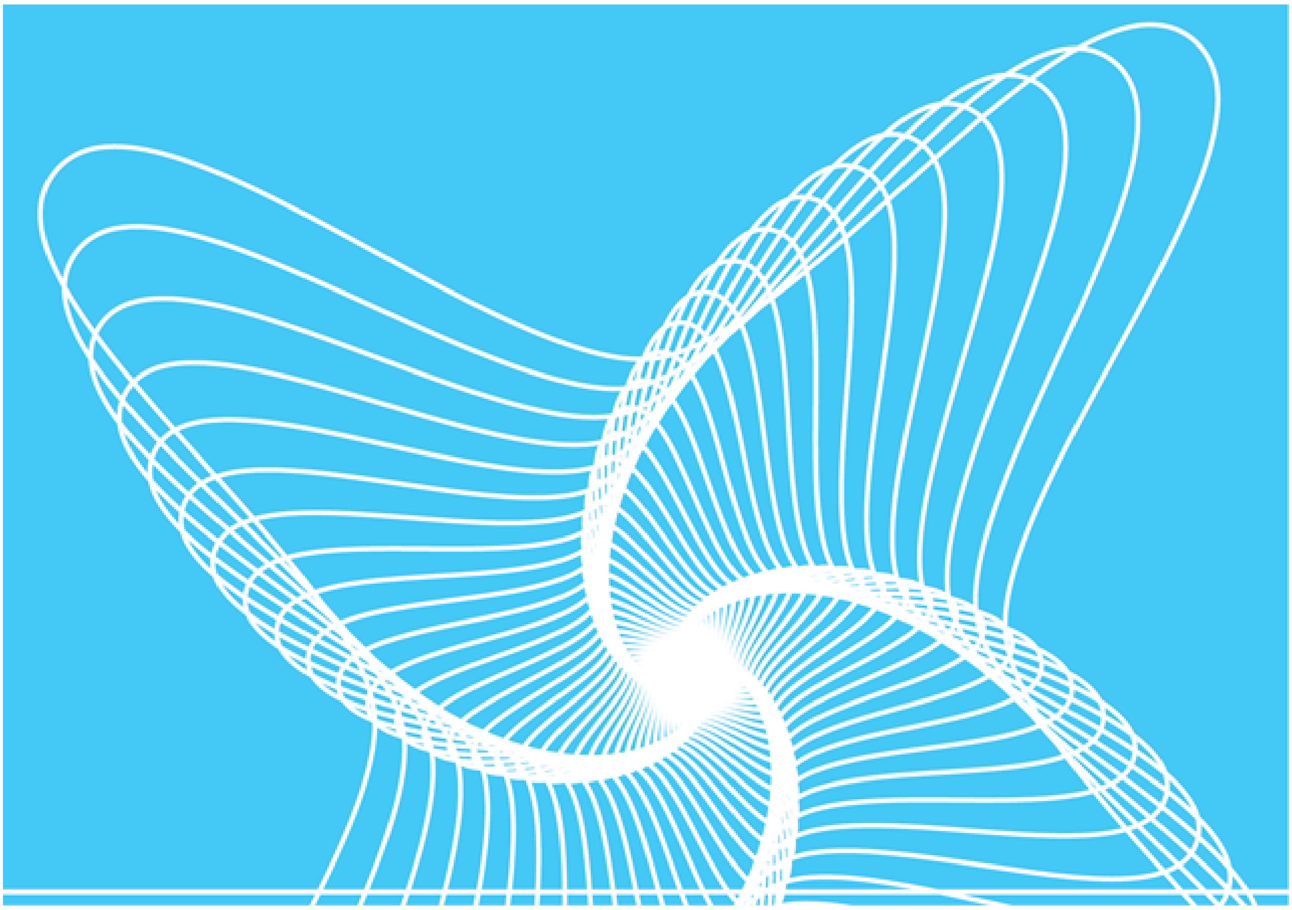
SESAM USER MANUAL

# STOFAT

## Fatigue Damage Calculation of Welded Plates and Shells

Valid from program version 4.1-00



SAFER, SMARTER, GREENER

Sesam User Manual

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# 1 Introduction

## 1.1 General

Stofat is an interactive postprocessor performing stochastic fatigue calculations, and time domain analysis based on rainflow counting of welded shell and plate structures. The fatigue calculations are based on responses given as stress transfer functions. The stresses are generated by hydrodynamic pressure loads acting on the model. These loads are applied for a number of wave directions and for a range of wave frequencies covering the necessary sea states, or on time domain. The loads are applied to a finite element model of the structure whereupon the finite element calculation produces results as stresses in the elements. Stofat uses these results to calculate fatigue damages at given points in the structural model.

A brief overview of the program features is given in Chapter 2 of the present manual. Chapter 3 outlines shortly the use of Stofat and the execution is described in Chapter 4. The interactive commands are presented in Chapter 5.

Tutorial examples are given Appendix A. A description of load and response modelling is given in Appendix B. The fatigue strength calculation method used in Stofat is described in Appendix C. Finite elements implemented in Stofat and definition of fatigue check points are thoroughly described in Appendix D. Pull down menus and dialogue boxes of the graphic input mode are shown in Appendix F.

## 1.2 Stofat in the Sesam System

Stofat is an integrated part of the Sesam system of programs. Figure 1.1 shows the position of Stofat within the Sesam suit of programs. Shell and solid types of structures modelled by the Sesam preprocessors and subjected to hydrodynamic loading may be analysed using Sestra, which in turn creates a Results Interface File. As depicted in figure 1.2 Stofat reads this interface file and produces a database file. Model data and element stresses are transferred to Stofat and used in the calculation of fatigue damages. Note that the format of the Results Interface File must be direct access (.SIN), otherwise Prepost must be used to convert the formatted (.SIF) or unformatted (.SIU) file to a direct access (.SIN) file.

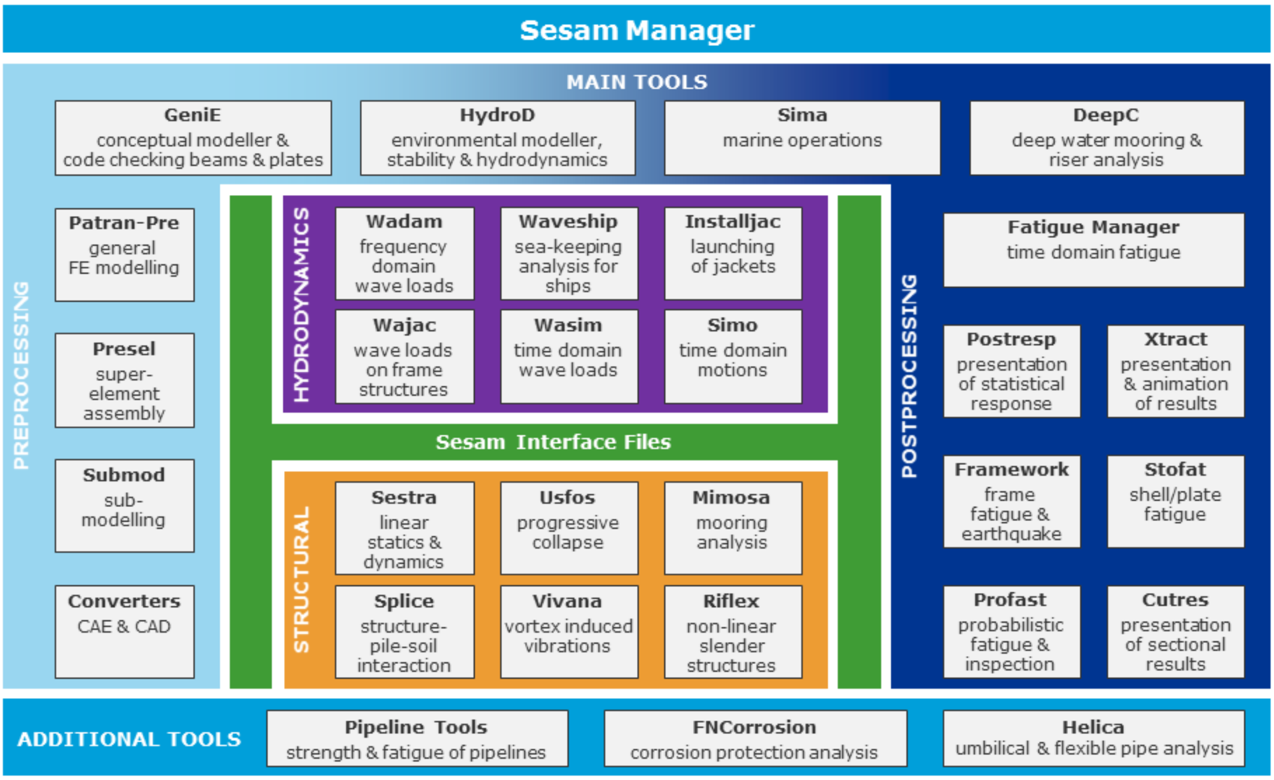


Figure 1.1: Stofat in the Sesam System

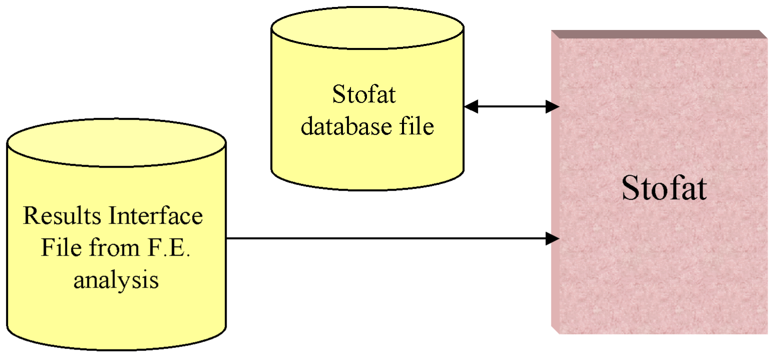


Figure 1.2: Stofat Environment

# 2 Features of Stofat

## 2.1 Analysis Capabilities

Stofat performs stochastic fatigue analysis on structures modelled by 3D shell and solid elements and assesses whether the structure is likely to suffer failure due to the action of repeated loading. The assessment is made by an SN-curve based fatigue approach accumulating partial damages weighted over sea states and wave directions or by analysis of a time domain analysis based on rainflow counting methodology. The program delivers usage factors representing the amount of fatigue damage that the structure has suffered during the specific period. The loads must be computed from a hydrodynamic analysis using a stochastic or time-domain approach. A stochastic approach implies that the computed loads are ‘complex’, comprising real and imaginary components. Stofat may also account for the effect of static stresses from still water load cases in the fatigue assessment.

From version V4.1 analysis can be performed on any units system. Previous versions would only be correct if the analysis was carried out in $N/m^2$. Results file could be in any other system but the user should transform stresses into $N/m^2$ using the features defined in command DEFINE SHELL FATIGUE CONSTANTS.

Current version identifies the results file units and transforms SN-curves in accordance.

## 2.2 Environment Loading

### 2.2.1 Wave Loading

The wave spectra are different types of wave load spectra. There are four different standard wave spectra available. The wave spectra are:

- Pierson-Moskowitz with input of the significant wave height $H_S$ and the zero up-crossing period $T_Z$.
- Jonswap with input of either the significant wave height $H_S$, the zero up-crossing period $T_Z$ and the parameters $\gamma$, $\sigma_A$ and $\sigma_B$.
- General Gamma, with input of the significant wave height $H_S$, the zero up-crossing period $T_Z$ and the parameters $l$ and $n$. When $l$ = 5 and $n$ = 4, the general gamma spectrum will correspond to a Pierson-Moskowitz spectrum.
- Torsethaugen, with input of the significant wave height $H_S$ and the period of the dominating spectral $T_P$, is a double peak spectral model for ocean waves described for locally fully developed sea states. For this model it is assumed that ocean waves at a location can be divide into two main parts; wind sea generated by the local wind and swell sea where waves are entering in to the location from other areas.

In addition the double peaks, six parameters Ochi-Hubble spectrum and the ISSC (International Ship and Offshore Structure Congress) spectrum are available. The Ochi-Hubble spectrum can be used to model double peaks present in a wave energy density, e.g. low frequency swell along with high frequency wind generated waves, and may represent almost all stages of development of a sea in a storm. The ISSC spectrum is a single peak spectrum with input of the significant wave height $H_S$ and the mean period $T_1$.

### 2.2.2 Wave Energy Spreading Function

The wave energy spreading functions are used when statistical calculations are required for short crested sea, i.e. if the user wants to take into account other directions than the current main wave direction.

The wave energy spreading function may be a $\cos^n(\theta)$ where $n$ is an integer value, i.e. $\cos^2(\theta)$, $\cos^3(\theta)$ etc. The function value is not directly the $\cos^n(\theta)$ value, but the integral of the function from $-\Delta\theta/2$ to $+\Delta\theta/2$.

A user specified spreading function is typed in with the relative directions and the corresponding weights.

When a wave spreading function based on a cosine function is printed, displayed or plotted, the program will ask for which relative spacing to use in the presentation.

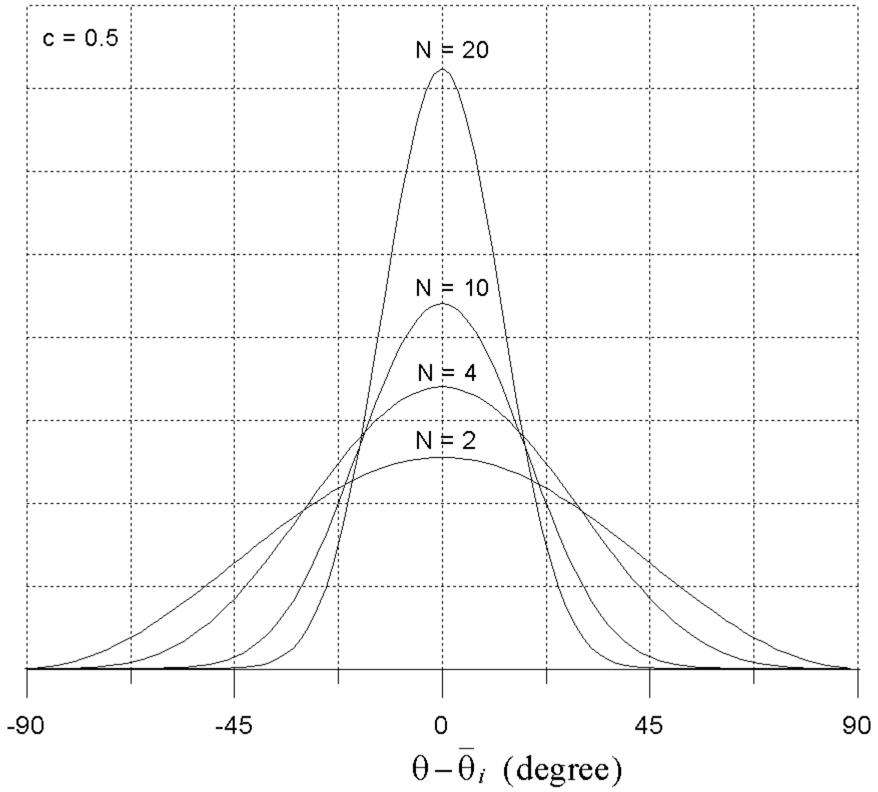


Figure 2.1: Wave spreading functions for different values of the cosine power N

### 2.2.3 Wave Statistics

The wave statistics model describes the sea state conditions during a long term period and consists of mainly zero up-crossing periods $T_Z$, significant wave heights $H_S$ and their probability of occurrence. These values may be given by specifying a scatter diagram directly. The wave statistic models are given names and may be assigned to correct wave direction independently of each other. The scatter diagram type offered is a $H_S$, $T_Z$ diagram where the probability of each non-zero 'box' in the diagram must be specified. The diagram may be identical for all wave directions, or it may be wave direction dependent. The ISSC scatter diagram is a $H_S$, $T_1$ (mean period) diagram associated with ISSC wave spectrum type.

If the wave statistics has been defined through an "all parameter scatter diagram", all necessary parameters are given through the CREATE WAVE-STATISTICS command, and hence a wave spectrum shape shall not be assigned to the wave statistics. The wave statistics may be printed. Neither display nor plot capabilities are available.

### 2.2.4 Wave Direction Probability

This defines the probability of occurrence for each main wave direction specified in the hydrodynamic analysis. The data is required in order to calculate the contribution of each main wave direction to the gross fatigue damage.

