SESAM
USER MANUAL

FatFree



Fatigue analysis of free spanning pipelines

DET NORSKE VERITAS

SESAM
User Manual

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Fatigue analysis of free spanning pipelines

July 19, 2013

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DNV Software Report

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1 INTRODUCTION

1.1 FatFree – Fatigue analysis of free spanning pipelines

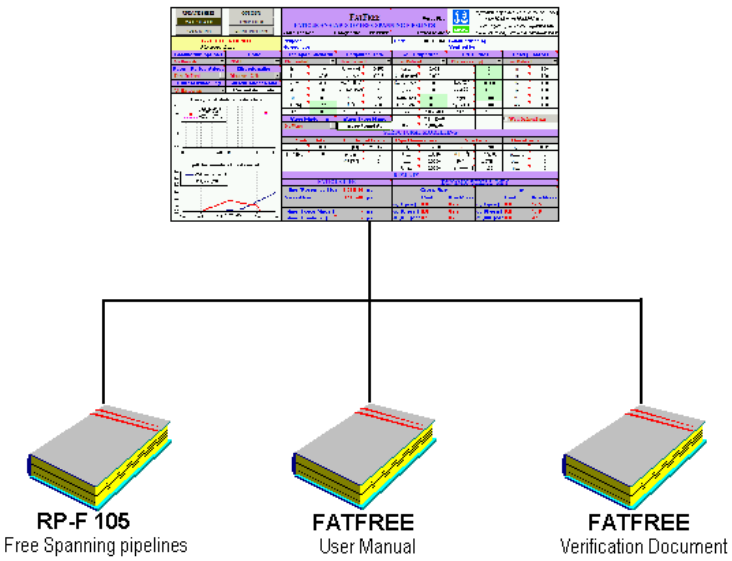
FatFree is a Microsoft Excel VBA spreadsheet developed by DNV for design and (re-) assessment of submarine pipeline spans in compliance with DNV-RP-F105 "Free Spanning Pipelines", issued February 2006 (Ref. /1/). FatFree calculates the fatigue life due to**:**

- 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).
- 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.

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 Scope of the manual

The manual is intended to provide the user with a guide to operate the program. More details of pipeline free-span analysis are provided in the DNV-RP-F105, Ref. /1/ and the FatFree Verification Document, Ref. /2/. Further, FatFree contains a comprehensive list of comments describing the various parameters entering the analysis.



1.3 How to read the manual

The manual can be read successively chapter by chapter as well as only chapter-wise:

- Read chapter 1 INTRODUCTION to obtain a brief overview of FatFree.
- Read chapter 2 GETTING STARTED to get up and running with FatFree.
- Read chapter 3 FEATURES OF FATFREE to find out about the features/options of FatFree.
- Read chapter 4 VIEWING RESULTS to learn how to interpret the results.
- Read chapter 5 MULTI-MODE ANALYSIS to get familiar with the multi-mode features, applicable for very long free spans.
- Read chapter 6 ASSESSMENT OF SEVERAL SPAN CASES for more advanced execution modes of FatFree.

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

1.5 Status list

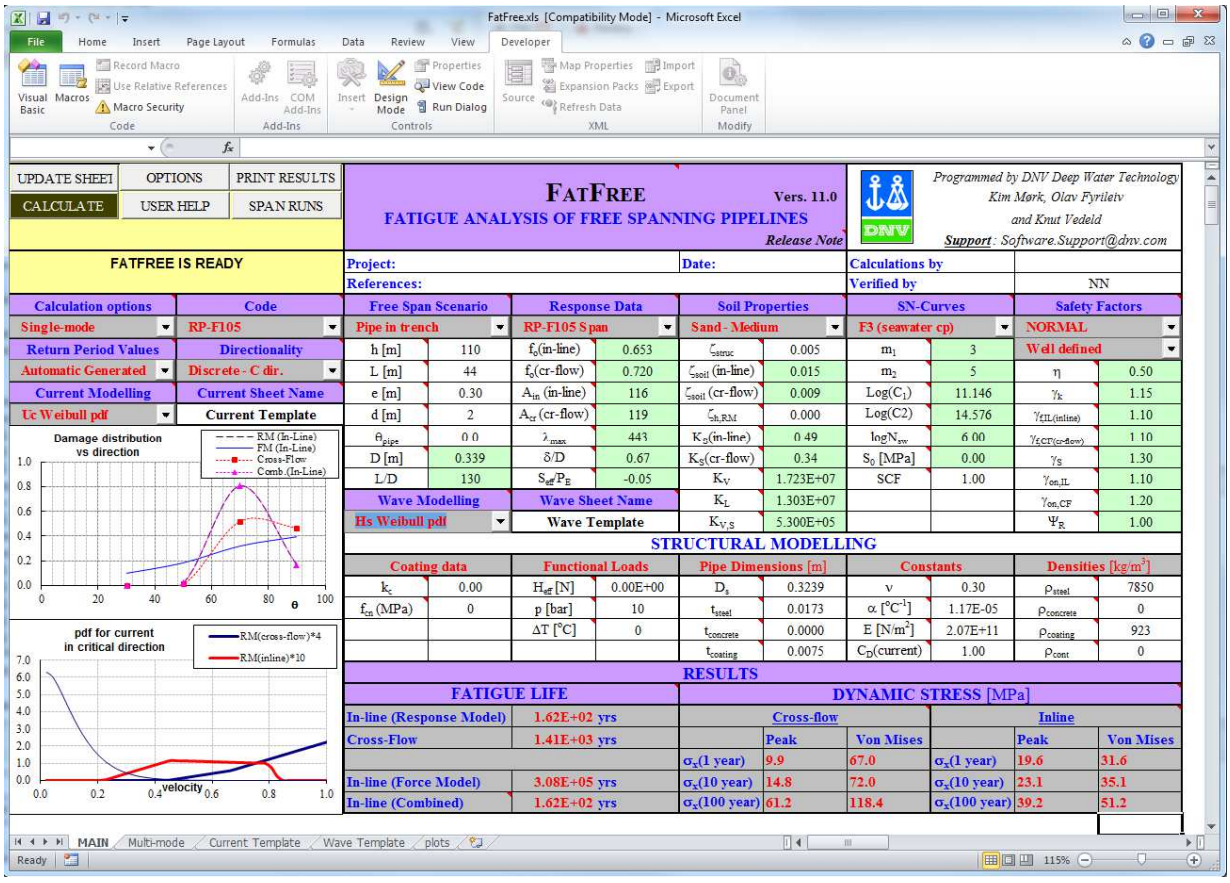
Updated status lists are available through the SESAM download system. The FatFree status list can be accessed from the DNV Software home page: http://www.dnv.com/software.

2 GETTING STARTED

2.1 User interface

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

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.

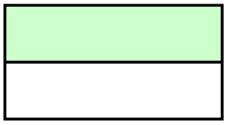
In FatFree the following kinds of sheets are available:

- **"MAIN" sheet** — Contains all important input and output except environmental data.
- **"Current" sheets** — Contains the current data (may have several sheets, one pair for each environmental zone).

