1.60E-03	1.60E-03
7.7	1.20E-03	9.00E-04	3.00E-04	4.00E-04	1.00E-03	1.00E-03
8.4	9.50E-04	7.13E-04	2.38E-04	3.17E-04	7.92E-04	7.92E-04
9.1	4.75E-04	3.56E-04	1.19E-04	1.58E-04	3.96E-04	3.96E-04
9.8	2.25E-04	1.69E-04	5.63E-05	7.50E-05	1.88E-04	1.88E-04
10.5	1.50E-04	1.13E-04	3.75E-05	5.00E-05	1.25E-04	1.25E-04
probability	0.250	0.187	0.062	0.083	0.208	0.208
mean value	2.860	2.860	2.860	2.860	2.860	2.860
1 year	8.75	8.05	6.65	7.35	8.75	8.75
10 year	10.85	10.15	9.45	9.45	10.15	10.15
100 year	10.85	10.85	10.85	10.85	10.85	10.85

H_s-T_p Scatter Diagram input

Scatter Hs-Tp	← Identification header: do not change name or location to subsequent data

direction	0	E[H_s]	CoV	σ	δ	κ	Shape (β)	Scale (α)	Location (γ)	H_s (1 year)	H_s (10 year)	H_s (100 year)
sector probability	0.27	1.866	0.596	1.112	1.557	6.027	1.182	1.386	0.556	10.79	13.79	16.78

H_s \ T_p	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2	11.9	12.6	13.3	14.0	14.8
0.5	0	0.0035	0.0094	0.0035	0.0013	0.0001	0	0	0	0	0	0	0	0	0	0	0
1	0	0.0022	0.0198	0.0234	0.0215	0.0066	0.0017	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0.0001	0.0044	0.0216	0.017	0.0116	0.0044	0.0016	0.0004	0	0	0	0	0	0	0
2	0	0	0.0001	0	0.0011	0.0089	0.0141	0.0089	0.004	0.0007	0.0001	0	0	0	0	0	0
2.5	0	0	0	0	0.0001	0.0014	0.0094	0.0104	0.0052	0.0017	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0.0016	0.0064	0.0057	0.0021	0.0002	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0.0012	0.0068	0.0022	0.0001	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0.0024	0.004	0.0008	0.0004	0.0001	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0.0001	0.0017	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001	0
5	0	0	0	0	0	0	0	0	0	0.0001	0.002	0.0003	0.0001	0.0001	0.0002	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0.0013	0.001	0.0002	0	0.0001	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0.0007	0.0002	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0.0003	0.0002	0.0001	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0003	0.0002	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5.3.2 Common Data

Some general wave data have to be specified at the top of the current sheet:

Peakedness parameter i Wave Spectrum γ;	0.00
Wave Speading Constant	8.0
Number of discrete directions	8
Number of discrete H_s values (<20)	15
Number of discrete T_p values (<20)	17
Time between independent sea-states [hour]	3
Reduction factor R_D	0.95

Return period values for ULS design Check			
	1	10	100
H_S	7.16	9.44	11.60
T_p	13.54	14.71	15.64
U_w	0.24	0.40	0.57

Peak Period Model →

$Tp=c\ H_s^n$	
factor, c (default = 7.5)	7.5
exponent, n (default=0.3)	0.3

The values to be specified are:

Peakedness parameter (peak-enhancement factor) in wave spectrum	Factor as specified in DNVGL-RP-F105. FatFree only supports Pierson-Moskowitz like spectra and only JOWNSWAP if peakedness parameter is dependent

	on H_s and/or T_p.
Wave Spreading Constant	Factor as specified in DNVGL-RP-F105.
Number of discrete directions	Number of directions in case wave distribution for different directions are specified.
Number of discrete H_s values	Number of discrete H_s values used in case a histogram or scatter diagram is used to specify the long-term distribution. It is recommended to keep at maximum 20 different values.
Number of discrete T_p values	Number of discrete T_p values used in case a scatter diagram is used to specify the long-term distribution. It is recommended to keep at maximum 20 different values.
Time between independent sea-states [hour]	This correlates to the number of events considered for the extreme value calculations. All calculations related to extreme events are based on 1 independent event occurring in 1, 10 or 100 years.

Unless H_s-T_p scatter diagrams option is used, user must specify the parameters for the peak period estimation. The relation between H_s and T_p is fixed in FatFree in the form:

$$T_p = c \cdot {H_s}^n$$

5.3.3 Hs Weibull pdf

Hs Weibull pdf	←	Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)		
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)
0	2.63E-01	1.1720	1.4950	0.8500	2.27	0.53	8.37	10.55	12.64
30	1.04E-01	1.0830	0.7380	0.8100	1.53	0.43	4.50	5.86	7.18
60	9.46E-02	1.0760	0.7790	0.8400	1.60	0.44	4.72	6.17	7.60
90	1.48E-01	1.1630	1.0610	0.6500	1.66	0.52	5.65	7.24	8.77
120	1.91E-01	1.6110	2.8980	0.2900	2.89	0.57	9.39	11.33	13.08
150	2.00E-01	1.7710	2.8620	0.9100	3.46	0.43	9.05	10.60	11.98

Here the three Weibull parameters are given together with the sector probability of occurrence for different directions. Dimensional parameters, α and γ, are defined in [m].

In order to check the specified data, some key statistical data and the extreme values are presented.

5.3.4 Hs pdf - RPV

Hs pdf - RPV	←	Identification header: do not change name or location to subsequent data

Direction relative to geographic North	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β)			Statistics		Return period (years)			Calculated 100 year RPV
		Shape (β)	Scale (α)	Location (γ)	Mean value	CoV	1 (m)	10 (m)	100 (m)	
0	2.63E-01	1.170	1.477	1.272	2.67	0.45	8.06	10.25	12.35	
30	1.04E-01	1.099	0.777	0.135	0.89	0.77	3.51	4.89	6.24	
60	9.46E-02	1.105	0.854	-0.338	0.48	1.54	3.28	4.78	6.23	
90	1.48E-01	1.220	1.248	-0.991	0.18	5.42	3.96	5.65	7.24	
120	1.91E-01	1.639	3.037	-0.091	2.63	0.65	8.62	10.65	12.46	
150	2.00E-01	1.852	3.210	0.083	2.93	0.54	8.28	9.93	11.38	

Here the three extreme values for 1, 10 and 100 year return periods are given together with the sector probability of occurrence for different directions.

In order to check the specified data, mean value, coefficient of variation (CoV) and the fitted Weibull parameters are listed. In some cases a fit using all three extreme values is not possible. Then the 1 and 10 year values are used, and the estimated 100 year value is listed (in the right column) to check the deviation from the specified one. Normally all three extreme values are used, and a "-" is given in the right column.

Note that care should be observed when using this way of specifying the long-term current distribution. A fitting procedure based on tail distribution values based on tail distribution values is considered, which could lead to a poor representation of the actual wave distributions and erroneous fatigue results.

5.3.5 Hs Histogram

Hs Histogram	←	Identification header: do not change name or location to subsequent data

	Direction relative to Geographic North					
H_s (m)	0	30	60	90	120	150
0.7	5.50E-04	4.13E-04	1.38E-04	1.83E-04	4.58E-04	4.58E-04
1.4	5.12E-02	3.84E-02	1.28E-02	1.71E-02	4.26E-02	4.26E-02
2.1	6.84E-02	5.13E-02	1.71E-02	2.28E-02	5.70E-02	5.70E-02
2.8	4.89E-02	3.66E-02	1.22E-02	1.63E-02	4.07E-02	4.07E-02
3.5	3.21E-02	2.41E-02	8.02E-03	1.07E-02	2.67E-02	2.67E-02
4.2	2.04E-02	1.53E-02	5.09E-03	6.79E-03	1.70E-02	1.70E-02
4.9	1.27E-02	9.53E-03	3.18E-03	4.23E-03	1.06E-02	1.06E-02
5.6	7.08E-03	5.31E-03	1.77E-03	2.36E-03	5.90E-03	5.90E-03
6.3	3.80E-03	2.85E-03	9.50E-04	1.27E-03	3.17E-03	3.17E-03
7	1.93E-03	1.44E-03	4.81E-04	6.42E-04	1.60E-03	1.60E-03
7.7	1.20E-03	9.00E-04	3.00E-04	4.00E-04	1.00E-03	1.00E-03
8.4	9.50E-04	7.13E-04	2.38E-04	3.17E-04	7.92E-04	7.92E-04
9.1	4.75E-04	3.56E-04	1.19E-04	1.58E-04	3.96E-04	3.96E-04
9.8	2.25E-04	1.69E-04	5.63E-05	7.50E-05	1.88E-04	1.88E-04
10.5	1.50E-04	1.13E-04	3.75E-05	5.00E-05	1.25E-04	1.25E-04
probability	0.250	0.187	0.062	0.083	0.208	0.208
mean value	2.860	2.860	2.860	2.860	2.860	2.860
1 year	8.75	8.05	6.65	7.35	8.75	8.75
10 year	10.85	10.15	9.45	9.45	10.15	10.15
100 year	10.85	10.85	10.85	10.85	10.85	10.85

Here the probability of occurrence for different directions and H_s values, in [m] are given. The probability of occurrence over all H_s and directions shall sum up to 1.00 (100%). The discrete measurements are sorted into sample bins. Bin reference value are given in leftmost column with one row per value from lowest to highest, and those are used in FatFree calculations. Appropriate histograms shall include extreme events.