## 2.3 Stochastic Fatigue Calculations

A stochastic fatigue analysis requires that a linearised frequency domain hydrodynamic analysis (Wadam) followed by a quasi-static structural analysis (Sestra) is executed first. Harmonic waves of unit amplitude at different frequencies and directions are passed through the structure and generate a set of stress transfer functions which are read into Stofat through the Result Interface File and used in the long term stochastic fatigue calculations.

The long term fatigue calculation is based directly on a scatter diagram where Rayleigh distributions of the stress ranges are assumed and takes response spectrum and SN-curves as input. Usage factors indicating the extent of fatigue damage are calculated and printed.

The long term fatigue calculation may also be based on generation of stress time series by Fast Fourier Transform (FFT) from stress auto spectrum, i.e. rainflow cycle counting in the time domain. This option is turned on by the command DEFINE FATIGUE-RAINFLOW-COUNTING.

Static stresses from still water load cases may be accounted for in the fatigue evaluation by the command DEFINE STATIC-LOAD.

## 2.4 Time Domain Fatigue Calculations

Almost intuitively, fatigue can be understood as the weakening of a given structural component by application of a repeatedly applied cyclic loads. It has a progressive and localized effect, usually computed and commonly designated as "damage".

Stofat's current version only supports time domain fatigue damage calculations for selected elements and and hotspots.

A stress time history will present an evolution of the stresses along time, where cyclic behavior might not be present. Without a measure of the number of cycles no fatigue damage can be computed. To circumvent this problem, engineers come up with an algorithm "rainflow counting". This algorithm reduces a spectrum of varying stress into a set of simple stress reversals. The rainflow counting algorithm implemented is presented in [10].

Stresses are retrieved from a results file for the required stress result points. A time domain fatigue analysis requires a direct time integration with arbitrary time variating load (Wasim), using HydroD as pre-processor.

A dynamic analysis in (Sestra) is run prior to a Stofat analysis. Currently Stofat only supports element selection analyses with the possibility of selecting groups of fatigue points within selected elements. For each fatigue point a stress time history is retrieved and correspondent principal stress computed for each time instant.

Time domain fatigue analysis in Stofat comprises three main steps: peaks and valleys identification, stress range calculations and damage computations. Peaks and valleys are computed by analyzing the slopes by three consecutive points. This method skips any peak or valley that could be located on the first or last time instant of the time series. Stress range calculations are based on [10], presented as in accordance with algorithm 2. Damage calculations, are as usual, dependent on the definition of the SN curve, namely the number of slopes defining the SN curve.

It is also possible to establish which direction to take into consideration by using the weld normal line (WNL) feature. The stress ranges are then obtained by using a rainflow counting algorithm on the principal stress time series.

Current Stofat version only allows to perform calculations for thin shell elements FQUS(24) and FTRS(25) when a Weld Normal Line is defined. If the elements are thick shell SCQS(28) and SCTS(26), the same procedure will be applied if the stress representation is two-dimensional. If the Weld Normal Line is not defined, fatigue calculations will be skipped, and a message is provided. Not including the directional effect provided by the Weld Normal Line might leads to a conservative analysis. Results will be conservative because the calculation will account for principal stresses from all directions, and moreover will include spurious principal stresses perpendicular to the element plane (principal stresses close to zero), neglecting negative principal stress values if both principal stresses are negative. Including the Weld Normal concept will remove the near-zero principal stresses perpendicular to the finite element plane. For more information, and how to apply the Weld Normal Line concept, please check section B.7.

If intended to keep the planar stress state, then it is advised to use the weld normal line concept (WNL) and the results will be the same as if the planar stress plane was considered.

The same technique can be used to compute the planar (two-dimensional principal stresses) by setting the stress sector angle to 90 °.

Previous Stofat version (V4.0-03) produces a fatigue damage file F1.SIF (or .SIN/SIU). Those files were created based on beam-type damage results transfer but a plate-type damage results transfer shall be implemented. Previous version of fatigue damage file could not be used. Current version will not produce fatigue damage files until further developments are carried out.

Stofat handles a maximum of 110000 time steps, where each time step is represented by a loadcase register.

During the analysis (.TMS) file will contain, as per users requirement, time history principal stresses for all selected fatigue points, sorted or unsorted stress ranges per hotspot and fatigue damage parameters. It gives information per element number, position, damage, number of cycles and etc. Summarizing, (.DMP) a dump file will contain worst damage information. with similar information.

Below, it can be seen a simple example of a time domain analysis where weld normal line option is included in order to retrieve principal stresses within a 45 °.

**EXAMPLE:**

```
FILE OPEN SIN-DIRECT-ACCESS ' ' R1
FILE TRANSFER 1 MODEL LOADS None
DEFINE TIME-HISTORY-FATIGUE-TIME TIME-SERIES-DURATION 60.0 180.0 1 1.E1
DEFINE FATIGUE-RESULTS-DUMP FILE-NAME FatDmpFile
DEFINE FATIGUE-RESULTS-DUMP TIME-FATIGUE-DAMAGE ON
DEFINE FATIGUE-RESULTS-DUMP FATIGUE-STRESS-TIME-SERIES ALL-HOTSPOTS
DEFINE FATIGUE-RESULTS-DUMP TIME-SERIES-STRESS-RANGES SORTED
ASSIGN STRESS-TYPE-K-FACTORS CURRENT 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
1.0 1.0 1.0 1.0 1.0
%
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK CENTRE-SURFACE-POINTS BOTH-SIDES CURRENT-SUPERELEMENT
CREATE WELD-NORMAL-LINE ONLY TESTWNL None NODES 2368 2370 45.0
SELECT ELEMENTS INCLUDE 2739
ASSIGN WELD-NORMAL-LINE ON TESTWNL ELEMENT DEFAULT
ASSIGN WELD-NORMAL-LINE-METHOD AREA-STRESS
%
ASSIGN SN-CURVE DEFAULT DNVC-I
%
% test print out for csv file
SET PRINT DESTINATION CSV-FILE
SET PRINT PAGE-HEIGHT 60
SET PRINT SCREEN-HEIGHT 24
SET PRINT FILE ' ' STOFAT
SET PRINT PAGE-ORIENTATION PORTRAIT
%
RUN FATIGUE-CHECK NONE NONE ELEMENT-FATIGUE-CHECK ALL YES
```

## 2.5 SN-curves

This is used to define the fatigue characteristics of a material subjected to repeated cycle of stress of constant magnitude. The SN-curve delivers the number of cycles required to produce failure for a given magnitude of stress. The SN-curve may be calculated by the program or it may be user defined. Different SN-curves may be assigned to individual elements. Default SN-curve of Stofat is DNVC-I.

Table 2.1: Library of predefined SN Curves

| | |
|---|---|
| API: | API-X and API-XP |
| DNV Older ( CN 30.7, 2005): | DNV-n, n = curve name X, I, IB, II, IIb, III, IV, |
| DNV CN-30.7-2010: | DNV2010DNV-n, n = curve name I, III, IV, |
| DNV RP-C203-2010: | 1. Curves in air named DNV2010_n-AIR,<br>2. curves for sea water, cathodic protection, named DNV2010_n-SEACP,<br>3. curves for sea water, free corroction, named DNV2010_n-SEAFC,<br>4. curves for high stregth steel in air and for sea water with cathodic protection, named DNV2010_HS-AIR, DNV2010_HS-SEACP,<br>5. curves for small diameter pipe umbilicals, base material and thickness correction DNV2010_UM-BM, DNV2010-UM-TC |
| NS3472: | Curves for sea water, cathodic protection; named NS-n-SEA, n = curve name |
| NORSOK: (DNV-RP-C203, 2001): | Curve for sea water, cathodic protection; named NO-n-S, n = curve name |
| HSE: | Curves for sea water, cathodic protection named HSE-n-CP, free corrosion named HSE-n-FC and in air named HSE-n-AI, n = curve name |
| ABS: | Curves for sea water, cathodic protection named ABS-n-CP, free corrosion named ABS-n-FC and in air named ABS-n-A, n = curve name |
| DOE (in air): | Curves in air named DOE-n, n = curve name |

The DNV-X curve, is similar to the X-curve stipulated by the American Welding Society, AWS D1.1 1972 section 10. The SN-curves calculated by the program are converted from SI base units to the current set of consistent units based on the assumption that the Young's modulus of the material corresponds to steel (with $E = 2.1 \times 10^{11} \frac{N}{m^2}$).

The user defined SN-curve requires the definition of slopes and intersection points. Three options are available:

- USER: Stress level at end of first segment is given
- LOGA: Intercept value of $logN$-axis by first line segment of SN-curve is given
- STOCHASTIC: Intercept of $logN$-axis by first line segment of mean SN-curve is given together with standard devation of $logN$.

A maximum of three slopes (and two intersection points) may be specified. A consistent set of units must be used.

## 2.6 Structural Model and Fatigue Points

Stofat utilizes the structural model information read from the Results Interface File. Before accessing Stofat, a (.SIN) file containing a complete model description of the structure and stress transfer functions of the loadings must have been generated. Stofat may handle both 32 and 64 bits Results Interface Files.

Stofat operates on first level superelements and handles one superelement at the time. A structure modelled by several first level superelements requires a new start-up of Stofat for each new superelement with opening of the (.SIN) file and transfer of the superelement data to Stofat. Several fatigue check runs may, however, be performed for each superelement.

Stofat performs fatigue checks for 3D shell and solid elements. Elements implemented in Stofat are described in Appendix D. When other elements are represented in the model, Stofat passes them without performing any fatigue damage calculation.

Fatigue assessment may be executed by performing an element fatigue check (ELEMENT-FATIGUE-CHECK option) or a hotspot fatigue check (HOTSPOT-FATIGUE-CHECK option), see command RUN FATIGUE-CHECK. The element fatigue check runs through all elements selected for the fatigue assessment and delivers one usage factor per element. The hotspot fatigue check performs fatigue assessment of specific points in the structure defined by the user and delivers one usage factor per hotspot. The hotspots may be placed anywhere inside the superelement model treated by Stofat, but must be located at or inside the borders of elements implemented in Stofat. Hotspots are generated directly in Stofat.

In an element fatigue assessment the fatigue points may be located 1) at element stress points, 2) at element surfaces, 3) at element corners or 4) at middle planes of the shell elements. The number of fatigue check points is the same as the number of stress points for the elements. For the middle plane location, the number of fatigue points is half the number of stress points. Fatigue damage is calculated for all the fatigue points and the usage factor of the point suffering most damage within an element is taken as the usage factor of the element. For further details, see Appendix D.

Calculation of the fatigue damage is based on the maximum principal stress component (real and imaginary parts) of the fatigue check point. Stresses are interpolated component by component to the fatigue check point whereupon the principal stresses are calculated and applied in the fatigue damage assessment. The stresses may be multiplied with stress concentration factors (K-factors) when applied in the fatigue calculation. For shell elements, stress type dependent K-factors may be specified for the membrane-, bending- and shear stresses and assigned to elements.

A Weld Normal (WN) line may be defined with the purpose of selecting the maximum principal stress within a given stress sector for use in the fatigue calculation and disregard principal stresses outside this sector. This facility may be useful when assessing fatigue damage at weld toes of welded structures where stresses within a sector of 45 degrees to the weld normal contribute mostly to the fatigue damage. Further details are given in Appendix B.7.

## 2.7 Long Term Response

Long term response is calculated on basis of the short term response for a given response spectrum and a scatter diagram for the sea state conditions during the long term period. The short term response spectrum is formed by the energy spectrum for a stationary sea state and the transfer function for the structure.

The print from the long term calculation includes response levels for given probability levels or return periods, defined by the user. Up to 5 levels may given. Weibull parameters of the Weibull distribution function are calculated fitting the response parameters to response levels. All of these are printed for each wave direction calculated and, if requested, with all wave directions included.

Results are given in form of table print of the response parameters and print to a vtf file for graphic presentation of results in Xtract. The following parameters may be printed: Maximum and minimum stress, return periods or probability levels, exceedances, Weibull scale and shape parameters, stress amplitude and static stress.

The response parameters may be calculated on basis of various stress components including the principal stresses, normal and shear stress components, and the von Mises equivalent stress component.

## 2.8 Analysis Results

Stofat produces usage factors expressing the extent of fatigue damage to the structure as a consequence of the applied loading. Analysis results are presented to the user in form of tabulated prints and graphic display of the usage factors. Along with the usage factors key parameters related to the fatigue check points are printed. Examples of tabulated prints of results are given in A.4.

Extended print of detailed results (dump print) is possible by executing the command DEFINE FATIGUE-RESULTS-DUMP prior to the RUN command or PRINT FATIGUE-RESULTS-DUMP after the runs have been executed if results are saved. Such print includes print of hotspot transfer functions, moments of response spectrum, damages per sea state, damages per sea directions, damages per hotspots/elements, exceedence probabilities and stress range levels. The number of pages may easily be very large and this print option should therefore be used with care.

The fatigue analysis results may be written to file (.VTF) and displayed as contour plots by Xtract, see command DEFINE FATIGUE-RESULTS-VTF-FILE and PRINT FATIGUE-RESULTS-VTF-FILE. Stresses as function of the angular frequencies may also be written to file (.VTF) by the command DISPLAY STRESS-TRANSFER-FUNCTION and displayed as 2D curve plots by Xtract.

# 3 User's Guide to Stofat

Typical steps in use of the Stofat program to perform fatigue calculations in welded shell and plate structures are given in the following sections.

## 3.1 Modelling

Create a finite element model using either of the programs Prefem, GeniE or ship modeller. The structure should be modelled in sufficient detail so that the distribution of forces within the model is correctly represented and the structural parts to be checked are adequately described. The model should also be sufficiently large to apply loads without disturbing the stress distribution in critical areas. For a structure floating in water it may be necessary to model the wet surface of the structure.

Modelling and computations in several steps of refinement may be needed to attain satisfactory model representation of critical areas, see 3.5.

## 3.2 Hydrodynamic Load

The Sesam program Wadam may be used to calculate hydrodynamic pressure loads acting on the model. Loads should be calculated for a number of wave directions and for a range of wave frequencies covering the wave statistics to be used.

See the Wadam User Manual for further information.

## 3.3 Structural Analysis

The Sesam program Sestra performs the finite element calculation and equation solution and produces results represented as stresses in the elements caused by the loads on the model.

A linear static calculation may be sufficient in cases when the structure does not have resonance frequencies within the range of wave frequencies.

If the structure may have modes of vibration that may be excited by the wave frequencies, dynamic analysis must be considered.

See the Sestra User Manual for more information.

## 3.4 Fatigue Calculation

### 3.4.1 Results File

The Stofat program reads the results from Sestra and performs the fatigue damage calculation.

The results file is identified by:

- FILE OPEN SIN-DIRECT-ACCESS prefix name item FILE TRANSFER superel name loaset

### 3.4.2 Wave Statictics

Long term wave statistics data are represented in the program as a "Scatter diagram".

A few scatter diagrams according to DNV classification note 30.7 "Fatigue Assessment of Ship Structures" (1998) are predefined in the program. Other scatter diagrams according to other specifications, or measurements may be specified by selecting CREATE WAVE-STATISTICS SCATTER-DIAGRAM. If the wave statistics has been defined through an "all parameter scatter diagram", all necessary parameters are given through the CREATE WAVE-STATISTICS command, and hence a wave spectrum shape shall not be assigned to the wave statistics.

For a sailing ship the same scatter diagram is normally used for all wave directions. For a fixed structure on a specific location, different scatter diagrams may be used for different wave directions based on local measurements. The scatter diagram to use is selected by ASSIGN WAVE-STATISTICS.

### 3.4.3 Wave Direction Probability

The main wave directions for calculation of fatigue damage are determined by the directions of the wave loads specified as input to the load calculation program (e.g. Wadam).

The probability of waves from different wave directions must be specified by selecting ASSIGN WAVE-DIRECTION-PROBABILITY and filling in the probability of waves from the different directions. The sum of probabilities for all directions must be 1.0.

For a slow moving sailing ship, the wave direction probability is typically equal for all directions. For a fixed structure, the probability may be different for different directions based on local measurements.

For a slow moving sailing ship, the wave direction probability is typically equal for all directions.

For a fixed structure, the probability may be different for different directions based on local measurements.

### 3.4.4 Wave Spreading

Real sea waves are not all moving in the same direction even within a short period of time. In Stofat a wave energy spreading function is assumed to be independent of the wave frequency. The wave energy is assumed to be spread over a set of directions +90 to -90 degrees on both sides of each main wave direction.