- **"Wave" sheets** Contains the wave data (may have several sheets, one pair for each environmental zone).
- **"Plots" sheet** Contains results for graphical presentation and (user defined) default settings.
- **"Multi-mode" sheet** Contains information about potentially activated higher order modes.
- **"Span Runs" sheet** Allows running several span cases at one time (these sheets are created when the "Span Runs" button on the "MAIN" sheet is pushed for the first time).

The user can copy the environmental-data sheets and the "Span Runs" sheets, but the program can only operate with a single "MAIN" sheet.

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



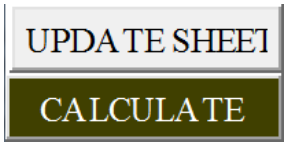
calculated

user defined

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

2.2 Calculations

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



"UPDATE SHEET" 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.

2.3 Simple use of FatFree

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

1. Perform “Structural Modelling”: provide pipe and operational data.
2. Push the "UPDATE SHEET" button to check the intermediate results.
3. Describe “Free Span Scenario”: give the span length, water depth, etc.
4. Select single-mode or multi-mode behaviour in “Calculation Options”.
5. Specify “Response Data”, damping (under “Soil Properties”), “SN-Curves” and “Safety Factors” by using pull-down menus or giving input values.
6. Define the environmental conditions in terms of long-term wave and current distributions on the wave and current sheets:
    a) Copy the template sheets "Wave Template" and "Current Template" to properly named wave and current sheets (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.
7. Push the "CALCULATE" button.

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

2.4 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 DNV-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.

3 FEATURES OF FATFREE

3.1 General

The main structure of the "MAIN" sheet of FatFree is described below:

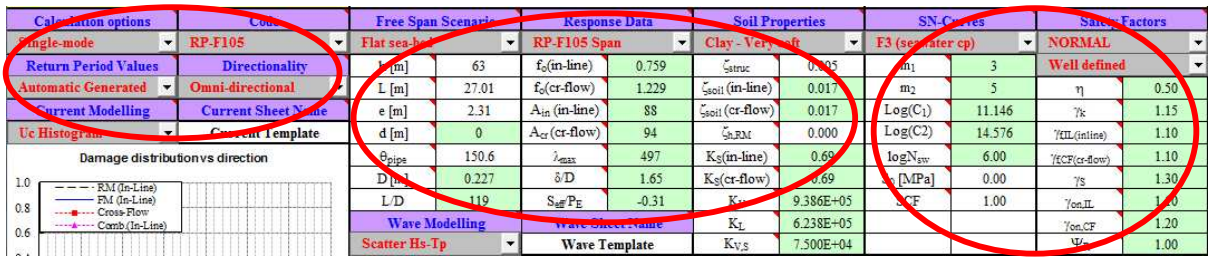
Heading area



Calculation options

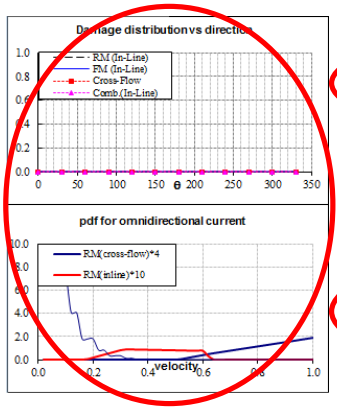
Span & soil data

SN-curves & Safety factors



Graphical results area

Structural modelling area



STRUCTURAL MODELLING

Coating data		Functional Loads		Pipe Dimensions [m]		Constants		Densities [kg/m³]	
k_c	0.00	H_{eff} [N]	0.00E+00	D_s	0.2191	ν	0.30	ρ_{steel}	7850
f_{cn} (MPa)	42	p [bar]	68.95	t_{steel}	0.0127	α [°C⁻¹]	1.17E-05	$\rho_{concrete}$	0
		ΔT [°C]	0	$t_{concrete}$	0.0000	E [N/m²]	2.07E+11	$\rho_{coating}$	1087
				$t_{coating}$	0.0040	C_D(current)	1.00	ρ_{cont}	820

Main results area

RESULTS

FATIGUE LIFE		DYNAMIC STRESS [MPa]					
In-line (Response Model)	1.93E+02 yrs		Cross-flow			Inline	
Cross-Flow	2.54E+03 yrs		Peak	Von Mises		Peak	Von Mises
		σ_x(1 year)	10.9	126.8	σ_x(1 year)	8.9	55.9
In-line (Force Model)	5.69E+06 yrs	σ_x(10 year)	12.0	127.8	σ_x(10 year)	9.3	56.3
In-line (Combined)	1.93E+02 yrs	σ_x(100 year)	13.4	129.1	σ_x(100 year)	9.7	56.7

3.2 "MAIN" sheet input

The following describes the basic use of FatFree where most of the input is specified on the "MAIN" sheet.

3.2.1 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	0.00	H_{eff} [N]	0.00E+00	D_s	0.2191	ν	0.30	ρ_{steel}	7850
f_{cn} (MPa)	42	p [bar]	68.95	t_{steel}	0.0127	α [$^oC^{-1}$]	1.17E-05	$\rho_{concrete}$	0
		ΔT [^oC]	0	$t_{concrete}$	0.0000	E [N/m^2]	2.07E+11	$\rho_{coating}$	1087
				$t_{coating}$	0.0040	C_D(current)	1.00	ρ_{cont}	820

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.

Functional Loads

H_{eff}	Residual lay tension (effective axial force at seabed).
p	Internal pressure at spanning pipe (normally the operational pressure).
ΔT	Temperature change relative to ambient temperature during installation.

Pipe Dimensions

D_s	Steel outer diameter.
t_{steel}	Thickness of steel wall.
$t_{concrete}$	Thickness of concrete coating.
$t_{coating}$	Thickness of corrosion coating.

Constants

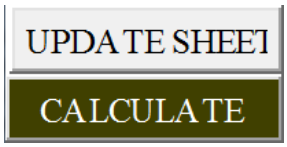
ν	Poisson's number.
α	Temperature expansion coefficient.
E	Young's modulus.
C_d	Drag coefficient for steady flow to specify the cross-flow amplification in von-Mises stress.

Densities

ρ_{steel}	Densities of pipe steel.

$\rho_{concrete}$	Density of concrete.
$\rho_{coating}$	Density of corrosion coating. In case more than two layers of coatings are applied, the density of the coating shall be adjusted to give the correct weight of the pipeline.
$\rho_{content}$	Density of content.

By pushing the "UPDATE SHEET" or "CALCULATE" buttons;



all structural modelling results will be updated. These intermediate results appear on the “plots” sheet:

STRUCTURAL MODELLING INTERMEDIATE RESULTS					
Static Stress [MPa]		Transfer values		Areas [m^2]	
σ_h	50.9	EI_{steel}	9.11E+06	A_i	0.02947
σ_N	11.7	m_e	133	A_{steel}	0.00823
$\sigma_{M,cr}$	94.2	q	493	$A_{coating}$	0.00280
$\sigma_{M,in}$ (100y)	9.5	S_{eff}	-8.13E+04	$A_{concrete}$	0.00000
		C_a	1.00	A_e	0.04051
		CSF	0.00		
		ρ_s/ρ	2.21		

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.
$\sigma_{M,in}$	Bending stress in in-line direction.

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.