The sectors are given in the uppermost row and the sector probability is the sum of a given column. In order to check the specified data, some key statistical data and the extreme values are presented.

Histograms or scatter diagrams shall be used if wave height distribution does not follow a Weibull distribution, but histograms may be used for Weibull distributions as well.

Due to the process to obtain the extreme event values, inputs should be zero or greater than 1 event in 100 years or a numerical error may occur.

It is recommended that at least two H_s values are given as input.

5.3.6 Hs-Tp scatter diagram

Scatter Hs-Tp	←	Identification header: do not change name or location to subsequent data

direction	0	E[H_s]	CoV	σ	δ	κ	Shape (β)	Scale (α)	Location (γ)	H_s (1 year)	H_s (10 year)	H_s (100 year)
sector probability	0.27	1.866	0.596	1.112	1.557	6.027	1.182	1.386	0.556	10.79	13.79	16.78

$H_S \backslash T_p$	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.8	10.5	11.2	11.9	12.6	13.3	14.0	14.8
0.5	0	0.0035	0.0094	0.0035	0.0013	0.0001	0	0	0	0	0	0	0	0	0	0	0
1	0	0.0022	0.0198	0.0234	0.0215	0.0066	0.0017	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0.0001	0.0044	0.0216	0.017	0.0116	0.0044	0.0016	0.0004	0	0	0	0	0	0	0
2	0	0	0.0001	0	0.0011	0.0089	0.0141	0.0089	0.004	0.0007	0.0001	0	0	0	0	0	0
2.5	0	0	0	0	0.0001	0.0014	0.0094	0.0104	0.0052	0.0017	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0.0016	0.0064	0.0057	0.0021	0.0002	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0.0012	0.0068	0.0022	0.0001	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0.0024	0.004	0.0008	0.0004	0.0001	0	0	0	0
4.5	0	0	0	0	0	0	0	0	0.0001	0.0017	0.0009	0.0001	0.0001	0.0001	0.0001	0.0001	0
5	0	0	0	0	0	0	0	0	0	0.0001	0.002	0.0003	0.0001	0.0001	0.0002	0	0
5.5	0	0	0	0	0	0	0	0	0	0	0.0013	0.001	0.0002	0	0.0001	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0.0007	0.0002	0	0	0	0
6.5	0	0	0	0	0	0	0	0	0	0	0	0.0003	0.0002	0.0001	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0.0001	0.0003	0.0002	0	0	0
7.5	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0001	0	0
8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Here the probability of occurrence for different H_s - T_p values are given for each direction separately (one table like the one above for each direction considered). Wave height reference values in [m] are given in leftmost column with one row per value from lowest to highest, and those are used in FatFree calculations. The wave reference peak periods in [s] are given in the uppermost row, with one collumn per value in ascending order from left to right, and those are used in FatFree calculations. Each direction table shall contain exactly the same reference values and in the same order.

The sector probability is the sum of probabilities in a direction table, i.e. it is the sum of the total probability of occurrence for waves in that direction. In order to check the specified data, some key statistical data and the extreme values are presented. The sum of all sector probabilities shall be 1.00 (100%).

Histograms or scatter diagrams shall be used if wave height distribution does not follow a Weibull distribution, but scatter diagrams may be used for Weibull distributions as well.

Scatter diagrams shall be used if H_s and T_p relationship differs from the fixed one, see Section 5.3.2, but may be used if they confirm to that relationship as well.

Due to the process to obtain the extreme event values, inputs should be zero or greater than 1 event in 100 years or a numerical error may occur.

6 MULTI-MODE ANALYSIS

6.1 Overview

The higher order modal data can be either computed based on the beam theory estimates or can be provided as user defined input, for example based on FE-analyses. Options are available to specify the mode shapes or associated stress amplitude and eigen-frequencies for each mode. FatFree computes the fatigue damage along the entire span length and outputs the lowest fatigue life location in "MAIN" sheet if multilocation calculate is performed. Location-wise results are available in "MultiMode Output" sheet.

6.2 MultiMode worksheet preparation

The worksheet is used in case "User Defined" option is selected under Response Data. In this case, the user is required to provide additional input. Otherwise FatFree calculates automatically the input and display the results in the Results sheet, so previous input is not overwritten.

The following input is required to set-up the analysis:

Number of in-line	Defines the total number of in-line modes to be considered in analyses.
Number of cross-flow	Defines the total number of in-line modes to be considered in analyses
Number of evaluation points	Defines the number of data entries considered. The multi-mode analyses can be either single location (1 evaluation point) or multi-location (minimum of 5 evaluation points).
Stress Amplitude calculation options	Defines the input format of stress. Two options are available:

- **Direct Stress Amplitude input** — Unit diameter stress amplitude for each evaluation point is required. FatFree will consider all points provided. Stress amplitude provided should be at mid-wall and in [MPa]. This is the only option available for single location.
- **Mode shape input only** — Mode shape is included as input. Based on mode-shape curvature FatFree will calculate the stress amplitude for each evaluation point, disregarding the first and last two points; i.e. total number of points analysed is ("number of evaluation points" -4). The mode shape shall be normalized to maximum amplitude, i.e. the input values shall be between -1 and 1.

NB: Multimode force model formulation is only supported for the mode shape input option. In all other cases the force model equivalent stress is based on the first in-line mode modal stress multiplied by the mode shape factor for the first mode, λ_1, which is given in the "MAIN" sheet.

After setting the required input, the "Format Sheet" button should be pressed.

FatFree will clean the "MultiMode" sheet and create the appropriate formatting for modal information input.

After giving the required (stress or mode shape) input, the "Update" button may be pressed.

FatFree will update all relevat information based on the given input data.

6.3 Single location analysis

Multi-mode single location analysis is defined when the number of evaluation points is one.

There are two input possibilities, whether the "Response Data" option is chosen as "User Defined" or not:

"Response Data" option in "MAIN" sheet	"Response Data" fields in "Multi-mode" worksheet	Comments
• "RP-F105 Span" • "pinned-pinned" • "pinned-fixed" • "fixed-fixed"	• Based on simplified beam theory. The unit stress amplitude will correspond to the maximum unit stress amplitude for each mode. • Fields are updated automatically.	• Conservative approach. • Maximum stresses occur at different locations along the length of span for each mode. However, they are combined assuming that they are occurring at the same location.
• "User Defined"	• Allows input of response quantities obtained by more detailed methods, such as FE. • The unit stress amplitude for each mode can be given at a specific location along the free span. • All fields need to be input manually.	• Less conservative approach. • If unit stress amplitude is considered for a given location there is no direct information to specify where.

When the "Response Data" in the "MAIN" sheet is selected not to be "User Defined" (e.g., "RP-F105 Span") then the modal response quantities are automatically calculated by FatFree and presented in the "MultiMode Output" sheet instead. Four in-line modes and three cross-flow modes will be considered. This default setting cannot be changed.

When the "Response Data" in the "Main" sheet is selected to be "User Defined", then the number of in-line and cross-flow can be defined. For each mode frequency in [Hz] and unit stress amplitude at mid-wall in [MPa] shall be given.