A typical wave spreading function is defined by selecting CREATE WAVE-SPREADING-FUNCTION COSINE-POWER.

The wave spreading function is discretised into the wave directions available and scaled such that the sum of the probabilities are 1.0.

The wave spreading function may also be specified directly as a histogram.

The wave spreading function to be used is selected by ASSIGN WAVE-SPREADING-FUNCTION.

If no wave spreading function is assigned, long crested waves are assumed.

### 3.4.5 Wave Spectrum

A short-term sea-state is characterized by a wave spectrum. This spectrum accounts for the variation of the wave energy over the frequencies in the sea-state.

The most commonly used spectrum is the Pierson-Moskowitz spectrum. The Pierson-Moskowitz spectrum applies to deep water conditions and fully developed seas.

The ISSC spectrum, recommended by the 15th ITTC (International Towing Tank Conference) is available and applies to open sea conditions and fully developed sea.

The Jonswap spectrum is also available and applies to limited fetch areas and homogenous wind fields.

The wave spectrum type to be used is selected by ASSIGN WAVE-SPECTRUM-SHAPE.

If the wave statistics has been defined through an “all parameter scatter diagram”, all necessary parameters are given through the CREATE WAVE-STATISTICS command, and hence a wave spectrum shape shall not be assigned to the wave statistics.

### 3.4.6 SN-Curve

SN curves represent material strength properties obtained from fatigue tests. The SN-curve defines the predicted number of cycles to failure N for a stress range S.

Some SN curves are predefined in the program according to DNV Classification note 30.7 and Norwegian Standard NS 3472. These S-N curves are based on mean measurement results minus 2 times the standard deviations for the experimental data. The SN-curves are thus associated with 97.6% probability of survival.

Other SN-curves may be defined by command CREATE SN-CURVE.

Each SN-curve defined by NS 3472 is established for a class of structural details according to:

- The geometrical arrangement of the detail
- The direction of the fluctuating stress relative to the detail
- The method of fabrication and inspection of the detail

The SN curve is then used directly for fatigue check of the detail without use of stress concentration factors.

SN-curves specified by DNV classification note 30.7 correspond to test results from smooth specimens having a stress concentration factor K = 1.0. These should be adjusted with the SCF for the actual geometry.

SN-curves may be assigned to individual elements by the command ASSIGN SN-CURVE.

The default SN-curve to be used in fatigue calculation is specified by DEFINE SHELL-FATIGUE-CONSTANTS DEFAULT-SN-CURVE. Note that, if the default SN-curve is changed, the new default curve is applied to all elements in the model and supersedes all previously SN-curve assignments.

Library SN-curves of Stofat are converted from SI base units to the current set of consistent units based on the assumption that the Young's modulus of the material corresponds to steel (with $E = 2.1 \times 10^{11} \frac{N}{m^2}$).

### 3.4.7 Stress Concentration Factor

Fatigue computation according to DNV Classification note 30.7 requires use of Stress concentration factors (K-factors). Stress concentration factors are dependent upon the level of detail in the model.

The geometrical stress concentration factor, denoted Kg, is specified when the structural analysis has calculated nominal stresses in the structural parts, but for a mesh too coarse to represent local stress gradients. The geometrical stress concentration factor may be estimated from the rules by experience, or from a detailed finite element computation.

When the finite element analysis is sufficiently accurate to simulate the stress gradient caused by the structural detail, the common practice is to omit the geometrical stress concentration factor, that is set it to 1.0. To achieve this the finite elements near the detail should have sizes approximately equal to the plate thickness.

A stress concentration factor due to the weld itself, denoted $K_w$, is usually taken from the rules.

For 2D shell elements, stress type dependent K-factors may be specified for the membrane-, bending- and shear stresses and assigned to shell elements. It is not possible to assign stress dependent K-factors to 3D solid elements.

Default values of the stress concentration factors are specified by the command DEFINE SHELL-FATIGUE-CONSTANTS. Values assigned to individual elements are specified by the commands ASSIGN K-FACTORS (same K-factor for all stress components) and ASSIGN STRESS-TYPE-K-FACTORS (K-factor specified for membrane-, bending- and shear stresses components).

### 3.4.8 Inclusion of Static Stresses

Static stresses due to still water loads may considered in the fatigue calculation. The effect of static stresses is accounted for by performing a possible reduction in the cyclic stress range according to procedure described in DNV Classification Notes No. 30.7, see [30]. A stress range reduction factor is calculated and applied to principal stresses before entering the SN-curve. Further details are described in Appendix B.6.

Stresses of the static load case to be applied in the fatigue analysis must be added to the SIN result interface file containing the stress transfer functions of the wave loading before being read by Stofat. If the static load case is a combination of basic static load cases, Stofat will combine the stresses of the basic load cases provided they are present on the interface file together with data type records defining the load case combination.

Static load case is accounted for by the command DEFINE STATIC-LOAD-CASE.

### 3.4.9 Use of Weld Normal Lines

DNV Classification Notes No. 30.7, see [30], prescribes that the maximum principal stress range within a sector of 45 degrees of the weld normal at the weld toe, should be used for fatigue assessment of welded structures. Fatigue damage at the weld toe is mostly caused by stresses within this sector.

The Weld Normal (WN) line facility of Stofat may be used to introduce such a stress sector in the fatigue calculation. A WN line is specified by the user together with an angle, $\alpha$, defining the extension of the stress sector. The angle $\alpha$ is counted from the WN line to the border of the stress sector and may have values between $\alpha = 0$°and $\alpha = +90$ °.

Principal stresses and principal directions are calculated on basis of component stresses at the fatigue check point. The principal stress axes are tested to be inside or outside the stress sector. The maximum stress component of the principal axes inside the sector is applied in the fatigue assessment.

A WN line must be assigned to an element or a hotspot to be applied in the fatigue calculation. A WN line is created by the command CREATE WELD-NORMAL-LINE and assigned to elements and hotspots by the command ASSIGN WELD-NORMAL-LINE. WN line concept can be applied to time domain analysis in order to select a preferencial direction when considering principal stresses calculations.

### 3.4.10 Creating Fatigue Check Points

Two types of fatigue checks may be performed by Stofat *element fatigue check* and *hotspot fatigue check*.

The element fatigue check calculates fatigue usage factors for the current selection of elements. Location of the fatigue check points within the elements is set by the command CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK. Four options are available; 1) element stress points, 2) element middle plane, 3) element surfaces and 4) element corners. In addition an option for using membrane stresses in the fatigue calculation for shell elements is available. Membrane stresses are in-plane stresses at the middle plane of the shell elements. For 3D solid elements the middle plane and membrane stress options are converted to the element stress point option.

The hotspot fatigue check calculates fatigue usage factors at individual points (fatigue points) defined by the user. A detailed description is given in Appendix D. Hotspots are created by the command CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK.

### 3.4.11 Computing Fatigue Usage Factors

The RUN FATIGUE-CHECK command performs fatigue calculation for current selection of elements when the ELEMENT-FATGUE-CHECK option is selected, and for current selection of hotspots when the HOTSPOT-FATIGUE-CHECK option is selected. ELEMENT-FATIGUE-CHECK is the default option.

Note that an element fatigue check and a hotspot fatigue check *cannot* be executed in the same run.

Each time the RUN command is repeated a different name must be specified.

A table of results may be stored on a print file, or displayed in a window by the command PRINT FATIGUE-CHECK-RESULTS.

A wireframe display of the model may be performed with usage factors annotated on the display by the command DISPLAY FATIGUE-CHECK-RESULTS.

Contour plots of the fatigue results may be displayed by the visualization program Xtract. Xtract reads a (.vtf) file containing the Stofat results. Stofat writes results to the vtf file during the run when the YES option of the command DEFINE FATIGUE-RESULTS-VTF-FILE is applied before the RUN command is executed.

## 3.5 Submodel Analysis

If fatigue sensitive areas in the structure have been identified, but uncertainties remain about stress concentration factors or stress gradients, analysis of a submodel may be useful. Submodelling is performed by the program Submod. Typical steps are:

- Make a new finite element model of the area in question
- Apply a refined mesh to represent local stress gradients of the area with sufficient accuracy

- Specify prescribed (“driven”) boundary conditions around the perimeter where the submodel is to be connected to the original model
- Run Submod to transfer displacement results from the original model into prescribed displacement along the boundary of the submodel

A finite element analysis of the submodel in Sestra and further studies in Stofat may then be performed.

For further details, see the Submod User Manual.

## 3.6 Long Term Response Calculation

In order to perform calculation of long term responses, stress components must be defined by the command DEFINE LONG-TERM-STRESS prior run execution since spectral moments of the stress components are required to be calculated during the run.

Response parameters may be printed for probability levels and return periods defined by the commands DEFINE LONG-TERM-PROBABILITY and DEFINE LONG-TERM-RETURN-PERIOD.

Table print of the response parameters is obtained by the command PRINT LONG-TERM-RESPONSE and print to the vtf file is obtained by the command PRINT FATIGUE-RESULTS-VTF-FILE LONG-TERM-RESPONSE. The command DEFINE FATIGUE-RESULTS-VTF-FILE LONG-TERM-RESPONSE prints one response parameter to the vtf file during run execution.

Print is performed for selected response parameters, wave directions and stress components. Print to the vtf file is performed for a single probability level and return period, entered in the print command.

## 3.7 Saving of Analysis Results and Limitation of Model Size to be Executed

Analysis results of Stofat may be saved in order to postprocess the fatigue results. When Stofat has been started several Stofat analyses may be carried out and results of the analyses may be postprocessed after the runs are completed provided that results are saved.

Saving of results is decided by the user in the RUN command, see Chapter 5.

If results are not saved, postprocessing will not be available with respect to dump print and print of results to the vtf file. However, such print will be generated during the analysis process if the commands DEFINE-FATIGUE-RESULTS-VTF-FILE and DEFINE FATIGUE-RESULTS-DUMP are set prior to the run.

Stofat saves principal stresses and part damage results for all sea states at all stress points of the elements included in the run. For large models this may sum up to quit a big number of data to be saved. The data base applied by Stofat has limitation in the number of data that may be stored. Saved data are stored in 10 different directories of the data base. The size of each directory has a upper limit of $256 \times 2^{20} = 268435456$ spaces.

The size limit of the data base directories puts restrictions on the size of the problem that may be handled by Stofat. For very big models it may happen that the model itself is too big to be saved in the data base directory and reading of the SIN file will fail in Stofat. However, if the model has been successfully transferred to Stofat the size limit is practically not present when fatigue results are not saved during the run but printed directly to the vtf file if required. The size limit is a function of the number of wave directions, wave frequencies, sea states and elements included in a Stofat run. Analysis results are stored in 8 data base directories (numbered from 3 to 10) and provides a maximum possible utilization of the data base capacity for a Stofat run.

The required number of results to be saved for an element is a product of the number of element stress points and the number of wave directions, wave frequencies and sea states as given below.

The number of data saved for an element in directory 3 and 4:

$$nsave_3 = npnt \times (1 + 2 \times nwdir \times nfreq) + 21$$

$$nsave_4 = npnt \times (3 + 2 \times nwdir \times nfreq) + 21$$

The number of data saved for an element in each of the directories 5 to 10:

$$nsave_{5-10} = npnt \times nsea + 15$$

where:

$npnt$ = number of stress points of the element

$nsea$ = number of sea states (= nwdir*nscpnt, in case of same scatter diagram for all wave directions)

$nwdir$ = number of wave directions

$nscpnt$ = number of points of scatter diagram

$nfreq$ = number of wave frequencies

$nsave3$ = Number data saved for each element in directory 3

$nsave4$ = Number data saved for each element in directory 4

$nsave5 - 10$ = Number data saved for each element in each of the directories 5 to 10

The number of stress points of the elements varies from 1 to 10 points depending on the element types applied, see Table D.1 in D .

The data base uses a paging system when storing data. The size of a data base page is $4096$ and the number of pages of a directory is $65536$. If the number of result data in a data block to be saved exceed the size of one page, as many pages as necessary are used for storage of the data block. Each new saved data block starts at the beginning of a new page when the data block exceeds on page in size.

Knowing the storing system of the data base, the number of elements that may be included in a Stofat run without exceeding the saving capacity may be estimated. Stofat puts analysis results into the data base in blocks element by element. When such a block occupies one data base page in size, a maximum of $65535$ elements may be included in a Stofat run supposing that no other runs have been executed in advance (one page is used for administration data). When the block occupies two data base pages in size, $32767$ elements may be included in the run, and so on.

In Table 3.1 the maximum number of elements that may be included in a Stofat run are listed as function the number of sea states, wave directions and wave frequencies. The maximum number of the elements depends also on the number of element stress points for the element types applied. In Table 3.1 all elements are assumed to have 8 stress points.

An example of how to find the maximum element capacity of a problem may be illustrated by assuming $npnt = 8$, $nwdir = 12$, $nfreq = 20$, $nscpnt = 100$. It is assumed that the same scatter diagram is applied to all wave directions which gives $nsea = nwdir \times nscpnt = 1200$. From Table 3.1 it is found that the capacities of the data base directories are $218454$ elements (column 1: $nsea = 1200$) and $65535$ elements (column 2: $nwdir \times nfreq = 240$), respectively, which, gives an upper limit of elements of $21845$ without exceeding the storage capacity of the data base.

At the commence of a run (when the run command is executed), Stofat estimates required data base space for saving results of the problem to be analysed. If the required space exceeds the storage capacity of the data base, the run is stopped and capacity limits are printed. Also, during the run execution, the program currently checks remaining free space of the data base and stops the execution when the free space left is too small to save results of the element to be analysed.

The problem size must be reduced if the saving capacity of the data base is being exceeded. This may be done by either reducing the number of sea states, wave direction or elements. The most convenient way to handle this problem is to establish suitable element sets of the model with respect to the fatigue analysis and run set by set in several fatigue check runs. Element sets can not be generated by Stofat, and must be established by the preprocessors.

When fatigue checks are split into more than one Stofat run for very large models, Stofat must be closed down and started again in order to empty the data base directories between each run. When Stofat is closed down after a run the model and analysis results of the run are saved in the STOFAT.MOD file. This file is deleted and an empty STOFAT.MOD file is opened when the NEW option is chosen in the opening sequence of Stofat. The OLD option opens the existing STOFAT.MOD file without emptying it.

When several Stofat runs are executed in a sequence of closing and restarting processes of Stofat, and an empty data base is accessed each time, the STOFAT.MOD file should be renamed prior to each restart if postprocessing of results of the various runs are necessary to perform later on (e.g STOFAT1.MOD, STOFAT2.MOD, etc.) Saved MOD files may be accessed by choosing the "Old" option of the database status in the opening sequence of Stofat. However, the MOD file that is accessed must be named STOFAT.MOD.