Transfer values

EI_{steel}	Bending stiffness of the steel pipe.
m_e	Effective (dynamic) mass, including structural mass, added mass and mass of content.
q	Submerged weight.
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.
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}.
ρ_s/ρ	Specific mass ratio between the pipe mass (not including added mass) and the displaced water.

Areas

A_i	Internal cross-sectional area.
A_{steel}	Steel cross-sectional area.
$A_{coating}$	Corrosion-coating area.
$A_{concrete}$	Concrete-coating area.
A_e	Total (external) cross-sectional area.

The following should be noted:

- Different phases of the pipeline may be simulated by changing the density of the content, the internal pressure and the temperature in the pipeline.
- The effective axial force is a very important parameter in the free span 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 when the “Response Data” is set as “User Defined”, where both the natural frequencies and the associated stress ranges are determined by FE analysis.

3.2.2 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		RP-F105 Span		Clay - Very soft	
h [m]	63	f_o(in-line)	0.759	ζ_{struc}	0.005
L [m]	27.01	f_o(cr-flow)	1.229	ζ_{soil} (in-line)	0.017
e [m]	2.31	A_{in} (in-line)	88	ζ_{soil} (cr-flow)	0.017
d [m]	0	A_{cr} (cr-flow)	94	$\zeta_{h,RM}$	0.000
θ_{pipe}	150.6	λ_{max}	497	K_S(in-line)	0.69
D [m]	0.227	δ/D	1.65	K_S(cr-flow)	0.69
L/D_s	123	S_{eff}/P_E	-0.31	K_V	9.386E+05
Wave Modelling		Wave Sheet Name		K_L	6.238E+05
Scatter Hs-Tp		Wave Template		$K_{V,S}$	7.500E+04

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.

Free Span Scenario

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. Note, not in contrast to an uneven seabed.

The following parameters are to be given:

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

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

Response Data

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

- **User Defined** All values specified by user
- **RP-F105 Span** Recommendations according to DNV-RP-F105
- **Pinned-pinned** Classical pinned-pinned boundary conditions
- **Pinned-fixed** Classical pinned-fixed boundary conditions
- **Fixed-fixed** Classical 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. /3/, /4/.

If the “Calculation Options” is set as “Multi-mode”, the “User Defined” data needs to be input from the “Multi-mode” worksheet. More information on the “Multi-mode” option is presented in chapter 5 MULTI-MODE ANALYSIS.

The parameters in the “Response Data” section are described below:

f_o(in-line)	Natural frequency in the in-line direction.
f_o(cr-flow)	Natural frequency in the cross-flow direction.
A_{in}(in-line)	Maximum stress amplitude associated with the in-line mode shape given a maximum deflection of one pipe outer diameter, 1D.
A_{cr}(cr-flow)	Maximum stress amplitude associated with the cross-flow mode shape given a maximum deflection of one pipe outer diameter, 1D.
λ_{max}	Equivalent stress amplitude used in the force model.
δ/D	Normalised static deflection of pipe at mid-span.
S_{eff}/P_E	Normalised effective axial force (with Euler buckling load). Truncated at a compression level defined in worksheet (plots).

Soil Properties

The user selects the soil type specific to the region through which the soil damping parameters and soil stiffness are automatically updated. 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**

Damping

The soil damping parameters are defined according to the soil type and the length/diameter ratio, see DNV-RP-F105 for further information. The hydrodynamic damping parameters are also computed automatically. 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.
K_L	Lateral (horizontal) dynamic soil stiffness.
$K_{V,S}$	Vertical static soil stiffness.

3.2.3 SN-curves and safety factors

The utilised SN-curves and safety factors are defined in the below areas:

SN-Curves		Safety Factors	
F3 (seawater cp)		NORMAL	
m_1	3	Well defined	
m_2	5	η	0.50
$Log(C_1)$	11.146	γ_k	1.15
Log(C2)	14.576	$\gamma_{f,IL(inline)}$	1.10
$logN_{sw}$	6.00	$\gamma_{f,CF(cr-flow)}$	1.10
S_0 [MPa]	0.00	γ_S	1.30
SCF	1.00	$\gamma_{on,IL}$	1.10
		$\gamma_{on,CF}$	1.20
		Ψ_R	1.00

SN-Curves

A pull-down menu allows the choice between:

- **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:

m_1	Inverse slope of SN curve for $N < N_{sw}$.
m_2	Inverse slope of SN curve for $N > N_{sw}$.
$Log(C_1)$	Fatigue constant, intercept of logN curve with SN-curve with slope m_1.
$logN_{sw}$	Point at logN axis where SN-curve change slope from m_1 to m_2 (= 6 for seawater with cathodic protection, = 7 for air, = 8 for single slope curves).
S_0	Cut-off stress range, normally = 0, i.e., not applicable.
SCF	Stress concentration factors, included in the F-curves.

Safety Factors

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

- **LOW**
- **NORMAL**

- **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 defined**
- **Not well defined**

All safety factors are set automatically.

3.2.4 Calculation options and environmental modelling

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

Calculation options	Code
Single-mode	RP-F105
Return Period Values	**Directionality**
Automatic Generated	Omni-directional
Current Modelling	**Current Sheet Name**
Uc Histogram	Current Template

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

Calculation options:

FatFree offers two possibilities to perform free span analysis:

- **Single-mode** — The "Single-mode" option which is sufficient for small to moderately long spans. Typically, for spans with length to diameter (L/D) ratio less than 140, it would be sufficient to do a "Single-mode" analysis.
- **Multi-mode** — For cases of very long spans exposed to high current velocities for long duration, the multi-mode behaviour for in-line, cross-flow and cross-flow induced in-line needs to be taken into account. Typically, when the span lengths are very long, i.e., when the L/D ratio exceeds 140, the "Multi-mode" option should be used. More information about higher modes can be found in Ref. /5/.

Code:

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

Return Period Values:

A pull down menu allows the choice between:

- **Automatic Generated** Return period values (1, 10 and 100 year) are generated automatically from the specified wave and current distributions.
- **User Defined** To be specified by the user in the “Current Template” and “Wave Template” sheets.

Current Modelling:

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

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

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 become unphysical. Use of this option must be based on experience and engineering judgement.

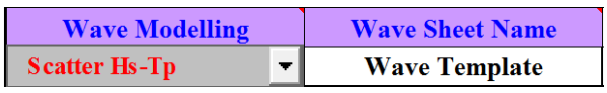
Current Sheet Name:

Different current sheets can be defined within the same workbook. Thus, all free span assessment 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 3.3 ENVIRONMENTAL DATA.

Wave Modelling:

The wave modelling option has a similar structure to the current modelling option:



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

- **No Wave** No waves.
- **Hs Weibull pdf** Weibull distribution defined by the 3 parameters.
- **Hs pdf - RPV** Weibull distribution estimated from 1, 10 and 100 year return period values.
- **Hs histogram** A series of discrete values/measurements.
- **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 become unphysical. Use of this option must be based on experience and engineering judgement.

Wave Sheet Name:

Different wave sheets can be defined within the same workbook. Thus, all free span assessment 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 3.3 ENVIRONMENTAL DATA.