A sample of "MultiMode" sheet for single location is presented below:

Number of in-line	4	Number of evaluation points	1	Format Sheet	
Number of cross-flow	3	Number of span areas	1		
Stress Amplitude calculation options		Static stress option for Von Mises stress calculation		☐ Sensitivity on damage from individual modes	
Direct Stress Amplitude input		Disregard static stress			

Location [m]	Span and modal estimates													
	IN-LINE								CROSS-FLOW					
	IL Mode 1		IL Mode 2		IL Mode 3		IL Mode 4		CF Mode 1		CF Mode 2		CF Mode 3	
	☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate	
	f	0.7731542	f	2.0875165	f	4.17503291	f	6.262549	f	0.831297	f	2.174225	f	4.34845
	A_IL	111.28469	A_IL	344.98253	A_IL	689.965063	A_IL	1034.948	A_CF	121.0221	A_CF	375.1684	A_CF	750.3369

Please note that the mode shape weightning factor for the first in-line mode for the force model, λ_1, shall be given in the "MAIN" sheet.

6.4 Multiple location analysis

Multiple location analysis is defined when the number of evaluation points is five or greater. Multiple span areas are allowed in analysis and FatFree will select the appropriate modes based on the active and contributing modes as per DNVGL-RP-F105 definitions. Two different input sets are available:

Mode shape input only:

Number of in-line modes	4	Format sheet
Number of cross-flow modes	3	
Number of locations along span	21	UPDATE
Stress amplitude calculation option:	Mode shape input only	

Location [m]	Modal input													
	IN-LINE								CROSS-FLOW					
	IL Mode 1		IL Mode 2		IL Mode 3		IL Mode 4		CF Mode 1		CF Mode 2		CF Mode 3	
	☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate		☐ Deactivate	
	f	2	f	4	f	6	f	10	f	3	f	6	f	9
	A_IL	84.42196826	A_IL	337.6539239	A_IL	759.3946964	A_IL	2102.117923	A_CF	84.42196826	A_CF	337.6539239	A_CF	759.3946964
	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude
0	0	0.001	0	0.001	0	0.001	0	0.001	0	0.001	0	0.001	0	0.001
0.92565	0.156434465	0.001	0.309016994	0.001	0.4539905	0.001	0.707106781	0.001	0.156434465	0.001	0.309016994	0.001	0.4539905	0.001
1.8513	0.309016994	26.08782289	0.587785252	198.4679969	0.809016994	614.3632148	1	2102.117923	0.309016994	26.08782289	0.587785252	198.4679969	0.809016994	614.3632148
2.77695	0.4539905	38.32677156	0.809016994	273.1677627	0.987688341	750.0452875	0.707106781	1486.421839	0.4539905	38.32677156	0.809016994	273.1677627	0.987688341	750.0452875
3.7026	0.587785252	49.62198792	0.951056516	321.1279646	0.951056516	722.2272745	0	5.06486E-13	0.587785252	49.62198792	0.951056516	321.1279646	0.951056516	722.2272745
4.62825	0.707106781	59.69534624	1	337.6539239	0.707106781	536.9731394	-0.707106781	1486.421839	0.707106781	59.69534624	1	337.6539239	0.707106781	536.9731394
5.5539	0.809016994	68.29880702	0.951056516	321.1279646	0.309016994	234.6658666	-1	2102.117923	0.809016994	68.29880702	0.951056516	321.1279646	0.309016994	234.6658666
6.47955	0.891006524	75.22052451	0.809016994	273.1677627	-0.156434465	118.7955031	-0.707106781	1486.421839	0.891006524	75.22052451	0.809016994	273.1677627	-0.156434465	118.7955031
7.4052	0.951056516	80.29006304	0.587785252	198.4679969	-0.587785252	446.3610032	0	1.01297E-12	0.951056516	80.29006304	0.587785252	198.4679969	-0.587785252	446.3610032
8.33085	0.987688341	83.38259374	0.309016994	104.3408007	-0.891006524	676.6256289	0.707106781	1486.421839	0.987688341	83.38259374	0.309016994	104.3408007	-0.891006524	676.6256289
9.2565	1	84.42196826	1.22515E-16	3.76699E-12	-1	759.3946964	1	2102.117923	1	84.42196826	1.22515E-16	3.76699E-12	-1	759.3946964
10.18215	0.987688341	83.38259374	-0.309016994	104.3408007	-0.891006524	676.6256289	0.707106781	1486.421839	0.987688341	83.38259374	-0.309016994	104.3408007	-0.891006524	676.6256289
11.1078	0.951056516	80.29006304	-0.587785252	198.4679969	-0.587785252	446.3610032	0	2.53243E-12	0.951056516	80.29006304	-0.587785252	198.4679969	-0.587785252	446.3610032
12.03345	0.891006524	75.22052451	-0.809016994	273.1677627	-0.156434465	118.7955031	-0.707106781	1486.421839	0.891006524	75.22052451	-0.809016994	273.1677627	-0.156434465	118.7955031
12.9591	0.809016994	68.29880702	-0.951056516	321.1279646	0.309016994	234.6658666	-1	2102.117923	0.809016994	68.29880702	-0.951056516	321.1279646	0.309016994	234.6658666
13.88475	0.707106781	59.69534624	-1	337.6539239	0.707106781	536.9731394	-0.707106781	1486.421839	0.707106781	59.69534624	-1	337.6539239	0.707106781	536.9731394
14.8104	0.587785252	49.62198792	-0.951056516	321.1279646	0.951056516	722.2272745	0	3.03892E-12	0.587785252	49.62198792	-0.951056516	321.1279646	0.951056516	722.2272745
15.73605	0.4539905	38.32677156	-0.809016994	273.1677627	0.987688341	750.0452875	0.707106781	1486.421839	0.4539905	38.32677156	-0.809016994	273.1677627	0.987688341	750.0452875
16.6617	0.309016994	26.08782289	-0.587785252	198.4679969	0.809016994	614.3632148	1	2102.117923	0.309016994	26.08782289	-0.587785252	198.4679969	0.809016994	614.3632148
17.58735	0.156434465	0.001	-0.309016994	0.001	0.4539905	0.001	0.707106781	0.001	0.156434465	0.001	-0.309016994	0.001	0.4539905	0.001
18.513	0	0.001	0	0.001	0	0.001	0	0.001	1.22515E-16	0.001	0	0.001	0	0.001

Inputs are the eigen-frequencies in [Hz], location of evaluation points in [m] and modal coordinate at each evaluation point.

Evaluation points shall be equally spaced or as close as possible to it. The actual value of the evaluation points is only used for reference, but the difference between the first and second points is used to obtain the modal curvature and, consequently, the unit stress amplitude per location and mode shape weightning factors for force model. The modal coordinate defines the mode shape. It should be normalized by the maximum displacement; this is a common output from FE analyses. Based on those, FatFree calculates the unit stress amplitude for each location, excluding the first and last two locations.

FatFree will present the actual stress ranges used in the calculations in the greyed out Stress Amplitudes cells for inspection.

Please note that the mode shape weightning factors for the force model will be calculated by FatFree for all in-line modes given.

Direct Stress Amplitude input:

Number of in-line modes	4	Format sheet
Number of cross-flow modes	3	
Number of locations along span	21	UPDATE
Stress amplitude calculation option:	Direct Stress Amplitude input	