Table 3.1: Maximum number of elements that may be included in a Stofat run

| Number of sea states $(nsea)$ | Number of wave direction frequencies $(nwdir \times nfreq)$ | Data base pages to store results of one element | Maximum number of elements that may be included in a Stofat run |
|---|---|---|---|
| $6143 - 6654$ | $3070 - 3326$ | $13$ | $5040$ |
| $5631 - 6142$ | $2814 - 3069$ | $12$ | $5460$ |
| $5119 - 5630$ | $2558 - 2813$ | $11$ | $5956$ |
| $4607 - 5118$ | $2302 - 2557$ | $10$ | $6553$ |
| $4095 - 4606$ | $2046 - 2301$ | $9$ | $7281$ |
| $3583 - 4094$ | $1790 - 2045$ | $8$ | $8192$ |
| $3071 - 3582$ | $1534 - 1789$ | $7$ | $9362$ |
| $2559 - 3070$ | $1278 - 1533$ | $6$ | $10922$ |
| $2047 - 2558$ | $1022 - 1277$ | $5$ | $13107$ |
| $1535 - 2046$ | $766 - 1021$ | $4$ | $16383$ |
| $1023 - 1534$ | $510 - 765$ | $3$ | $21845$ |
| $511 - 1022$ | $254 - 509$ | $2$ | $32767$ |
| $255 - 510$ | $126 - 253$ | $1$ | $65535$ |
| $69 - 254$ | $83 - 125$ | $1/2$ | $131070$ |
| $127 - 168$ | $62 - 82$ | $1/3$ | $191605$ |
| $101 - 126$ | $49 - 61$ | $1/4$ | $262140$ |
| $84 - 100$ | $40 - 48$ | $1/5$ | $327675$ |
| $72 - 83$ | $34 - 39$ | $1/6$ | $393210$ |
| $63 - 71$ | $30 - 33$ | $1/7$ | $458745$ |
| All elements are assumed to have 8 stress points | | | |

# 4 Execution of Stofat

## 4.1 Files

Stofat uses the following files:

| | |
|---|---|
| Database | The database file is a direct access file that is used to keep the model and analysis results. It has the extension .mod. |
| Journal | The journal file is a log of the commands that are accepted during a Stofat session. If an existing (Old) database is opened, the journal will be appended to the corresponding old journal file. The journal file has the extension .jnl. |
| Command Input | This file is used to read commands and data into StofatṪhe default extension of acommand input file is .jnl, but this default is not used if another extension is specified. |
| Print | The print file is used to keep output from the PRINT command when the print destination is set to File or Csv File in the SET PRINT command. The extension is .lis for the SET PRINT FILE option and .csv for the SET PRINT CSV-FILE option.The purpose of the Csv File option is to print a more proper format for spreadsheets. The .csv file has separation signs (semicolons) between fields of table results.The semicolons serve as column delimiters when the file is opened inspreadsheet.<br>The print file name and settings are specified by the command SET PRINT. It is possible to use more than one print file during the same Stofat session, but only one can be open at a time. |
| Print Dump | The print dump files are generated when print details of the fatigue analysis results are turned on by the command DEFINE FATIGUE DUMP. A print fileDmp.lis with default name StofatDmp.lis is generated when print of stress transfer functions, moments of response spectrum, or fatigue damages are turned on. They may be changed by the user. Likewise a print file Pex.lis with default name StofatPex.lis is generated when print of probability exceedence levels, or stress range distributions are turned on. Note that the print options have to be turned on before the RUN command is executed to generate the print dump files. |
| Message log | The start-up heading and messages printed on the screen during the execution are written to the file stofat.mlg. |
| Plot | The plot file is used to keep output from the DISPLAY command when the display destination is set to file. The plot file name and settings is specified using the command:SET PLOT. The extension of the plot file depends on the plot format used. Several formats are available. It is possible to use more than one plot file during the same Stofat session, but only one can be open at a time. |
| Results Interface File | The Sesam Results Interface File is used for transferring data from the structural analysis program. The file consists of all modelling data of the structure and stress transfer functions generated from the hydrodynamic pressure loads acting on the model.<br>It is required that the Results Interface File is given on DIRECT ACCESS format (i.e. R#.SIN) |

| | |
|---|---|
| vtf | vtf files (extension .vtf) are written in ViewTech File (vtf) - ASCII format and are used as input files for presentation of Stofat results by Xtract. Stofat results are written to a vtf file by executing the command DEFINE FATIGUE-RESULTS-VTF-FILE. Stress transfer functions are written to a vtf file by executing the command DISPLAY STRESS-TRANSFER-FUNCTION. The commands must be executed before the RUN command is executed. The vtf files have the extension .vtf and the default name is Stofat. vtf and StofatStf.vtf, respectively. It is possible to write Stofat results to more than one vtf file during a Stofat session by changing the file name from one run to the next. Only one result type is written to the file during a run execution. |
| Long Term Response | Print of long term response parameters is accessed by the PRINT LONG-TERM-RESPONSE command. Table print of results may be generated for both element and hotspot fatigue check runs provided that long term stress components are defined prior to the runs. The print can not be executed unless long term probabilities or long term return periods are defined. A print file .lis with default name StofatLtr.lis is generated. They may be changed by the user. |

Stofat has been designed to protect the user against loss of valuable data. Thus, for some of the errors that may occur Stofat will close the database file before exiting the program. It is however not always possible to catch a program crash and close the database file properly when it happens.

If the database file has been corrupted, the information may be reconstructed by use of the journal file. It is therefore recommended to take good care of the journal files. It can also be a good idea to take backup copies of the journal and database file at regular intervals.

## 4.2 Starting Stofat

Stofat application may be run in line mode (text input mode) and/or in graphic mode (with a graphic user interface).

The graphic mode applies user interface menus. The menus are presented graphically with pulldown menus, fixed menus, push buttons, dialogue boxes, etc., which initiate program actions, or open dialogue windows for user communication.

In line mode the text input lines are interpreted directly by the program. The line mode facilities are also available in the graphic mode through a window which accept line mode input.

Stofat logs all commands given by the user independent of the mode actually used. This implies that it is possible to run Stofat with a command input file originally created from a graphic mode run. The functionality is identical in the two modes.

### 4.2.1 Starting Stofat from Manager with Result Menu

In Manager the ‘Result’ menu will be available when a Results Interface File exits for the current project. In the ‘Result’ menu Stofat is available under the selection ‘Shell fatigue STOFAT...’, see Figure 4.1. If the ‘Result’ menu is not available (“grey out”), click ‘Option/Superelement’ to specify the actual superelement.

The ‘Shell Fatigue Postprocessing’ dialogue for Stofat see Figure 4.2, has the following parameters:

Database status:

| | |
|---|---|
| New | When Stofat has not been run before, or when it is wanted to start Stofat with and empty database. |
| Old | To restart Stofat with an existing model. |
| Reconstruct | To reconstruct accumulated journal file into a new database and restart Stofat. |

Input mode:

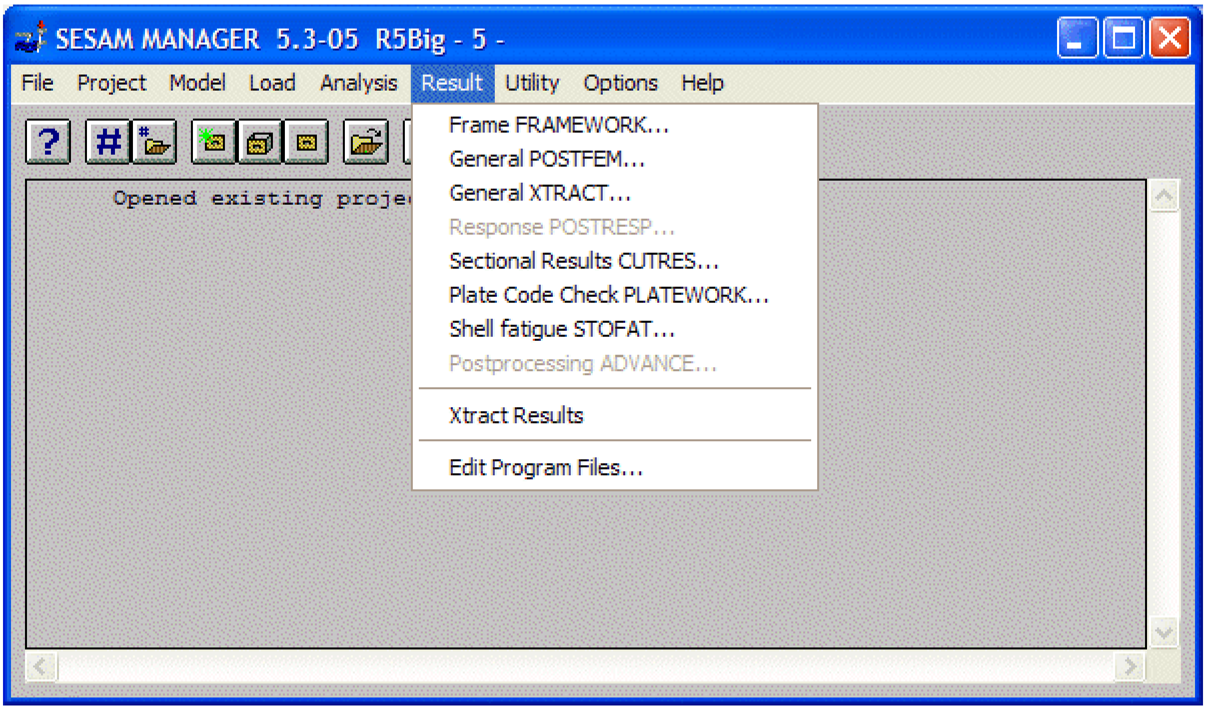


Figure 4.1: Main dialague of Manager and the Result menu

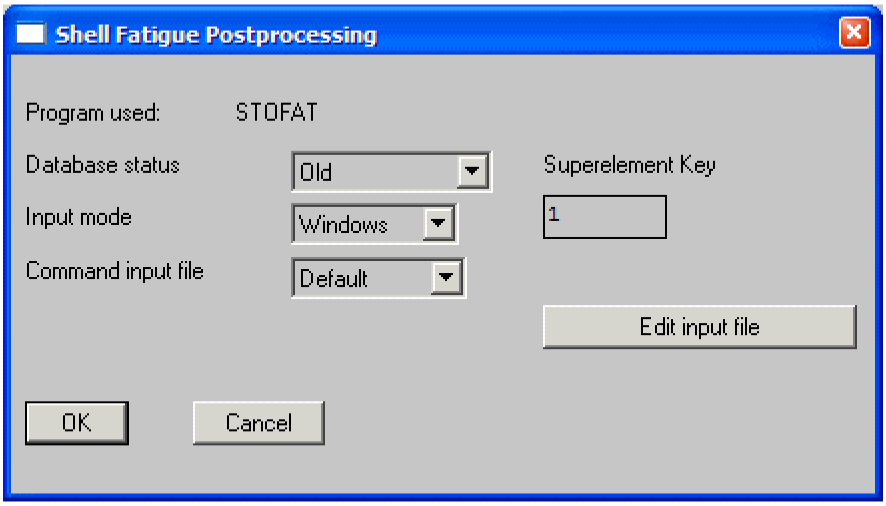


Figure 4.2: Dialogue window for Stofat

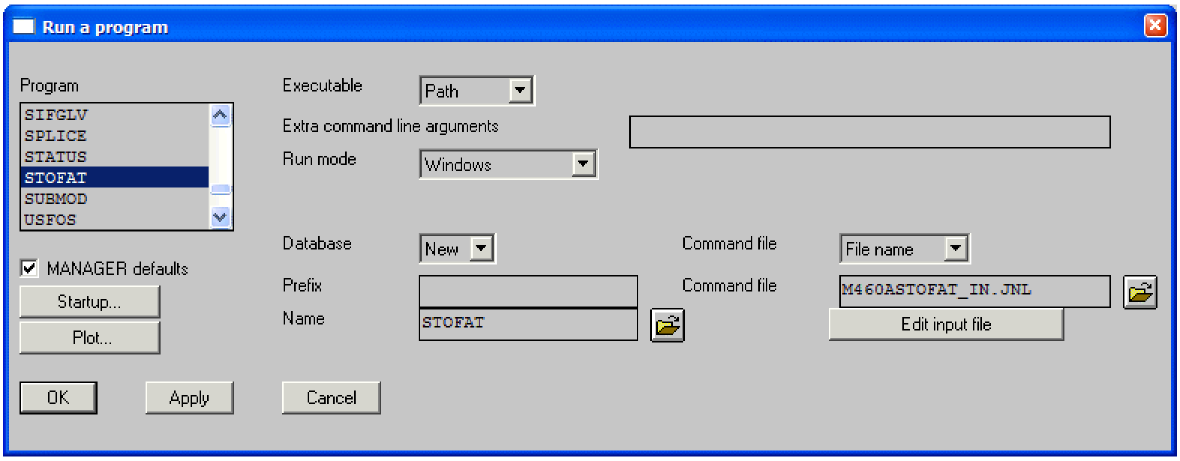


Figure 4.3: The 'Run a program' dialogue of Manager

Window The only alternative available.

Command input file:

None Stofat will be started and wait for input from the user.

Default Manager will create a few commands to make Stofat establish a model file for the current superelement.

File Name An existing journal file containing commands for Stofat should be selected. The commands in the file will be processed by Stofat when it is started.

Superelement key:

number The superelement key parameter appears/disappears when a superelement/direct analysis has been performed. A description of the parameter is given in Prepost.

### 4.2.2 Starting Stofat from Manager with Utility/Run Menu

Select 'Run. . . ' in the 'Utility' menu of Manager. The 'Run a program' dialogue appears, see Figure 4.3.

- Select Stofat in the 'Program' selection box and the program executable in the 'Executable' selection box, if alternatives are present.
- Specify the 'Run mode'. Alternatives are 'Windows' or 'Background'. If 'Background' is selected, Stofat is executed without the Stofat dialogue window appearing on the screen.
- Specify 'Prefix', 'Name' and status of the 'Database' file. Status of the database is either 'New', or 'Old', see description of the 'Shell Fatigue Postprocessing' dialogue.
- Select 'File name' and enter name of the 'Command file' for reading an existing journal file containing command lines input for Stofat. If 'None' (default) is selected, Stofat will wait for input from the user.
- Click the OK, or APPLY button to start the Stofat execution. The dialogue window of Stofat appears on the screen and Stofat may now be operated as described in this manual. Exit Stofat and the 'Run a program' dialogue of Manager appears. A new start-up of Stofat may be performed, or the session closed by clicking the CANCEL button and exit the 'Run a program' dialogue.

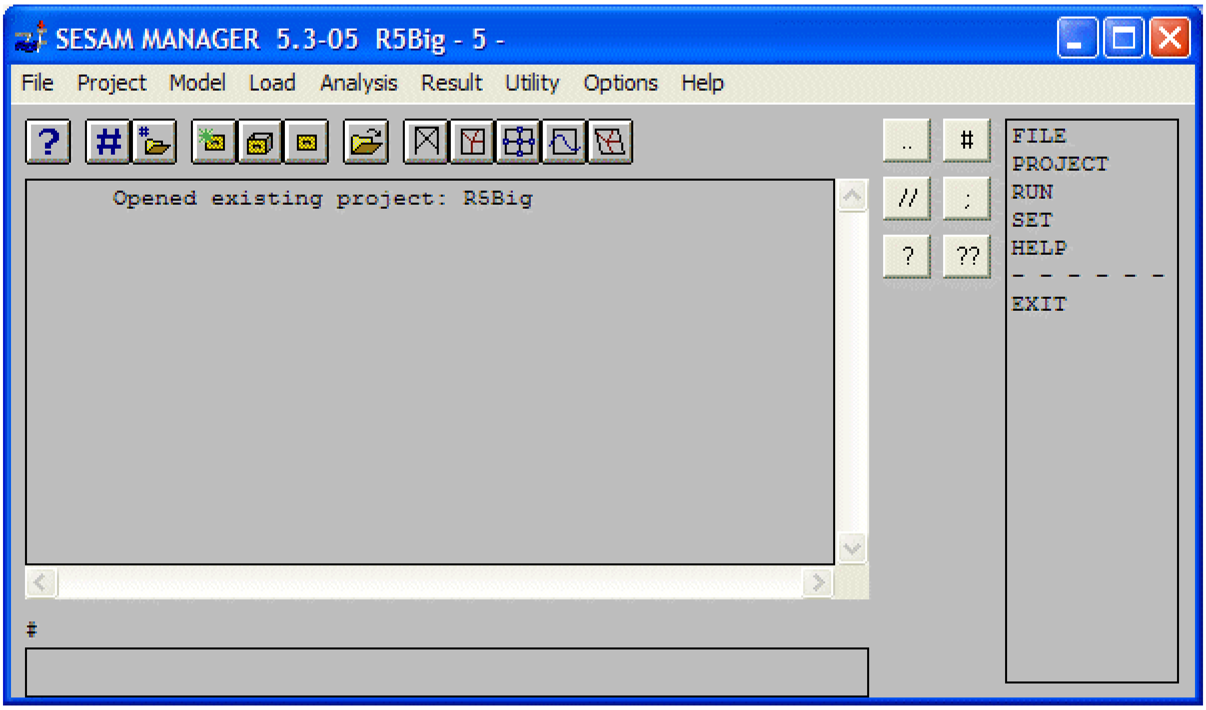


Figure 4.4: Command line mode dialogue of Manager

### 4.2.3 Starting Stofat from Manager Command Line or Journal File.

Click the toggle command button  and switch to the command line mode, see Section 4.3. The command line area appears in the dialogue window along with a list of main commands, see Figure 4.4. Enter appropriate commands by clicking in the command list, or type commands directly in the command line. Stofat is started by entering ‘Run’, ‘Stofat‘ and Command Input File (optional).

### 4.2.4 Starting Stofat on PC with Windows

Stofat may be started on a PC with Windows by creating a shortcut to the executable file stofat.exe. Then specify the path to the analysis project directory in the ‘Start in’ field.