Directionality:

A basic and conservative assumption made in FatFree is that wave-induced flow and current are co-linear, i.e., they act in the same direction. A pull down menu allows the choice between different ways of defining the probability of occurrence:

- **Omni-directional** All directions have the same probability of occurrence and omni-directional data is used.
- **Discrete - W dir**. Given as the discrete occurrence data for waves (wave dominated fatigue).
- **Discrete - C dir.** Given as the discrete occurrence data for current (current dominated fatigue).

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 “Omni” under 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 "Omni" under identification header "Hs Histogram" of "Wave Template" are used in calculations.

3.3 Environmental data

The environmental information is defined in the form of long term probability distributions for the current and the waves. The information can be given as:

- Directional data with a given sector probability.
- Omni-directional data, i.e., all directions are equally probable.

Note that the sum of sector probability must add up to 1.00. This information is stored in the wave and current sheets. The actual wave and current sheets used in the free span assessment is those listed under "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.

3.3.1 Current data

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

Turbulence intensity; I_c	0.05
Measurement ref. Height; z_r [m]	1.0
On-bottom roughness, z_0 [m]	4.0E-05
Number of discrete directions	16
Number of discrete current measurements (max 20)	12
Time between independent current events [hour]	0.33
Reduction factor R_c	1.09

The values to be specified are:

Turbulence intensity, I_c	Factor as specified in RP-F105.
Measurement reference height, z_r [m]	Height above seabed where the current measurements where made (regardless on how the current distribution is specified).
On-bottom roughness, z_0 [m]	Factor depending on the type of seabed, see RP-

F105.

Number of discrete directions	Number of directions in case current distributions for different directions is specified.
Number of discrete current measurements (max 20)	Number of measurements in case a discrete current measurement is used to specify the long-term distribution.
Time between independent current events [hour]	For the extreme value calculation, normally taken as 10 minutes.

In addition the user may specify the extreme (1, 10 and 100 year) values to be used in the ULS design check (instead of the extreme values calculated from the long-term distribution).

The current distribution may be given in one of the following forms:

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

Uc Weibull pdf:

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

Direction relative to geographic N	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β) Shape (β)	Scale (α)	Location (γ)	Statistics mean value	CoV	Return period (years) 1 (m/s)	10 (m/s)	100 (m/s)
Omni	1	2.180	0.199	0.082	0.259	0.330	0.53	0.60	0.67
0	0.25	2.180	0.199	0.082	0.259	0.330	0.48	0.56	0.63
30	0.25	2.180	0.199	0.082	0.259	0.330	0.48	0.56	0.63
60	0.25	2.180	0.199	0.082	0.258	0.330	0.48	0.56	0.63
90	0.25	2.180	0.199	0.082	0.259	0.330	0.48	0.56	0.63

Here the three Weibull parameters are given together with the sector probability of occurrence for different directions (relative to geographic North). In order to check the specified data, some key statistical data and the extreme values are presented.

Uc pdf - RPV:

Uc pdf - RPV	Identification header: do not change name or location to subsequent data										
Direction relative to geographic N	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β) Shape (β)	Scale (α)	Location (γ)	Statistics mean value	CoV	Return period (years) 1 (m/s)	10 (m/s)	100 (m/s)	calculated 100 year rpv
Omni	1	2.880	0.178	0.000	0.159	0.377	0.33	0.37	0.40	0.403
0	0.189	2.667	0.143	0.080	0.207	0.247	0.33	0.37	0.40	-
30	0.107	2.667	0.127	-0.020	0.093	0.491	0.19	0.23	0.26	-
60	0.06	1.942	0.098	-0.004	0.083	0.562	0.17	0.23	0.28	-
90	0.053	1.639	0.101	-0.001	0.089	0.632	0.19	0.28	0.35	-
120	0.067	1.587	0.115	0.000	0.103	0.645	0.24	0.34	0.42	-
150	0.128	2.083	0.149	-0.010	0.122	0.545	0.27	0.35	0.40	-
180	0.151	2.569	0.122	0.000	0.109	0.418	0.21	0.25	0.28	0.283
210	0.064	2.564	0.105	-0.015	0.078	0.496	0.15	0.19	0.22	-
240	0.031	1.887	0.078	-0.004	0.065	0.588	0.12	0.17	0.22	-
270	0.026	1.418	0.072	0.003	0.068	0.683	0.13	0.21	0.28	-
300	0.034	1.117	0.077	0.012	0.086	0.768	0.19	0.33	0.46	-
330	0.088	1.575	0.117	0.004	0.109	0.627	0.26	0.36	0.45	-

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 (relative to geographic North). Omni-directional data with a probability of 1.00 may also be used.

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 minus sign ("-") is given in the right column.

Note that care should be observed when using this way of specifying the long-term current distribution as it may easily lead to unrealistic current distributions and erroneous fatigue results.

Uc histogram:

Uc Histogram	Identification header: do not change name or location to subsequent data												
current velocity	Direction relative to gepgraphic North												
	omni	30	60	90	120	150	180	210	240	270	300	330	360
0.0125	0.0329	0.003	0.0029	0.0027	0.0025	0.0024	0.0027	0.0026	0.0027	0.0028	0.0029	0.0028	0.003
0.05	0.2065	0.0237	0.025	0.0182	0.0123	0.0116	0.0132	0.0182	0.0225	0.0184	0.0131	0.0133	0.017
0.1	0.2835	0.04	0.051	0.0247	0.0128	0.0102	0.014	0.0289	0.0435	0.0232	0.0094	0.0092	0.0167
0.15	0.2476	0.0333	0.0536	0.0218	0.0084	0.0066	0.0099	0.0286	0.0511	0.0164	0.0051	0.0046	0.0081
0.2	0.1452	0.0118	0.0299	0.0154	0.0064	0.0045	0.0055	0.0176	0.0381	0.0093	0.0025	0.0017	0.0026
0.25	0.0558	0.0017	0.0083	0.009	0.0038	0.0024	0.0022	0.0055	0.0163	0.0046	0.0009	0.0005	0.0007
0.3	0.0179	0.0003	0.002	0.0045	0.0022	0.0013	0.0009	0.0009	0.0031	0.0022	0.0004	0.0001	0.0001
0.35	0.0062	0	0.0004	0.0023	0.001	0.0005	0.0003	0.0001	0.0007	0.0008	0.0002	0	0
0.4	0.0025	0	0.0001	0.001	0.0006	0.0003	0.0002	0	0.0001	0.0003	0.0001	0	0
0.45	0.0011	0	0	0.0005	0.0003	0.0001	0	0	0	0.0001	0	0	0
0.5	0.0005	0	0	0.0002	0.0001	0.0001	0	0	0	0	0	0	0
0.55	0.0002	0	0	0.0001	0.0001	0	0	0	0	0	0	0	0
0.6	0.0001	0	0	0	0.0001	0	0	0	0	0	0	0	0
probability	1.000	0.114	0.173	0.100	0.051	0.040	0.049	0.102	0.178	0.078	0.035	0.032	0.048
mean value	0.129	0.115	0.134	0.149	0.138	0.123	0.116	0.130	0.146	0.126	0.097	0.087	0.093
1 year	0.425	0.225	0.275	0.375	0.325	0.275	0.275	0.275	0.325	0.325	0.225	0.175	0.225
10 year	0.575	0.325	0.375	0.525	0.525	0.425	0.375	0.325	0.375	0.425	0.375	0.275	0.275
100 year	0.625	0.325	0.425	0.575	0.625	0.525	0.425	0.375	0.425	0.475	0.425	0.325	0.325

Here the probability of occurrence for different directions (relative to geographic North) and current velocities are given. The probability of occurrence over all velocities and directions shall

sum up to 1.00. The discrete measurements are sorted into sample bins with equal current velocity range. The bin identification uses the peak current in that velocity range. In order to check the specified data, some key statistical data and the extreme values are presented.