Location [m]	Modal input													
	IN-LINE								CROSS-FLOW					
	IL Mode 1		IL Mode 2		IL Mode 3		IL Mode 4		CF Mode 1		CF Mode 2		CF Mode 3	
	Deactivate		Deactivate		Deactivate		Deactivate		Deactivate		Deactivate		Deactivate	
	f	2	f	4	f	6	f	10	f	3	f	6	f	9
	A_IL	84.42196826	A_IL	337.6539239	A_IL	759.3946964	A_IL	2102.117923	A_CF	84.42196826	A_CF	337.6539239	A_CF	759.3946964
	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude	Mode Shape	Stress Amplitude
0		0.001		0.001		0.001		0.001		0.001		0.001		0.001
0.92565		0.001		0.001		0.001		0.001		0.001		0.001		0.001
1.8513		26.08782289		198.4679969		614.3632148		2102.117923		26.08782289		198.4679969		614.3632148
2.77695		38.32677156		273.1677627		750.0452875		1486.421839		38.32677156		273.1677627		750.0452875
3.7026		49.62198792		321.1279646		722.2272745		5.06486E-13		49.62198792		321.1279646		722.2272745
4.62825		59.69534624		337.6539239		536.9731394		1486.421839		59.69534624		337.6539239		536.9731394
5.5539		68.29880702		321.1279646		234.6658666		2102.117923		68.29880702		321.1279646		234.6658666
6.47955		75.22052451		273.1677627		118.7955031		1486.421839		75.22052451		273.1677627		118.7955031
7.4052		80.29006304		198.4679969		446.3610032		1.01297E-12		80.29006304		198.4679969		446.3610032
8.33085		83.38259374		104.3408007		676.6256289		1486.421839		83.38259374		104.3408007		676.6256289
9.2565		84.42196826		3.76699E-12		759.3946964		2102.117923		84.42196826		3.76699E-12		759.3946964
10.18215		83.38259374		104.3408007		676.6256289		1486.421839		83.38259374		104.3408007		676.6256289
11.1078		80.29006304		198.4679969		446.3610032		2.53243E-12		80.29006304		198.4679969		446.3610032
12.03345		75.22052451		273.1677627		118.7955031		1486.421839		75.22052451		273.1677627		118.7955031
12.9591		68.29880702		321.1279646		234.6658666		2102.117923		68.29880702		321.1279646		234.6658666
13.88475		59.69534624		337.6539239		536.9731394		1486.421839		59.69534624		337.6539239		536.9731394
14.8104		49.62198792		321.1279646		722.2272745		3.03892E-12		49.62198792		321.1279646		722.2272745
15.73605		38.32677156		273.1677627		750.0452875		1486.421839		38.32677156		273.1677627		750.0452875
16.6617		26.08782289		198.4679969		614.3632148		2102.117923		26.08782289		198.4679969		614.3632148
17.58735		0.001		0.001		0.001		0.001		0.001		0.001		0.001
18.513		0.001		0.001		0.001		0.001		0.001		0.001		0.001

Inputs are the eigen-frequencies in [Hz], location of evaluation points in [m] and unit stress amplitude at mid-wall in [MPa] at each evaluation point. Based on those, FatFree calculates the fatigue life at each location. The evaluation points are only used for reference.

Please note that the mode shape weightning factor for the first in-line mode for the force model, λ_1, shall be given in the "MAIN" sheet.

6.5 MultiMode Output worksheet

The "MAIN" sheet presents a summary of multi-mode analyses results, i.e. the lowest fatigue life and the maximum peak stresses. More details can be found at the "MultiMode Output" sheet.

Numerical results:

IN-LINE								CROSS-FLOW					
IL Mode 1		IL Mode 2		IL Mode 3		IL Mode 4		CF Mode 1		CF Mode 2		CF Mode 3	
f	1.28633434	f	3.27156751	f	6.46573549	f	9.65763876	f	1.43519454	f	3.39823671	f	6.7190284
A_IL	90.6283997	A_IL	280.948039	A_IL	561.896078	A_IL	842.844117	A_CF	97.939959	A_CF	303.613873	A_CF	607.227746

For non-"user defined" response data the eigen-frequencies in [Hz] and unit stress amplitude at mid-wall in [MPa] are presented here for user reference.

FATIGUE AND DAMAGE RESULTS PER LOCATION																			
	Fatigue Life Results				Fatigue Damage Results (per year)				Peak Environmental Loading IL			Peak Environmental Loading CF			Von Mises stresses		
Location	IL RM	IL FM	IL Comb	CF RM	IL RM	IL FM	IL Comb	CF RM	$M_{E,1\text{-}year}$ (kNm)	$M_{E,10\text{-}year}$ (kNm)	$M_{E,100\text{-}year}$ (kNm)	$M_{E,1\text{-}year}$ (kNm)	$M_{E,10\text{-}year}$ (kNm)	$M_{E,100\text{-}year}$ (kNm)	$\sigma_{VM,1\text{-}year}$	$\sigma_{VM,10\text{-}year}$	$\sigma_{VM,100\text{-}year}$
0	1000000	500100.02	500100.02	1000000	0.000001	1.9996E-06	1.9996E-06	0.000001	0	0	0	0	0	0	7.44103025	7.44103025	7.44103025
0.92565	1000000	500100.02	500100.02	1000000	0.000001	1.9996E-06	1.9996E-06	0.000001	0	0	0	0	0	0	7.44103025	7.44103025	7.44103025
1.8513	5.51573207	500100.02	5.51567419	38398.0619	0.1812996	1.9996E-06	0.1813015	2.6043E-05	1.75226208	3.32519677	5.05287732	0.57581957	1.09270948	1.66045119	16.2041612	24.2541094	33.1403807
2.77695	1.97406784	500100.02	1.97406049	5610.08704	0.5065682	1.9996E-06	0.50657009	0.00017825	2.41178185	4.57674072	6.95468899	0.84596194	1.6053477	2.4394421	19.6550232	30.8483547	43.1852517
3.7026	1.63202491	500100.02	1.63201989	1542.08547	0.61273574	1.9996E-06	0.61273763	0.00064847	2.8352196	5.38028139	8.17572725	1.09527391	2.07845694	3.15836585	22.0083119	35.3380465	50.0194812
4.62825	2.34981425	500100.02	2.34980373	612.03533	0.42556555	1.9996E-06	0.42556746	0.00163389	2.98112631	5.65716264	8.59646836	1.31761661	2.50038766	3.79952015	23.0798778	37.3809682	53.1283492
5.5539	4.24771873	500100.02	4.24768485	312.186478	0.23542048	1.9996E-06	0.23542236	0.00320321	2.8352196	5.38028139	8.17572725	1.50751521	2.86075055	4.34711765	22.8447299	36.9327313	52.4462731
6.47955	9.1241391	500100.02	9.12398464	192.674282	0.10959938	1.9996E-06	0.10960124	0.00519011	2.41178185	4.57674072	6.95468899	1.66029379	3.15067226	4.78767469	21.4657414	34.3033238	48.4446757
7.4052	12.1166222	500100.02	12.1163549	139.089411	0.08253125	1.9996E-06	0.08253307	0.00718962	1.75226208	3.32519677	5.05287732	1.77219042	3.36301397	5.11034329	19.3457013	30.257841	42.28613
8.33085	6.14364196	500100.02	6.14357433	115.179269	0.1627699	1.9996E-06	0.16277169	0.00868212	1.25298408	1.7481594	2.65645481	1.84044984	3.49254711	5.30717828	18.0553442	26.2330351	36.1559892
9.2565	4.55648171	500100.02	4.5564454	108.278975	0.21946758	1.9996E-06	0.21946933	0.0092354	1.4062569	1.4062569	1.4062569	1.86339128	3.53608215	5.37333292	18.5795336	25.7439489	34.2931818
10.18215	6.14364196	500100.02	6.14357433	115.179269	0.1627699	1.9996E-06	0.16277169	0.00868212	1.25298408	1.7481594	2.65645481	1.84044984	3.49254711	5.30717828	18.0553442	26.2330351	36.1559892
11.1078	12.1166222	500100.02	12.1163549	139.089411	0.08253125	1.9996E-06	0.08253307	0.00718962	1.75226208	3.32519677	5.05287732	1.77219042	3.36301397	5.11034329	19.3457013	30.257841	42.28613
12.03345	9.1241391	500100.02	9.12398464	192.674282	0.10959938	1.9996E-06	0.10960124	0.00519011	2.41178185	4.57674072	6.95468899	1.66029379	3.15067226	4.78767469	21.4657414	34.3033238	48.4446757
12.9591	4.24771873	500100.02	4.24768485	312.186478	0.23542048	1.9996E-06	0.23542236	0.00320321	2.8352196	5.38028139	8.17572725	1.50751521	2.86075055	4.34711765	22.8447299	36.9327313	52.4462731
13.88475	2.34981425	500100.02	2.34980373	612.03533	0.42556555	1.9996E-06	0.42556746	0.00163389	2.98112631	5.65716264	8.59646836	1.31761661	2.50038766	3.79952015	23.0798778	37.3809682	53.1283492
14.8104	1.63202491	500100.02	1.63201989	1542.08547	0.61273574	1.9996E-06	0.61273763	0.00064847	2.8352196	5.38028139	8.17572725	1.09527391	2.07845694	3.15836585	22.0083119	35.3380465	50.0194812
15.73605	1.97406784	500100.02	1.97406049	5610.08704	0.5065682	1.9996E-06	0.50657009	0.00017825	2.41178185	4.57674072	6.95468899	0.84596194	1.6053477	2.4394421	19.6550232	30.8483547	43.1852517
16.6617	5.51573207	500100.02	5.51567419	38398.0619	0.1812996	1.9996E-06	0.1813015	2.6043E-05	1.75226208	3.32519677	5.05287732	0.57581957	1.09270948	1.66045119	16.2041612	24.2541094	33.1403807
17.58735	1000000	500100.02	500100.02	1000000	0.000001	1.9996E-06	1.9996E-06	0.000001	0	0	0	0	0	0	7.44103025	7.44103025	7.44103025
18.513	1000000	500100.02	500100.02	1000000	0.000001	1.9996E-06	1.9996E-06	0.000001	0	0	0	0	0	0	7.44103025	7.44103025	7.44103025