Stofat uses a database file and a journal file. These files are named with a prefix, name and extension. The prefix and name are provided by the user. The extension is .mod for the database and .jnl for the journal file.

When the shortcut is activated, the program will start with the graphic user interface and show a dialogue box requesting the database file prefix, name and status, see Figure 4.5.

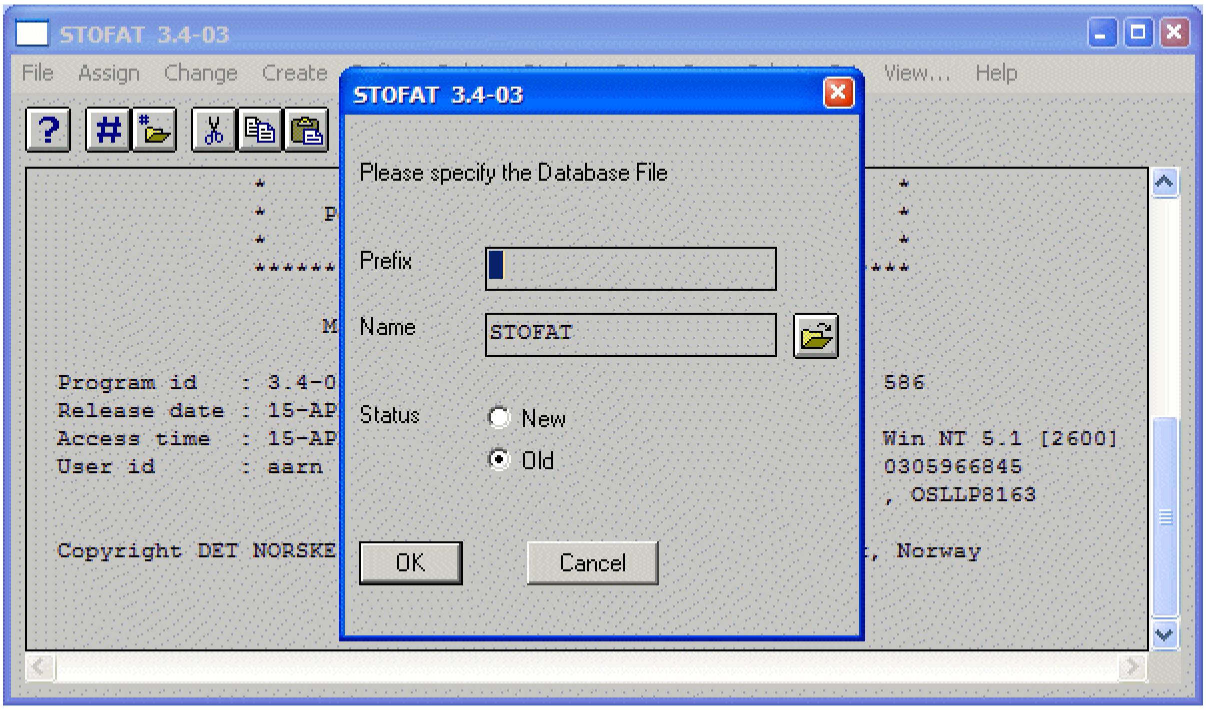


Figure 4.5: Start-up dialogue of Stofat

Note that the default status is Old even when Stofat suggests a new database file. Type in file prefix, name and select proper status, then press the OK button (or the Return key). Pressing the Cancel button will abort the session.

Stofat will open the database file and a journal file. The program will then print a start-up heading on the screen similar as shown Figure 4.6. The heading and messages printed on screen are sent to the log file stofat.mlg.

```
  ******      ******       ******       ******      ** ***  ****
 ********    ********     ********     ********     *************
**      **  **      **   **      **   **      **     **    **    **
**          **      **   **                    **     **    **    **
 *******    **********    *******     *********     **    **    **
  *******   *********     *******    **********    **    **    **
        **  **                   **   **      **     **    **    **
**      **  **      **   **      **   **      **     **    **    **
 ********    ********     ********     *********    **    **    **
  ******      ******       ******       ****** **   **    **    **


          ***********************************************
          *                                             *
          *                S T O F A T                  *
          *                                             *
          *    Postprocessor for stochastic fatigue     *
          *                                             *
          ***********************************************

               Marketing and Support by DNV Software

Program id    : 3.4-03                   Computer          : 586
Release date  : 15-APR-2011              Impl. update      :
Access time   : 15-APR-2011 10:46:06     Operating system  : Win NT 5.1 [2600]
User id       : aarn                     CPU id            : 0305966845
                                         Installation      : , OSLLP8163

Copyright DET NORSKE VERITAS AS, P.O.Box 300, N-1322 Hovik, Norway


    Siftool    version 8.3-07   13-APR-2011


    ============================================
    |                                          |
    | ............. Please wait .............. |
    | Initializing the STOFAT model file       |
    |                                          |
    ============================================

    Initialization completed correctly

    NEW journal file created

    Please proceed as follows:
    --------------------------

    Step 1 :........ Read a Results Interface File
                     First use : FILE OPEN
                     and then  : FILE TRANSFER

    Step 2 :........ Proceed with your task

    Total probability of the scatter diagram is:   1.00
    Total probability of the scatter diagram is:   1.00
    Current Graphics Device : WINDOWS
```

Figure 4.6: Start-up header printed on screen

The graphic user interface available are described in Section 4.3.

To exit the program choose the Exit option under the File menu.

### 4.2.5 Starting Stofat from DOS Command Window or with a Batch Script

Stofat may also be started in a DOS window, or with a .bat file.

```
<path>stofat.exe /INTERFACE=LINE /NAME=nname /STATUS=NEW /COMMAND-FILE=cname
/FORCED-EXIT
```

This command will run Stofat and perform the commands in the journal file cname.

It will create a new model file and journal file with name nname.mod and nname.jnl respectively. The two names nname and cname must be different. The option /FORCED-EXIT is needed to avoid an infinite loop when the commands are completed.

The header and messages generated by Stofat are sent to the log file stofat.mgl.

## 4.3 The Graphic Mode User Interface

The main dialogue window of Stofat is shown in Figure 4.7 and has the following parts (from top to bottom):

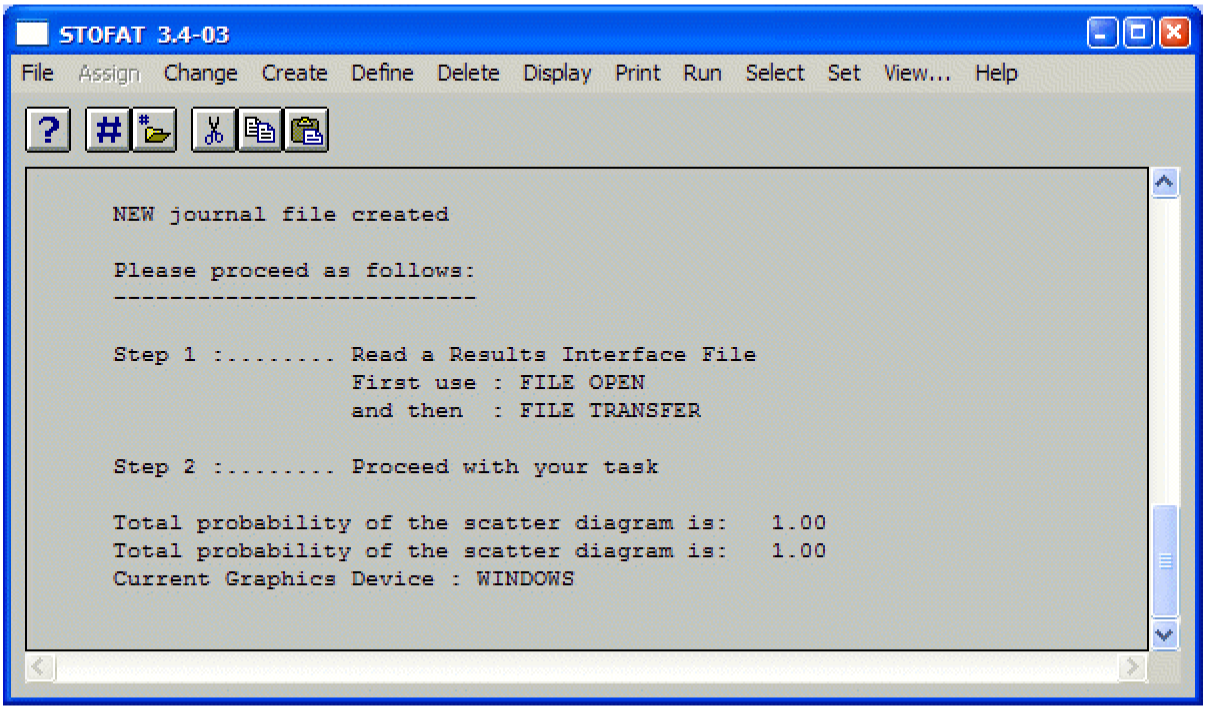


Figure 4.7: The main dialogue window at the strat of the operation of Stofat

- Title bar. This is the name of the program and the current program version.
- Main menu. This menu gives access to all the commands of Stofat.
- Shortcut buttons. From left the functions of the buttons are:
  -  Prints status list for Stofat. The status list is logged on the print file status.mlg.
  -  Toggles command input mode on and off.
  -  Reads command input file. The file must have the extension .jnl.
  -  Cuts selected text to the clipboard.
  -  Copies selected text to the clipboard.
  -  Pastes text from the clipboard.

Message area. This area is used to show messages to the user plus commands that have been typed into the command input line and commands that have been read from command input files.

The command buttons in the main manu may take three different actions:


A button with a command name starts a programs execution immediately.


A botton with a command name followed by three dots opens a dialogue window.


A button with a command name followed by an arrow has subcommands connected to the command. Drag to the right to see the subcommands.

In addition to the parts seen in Figure 4.7, the graphics area and command line areas may be visible as shown in Figure 4.8. These areas are described in more details in the following:

- The graphics area is displayed the first time the need for displaying a drawing arises.
- The command line area appears/disappears when clicking on the toggle command input mode button. This line contains the prompt for line mode input (showing the default when this is available) followed by a field which is used to type line mode commands. Along with the command line a command list at the right and the six shortcut buttons are displayed. The command list are used to give line mode commands to Stofat. A command can be entered by clicking in the command list, or by typing text in the command line followed by Enter. The shortcut buttons all have explanatory texts (tool tips) attached, visible when the mouse pointer is paused over the button. Two extra buttons appear when a command line input file is opened.
- Pull down menus from the items in the main menu. These are activated by clicking on the item with the left mouse button, or by holding the left mouse button down on an item. Similarly, some of the items in the pull down menu may have a submenu sliding sideways from the parent menu. To select an item in a pull down menu, click or drag the mouse pointer to the item and release the button. Pull down menus of the items in the main menu of Stofat are shown in Appendix F.
- Dialogue windows. Much of the user interaction will be performed through dialogue windows. Those items in the pull down menus that have three dots following the item label all open a dialogue window when selected (see illustration below). The dialogue windows of Stofat are shown in Appendix F.
- Print window. After the first Print command has been issued a print window will pop up. This is a scrollable window that contains all the output from the Print command when directed to the screen. The window has a limited buffer so, if a single print command generates excessive amounts of print, some of it may disappear out of the top of the window. The print window may be iconised separately from the main window. It is possible to print inside an iconised print window. It does however not pop up automatically from an iconised state when something is printed.

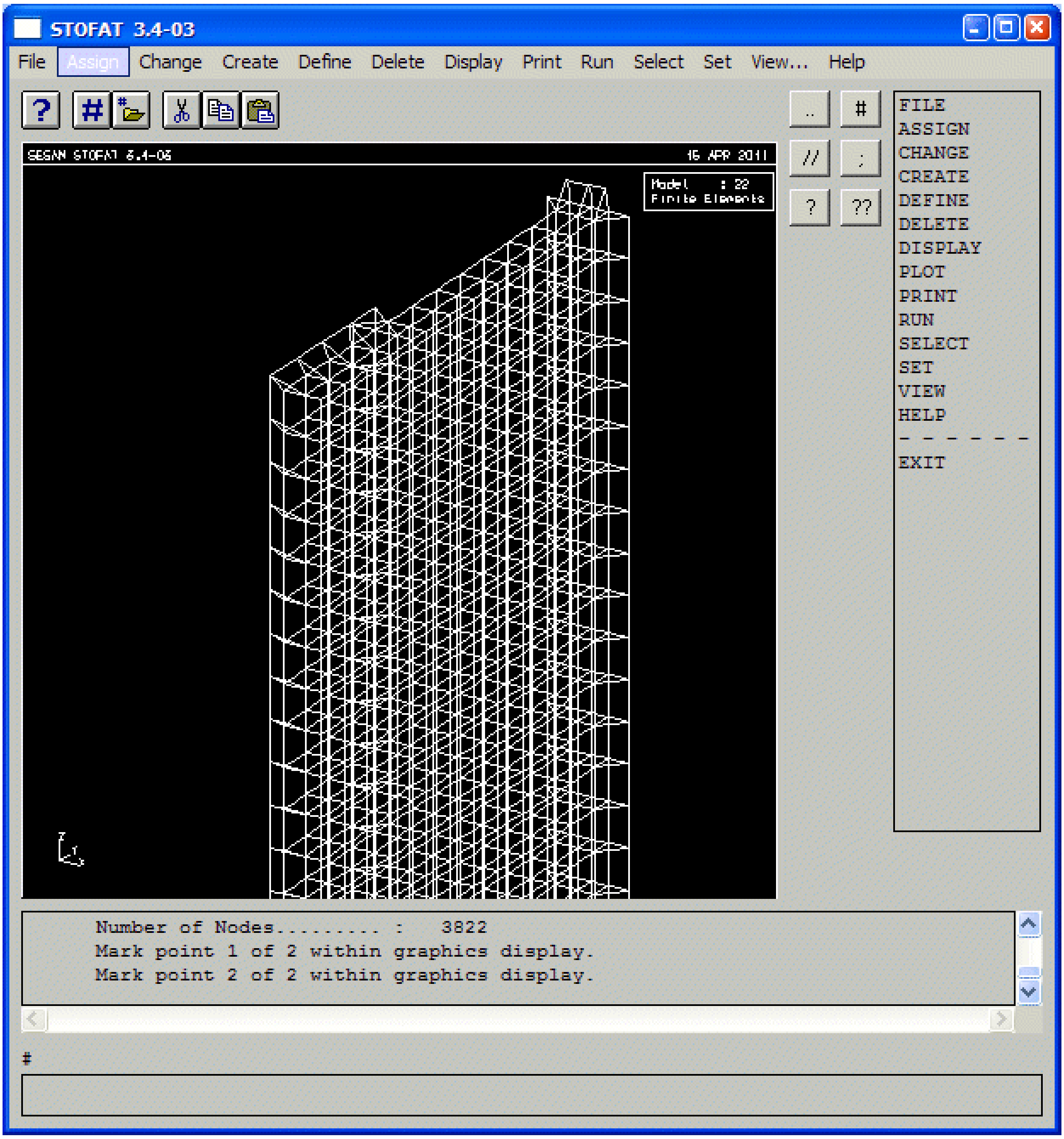


Figure 4.8: Main dialogue window with graphics area and line mode command input areas

# 5 Command Description

The hierarchical structure of the commands and numerical data is documented in this chapter by use of tables. How to interpret these tables is explained below. Examples are used to illustrate how the command structure may diverge into multiple choices and converge to a single choice.

In the example below command A is followed by either of the commands B and C. Thereafter command D is given. Legal alternatives are, therefore, A B D and A C D.

<table>
<tr><td rowspan="2">A</td><td>B</td><td rowspan="2">D</td></tr>
<tr><td>C</td></tr>
</table>

In the example below command A is followed by three selections of either of commands B and C as indicated by *3. For example: A B B B, or: A B B C, or A C B C, etc.

<table>
<tr><td rowspan="2">A</td><td>B</td><td rowspan="2">*3</td></tr>
<tr><td>C</td></tr>
</table>

In the example below the three dots in the left-most column indicate that the command sequence is a continuation of a preceding command sequence. The single asterisk indicate that B and C may be given any number of times. Conclude this sequence by the command END. The three dots in the right-most column indicate that the command sequence is to be continued by another command sequence.