3.3.2 Wave data

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

Peakedness parameter in wave spectrum γ;	0.00
Wave Speading Constant	8.0
Number of discrete directions	16
Number of discrete H_s values (<20)	9
Number of discrete T_p values (<20)	19
Time between independent sea-states [hour]	3
Reduction factor R_D	0.95

The values to be specified are:

Peakedness parameter in wave spectrum	Factor as specified in RP-F105.
Wave Spreading Constant	Factor as specified in RP-F105.
Number of discrete directions	Number of directions in case wave distribution for different directions are specified.
Number of discrete H_s values (<20)	Number of discrete H_s values used in case a scatter diagram is used to specify the long-term distribution.
Number of discrete T_p values (<20)	Number of discrete T_p values used in case a scatter diagram is used to specify the long-term distribution.
Time between independent sea-states [hour]	For the extreme value calculation, normally taken as 3 hours.

In addition the user must specify the parameters for the peak period estimation in case the wave distribution is made in terms of H_s only (not relevant for the H_s-T_p scatter diagrams):

$T_p = c\ H_s^n$	
factor, c (defalt = 7.5)	7.3
exponent, n (default=0.3)	0.3

The wave distribution may be given in one of the following forms:

- **Hs Weibull pdf** Weibull distribution defined by the 3 parameters.

- **Hs pdf - RPV** Weibull distribution estimated from 1, 10 and 100 year return period values.
- **Hs histogram** A series of discrete values/measurements.
- **Scatter Hs - Tp** A scatter diagram giving joint probability of discrete H_s, T_p values.

Weibull pdf:

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

Direction relative to geographic N	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β) Shape (β)	Scale (α)	Location (γ)	Statistics mean value	CoV	Return period (years) 1 (m)	10 (m)	100 (m)
Omni	1.00E+00	1.343	2.057	0.939	2.83	0.50	10.60	12.60	14.50
0	1.67E-01	1.343	2.057	0.939	2.83	0.50	8.25	10.43	12.45
15	1.67E-01	1.343	2.057	0.939	2.83	0.50	8.25	10.43	12.45
30	1.67E-01	1.343	2.057	0.939	2.83	0.50	8.25	10.43	12.45
45	1.67E-01	1.343	2.057	0.939	2.83	0.50	8.25	10.43	12.45
60	1.67E-01	1.343	2.057	0.939	2.83	0.50	8.25	10.43	12.45
75	1.67E-01	1.343	2.057	0.939	2.83	0.50	8.25	10.43	12.45

Here the three Weibull parameters are given together with the sector probability of occurrence for different directions (relative to geographic North). Omni-directional data with a probability of 1.00 may also be used. In order to check the specified data, some key statistical data and the extreme values are presented.

Hs pdf - RPV:

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

Direction relative to geographic N	Sector probability	Weibull parameters F(x)=1-exp(-((x-γ)/α)^β) Shape (β)	Scale (α)	Location (γ)	Statistics mean value	CoV	Return period (years) 1 (m)	10 (m)	100 (m)	calculated 100 year rpv
Omni	1.00E+00	1.250	2.088	0.621	2.565	0.610	11.62	14.09	16.45	
0	1.89E-01	1.020	1.499	3.227	4.71	0.31	12.35	15.59	18.83	
30	1.07E-01	1.111	1.051	2.584	3.59	0.25	7.65	9.45	11.20	
60	6.00E-02	1.399	1.000	2.634	3.55	0.19	5.87	6.85	7.74	
90	5.30E-02	1.361	1.164	3.439	4.51	0.18	7.26	8.48	9.60	
120	6.70E-02	1.250	1.757	4.887	6.52	0.20	11.53	13.77	15.87	
150	1.28E-01	1.399	1.849	3.546	5.23	0.23	10.14	11.89	13.50	
180	1.51E-01	1.274	1.679	3.291	4.85	0.25	10.23	12.21	14.08	
210	6.40E-02	1.379	1.620	4.610	6.09	0.18	9.99	11.61	13.11	
240	3.10E-02	1.325	1.445	5.695	7.03	0.14	10.20	11.84	13.36	
270	2.60E-02	1.266	1.498	6.115	7.51	0.15	10.88	12.79	14.57	
300	3.40E-02	1.093	1.656	5.931	7.53	0.19	12.62	15.63	18.55	
330	8.80E-02	1.070	1.825	4.823	6.60	0.25	13.88	17.35	20.76	

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 (relative to geographic North). Omni-

directional data with a probability of 1.00 may also be used, see comments given for "Uc pdf-RPV".

Hs histogram:

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

	Direction relative to geographic north												
H_s	omni	30	60	90	120	150	180	210	240	270	300	330	360
0.50	0.1677	0.0144	0.0129	0.01	0.0119	0.0267	0.0318	0.0053	0.0093	0.0092	0.0083	0.0113	0.0167
2.00	0.6123	0.0627	0.069	0.0534	0.0493	0.105	0.0819	0.0095	0.0267	0.0353	0.0342	0.0351	0.0502
4.00	0.1791	0.0181	0.029	0.0255	0.0187	0.0314	0.0113	0.0015	0.0039	0.0108	0.011	0.0076	0.0104
6.00	0.0322	0.0026	0.0039	0.0053	0.0047	0.008	0.0016	0.0002	0.0006	0.0018	0.0018	0.0006	0.0014
8.00	0.0073	0	0.0003	0.0015	0.0018	0.003	0.0004	0	0	0.0002	0.0001	0	0
10.00	0.0013	0	0	0.0001	0.0003	0.0008	0.0001	0	0	0	0	0	0
12.00	0.0001	0	0	0	0.0001	0	0	0	0	0	0	0	0
probability	1.00	0.10	0.12	0.10	0.09	0.17	0.13	0.02	0.04	0.06	0.06	0.05	0.08
mean valuie	2.29	2.26	2.49	2.70	2.61	2.45	1.88	1.75	1.91	2.28	2.31	2.01	2.02
1 year	11.00	7.00	7.00	9.00	11.00	11.00	9.00	5.00	7.00	7.00	7.00	7.00	7.00
10 year	13.00	7.00	9.00	11.00	13.00	11.00	11.00	7.00	7.00	9.00	9.00	7.00	7.00
100 year	13.00	7.00	9.00	11.00	13.00	11.00	11.00	7.00	7.00	9.00	9.00	7.00	7.00

Here the probability of occurrence for different directions (relative to geographic North) and H_s values are given. The probability of occurrence over all H_s and directions shall sum up to 1.00. The discrete measurements are sorted into sample bins with equal H_s range. The bin identification uses the mean H_s in that H_s range. In order to check the specified data, some key statistical data and the extreme values are presented.