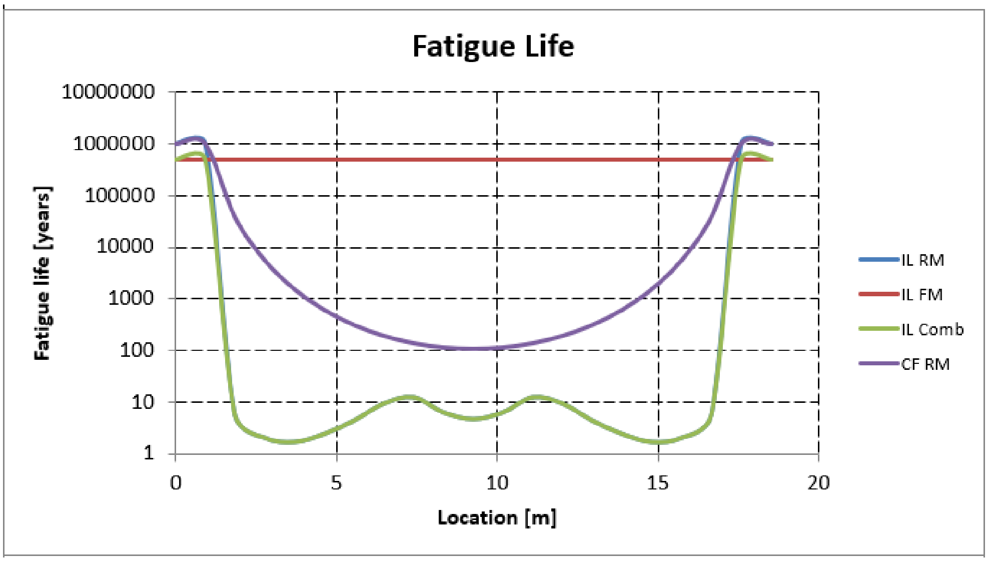
Location-wise results are given: fatigue life, annual fatigue damage, peak environmental loading and von Mises stresses. The von Mises stresses presented for multi-location analyses do not include the static contribution from self-weight nor drag.

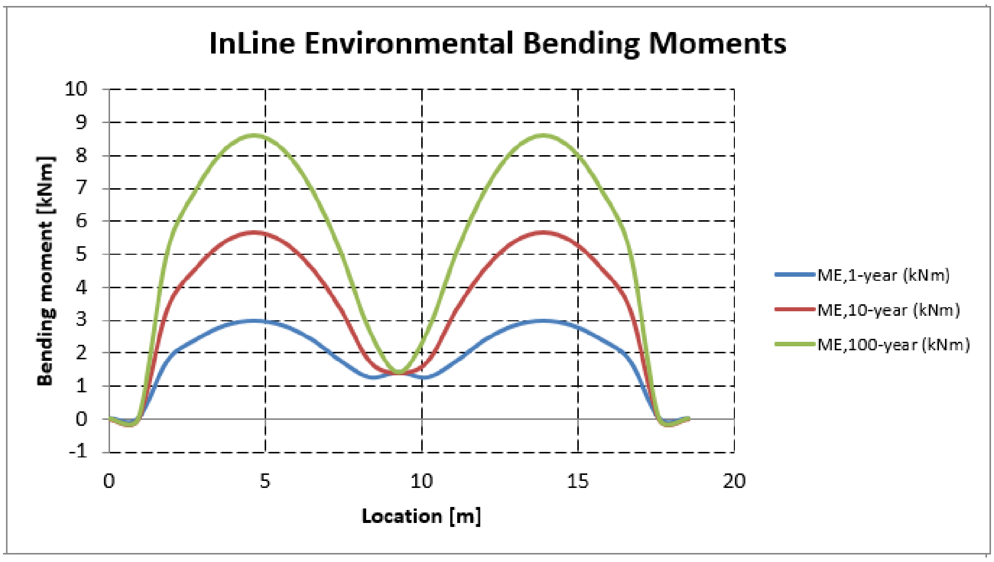
Fatigue life and annual fatigue damage results are shown the worst between the two SN-curves considered. Minimum fatigue life and maximum fatigue damage between weld cap and weld root is provided for each location.

Peak environmental loading is the bending moment associated with the peak stress. As such no safety factor is considered. The von Mises stress presented is calculated at the weld cap without safety factors and without SCF.

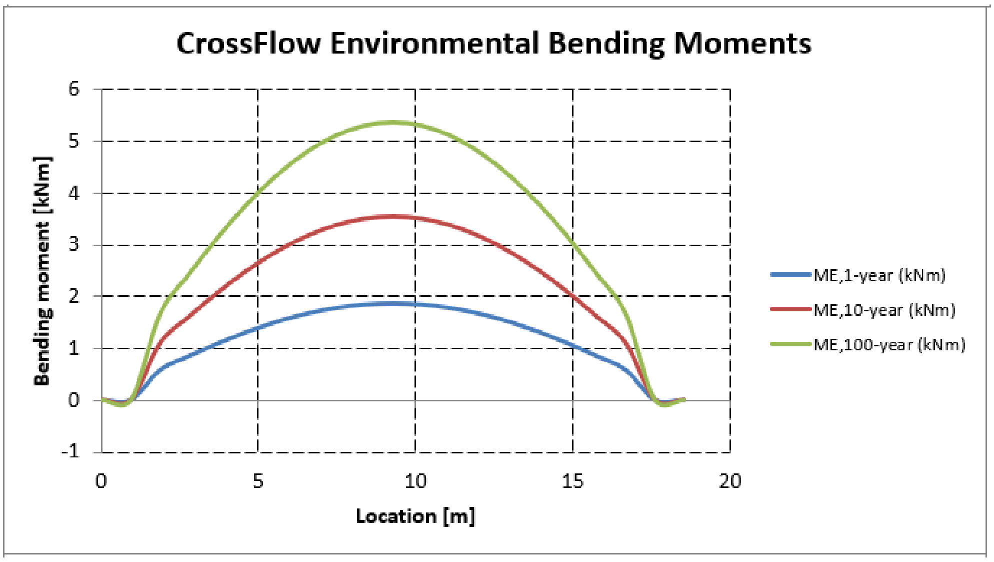
Graphical results:

Four graphical results are given.

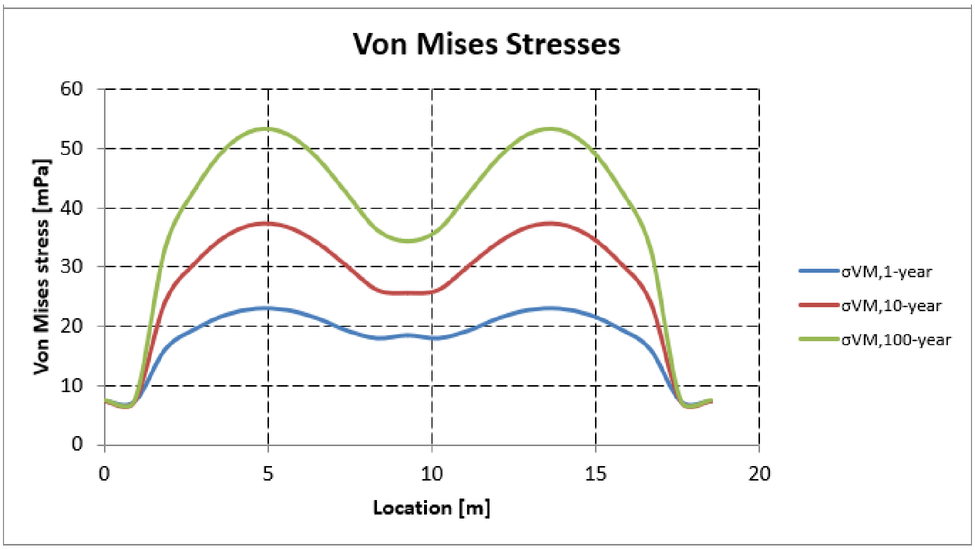




InLine Environmental Bending Moments
Bending moment [kNm]
10
9
8
7
6
5
4
3
2
1
0
-1
0
5
10
15
20
Location [m]
ME,1-year (kNm)
ME,10-year (kNm)
ME,100-year (kNm)