<table>
<tr><td rowspan="3">...</td><td rowspan="3">A</td><td>B</td><td rowspan="2">*</td><td rowspan="3">...</td></tr>
<tr><td>C</td></tr>
<tr><td colspan="2">END</td></tr>
</table>

In the example below command A is followed by any number of repetitions of either of the sequences B D and C D. Note that a pair of braces ({ }) is used here merely to a sequence that may be repeated. The braces are not commands themselves.

<table>
<tr><td rowspan="2">A</td><td rowspan="2">{</td><td>B</td><td rowspan="2">D</td><td rowspan="2">}</td></tr>
<tr><td>C</td></tr>
</table>

The characters A, B, C and D in the examples above represent parameters being COMMANDS (written in upper case) and numbers (written in lower case). All numbers may be entered as real or integer values. Brackets ([ ]) are used to enclose optional parameters.

A parameter followed by a '+' means that a selection of one or more numerical values, names or text strings shall be done from a list of items.

**Note: Line mode commands are in this chapter presented in upper case including hyphens. In graphics mode the commands appear in mixed case and without hyphens.**

**Note: Graphics mode commands are irrelevant at a given time are masked out (shown grey in graphics mode).**

**Note: The command END is generally used to end repetitive entering of data. Using double dot (..) rather than END to terminate a command will, depending on at which level in the command it is given, save or discard the data entered. Generally, if the data entered up to the double dot is complete and self-contained the double dot will save the data. If in doubt, it is always safest to leave a command by entering the required number of END commands.**

Use of Stofat in graphics mode is described in Section 4.3. Pull down menus and dialogue boxes of the graphic mode are shown in Appendix F. Tutorial examples of line mode command input are given in Appendix A.

The HELP command is not described here. It is intended purely to serve as on-line help. Usage of the HELP command is not logged. When in doubt how to do things try the HELP command.

## 5.1 Line-Mode Commands

ASSIGN
ASSIGN K-FACTORS
ASSIGN SN-CURVE
ASSIGN SN-CURVE-SORTED
ASSIGN STRESS-TYPE-K-FACTORS
ASSIGN THICKNESS-CORRECTION
ASSIGN WAVE-DIRECTION-PROBABILITY
ASSIGN WAVE-SPECTRUM-SHAPE
ASSIGN WAVE-SPREADING-FUNCTION
ASSIGN WAVE-STATISTICS
ASSIGN WELD-NORMAL-LINE
ASSIGN WELD-NORMAL-LINE-METHOD

CHANGE
CHANGE SN-CURVE
CHANGE WAVE-SPREADING-FUNCTION
CHANGE WAVE-STATISTICS

CREATE
CREATE FATIGUE-CHECK-POINTS
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK
CREATE SN-CURVE
CREATE WAVE-SPREADING-FUNCTION
CREATE WAVE-STATISTICS
CREATE WELD-NORMAL-LINE

DEFINE
DEFINE FATIGUE-RAINFLOW-COUNTING
DEFINE FATIGUE-RESULTS-DUMP
DEFINE FATIGUE-RESULTS-VTF-FILE
DEFINE LONG-TERM-PROBABILITY
DEFINE LONG-TERM-RETURN-PERIOD
DEFINE LONG-TERM-STRESS
DEFINE LONG-TERM-STRESS-AMPLITUDE
DEFINE SHELL-FATIGUE-CONSTANTS
DEFINE STATIC-LOAD-CASE
DEFINE TIME-HISTORY-FATIGUE-TIME
DEFINE WEIBULL-PARAMETERS
DEFINE WIDE-BAND-CORRECTION-FACTOR

DELETE
DELETE HOTSPOT
DELETE RUN
DELETE SN-CURVE
DELETE WAVE-SPREADING-FUNCTION
DELETE WAVE-STATISTICS
DELETE WELD-NORMAL-LINE

DISPLAY
DISPLAY FATIGUE-CHECK-RESULTS
DISPLAY LABEL

DISPLAY PLOT
DISPLAY PRESENTATION
DISPLAY REFRESH
DISPLAY SN-CURVE
DISPLAY SN-CURVE-SORTED
DISPLAY STRESS-TRANSFER-FUNCTION
DISPLAY SUPERELEMENT
DISPLAY WAVE-SPREADING-FUNCTION

FILE
FILE EXIT
FILE OPEN
FILE PLOT
FILE SELECT-PRINTER
FILE TRANSFER

PLOT

PRINT
PRINT FATIGUE-CHECK-RESULTS
PRINT FATIGUE-RESULTS-DUMP
PRINT FATIGUE-RESULTS-VTF-FILE
PRINT LONG-TERM-RESPONSE
PRINT RUN
PRINT RUN-OVERVIEW
PRINT RUN-OVERVIEW ALL
PRINT RUN-OVERVIEW APPLIED-K-FACTORS
PRINT RUN-OVERVIEW ELEMENT MATERIAL DATA
PRINT RUN-OVERVIEW ELEMENTS
PRINT RUN-OVERVIEW HOTSPOTS
PRINT RUN-OVERVIEW LONG-TERM-PROBABILITIES
PRINT RUN-OVERVIEW NAMED-ELEMENT-SETS
PRINT RUN-OVERVIEW RUNS
PRINT RUN-OVERVIEW WAVE-DIRECTION-DATA
PRINT RUN-OVERVIEW WELD-NORMAL-LINES
PRINT SIN-FILE-LOAD-CASES
PRINT SN-CURVE
PRINT SN-CURVE-SORTED
PRINT SUPERELEMENT
PRINT WAVE-SPREADING-FUNCTION
PRINT WAVE-STATISTICS

RUN
RUN FATIGUE-CHECK

SELECT
SELECT ELEMENTS
SELECT SET-ELEMENTS

SET
SET COMPANY-NAME
SET DISPLAY
SET DRAWING
SET GRAPH
SET GRAPH LINE-OPTIONS
SET GRAPH XAXIS-ATTRIBUTES
SET GRAPH YAXIS-ATTRIBUTES
SET GRAPH ZAXIS-ATTRIBUTES
SET PLOT

SET PRINT
SET TITLE

VIEW
VIEW FRAME
VIEW PAN
VIEW POSITION
VIEW ROTATE
VIEW ZOOM

## 5.2 ASSIGN

| | | |
|---|---|---|
| ASSIGN | K-FACTORS | ... |
| | SN-CURVE | |
| | SN-CURVE-SORTED | |
| | STRESS-TYPE-K-FACTORS | |
| | THICKNESS-CORRECTION | |
| | WAVE-DIRECTION-PROBABILITY | |
| | WAVE-SPECTRUM-SHAPE | |
| | WAVE-SPREADING-FUNCTION | |
| | WAVE-STATISTICS | |
| | WELD-NORMAL-LINE | |
| | WELD-NORMAL-LINE-METHOD | |

**PURPOSE:**
The assign command is used to assign K-factors, SN curve, thickness correction, wave spectrum, wave energy spreading functions to wave statistics models, assign probabilities and wave statistics models to existing wave directions and weld normal lines to elements and hotspots.

## 5.3 ASSIGN K-FACTORS

| | | | | |
|---|---|---|---|---|
| ... | K-FACTORS | elmnam | GEOMETRIC-STRESS-CONCENTRATION | gstrco |
| | | | WELD-STRESS-CONCENTRATION | wstrco |
| | | | ECCENTRICITY-STRESS-CONCENTRATION | estrco |
| | | | ANGULAR-MISMATCH-FACTOR | anmfac |
| | | | LATERAL-PANEL-LOAD-FACTOR | lplfac |

**PURPOSE:**
To assign K-factors to elements.

**PARAMETERS:**

| | |
|---|---|
| elmnam | Element or element set to which the K-factors shall be assigned. |
| GEOMETRIC-STRESS-CONCENTRATION gstrco | Geometric stress concentration factor |
| WELD-STRESS-CONCENTRATION wstrco | Welded stress concentration factor |
| ECCENTRICITY-STRESS-CONCENTRATION estrco | Eccentricity stress concentration factor |
| ANGULAR-MISMATCH-FACTOR anmfac | Angular mismatch factor |
| LATERAL-PANEL-LOAD-FACTOR lplfac | Lateral panel load factor |

**NOTES:**
The resulting K-factor to be used for fatigue calculation is derived by multiplying the five factors above, see Appendix B.3.2. The default K-factors will be applied (see DEFINE SHELL-FATIGUE-CONSTANTS) if the resulting K-factor is zero or less than zero.

Note that according to DNV Classification Note 30.7, see [30], the lateral panel load factor (lplfac) is for unsymmetric stiffeners on laterally loaded panels, applicable when the nominal stress is derived from simple beam analysis. [30] prescribes different factors for the web and flange or the stiffener. In Stofat, which is based on stresses derived from finite element models, this factor should be applied with care, in accordance with rule specifcations and recommendations, and only to unsymmetric stiffeners when these are included in the Stofat model.

Elements that are not assigned K-factors take the default K-factors, see command DEFINE-SHELL-CONSTANTS.

**EXAMPLES:**

```
ASSIGN K-FACTORS Current 1.0 1.5 1.0 1.0 1.0
```

## 5.4 ASSIGN SN-CURVE

| ... | SN-CURVE | elmnam | snname+ |
|---|---|---|---|

**PURPOSE:**
To assign SN-curve to elements.

**PARAMETERS:**

| | |
|---|---|
| elmnam | Element or element set name to which the SN-curve shall be assigned. |
| snname+ | Name of SN-curve |

**NOTES:**
Elements that are not assigned a SN-curve take the default SN-curve.

When the default SN-curve is changed by the command DEFINE SHELL-FATIGUE-CONSTANTS DEFAULT-SN-CURVE, the new default SN-curve is applied to all elements and supersedes all previous SN-curve assignments.

Use the commands PRINT SN-CURVE and DISPLAY SN-CURVE to see curve data and shape.

Default thickness correction factors have been predefined for the tabulated SN curves defined on this manual. The correction reference thickness and cut-off thickness are applied in SI unit meters.

See also:

```
CHANGE SN-CURVE...
CREATE SN-CURVE...
DELETE SN-CURVE...
PRINT SN-CURVE...
DISPLAY SN-CURVE...
```

**EXAMPLES:**

```
ASSIGN SN-CURVE DEFAULT DNVC-I
ASSIGN SN-CURVE 25 DNVC-I
```

## 5.5 ASSIGN SN-CURVE-SORTED

<table>
<tr><td rowspan="11">...</td><td rowspan="11">SN-CURVE</td><td rowspan="11">elmnam</td><td colspan="2">ABS</td><td rowspan="11">sname+</td></tr>
<tr><td colspan="2">API</td></tr>
<tr><td rowspan="3">DNV</td><td>OLDER</td></tr>
<tr><td>RP-C203-2010</td></tr>
<tr><td>CN-30.7-2010</td></tr>
<tr><td colspan="2">DOE</td></tr>
<tr><td colspan="2">HSE</td></tr>
<tr><td colspan="2">NORSOK</td></tr>
<tr><td colspan="2">NS</td></tr>
<tr><td colspan="2">USER</td></tr>
<tr><td colspan="2">ALL</td></tr>
</table>

**PURPOSE:**
To assign SN-curve to elements.

**PARAMETERS:**

| | |
|---|---|
| elmnam | Element or element set name to which the SN-curve shall be assigned. |
| ABS | Selection of ABS SN-curves. |
| API | Selection of API SN-curves. |
| DNV | Selection of DNV SN-curves. |
| OLDER | Selection of DNV SN-curves older than 2010. |
| RP-C203-2010 | Selection of DNV SN-curves of Recommended Practice DNV-RP-C203, April 2010. |
| CN-30.7-2010 | Selection of DNV SN-curves of Classification Notes No. 30.7, June 2010. |
| DOE | Selection of DOE SN-curves. |
| HSE | Selection of HSE SN-curves. |
| NORSOK | Selection of NORSOK SN-curves. |
| NS | Selection of Norwegian Standard NS 3472 SN-curves. |
| USER | Selection of user defined SN-curves. |
| ALL | Selection of all available SN-curves. |
| snname+ | Name of SN-curve. |

**NOTES:**
Elements that are not assigned a SN-curve take the default SN-curve.
When the default SN-curve is changed by the command DEFINE SHELL-FATIGUE-CONSTANTS DEFAULT-SN-CURVE, the new default SN-curve is applied to all elements and supersedes all previous SN-curve assignments.
Use the commands PRINT SN-CURVE-SORTED and DISPLAY SN-CURVE-SORTED to see curve data and shape.
Default thickness correction factors have been predefined for the tabulated SN curves defined on this manual. The correction reference thickness and cut-off thickness are applied in SI unit meters.

See also:

```
CHANGE SN-CURVE...
CREATE SN-CURVE...
DELETE SN-CURVE...
PRINT SN-CURVE...
DISPLAY SN-CURVE...
```

**EXAMPLES:**

```
ASSIGN SN-CURVE-SORTED DEFAULT DNV RP-C203-2010 DNV2010_B1-SEAFC
ASSIGN SN-CURVE-SORTED 25 NS NS-F2-SE
```

## 5.6 ASSIGN STRESS-TYPE-K-FACTOR

<table>
<tr><td rowspan="18">...</td><td rowspan="18">STRESS-TYPE-K-FACTORS</td><td rowspan="18">elmnam</td><td colspan="2">Axial stress:</td></tr>
<tr><td>GEOMETRIC-STRESS-CONCENTRATION</td><td>gk-axi</td></tr>
<tr><td>WELD-STRESS-CONCENTRATION</td><td>wk-axi</td></tr>
<tr><td>ECCENTRICITY-STRESS-CONCENTRATION</td><td>ek-axi</td></tr>
<tr><td>ANGULAR-MISMATCH-FACTOR</td><td>ak-axi</td></tr>
<tr><td>LATERAL-PANEL-LOAD-FACTOR</td><td>lk-axi</td></tr>
<tr><td colspan="2">Bending stress:</td></tr>
<tr><td>GEOMETRIC-STRESS-CONCENTRATION</td><td>gk-bnd</td></tr>
<tr><td>WELD-STRESS-CONCENTRATION</td><td>wk-bnd</td></tr>
<tr><td>ECCENTRICITY-STRESS-CONCENTRATION</td><td>ek-bnd</td></tr>
<tr><td>ANGULAR-MISMATCH-FACTOR</td><td>ak-bnd</td></tr>
<tr><td>LATERAL-PANEL-LOAD-FACTOR</td><td>lk-bnd</td></tr>
<tr><td colspan="2">Shear stress:</td></tr>
<tr><td>GEOMETRIC-STRESS-CONCENTRATION</td><td>gk-shr</td></tr>
<tr><td>WELD-STRESS-CONCENTRATION</td><td>wk-shr</td></tr>
<tr><td>ECCENTRICITY-STRESS-CONCENTRATION</td><td>ek-shr</td></tr>
<tr><td>ANGULAR-MISMATCH-FACTOR</td><td>ak-shr</td></tr>
<tr><td>LATERAL-PANEL-LOAD-FACTOR</td><td>lk-shr</td></tr>
</table>

**PURPOSE:**

To assign stress type dependent K-factors to shell elements. K-factors are specified for the axial-, bending and shear stress components.

**PARAMETERS:**

| | |
|---|---|
| elmnam | Element or element set to which the K-factors shall be assigned. |
| GEOMETRIC-STRESS-CONCENTRATION gk-axi | Geometric concentration factor of axial stress components. |
| WELD-STRESS-CONCENTRATION wk-axi | Welded concentration factor of axial stress components. |
| ECCENTRICITY-STRESS-CONCENTRATION ek-axi | Eccentricity concentration factor of axial stress components. |
| ANGULAR-MISMATCH-FACTOR ak-axi | Angular mismatch factor of axial stress components. |
| LATERAL-PANEL-LOAD-FACTOR lk-axi | Lateral panel load factor of axial stress components. |
| GEOMETRIC-STRESS-CONCENTRATION gk-bnd | Geometric concentration factor of bending stress components. |
| WELD-STRESS-CONCENTRATION wk-bnd | Welded concentration factor of bending stress components. |
| ECCENTRICITY-STRESS-CONCENTRATION ek-bnd | Eccentricity concentration factor of bending stress components. |
| ANGULAR-MISMATCH-FACTOR ak-bnd | Angular mismatch factor of bending stress components. |
| LATERAL-PANEL-LOAD-FACTOR lk-bnd | Lateral panel load factor of bending stress components. |
| GEOMETRIC-STRESS-CONCENTRATION gk-shr | Geometric concentration factor of shear stress components. |

| | |
|---|---|
| WELD-STRESS-CONCENTRATION wk-shr | Welded concentration factor of shear stress components. |
| ECCENTRICITY-STRESS-CONCENTRATION ek-shr | Eccentricity concentration factor of shear stress components. |
| ANGULAR-MISMATCH-FACTOR ak-shr | Angular mismatch factor of shear stress components. |
| LATERAL-PANEL-LOAD-FACTOR lk-shr | Lateral panel load factor of shear stress components. |

**NOTES:**

The resulting K-factor of a stress type to be used in fatigue calculation is derived by multiplying the five factors of the stress type above, see Appendix B.3.2. The K-factors are applied to the element stress points stresses when read from the SIN file. Axial and bending stress components are calculated and multiplied with K-factors whereupon scaled values of the normal stress components are found, see Appendix B.3.2.