Scatter diagram:

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

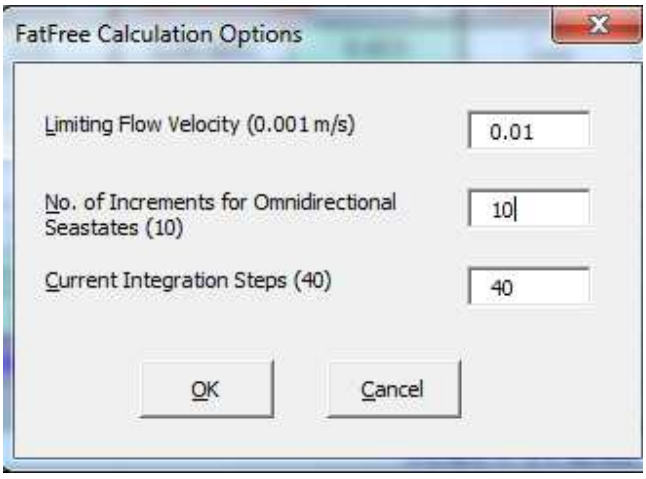
direction	omni	$E[H_s]$	CoV	σ	δ	κ	Shape (β)	Scale (α)	Location (γ)	H_s (1 year)	H_s (10 year)	H_s (100 year)
sector probability	1.00	2.828	0.503	1.421	1.280	5.285	1.343	2.057	0.939	10.60	12.61	14.50

H_s \ T_p	3	4	5	6	7	8	9	10	11	12	13	14	15	21
1	1.5E-03	8.7E-03	2.0E-02	2.6E-02	2.4E-02	1.8E-02	1.2E-02	6.9E-03	3.8E-03	2.1E-03	1.1E-03	5.6E-04	2.8E-04	9.9E-06
2	1.7E-04	3.8E-03	2.6E-02	4.9E-02	7.1E-02	7.3E-02	6.0E-02	4.1E-02	2.6E-02	1.5E-02	7.8E-03	4.0E-03	2.0E-03	5.0E-05
3	0.0E+00	9.0E-05	1.8E-03	1.1E-02	2.9E-02	4.6E-02	5.1E-02	4.3E-02	3.0E-02	1.8E-02	9.8E-03	4.9E-03	2.3E-03	2.0E-05
4	0.0E+00	0.0E+00	4.0E-05	7.9E-04	5.0E-03	1.5E-02	2.5E-02	2.8E-02	2.3E-02	1.5E-02	8.4E-03	4.1E-03	1.8E-03	9.9E-06
5	0.0E+00	0.0E+00	0.0E+00	2.0E-05	4.3E-04	2.8E-03	8.5E-03	1.4E-02	1.6E-02	1.2E-02	7.1E-03	3.4E-03	1.4E-03	0.0E+00
6	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	2.6E-04	1.7E-03	4.9E-03	7.8E-03	7.7E-03	5.2E-03	2.6E-03	1.0E-03	0.0E+00
7	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	1.7E-04	1.0E-03	2.7E-03	3.8E-03	3.2E-03	1.8E-03	7.1E-04	0.0E+00
8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	1.3E-04	6.4E-04	1.4E-03	1.6E-03	1.1E-03	4.8E-04	0.0E+00
9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	9.9E-05	3.7E-04	6.5E-04	5.8E-04	2.9E-04	0.0E+00
10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	7.0E-05	1.9E-04	2.4E-04	1.6E-04	0.0E+00
11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	4.0E-05	8.0E-05	7.0E-05	0.0E+00
12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	2.0E-05	3.0E-05	0.0E+00
13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-06	0.0E+00
14	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Here the probability of occurrence for different H_s - T_p values are given for each direction separately or as omni-directional (as shown above). The probability of occurrence over all wave heights (H_s) and wave periods (T_p) for each direction shall sum up to 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.

3.4 Calculation options

The user can chose to modify 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:

- Number of increments for omni-directional sea-states: specifies the number of divisions between 0 and 90º for the omni-directional current and waves.
- Limiting wave flow velocity: if the wave velocity is below this value then the wave effect is ignored completely (current only applied).
- Current integration steps: specifies the number of steps the current distribution is divided into (for numerical purposes).

The recommended default values are shown in brackets.

The applicability limits for the approximate response quantity model from DNV-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 prevent the calculations to be done.

- 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)

4 VIEWING RESULTS

4.1 Numerical results

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

FATIGUE LIFE	
In-line (Response Model)	1.93E+02 yrs
Cross-Flow	2.54E+03 yrs
In-line (Force Model)	5.69E+06 yrs
In-line (Combined)	1.93E+02 yrs

The design fatigue life for the in-line mode is a combination of the response model and the force model.

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

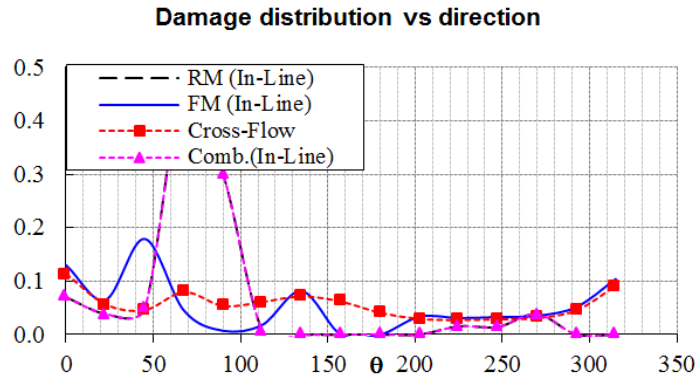
DYNAMIC STRESS [MPa]					
Cross-flow			Inline		
	Peak	Von Mises		Peak	Von Mises
σ_x(1 year)	10.9	126.8	σ_x(1 year)	8.9	55.9
σ_x(10 year)	12.0	127.8	σ_x(10 year)	9.3	56.3
σ_x(100 year)	13.4	129.1	σ_x(100 year)	9.7	56.7

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.

4.2 Graphical results

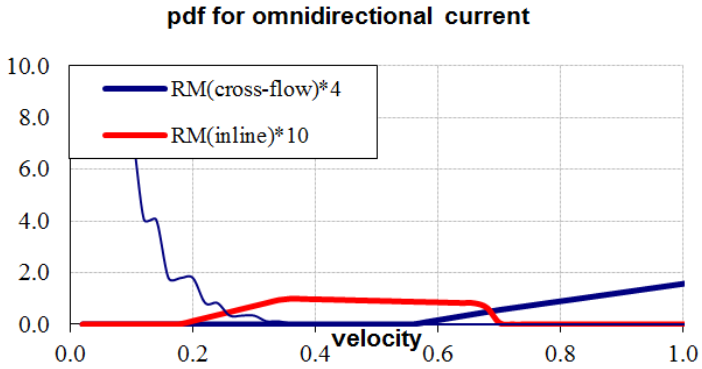
After completing the calculation the graphs are updated automatically. The results are normalised with the exception of the α-KC-VR chart. (α is the ratio of current velocity to total flow velocity, KC is the Keulegan-Carpenter number and VR the reduced velocity.)