CrossFlow Environmental Bending Moments
Bending moment [kNm]
6
5
4
3
2
1
0
-1
0
5
10
15
20
Location [m]
ME,1-year (kNm)
ME,10-year (kNm)
ME,100-year (kNm)



Von Mises Stresses
Von Mises stress [mPa]
60
50
40
30
20
10
0
0
5
10
15
20
Location [m]
σVM,1-year
σVM,10-year
σVM,100-year

7 ASSESSMENT OF SEVERAL SPAN CASES

This option is used to calculate several span cases in one run. Thus it can be used for screening purposes, to perform sensitivity studies or just to analyse many separate spans in one run and keep the input and results together in one data sheet. To generate the "SpanRuns" sheet press on the "MAIN" sheet:

FatFree will generate a "SpanRuns" sheet pre-filled with the input in "MAIN" sheet. If another sheet named "SpanRuns" exists, it will be deleted. The "SpanRuns" can be renamed and it is recommended to do so.

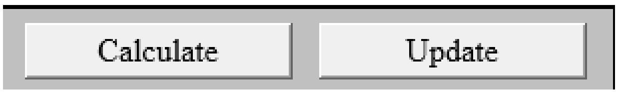
"Several span case analysis" is available only for single location and for a fixed set opf modes, 4 in-line and 3 cross-flow.

In a "Several span case analysis" each line of input represents a separate analysis. Most input can be given independently for each analysis, with the exception of:

- Environmental data template names,
- Options selected by drop-down menus, and
- Numerical inputs not available in the sheet.

Multiple "SpanRuns" sheets may use different options of environmental data template names and drop-down menus selection.

Input data is to be given in the "SpanRuns" sheet and analysis to be initiated from it, by clicking the "Calculate" button in the upper left corner of the sheet. A "Update" button is also available, by clicking it FatFree will populate all the automatically calculated values for all entries and delete existing fatigue and stress results.



<u>Numerical inputs:</u>

Numerical inputs include: water depth, span length, wall thickness, content density, etc. Multiple variations of those inputs can be handled by one "SpanRuns" sheet.

							First mode parameters					
KP		h [m]	L [m]	e [m]	d [m]	θ_{pipe}	D [m]	f_o(in-line)	f_o(cr-flow)	A_{in} (in-line)	A_{cr} (cr-flow)	λ_{max}
	1	110	30	0.40	0	0.0	0.400	0.773	0.831	111	121	359
	2	110	40	0.40	0	0.0	0.400	0.773	0.831	111	121	359
	3	110	50	0.40	0	0.0	0.400	0.773	0.831	111	121	359

Each line of input represents a separate analysis. Simply fill out the available fields or copy from initial row provided by FatFree, green background cells are filled by FatFree as in "MAIN" sheet. Each data row represents a different case to be run by FatFree and an empty row will indicate the end of cases. Don't skip rows while setting cases in "SpanRuns" sheet.

Most of the numerical input is available. The ones not presented in the "SpanRuns" sheet are to be given in the "MAIN" sheet. Those include:

$\zeta_{h,RM}$	Hydrodynamic damping ratio from damping outside forcing region for Response Model;
SCF	Stress concentration factors for both SN-curves considered;
k_c	Concrete Stiffness Factor;
f_{cn}	Construction strength of concrete coating;
ν	Poisson's ratio;
α	Temperature expansion coefficient;
E	Young's modulus;
also	
	All shielding and strake modelling parameters; and
	All "User Defined" input, with exception of "Response Data"

In addition a KP field is available to identify the different cases. Any identification can be used, including non-numerical values. This input is optional and it is not considered in analyses.

Erros and warnings found are given in dedicated message boxes.

<u>Additional inputs:</u>

Additional inputs are the dropdown menus and sheet name cells for current and wave data.

Environmental data template names		Current data model	Wave data model	Directionality	Return period values	Code	Frees
Current Template	Wave Template	Uc Weibull pdf	Hs Weibull pdf	Discrete - C dir.	Automatic Generated	RP-F105	Flat sea-

Those inputs cannot change between analyses initiated from the same "SpanRuns", i.e. the input displayed in the sheet is considered for all cases. If those input are required to change, multiple "SpanRuns" sheets are required. Remember to rename them before generating a new one.

The additional input considered in the analyses are the ones displayed in the "SpanRuns" sheet, regardless of the choices made in "MAIN" sheet.

<u>Results:</u>

Analyses results will be displayed in the "SpanRuns" sheet. Each input row will have a corresponding result row.

Fatigue Life (years)				Cross-Flow: Peak Dynamic Stress (MPa)			Inline: Peak Dynamic Stress (MPa)		
Inline Response	Inline Force	Inline Combined	Cross-flow	1 Year	10 Year	100 Year	1 Year	10 Year	100 Year
6.87E+00	8.55E+02	6.87E+00	6.76E-01	4.13E+01	7.09E+01	1.05E+02	1.43E+02	3.98E+02	8.98E+02
2.60E-01	7.24E+01	2.60E-01	1.76E-01	7.42E+01	8.50E+01	9.02E+01	4.22E+02	9.12E+02	1.58E+03
4.87E-02	1.63E+01	4.87E-02	1.16E-01	6.76E+01	7.80E+01	9.56E+01	6.18E+02	1.29E+03	2.30E+03
5.07E-02	5.87E+00	5.07E-02	1.17E-01	6.77E+01	8.75E+01	1.01E+02	8.00E+02	1.78E+03	3.14E+03
5.93E-02	2.74E+00	5.93E-02	1.11E-01	7.51E+01	8.39E+01	1.02E+02	1.03E+03	2.20E+03	3.92E+03
3.53E-02	1.49E+00	3.53E-02	3.53E-02	1.03E+02	1.03E+02	1.10E+02	1.22E+03	2.66E+03	4.73E+03
3.15E-02	8.65E-01	3.15E-02	2.74E-02	9.21E+01	9.25E+01	9.63E+01	1.43E+03	3.06E+03	5.46E+03

The available results are: fatigue life and peak dynamic stress for in-line and cross-flow. As in “MAIN” sheet, the fatigue life reported is the minimum between weld toe and weld cap and dynamic stresses are calculated at weld cap location ($D_s/2$).

In case the approximate response model restrictions are violated ($C_2 \cdot S_{eff}/P_E$ >-0.5; L/D < 140; δ/D < 2.5) or the wave induced flow velocity is too small a warning message is displayed at the end of the calculations in a message box.

8 THE "PLOTS" SHEET

8.1 General

The "plots" sheet provides the basis for the graphical results. It also contains additional information from analysis and settings. This section will present the information that can be found in the "plots" sheet.

8.2 Structural intermediate results

STRUCTURAL MODELLING INTERMEDIATE RESULTS					
Static Stress [MPa]		Transfer values		Areas [m^2]	
σ_h	-10.5	EI_{steel}	8.95E+07	A_i	0.10179
σ_N	-2.0	m_e	316	A_{steel}	0.02388
$\sigma_{M,cr}$	44.9	q	573	$A_{coating}$	0.00000
$\sigma_{M,in}$ (100y)	0.0	S_{eff}	9.00E+04	$A_{concrete}$	0.00000
		C_a	1.00	A_e	0.12566
		CSF	0.00		
		ρ_s/ρ	1.45		

Intermediate results are available. They are provided when the "UPDATE SHEET" or "CALCULATE" buttons are clicked in the "MAIN" sheet. The intermediate results are categorised as static stress, transfer values and areas and are described in the following:

Static Stress

σ_h	Hoop stress.
σ_N	Axial stress.
$\sigma_{M,cr}$	Bending stresses in cross-flow direction, due to self-weight.
$\sigma_{M,in}$	Bending stress in in-line direction, due to average drag.