Note that according to DNV Classification Notes 30.7, see [30], the lateral panel load factor (lk-axi, lkbnd, lk-shr) is for unsymmetric stiffeners on laterally loaded panels, applicable when the nominal stress is derived from simple beam analysis. [30] prescribes different factors for the web and flange ot he stiffener. In Stofat, which is based on stresses derived from finite element models, this factor should be applied with care, in accordance with rule specifcations and recommendations, and only to unsymmetric stiffeners when these are included in the Stofat model.

Stress type K-factors apply only to 2D shell elements. If the command is applied to 3D solid elements, the K-factors specified for the axial stress component will apply to all stress components of the 3D elements. Elements that are not assigned K-factors take the default K-factors, see command DEFINE SHELL-FATIGUE-CONSTANTS.

```
ASSIGN STRESS-TYPE-K-FACTORS Current 1.5 1.0 1.5 1.0 1.0 1.2 1.0 1.2 1.0 1.0
1.4 1.0 1.4 1.0 1.0
```

## 5.7 ASSIGN THICKNESS-CORRECTION

<table>
<tr><td rowspan="3">...</td><td rowspan="3">THICKNESS-CORRECTION</td><td rowspan="3">snname+</td><td colspan="4">NONE</td></tr>
<tr><td>STANDARD-T-CURVE</td><td colspan="3">tref</td></tr>
<tr><td>ARBITRARY</td><td>tref</td><td>tcut</td><td>exp</td></tr>
</table>

**PURPOSE:**

To assign thickness correction by modification of the SN-curve. The assignment overrides previous assignments.

**PARAMETERS:**

| | |
|---|---|
| snname+ | Name of SN-curve. |
| NONE | No thickness correction. |
| STANDARD-T-CURVES | Standard T-curve $(t_{cut} = t_{ref}, t_{exp} = 0.25)$. The reference thickness may e.g. be 0.032 metres, but must be given in current consistent units. |
| ARBITRARY | User specifies all the parameters used in the thickness correction formula. |
| tref | Reference thickness, for which the SN-curve is valid without correction. |
| tcut | Cut-off thickness. If the actual thickness is smaller, the cut-off thickness is applied in the formula below. |
| exp | Exponent. |

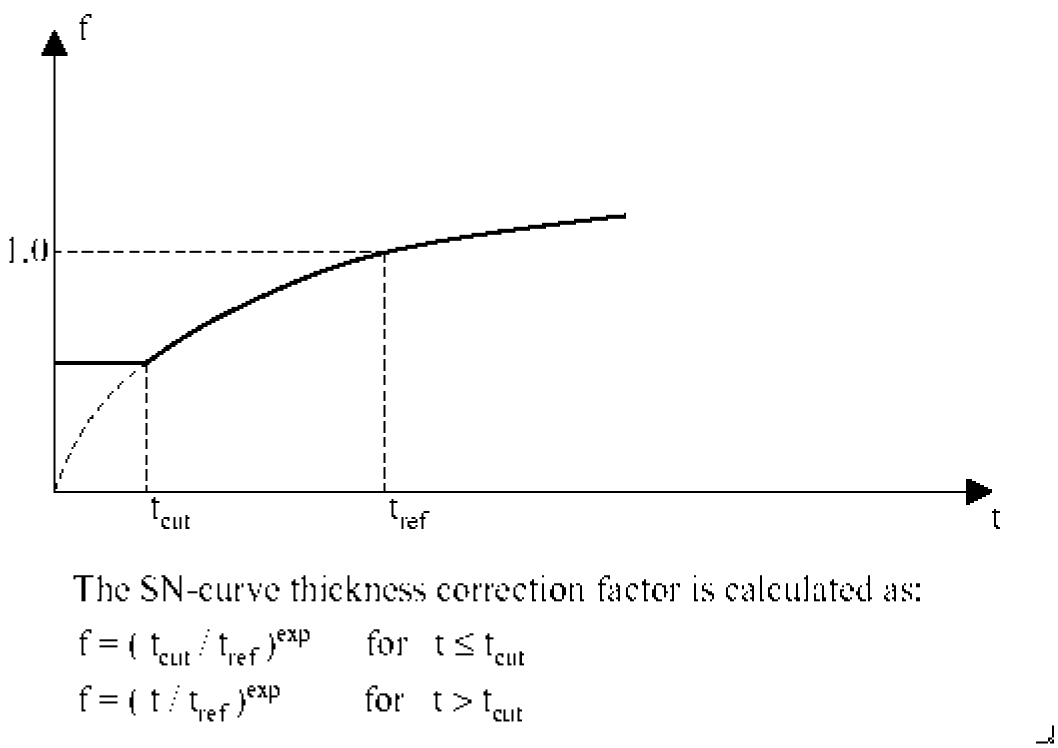


Figure 5.1: ThicknessCorrectionFactor

**NOTES:**

The unit of the thickness correction and cut-off criteria are related to the units of the SN-curve and the length unit applied in the analysis. For user defined SN-curves, both SN-curve data and thickness corrections must be consistent with the units applied in the analysis. Thickness corrections must accordingly be assigned in same length unit as applied in the analysis.

Build-in library SN-curves of Stofat may have predefined default thickness corrections (reference thickness and cut-off thickness) defined in SI unit meters. These values are multiplied with a unit length factor entered by the command DEFINE SHELL-FATIGUE-CONSTANTS. The purpose is to convert the thickness corrections to the length unit of the current analysis.

If the length unit of the analysis is mm and default thickness corrections (in meters) of library SN-curves are applied, a unit length factor of 1000 must be used. However, if thickness corrections are assigned by the user in same length unit as applied in the analysis, a unit length factor of 1.0 should be used.

Note that the unit length factor is only applied to thickness corrections of build-in library SN-curves and that the same unit length factor is applied to all library SN-curves applied in the analysis. Thickness corrections of all library SN-curves applied must accordingly be in same length unit, i.e if predefined thickness corrections are used for one library SN-curve, thickness corrections assigned to another library SN-curve by the user must also be in meters.

See also:

```
CHANGE SN-CURVE...
CREATE SN-CURVE...
DELETE SN-CURVE...
PRINT SN-CURVE...
DISPLAY SN-CURVE...
```

**EXAMPLES:**

```
ASSIGN THICKNESS-CORRECTION USE-X NONE
ASSIGN THICKNESS-CORRECTION USE-Y STANDARD-T-CURVE 0.032
```

## 5.8 ASSIGN WAVE-DIRECTION-PROBABILITY

| ... | WAVE-DIRECTION-PROBABILITY | dir | prob |
|---|---|---|---|

**PURPOSE:**

To assign a wave direction probability to an existing wave direction for later use in calculating statistics. The assignment will override the previous assignment. The probabilities should add up to 1.0.

**PARAMETERS:**

| | |
|---|---|
| dir | Wave direction. |
| prob | Probability of the wave direction. |

**EXAMPLES:**

```
ASSIGN WAVE-DIRECTION-PROBABILITY 210. 0.1666
ASSIGN WAVE-DIRECTION-PROBABILITY 180. 0.1666
ASSIGN WAVE-DIRECTION-PROBABILITY 240. 0.1666
ASSIGN WAVE-DIRECTION-PROBABILITY 270. 0.1666
ASSIGN WAVE-DIRECTION-PROBABILITY 300. 0.1666
ASSIGN WAVE-DIRECTION-PROBABILITY 330. 0.1666
```

## 5.9 ASSIGN WAVE-SPECTRUM-SHAPE

<table>
<tr><td rowspan="7">...</td><td rowspan="7">WAVE-SPECTRUM-SHAPE</td><td rowspan="7">name+</td><td colspan="4">PIERSON-MOSKOWITZ</td><td rowspan="3">...</td><td colspan="5" rowspan="2">ALL</td></tr>
<tr><td>JONSWAP</td><td>gam</td><td>sma</td><td>smb</td></tr>
<tr><td>GENERAL-GAMMA</td><td>lsp</td><td colspan="2">nsp</td><td>PART</td><td>hsl</td><td>hsu</td><td>tzl</td><td>tzu</td></tr>
<tr><td colspan="4" rowspan="2">ISSC</td><td rowspan="2">...</td><td colspan="5">ALL</td></tr>
<tr><td>PART</td><td>hsl</td><td>hsu</td><td>tll</td><td>t1u</td></tr>
<tr><td colspan="2" rowspan="2">TORSETHAUGEN</td><td colspan="2">FULL</td><td rowspan="2">...</td><td colspan="5">ALL</td></tr>
<tr><td colspan="2">SIMPLIFIED</td><td>PART</td><td>hsl</td><td>hsu</td><td>tpl</td><td>tpu</td></tr>
</table>

**PURPOSE:**

To assign a wave spectrum shape to a wave scatter diagram. The assignment may be to the total scatter diagram, or to a selected part of the diagram. The assignments will override the previous assignments.

It is only possible to assign a wave spectrum shape to the total sea state area if the wave statistics is described through a Nordenstrøm's model.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the wave statistics model. |
| PIERSON-MOSKOWITZ | Wave spectrum of type Pierson-Moskowitz. |
| JONSWAP | Wave spectrum of type Jonswap. |
| GENERAL-GAMMA | Wave spectrum of type general gamma. |
| ISSC | Wave spectrum of type ISSC (International Ship and Offshore Structure Congress). |
| TORSETHAUGEN | Wave spectrum of type Torsethaugen. |
| gam | Enhancement factor, $\gamma$, of Jonswap spectrum. |
| sma | Left width, $\sigma_a$, of Jonswap spectrum. |
| smb | Right width,$\sigma_a$, of Jonswap spectrum. |
| lsp | l-parameter in the General Gamma spectrum. |
| nsp | n-parameter in the General Gamma spectrum. |
| FULL | Full option for the Torsethagen spectrum. |
| SIMPLIFIED | Simplified option for the Torsethagen spectrum. |
| ALL | Wave spectrum shape will be assign to the total area of the wave statistics mode. |
| PART | Wave spectrum shape will be assign to an area of the scatter diagram limited by the square made of $H_{S-lower}$, $H_{S-upper}$ and $T_{Z-lower}$, $T_{Z-upper}$. |
| hsl | Lower limit of the significant wave height, $H_S$. |
| hsu | Upper limit of the significant wave height, $H_S$. |
| tzl | Lower limit of the zero up crossing wave period, $T_Z$. |
| tzu | Upper limit of the zero up crossing wave period, $T_Z$. |
| t1l | Lower limit of mean wave period, $T_1$. |
| t1u | Upper limit of mean wave period, $T_1$. |
| tpl | Lower limit of peak wave period, $T_p$. |
| tpu | Upper limit of peak wave period, $T_p$. |

**NOTES:**

If the command is not given a Pierson-Moskowitz spectrum will be assumed.

Stofat applies a quadratic interpolation rule in the calculation of the spectral moments for the Pierson-Moskowitz wave spectrum. This integration rule may, however, give negative spectral moments for abrupt and large changes in the wave spectrum (.e.g. big and sharp peaks at single frequencies). Negative spectral moments are not valid and are recalculated by using linear interpolation of the wave spectrum to ensure non-zero positive spectral moments. When negative spectral moments occur, a message is printed for first occurrence with output of the wave spectrum.

**EXAMPLES:**

```
ASSIGN WAVE-SPECTRUM-SHAPE BMT GENERAL-GAMMA 5.0 4.0 ALL
ASSIGN WAVE-SPECTRUM-SHAPE DNV-NA JONSWAP 3.3 0.07 0.09 ALL
ASSIGN WAVE-SPECTRUM-SHAPE DNV-WW PIERSON-MOSKOWITZ ALL
ASSIGN WAVE-SPECTRUM-SHAPE ISSC1 ISSC ALL
```

## 5.10 ASSIGN WAVE-SPREADING-FUNCTION

<table>
<tr><td rowspan="2">...</td><td rowspan="2">WAVE-SPREADING-FUNCTION</td><td rowspan="2">name+</td><td rowspan="2">sprnam+</td><td colspan="5">ALL</td></tr>
<tr><td>PART</td><td>hsl</td><td>hsu</td><td>tzl</td><td>tzu</td></tr>
</table>

**PURPOSE:**
To assign a wave energy spreading function to a wave statistics model. The assignment overrides previous assignment.

It is only possible to assign a wave spectrum shape to the total sea state area if the wave statistics is described through a Nordenstrøm's model.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the wave statistics model. |
| sprnam+ | Name of the wave spreading function. |
| ALL | Wave spreading function will be assigned to the total area of the wave statistics model. |
| PART | Wave spreading function will be assigned to an area of the scatter diagram limited by the square made of $H_{S-lower}$, $H_{S-upper}$ and $T_{Z-lower}$, $T_{Z-lower}$. |
| hsl | Lower limit of the significant wave height, $H_S$. |
| hsu | Upper limit of the significant wave height, $H_S$. |
| tzl | Lower limit of zero up crossing wave period, $T_Z$. $T_Z$ = mean period when ISSC wave statistics. |
| tzu | Upper limit of zero up crossing wave period, $T_Z$. $T_Z$ = mean period when ISSC wave statistics. |

**NOTES:**
Use wave spreading name NONE to remove assignment of a spreading function to a wave statistics model. A cosine spreading function spreads the wave energy over a set of directions in a range of $\pm\pi/2$ on both sides of the main direction and the cosine function is always integrated from $-\pi/2$ to $+\pi/2$ around this direction.

A symmetric cosine spreading of the wave energy for a given main direction requires equal spacing of wave directions in the range of $\pm\pi/2$ each side of the main direction, otherwise a non-symmetric spreading will take place. A symmetric cosine spreading for all main directions requires equal spacing of all wave direction in a 360 degrees range. If the condition for symmetric wave spreading is not met, a user defined specification of the spreading may alternatively be applied.

Stofat tests if symmetric spreading really takes place when cosine spreading is applied. If not, a warning together with information about the spreading are printed.

**EXAMPLES:**

```
ASSIGN WAVE-SPREADING-FUNCTION NRD USER1 ALL
ASSIGN WAVE-SPREADING-FUNCTION DNV-NA COS2 PART 1.0 5.0 2.0 6.0
ASSIGN WAVE-SPREADING-FUNCTION DNV-NA NONE ALL
```

## 5.11 ASSIGN WAVE-STATISTICS

| ... | WAVE-STATISTICS | dir+ | name+ |
|---|---|---|---|

**PURPOSE:**

To assign a wave statistics model to a wave direction. The assignment will override the previous assignment.

**PARAMETERS:**

| | |
|---|---|
| dir+ | Wave direction. |
| name+ | Name of the wave statistics model. |

**EXAMPLES:**

```
ASSIGN WAVE-STATISTICS 210. DNV-NA
ASSIGN WAVE-STATISTICS 240. DNV-NA
ASSIGN WAVE-STATISTICS 270. DNV-NA
ASSIGN WAVE-STATISTICS 300. DNV-NA
ASSIGN WAVE-STATISTICS 180. DNV-NA
ASSIGN WAVE-STATISTICS 330. DNV-NA
```

## 5.12 ASSIGN WELD-NORMAL-LINE

<table>
<tr><td rowspan="3">...</td><td rowspan="3">WELD-NORMAL-LINE</td><td colspan="7">OFF</td></tr>
<tr><td rowspan="2">ON</td><td rowspan="2">wnlnam+</td><td>ELEMENT</td><td colspan="4">elmnam</td></tr>
<tr><td>HOTSPOT</td><td>(</td><td>ONLY</td><td>hotnam+</td><td>)</td></tr>
</table>

**PURPOSE:**
To assign weld normal line to element and hotspot.

**PARAMETERS:**

| | |
|---|---|
| OFF/ON | Switch off/on using assigned weld normal lines in the fatigue calculation (default is OFF). |
| ELEMENT | Assign weld normal line to element. |
| HOTSPOT | Assign weld normal line to hotspot. |
| elmnam | Element or element set name to which the weld normal line shall be assigned. |
| hotnam+ | Hotspots to which the weld normal line shall be assigned. |
| wnlnam+ | Name of weld normal line. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
An element or a hotspot can be connected to only one WN line which are applied to all fatigue check points of the element and the interpolation points of the hotspot. If several assignments are made to the same element or hotspot the last assignment will apply.