Damage distribution vs. direction



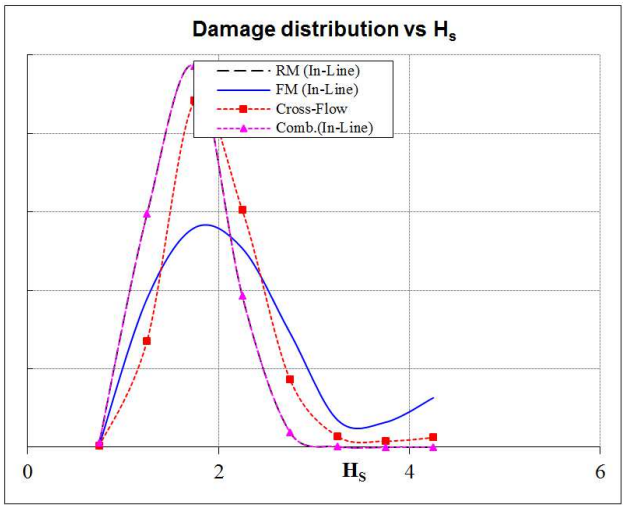
The "Damage distribution vs. direction" chart shows the contribution each direction relative to geographic North has to the individual fatigue components, i.e., in-line response model, in-line force model, combined in-line fatigue life and cross-flow fatigue life.

Pdf for omnidirectional current



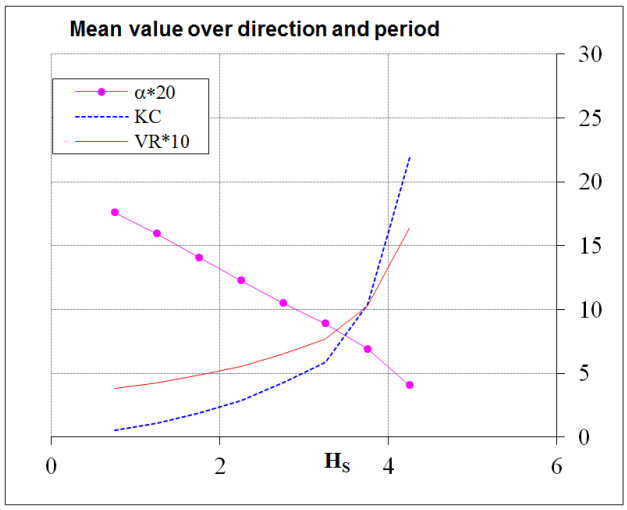
The "pdf for omni-directional current" chart indicates the likelihood of cross-flow or in-line motion occurring from the omni-directional current flow alone. The effect of waves can be evaluated by adding the wave induced flow velocities to the long-term current probability density function in the figure. Safety factors have been included.

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.

4.3 Printing results

All the sheets have been set up to allow simple print-out of input and results. To print from the "MAIN" sheet, click on “PRINT RESULTS”. To print from the scatter diagram sheets the user should use the Microsoft Excel print command.

5 MULTI-MODE ANALYSIS

5.1 General

The theoretical background for the multi-mode analysis can be found in Ref. /5/. The software usage is very identical for “Multi-mode” and “Single-mode” calculation options, only with a few exceptions. Additional data such as frequencies, unit stress amplitudes are required for the “Multi-mode” calculation option. These can be either computed based on the beam theory estimates or can be provided as user defined input, based on FE-analyses. Options are also available to specify the mode shapes and eigen-frequencies for the higher order modes, and FatFree computes the fatigue damage along the entire span length and outputs the lowest fatigue life location.

5.2 Multi-mode worksheet description

The “Multi-mode” worksheet is activated if the “Calculation Option” is set to “Multi-mode” in the “MAIN” sheet:

Template for Modelling the multiple modes for long free spans

Description: This is a template for specifying the mode shapes and frequencies of long free spans, where higher order modes could potentially be excited.

Mode shape data: Direct mode shape input

Response data

Parameter	First mode	Second mode	Third mode	Fourth mode
f_0(inline)	0.759	2.049	4.097	6.146
f_0(cr-flow)	1.229	2.137	4.274	7.272
A_{IL} (inline)	0	0	0	0
A_{CF} (cr-flow)	0	0	0	
λ_{max}	497	497	497	497

Direct mode shape input

Number of discrete points

	Mode 1	Mode 1	Mode 2	Mode 2	Mode 3	Mode 3	Mode 4
X-coordinate	Inline	Cross-flow	Inline	Cross-flow	Inline	Cross-flow	Inline
X	Y_{IL1}/Y_{MAXIL1}	Y_{CF1}/Y_{MAXCF1}	Y_{IL2}/Y_{MAXIL2}	Y_{CF2}/Y_{MAXCF2}	Y_{IL3}/Y_{MAXIL3}	Y_{CF3}/Y_{MAXCF3}	Y_{IL4}/Y_{MAXIL4}
0.000	0.000	0.005	0.001	0.005	0.001	0.006	0.001
2.500	0.000	0.005	0.000	0.005	-0.001	0.005	-0.003
5.000	-0.003	0.003	-0.009	-0.001	-0.016	-0.006	-0.025
7.500	-0.005	0.000	-0.010	-0.006	-0.010	-0.010	0.002
10.000	0.044	0.043	0.122	0.111	0.232	0.208	0.375
12.500	0.196	0.192	0.465	0.452	0.735	0.715	0.935
15.000	0.408	0.404	0.819	0.812	1.000	1.003	0.830
17.500	0.631	0.629	0.996	0.999	0.745	0.765	0.003

Two different options are available, namely:

- Single location analysis.
- Direct mode shape input

The “Response Data” field needs to be input, if the “Response Data” has been set as “User Defined” in the “MAIN” sheet. If the “Response Data” is set as “DNV-RP-F105”, the fields under “Response Data” section of “Multi-mode” sheet are automatically updated based on simplified beam theory based estimates.

5.3 Single location analysis

As for the single mode case two distinct possibilities arise, 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"	• Based on FE analysis. 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.	• Maximum accurate analysis. • More runs may be required to identify the location of the lowest fatigue life.

When the "Response Data" in the "Main" sheet is selected not to be "User Defined" (e.g., "RP-F105 Span") then the "Response data" fields in the "Multi-mode" sheet will appear in green background as shown below:

Mode shape dat | Single location analysis

Response data

Parameter	First mode	Second mode	Third mode	Fourth mode
f_0(inline)	0.759	2.049	4.097	6.146
f_0(cr-flow)	1.229	2.137	4.274	7.272
A_{IL} (inline)	88	271	543	814
A_{CF} (cr-flow)	94	292	584	
λ_{max}	497	497	497	497

The green background indicates that these fields are automatically updated.

When the "Response Data" in the "Main" sheet is selected to be "User Defined", then the "Response data" fields will appear in white background as shown below:

Mode shape dat	Single location analysis

Response data

Parameter	First mode	Second mode	Third mode	Fourth mode
f_0(inline)	0.759	2.049	4.097	6.146
f_0(cr-flow)	1.229	2.137	4.274	7.272
A_{IL} (inline)	88	271	543	814
A_{CF} (cr-flow)	94	292	584	
λ_{max}	497	497	497	497

The white background indicates that these cells need to be filled in manually.

The “Single location analysis” option can be used along with the “Span Runs” option discussed in chapter 6 ASSESSMENT OF SEVERAL SPAN CASES.