The bending stresses are determined from the given span length and boundary conditions accounting for bending due to self-weight (cross-flow) and 100-year current (in-line). Note that no corrosion allowance is accounted for, i.e. full wall thickness provided in structural modelling is considered.

Transfer values

EI_{steel}	Bending stiffness of the steel pipe [Nm²].
m_e	Effective (dynamic) mass per unit length, including structural mass, added mass and mass of content [kg/m].
q	Submerged weight per unit length [N/m].
S_{eff}	Effective axial force used in estimate of natural frequencies and span deflections. Conservatively, the effective axial force is calculated as for a fully restrained pipe. [N]
C_a	Added-mass coefficient depends on the spanning scenario and the span gap.
CSF	Bending-stiffness contribution from concrete and coating given as percentage of EI_{steel}. Note that combined steel and concrete bending stiffness is obtained

by multiplying the steel bending stiffness by (1+CSF).

ρ_s/ρ Specific mass ratio between the pipe mass (not including added mass) and the displaced water.

<u>Areas</u>

A_i Internal cross-sectional area [m²].

A_{steel} Steel cross-sectional area [m²].

$A_{coating}$ Corrosion-coating area [m²].

$A_{concrete}$ Concrete-coating area [m²].

A_e Total (external) cross-sectional area [m²].

8.3 "MAIN" sheet plots background

Damage distribution versus direction				
direction	RM (In-Line)	FM (In-Line)	Comb.(In-Line	Cross-Flow
0	0.00	0.10	0.00	0.00
45	0.05	0.04	0.05	0.00
90	0.40	0.06	0.40	0.30
135	0.04	0.04	0.04	0.00
180	0.00	0.05	0.00	0.00
225	0.07	0.29	0.07	0.02
270	0.40	0.18	0.40	0.64
315	0.04	0.23	0.04	0.03

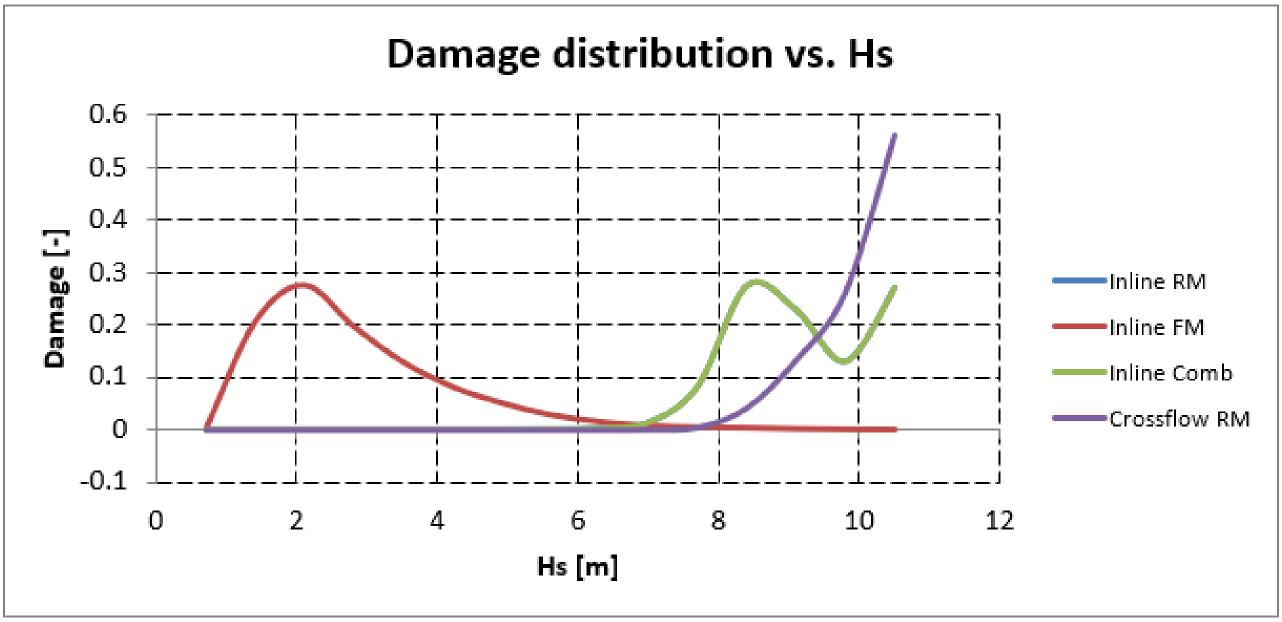
pdf for current in critical direction			
uc	pdf	RM(inline)*10	RM(cross-flow)*4
0.017	0.967	0.000	0.000
0.034	1.154	0.000	0.000
0.051	1.355	0.000	0.000
0.069	1.566	0.000	0.000
0.086	1.783	0.000	0.000
0.103	2.002	0.000	0.000
0.120	2.216	0.000	0.000
0.137	2.418	0.000	0.000
0.154	2.602	0.000	0.000
0.171	2.760	0.000	0.000
0.189	2.886	0.000	0.000
0.206	2.972	0.000	0.000
0.223	3.016	0.067	0.000
0.240	3.012	0.157	0.000
0.257	2.959	0.247	0.000

These tables stores the information presented in the graphical results presented in the "MAIN" sheet.

8.4 Sea-state information

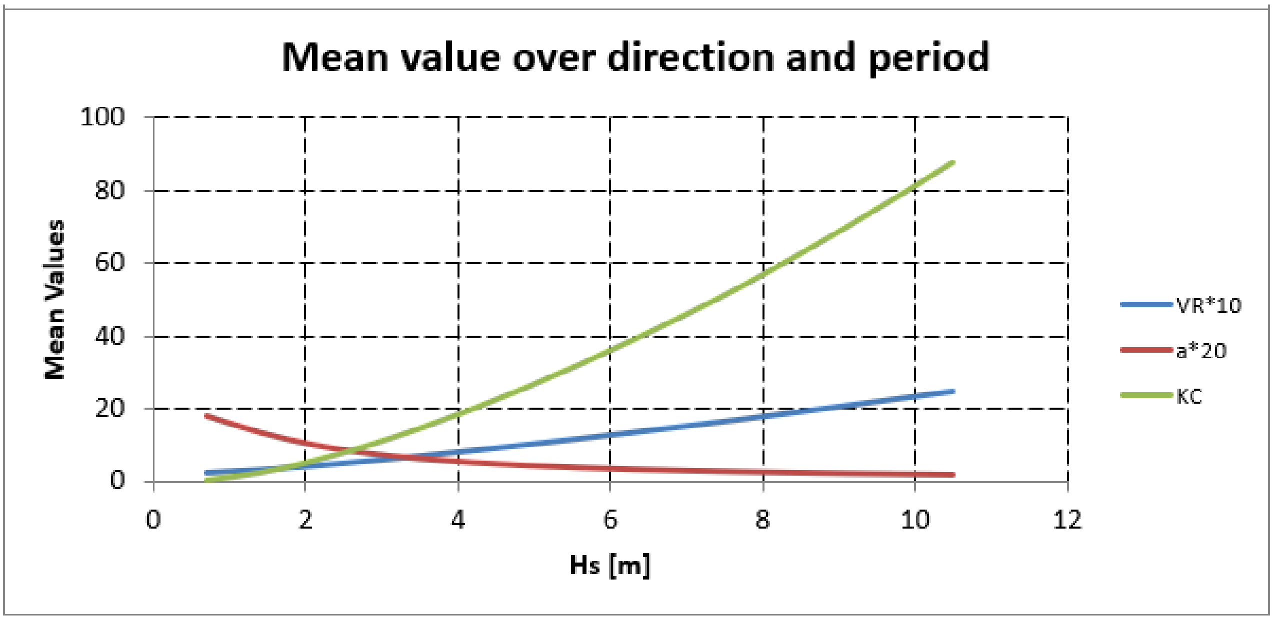
Results as function of sea-state, defined by H_s, is given in numerical and graphical form. This is only relevant when waves are accounted for.

Damage Distribution vs H_s



The "Damage distribution" chart shows the contribution each significant wave height (averaged over the wave periods) has to the individual fatigue components, i.e., in-line response model, in-line force model, combined in-line fatigue life and cross-flow fatigue life.