5.4 Direct mode shape input

The mode shapes and eigen-frequencies are given as input:

Direct mode shape input

Number of discrete points	21						
	Mode 1	Mode 1	Mode 2	Mode 2	Mode 3	Mode 3	Mode 4
X-coordinate	Inline	Cross-flow	Inline	Cross-flow	Inline	Cross-flow	Inline
X	Y_{IL1}/Y_{MAXIL1}	Y_{CF1}/Y_{MAXCF1}	Y_{IL2}/Y_{MAXIL2}	Y_{CF2}/Y_{MAXCF2}	Y_{IL3}/Y_{MAXIL3}	Y_{CF3}/Y_{MAXCF3}	Y_{IL4}/Y_{MAXIL4}
0.000	0.000	0.005	0.001	0.005	0.001	0.006	0.001
2.500	0.000	0.005	0.000	0.005	-0.001	0.005	-0.003
5.000	-0.003	0.003	-0.009	-0.001	-0.016	-0.006	-0.025
7.500	-0.005	0.000	-0.010	-0.006	-0.010	-0.010	0.002
10.000	0.044	0.043	0.122	0.111	0.232	0.208	0.375
12.500	0.196	0.192	0.465	0.452	0.735	0.715	0.935
15.000	0.408	0.404	0.819	0.812	1.000	1.003	0.830
17.500	0.631	0.629	0.996	0.999	0.745	0.765	0.003
20.000	0.823	0.823	0.901	0.911	0.074	0.095	-0.798
22.500	0.952	0.955	0.542	0.553	-0.624	-0.614	-0.814
25.000	1.000	1.005	0.021	0.028	-0.933	-0.928	-0.035
27.500	0.959	0.964	-0.507	-0.503	-0.665	-0.656	0.778
30.000	0.835	0.839	-0.882	-0.879	0.017	0.036	0.832
32.500	0.647	0.649	-0.999	-0.990	0.706	0.725	0.069
35.000	0.425	0.425	-0.840	-0.823	0.999	1.005	-0.788
37.500	0.218	0.217	-0.509	-0.486	0.785	0.769	-0.967
40.000	0.057	0.056	-0.153	-0.131	0.285	0.260	-0.446
42.500	-0.004	0.001	0.006	0.013	0.000	-0.003	-0.019
45.000	-0.004	0.002	0.010	0.012	-0.017	-0.008	0.026
47.500	0.000	0.005	0.001	0.005	-0.002	0.005	0.005
50.000	0.000	0.005	-0.001	0.005	0.001	0.006	-0.001

FatFree computes the fatigue damage along the entire span length and outputs the lowest fatigue life location. The "Response Data" needs to be set as "User Defined" in the "MAIN" sheet, to make use of this option.

The values to be specified are:

Number of discrete points	Specify the number of the discrete points at which the mode shape is defined.
X-coordinate	Specify the x-coordinate (x-axis is defined along the span length) and the dimensional value (in metres).
Y/Y_{max} coordinate	Defines the mode shape. The normalised value, i.e., the displacement (Y) at the given X-coordinate, which is normalised by the maximum displacement (Y_{max}) needs to be specified. Here Y_{max} is the maximum displacement over the entire span length for the given mode shape.

The "Response Data" section for the "Direct mode shape input" looks like this:



Response data

Parameter	First mode	Second mode	Third mode	Fourth mode
f_0(inline)	0.759	2.049	4.097	6.146
f_0(cr-flow)	1.229	2.137	4.274	NA
A_{IL} (inline)	88	271	543	814
A_{CF} (cr-flow)	94	292	584	
λ_{max}	497	497	497	497

Only the eigen-frequencies for the different mode shapes need to be specified as user input.

The "Direct mode shape input" option cannot be used along with the "Span Runs" option discussed in chapter 6 ASSESSMENT OF SEVERAL SPAN CASES.

6 ASSESSMENT OF SEVERAL SPAN CASES

6.1 General

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 "Span runs" sheet press on the "MAIN" sheet:



"Several span case analysis" is available for both Single-mode and Multi-mode options. The following rules apply when selecting the multiple span analysis:

Calculation option	Property
"Single-mode"	• "Response Data" can be "User Defined" implying FE-based input (i.e., frequencies and unit stress amplitudes for different span cases) can be given in the "Span runs" sheet. • "Response Data" can be "RP-F105", "pinned-pinned", "pinned-fixed" or "fixed-fixed", implying beam theory-based formulation can be used for calculating frequencies and unit stress amplitudes for different span cases.
"Multi-mode" : • "Single location analysis"	• "Response Data" can be "User Defined" implying FE-based input (i.e., frequencies and unit stress amplitudes for different span cases) can be given in the "Span runs" sheet. • "Response Data" can be "RP-F105", "pinned-pinned", "pinned-fixed" or "fixed-fixed", implying beam theory-based formulation can be used for calculating frequencies and unit stress amplitudes for different span cases.
"Multi-mode" : • "Direct mode shape input"	• Currently, the mode shape can be defined for only one span case at a time. Hence, the "Span Runs" option with different span cases is not permitted.

Some data, such as the environmental data, the SN-curves and the safety class (factors), cannot be varied during the several span case analyses. If for example, different environmental data are to be specified, the different sets of spans with identical environmental data must be assessed separately. After having calculated one set of data, the new environmental data have to be specified on the main sheet and the next set of spans calculated.

In general all input, which varies from one span to the other and which is not given explicitly on the "Span Runs" sheet, requires that separate data sets are prepared where this input is kept constant. Then each data set may be stored on its own "Span Runs" sheet, and the relevant data on the "MAIN" sheet is updated before each of these "Span Runs" sheets are updated/calculated.

6.2 “Span Runs” for non-“User Defined” response data

To analyse many different span cases and vary more than just the span length the "Span Runs" multiple span analysis button should be clicked on the “MAIN” sheet. A new sheet will be generated containing the information from the “MAIN” sheet listed along the first row. The information refers to the first span to be analysed. If a "Span Runs" sheet has already been generated it will be overwritten. To avoid losing results, the old "Span Runs" sheets should be renamed before commencing with the several span case analyses.

To generate more spans the first row of data can be copied as many times as required. The data can then be edited accordingly. Clicking the "CALCULATE" button will run the calculation for all the spans, and the results printed onto the sheet.

The frequencies and unit stress amplitude are calculated based on the “Response Data” option set in the “MAIN” sheet.

The user input defined by pull-down menus and push buttons on the “MAIN” sheet cannot be changed from span to span on the sheet. It must be set on the MAIN sheet before the calculations are initiated by the "CALCULATE" button.

To reduce the process time select the “Turn off screen updating” option.

6.3 “Span Runs” for “User Defined” response data

The methodology is identical with section 6.2. The only difference is that the frequencies and unit stress amplitude are provided as user input (based on FE analyses), since the “Response Data” option is set as “User Defined” in the “MAIN” sheet.

7 REFERENCES

/1/ DNV-RP-F105, “Free Spanning Pipelines”, February 2006.

/2/ FatFree Verification Document, DNV Report No 2013-0805, Rev.00, June 2013.

/3/ 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.

/4/ 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.

/5/ 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.