The α-KC Chart



The α-KC chart shows how the flow parameters vary over each of the significant wave heights.

Numerical results

Graphic presentation of results				Damage distribution versus Hs				Sea-states	
H_S	V_R*10	α*20	KC	RM (In-Line)	FM (In-Line)	Comb.(In-Line)	Cross-Flow	Total	Non-linear occurrences
0.32	0.00	20.00	0.00	0.00	0.00	0.00	0.00	0	0
0.64	11.25	19.98	0.01	0.00	0.00	0.00	0.00	1	0
0.95	10.58	19.92	0.02	0.01	0.00	0.01	0.00	6	0
1.27	10.42	19.77	0.07	0.06	0.00	0.06	0.00	8	0
1.59	10.52	19.55	0.15	0.07	0.00	0.07	0.00	8	0
1.91	10.67	19.27	0.25	0.08	0.00	0.08	0.00	8	0
2.23	10.87	18.93	0.39	0.09	0.00	0.09	0.00	8	0
2.54	11.10	18.54	0.56	0.09	0.00	0.09	0.00	8	0
2.86	11.37	18.11	0.77	0.09	0.00	0.09	0.00	8	0
3.18	11.68	17.65	1.00	0.09	0.00	0.09	0.00	8	0
3.50	12.02	17.16	1.27	0.09	0.00	0.09	0.01	8	8
3.81	12.39	16.66	1.58	0.09	0.00	0.09	0.01	8	8
4.13	12.79	16.15	1.91	0.08	0.00	0.08	0.01	8	8
4.45	13.22	15.64	2.27	0.05	0.00	0.05	0.01	8	8
4.77	13.68	15.13	2.67	0.03	0.01	0.03	0.01	8	8
5.09	14.16	14.62	3.09	0.02	0.02	0.02	0.02	8	8
5.40	14.68	14.12	3.55	0.01	0.02	0.01	0.02	8	8
5.72	15.22	13.63	4.04	0.00	0.03	0.00	0.03	8	8

This table presents the background for the previous graphical results.

It also contains an indication of which sea-states the Airy wave theory might not be applicable. A very conservative criterion is used and results should be evaluated by engineering judgement. More details are provided in Appendix B.

APPENDIX A
References

/1/ DNVGL-RP-F105, “Free Spanning Pipelines”, June 2017.

/2/ FatFree Verification Document, *for FatFree v. 13.0*, May 2019

/3/ FatFree Test Report - Regression tests, platform tests and stress tests, *for FatFree v. 13.0*, May 2019

/4/ Mørk, K.J., Fyrileiv, O., Verley, R., Bryndum, M. & Bruschi, R., “Introduction to the DNV Guideline for Free Spanning Pipelines”, OMAE 1998, July 6-9, 1998, Lisbon, Portugal.

/5/ Fyrileiv, O. & Mørk, K.J., “Assessment of Free Spanning Pipelines using the DNV Guideline for Free Spanning Pipelines”, ISOPE'98, May 24-29, 1998, Montreal, Canada.

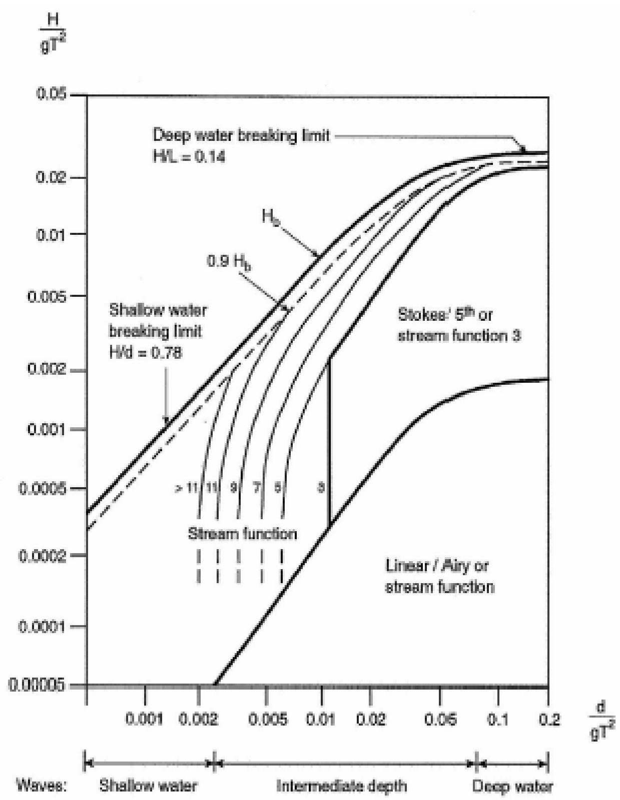
/6/ Mørk, K.J., Fyrileiv, O., Chezhian, M., Nielsen, F.G. & Søreide, T., “Assessment of VIV induced fatigue in long free spanning pipelines”, OMAE 2003, June 8-13, 2003, Cancun, Mexico.

/7/ DNVGL-RP-F114, “Pipe-soil interaction for submarine pipelines”, May 2017.

APPENDIX B
Linear Wave Check

DNV-RP-F105 utilizes Airy (linear) wave theory. This theory has a well-known applicability limitation in shallow waters. FatFree version 12.0 introduced a simplified check of the application of the linear wave theory. This check should provide the user additional information to evaluate a given sea-state applicability of linear theory in a given location.

The linear wave theory application check is in accordance with DNVGL-RP-C205 Figure 3-4, reproduced below. It compares the predicted horizontal velocity and acceleration by Airy theory with the solution obtained by stream functions. The limitation curve is defined for 1% error in predicted velocities and accelerations at the surface. The Airy wave theory error should be much smaller closer to the seabed than at the sea level.



FatFree considers irregular sea-state, while the above criterion is defined for a regular sea-state. Therefore a characteristic regular sea-state is defined for each irregular sea-state. The simplified check considers a regular wave defined by:

$H = H_{rms}$

$T = T_z$

Where, H_{rms} and T_z are the root mean square and the zero-up-crossing period of the irregular sea-state.

The results of the simplified check are presented in the “plots” sheet. The “damage distribution versus Hs” should provide some context to the simplified check results.

Graphic presentation of results				Damage distribution versus Hs				Sea-states	
H_S	V_R*10	α*20	KC	RM (In-Line)	FM (In-Line)	Comb.(In-Line)	Cross-Flow	Total	Non-linear occurrences
0.32	0.00	20.00	0.00	0.00	0.00	0.00	0.00	0	0
0.64	11.25	19.98	0.01	0.00	0.00	0.00	0.00	1	0
0.95	10.58	19.92	0.02	0.01	0.00	0.01	0.00	6	0
1.27	10.42	19.77	0.07	0.06	0.00	0.06	0.00	8	0
1.59	10.52	19.55	0.15	0.07	0.00	0.07	0.00	8	0
1.91	10.67	19.27	0.25	0.08	0.00	0.08	0.00	8	0
2.23	10.87	18.93	0.39	0.09	0.00	0.09	0.00	8	0
2.54	11.10	18.54	0.56	0.09	0.00	0.09	0.00	8	0
2.86	11.37	18.11	0.77	0.09	0.00	0.09	0.00	8	0
3.18	11.68	17.65	1.00	0.09	0.00	0.09	0.00	8	0
3.50	12.02	17.16	1.27	0.09	0.00	0.09	0.01	8	8
3.81	12.39	16.66	1.58	0.09	0.00	0.09	0.01	8	8
4.13	12.79	16.15	1.91	0.08	0.00	0.08	0.01	8	8
4.45	13.22	15.64	2.27	0.05	0.00	0.05	0.01	8	8
4.77	13.68	15.13	2.67	0.03	0.01	0.03	0.01	8	8
5.09	14.16	14.62	3.09	0.02	0.02	0.02	0.02	8	8
5.40	14.68	14.12	3.55	0.01	0.02	0.01	0.02	8	8
5.72	15.22	13.63	4.04	0.00	0.03	0.00	0.03	8	8

For each H_s the total number of sea states considered, defined by directionality and T_p, is presented. The number of sea states that failed the simplified test is presented under “Non-linear occurrences”.

Due the conservatism of the simplified check, it is expected that non-linear occurrences will be reported even in cases where linear wave theory is normally accepted, in particular for H_s closer to extreme values. Therefore applicability of linear wave theory shall ultimately be based on engineering judgment.

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