Assignments are deleted by the command DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT. Weld normal lines are created by the command CREATE WELD-NORMAL-LINE.

Use the command PRINT RUN-OVERVIEW WELD-NORMAL-LINES or press the Show button in the dialogue box to see current status on defined weld normal lines and assignments to elements and hotspots.

**EXAMPLES:**

```
ASSIGN WELD-NORMAL-LINE OFF
ASSIGN WELD-NORMAL-LINE ON WNL2 ELEMENT 86
SELECT ELEMENTS INCLUDE CURRENT
ASSIGN WELD-NORMAL-LINE ON WNL3 ELEMENT DEFAULT
ASSIGN WELD-NORMAL-LINE ON WNL1 HOTSPOT ( ONLY HOT1 HOT2 HOT3 HOT4 HOT5 HOT6 )
```

## 5.13 ASSIGN WELD-NORMAL-LINE-METHOD

| | | |
|---|---|---|
| ... | WELD-NORMAL-LINE-METHOD | SECTOR-STRESS |
| | | AREA-STRESS |

**PURPOSE:**
To assign weld normal line to element and hotspot.

**PARAMETERS:**

| | |
|---|---|
| SECTOR-STRESS | Apply sector stress method (default). |
| AREA-STRESS | Assign area stress method. |

**NOTES:**
The SECTOR-STRESS option applies maximum (first) principal stress in the fatigue calculation if the direction of this stress vector is inside or along the border of the stress sector, otherwise zero damage is imposed.
The AREA-STRESS method is the original method implemented in Stofat. This method applies the largest of the principal stresses which are inside the stress sector in the fatigue calculation. If no stress vector is located inside the sector, the principal stress which coincide closest with the weld normal line in direction is applied.

**EXAMPLES:**

```
ASSIGN WELD-NORMAL-LINE-METHOD SECTOR-STRESS
ASSIGN WELD-NORMAL-LINE-METHOD AREA-STRESS
```

## 5.14 CHANGE

| | | |
|---|---|---|
| CHANGE | SN-CURVE | ... |
| | WAVE-SPREADING-FUNCTION | |
| | WAVE-STATISTICS | |

**PURPOSE:**
This is used to change previously created SN-curves, wave spreading functions and wave statistic tools.

The options and subcommands are mainly the same as for the corresponding CREATE command. The program will ask for the name of the object and the default values of the different subcommands will be as given before.

## 5.15 CHANGE SN-CURVE

<table>
<tr><td rowspan="3">...</td><td rowspan="3">SN-CURVE</td><td rowspan="3">name</td><td>USER</td><td rowspan="3">txt</td><td>m0</td><td colspan="2">s0</td><td>logN0</td><td rowspan="3">...</td></tr>
<tr><td>LOGA</td><td>m0</td><td colspan="2">logA0</td><td>logN0</td></tr>
<tr><td>STOCHASTIC</td><td>m0</td><td>logK0</td><td>sdk</td><td>logN0</td></tr>
</table>

<table>
<tr><td rowspan="6">...</td><td colspan="5">DEFAULT-TAIL</td></tr>
<tr><td colspan="5">ALIGNED-WITH-FIRST</td></tr>
<tr><td colspan="5">HORISONTAL-TAIL</td></tr>
<tr><td rowspan="3">ARBITRARY-TAIL</td><td rowspan="3">m1</td><td colspan="3">ALIGNED-WITH-SECOND</td></tr>
<tr><td>HORISONTAL-TAIL</td><td colspan="2">logN1</td></tr>
<tr><td>ARBITRARY-TAIL</td><td>logN1</td><td>m2</td></tr>
</table>

**PURPOSE:**
To change the properties of a SN-curve.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the SN-curve. |
| USER | Only user defined option available. |
| LOGA | Option where the intercept of logN-axis and SN-curve, $\log A0$, is given. |
| STOCHASTIC | Option where the intercept of logN-axis and mean SN-curve, $\log K0$ and the standard deviation of $\log K0$, std, are given. |
| txt | Descriptive text of the SN-curve. |
| m0 | Slope of first segment. |
| s0 | Stress level at end first segment. |
| logN0 | Log cycles to failure at the end of first segment. |
| logA0 | Intercept of logN-axis and SN-curve. |
| logK0 | Intercept of $\log N$-axis and mean SN-curve. |
| sdk | Standard deviation of $\log K0$. Note: $\log A0 = \log K0 - 2 \cdot sdk$. |
| DEFAULT-TAIL | Second segment continues with $m1 = 2 \cdot m0 - 1$. |
| ALIGNED-WITH-FIRST | Second segment continues with $m1 = m0$. |
| HORISONTAL-TAIL | Second segment is horizontal. |
| ARBITRARY-TAIL | Second segment is arbitrary. |
| m1 | Slope of second segment. |
| ALIGNED-WITH-SECOND | Third segment continues with $m2 = m1$. |
| HORISONTAL-TAIL | Third segment is horizontal. |
| logN1 | Log cycles to failure at end second segment. |
| m2 | Slope of third segment. |

**NOTES:**
When the LOGA and STOCHASTIC input options are applied, the input values of logA0, logK0 and stdk must

be in accordance with the unit of the stresses applied in the analysis.

When LOGA option is applied the stress level s0 is calculated by:

$$\log_{10} s_0 = \frac{(\log_{10} A_0 - \log_{10} N_0)}{m_0} \tag{5.1}$$

When STOCHASTIC option is applied the stress level s0 is calculated by:

$$\log_{10} s_0 = \frac{(\log_{10} K_0 - sdk - \log_{10} N_0)}{m_0} \tag{5.2}$$

Calculation and conversion of SN curve parameters are thoroughly outlined in C.2.2.

**EXAMPLES:**

```
CHANGE SN-CURVE USE-X USER NONE 3.0 3.4 7.0 ARBITRARY-TAIL 5. HORISONTAL-TAIL 8.301
CHANGE SN-CURVE USE-Y USER NONE 3.0 3.4e+006 7.0 ALIGNED-WITH-FIRST
```

## 5.16 CHANGE WAVE-SPREADING-FUNCTION

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ... | WAVE-SPREADING-FUNCTION | name+ | txt | COSINE-POWER | power | | | | | | | |
| | | | | USER-DEFINED | ( | ONLY | { | dir | fact | }* | ) | |

**PURPOSE:**
To change energy spreading for elementary wave directions with user defined weights on each direction or by changing the power of a defined cosine function. The sum of the user defined weights does not need to be equal to 1 since the program will normalize the weights when using the spreading function.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the spreading function. |
| txt | Descriptive text of the spreading function. |
| COSINE-POWER | Cosine power spreading function. |
| power | Power of the cosine function given as an integer value. Default is 2. |
| USER-DEFINED | User defined spreading function. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |
| dir | Relative direction to the main wave direction in use. The range is, if spanning over 180 degrees, from -90 degrees to 90 degrees. |
| fact | Weight for each elementary wave direction relative to the main wave direction. |

**EXAMPLES:**

```
CHANGE WAVE-SPREADING-FUNCTION COS2 Continuous COSINE-POWER 2
CHANGE WAVE-SPREADING-FUNCTION USER1 'User Function' USER-DEFINED ( ONLY 150.0
0.125 180.0 0.125 210.0 0.125 240.0 0.125 270.0 0.125 300.0 0.125 330.0 0.125
350.0 0.125 )
```

## 5.17 CHANGE WAVE-STATISTICS

<table>
<tr><td rowspan="5">...</td><td rowspan="5">WAVE-STATISTICS</td><td rowspan="5">name</td><td rowspan="5">text</td><td rowspan="2">SCATTER-DIAGRAM</td><td colspan="2">{Hs,Tz,prob}*</td></tr>
<tr><td colspan="2">{Hs,Tz,occr}*</td></tr>
<tr><td rowspan="2">ISSC-SCATTER-DIAGRAM</td><td colspan="2">{Hs,T1,prob}*</td></tr>
<tr><td colspan="2">{Hs,T1,occr}*</td></tr>
<tr><td>ALL-PARAM-SCATTER</td><td>OCHI-HUBBLE</td><td>...</td></tr>
</table>

<table>
<tr><td rowspan="2">...</td><td>{Hss,Tps,Ls,Hsw,Tpw,Lw,prob}*</td></tr>
<tr><td>{Hss,Tps,Ls,Hsw,Tpw,Lw,occr}*</td></tr>
</table>

**PURPOSE:**
To change wave statistics data.

**PARAMETERS:**

| | |
|---|---|
| name | Name of wave statistics. |
| text | Text associated with the wave statistics. |
| SCATTER-DIAGRAM | The wave statistics is a scatter diagram defined by $H_S$, $T_Z$. |
| ISSC-SCATTER-DIAGRAM | The wave statistics is a ISSC scatter diagram defined by $H_S$, $T_1$. |
| ALL-PARAM-SCATTER | The wave statistics and spectrum shape are defined through a all parameter scatter diagram. |
| OCHI-HUBBLE | The wave spectrum is a 6 parameter Ochi-Hubble spectrum. |
| Hs | Significant wave height of one sea state. |
| Tz | Zero up-crossing period for one sea state. |
| T1 | Mean period for one sea state. |
| Hss | Significant wave height, swell part. |
| Tps | Peak spectral period, swell part. |
| Ls | Shape factor (Lambda), swell part. |
| Hsw | Significant wave height, wind (sea) part. |
| Tpw | Peak spectral period, wind (sea) part. |
| Lw | Shape factor (Lambda), wind (sea) part. |
| prob | Probability of occurrence for one sea state. |
| occr | Number of occurrences for one sea state. |

**NOTES:**
If the sea states of the scatter diagram are defined in terms of probability then the sum of all probabilities must be 1.0.

If the wave statistics data is defined in terms of occurrence, the occurrence must be greater than 10, otherwise input is handled as defined in terms of probability.

Scatter points with zero probabilities or zero occurrences should be omitted. All scatter points, zero points as well, are included as sea states in the analysis. The zero scatter points do not contribute to the fatigue damage but will, however, slow down the speed of computation and occupy unnecessary saving space in the data base for saving zero analysis results.

The Nordenstrøm model may NOT be used for fatigue analysis.

See also:

```
CREATE WAVE-STATISTICS...
ASSIGN WAVE-STATISTICS...
PRINT WAVE-STATISTICS...
```

**EXAMPLES:**

```
CHANGE WAVE-STATISTICS WS1 'Scatter diagram ' SCATTER-DIAGRAM ( ONLY
5.0 7.0 0.1
6.0 6.0 0.5
7.0 6.0 0.3
8.0 5.0 0.1 )
CHANGE WAVE-STATISTICS OH1 'Ochi-Hubble' ALL-PARAM-SCATTER OCHI-HUBBLE ( ONLY
7.25 20.25 10.0 7.0 9.0 3.0 0.3
8.25 25.25 10.0 7.5 9.5 3.0 0.7 )
```

## 5.18 CREATE

| | | |
|---|---|---|
| CREATE | FATIGUE-CHECK-POINTS | ... |
| | SN-CURVE | |
| | WAVE-SPREADING-FUNCTION | |
| | WAVE-STATISTICS | |
| | WELD-NORMAL-LINE | |

**PURPOSE:**

The create command is the main command for creation of fatigue check points and different tools such as SN-curves, wave spectra, wave energy spreading functions, wave statistics models and weld normal lines.

## 5.19 CREATE FATIGUE-CHECK-POINTS

| | | | |
|---|---|---|---|
| ... | FATIGUE-CHECK-POINTS | HOTSPOT-CHECK | ... |
| | | ELEMENT-CHECK | |

**PURPOSE:**
To create hotspot fatigue check points and to set location of element fatigue check points.

## 5.20 CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK

SUBCOMMAND:

<table>
<tr><td rowspan="9">...</td><td rowspan="9">ELEMENT-CHECK</td><td>ELEMENT-STRESS-POINTS</td><td rowspan="5">...</td><td>BOTH-SIDES</td><td rowspan="9">...</td><td rowspan="5">CURRENT-SUPERELEMENT</td></tr>
<tr><td>ELEMENT-SURFACES</td><td rowspan="2">-Z-SIDE</td></tr>
<tr><td>ELEMENT-CORNERS</td></tr>
<tr><td>CENTRE STRESS-POINTS</td><td rowspan="2">+Z-SIDE</td></tr>
<tr><td>CENTRE-SURFACE-POINTS</td></tr>
<tr><td colspan="3">ELEMENT-MIDDLE-PLANE</td><td rowspan="4">TOP-LEVEL-SUPERELEMENT</td></tr>
<tr><td colspan="3">ELEMENT-MEMBRANE</td></tr>
<tr><td colspan="3">CENTROID ELEMENT</td></tr>
<tr><td colspan="3">CENTROID-MEMBRANE</td></tr>
</table>

**PURPOSE:**
To create element fatigue check points.

**PARAMETERS:**

| | |
|---|---|
| ELEMENT-STRESS-POINTS | The fatigue check points are located at element stress points (default). |
| ELEMENT-SURFACES | The fatigue check points are located at element surface points. |
| ELEMENT-CORNERS | The fatigue check points are located at element corner points. |
| CENTRE-STRESS-POINTS | The fatigue check points are located at element centre stress points. Stress point stresses are interpolated to the centre positions of the element and applied in the fatigue damage calculation. Interpolations are performed in normal direction to the local z-axis of the element (parallel to the top and bottom surfaces) at the z-location of the element stress points. |
| CENTRE-SURFACE-POINTS | The fatigue check points are located at element centre surface points. Centre point stresses are extrapolated to the top and bottom surface of the element. |
| ELEMENT-MIDDLE-PLANE | Stress points are projected normal to the element middle plane and taken as the fatigue check points. This option is applicable for shell elements. For solid elements the element stress points option is applied when this option is used. |
| ELEMENT-MEMBRANE | Stress points are projected normal to the element middle plane and taken as the fatigue check points. Only the membrane stress components ($\sigma_x$, $\sigma_y$, $\tau_{xy}$) are considered. This option is applicable for shell elements. For solid elements the element stress points option is applied when this option is selected. |
| CENTROID-ELEMENT | The fatigue check points are located at centroid of the element. Centre point stresses are interpolated to the mid position of the element ($z = 0.0$). |
| CENTROID-MEMBRANE | The fatigue check points are located at centroid of the element.Centre point stresses are interpolated to the mid position of the element ($z = 0.0$). Only mebrane stresses are applied. This option is applicable for shell elements. For solid elements the centroid element option is applied when this option is selecteded. |

| | |
|---|---|
| BOTH-SIDES | Include all check points of the element (default). |
| -Z-SIDE | Include fatigue check points of the -z side of the shell element. -z is relative to the element normal (local element z-axis). This option has no effect for the 3D solid elements. |
| +Z-SIDE | Include fatigue check points of the +z side of the shell element.+z is relative to the element normal (local element z-axis). This option has no effect for the 3D solid elements. |
| CURRENT-SUPERELEMENT | The printed coordinates refer to current (1. level) superelement. |
| TOP-LEVEL-SUPERELEMENT | The printed coordinates refer to top level superelement. |

**NOTES:**
The element fatigue points may be located at the *stress points*, at the *surface point*, at the *corner points*, at the *middle plane points*, or at the *centre points* of the elements. The user selects which location to be used. The number of fatigue check points is the same as the number of stress points for the elements. For the middle plane, the number of fatigue points is half the number of stress points. For the centre points the number of fatigue check points are two if both sides are selected and one if only one of the side is selected. The centroid position has only one fatigue check point. For shell elements it is possible to select fatigue check points of only one element side, below (-z side) or above (+z side) the middle plane, to be included in the fatigue analysis. Stress points of both element sides is default.

Damage is calculated for all fatigue points at the selected positions of an element and the usage factor of the point that suffers most fatigue damage is taken as the usage factor of the element and made available to the user in tabulated print of the fatigue results. Usage factors of all the fatigue points may, however, be written to the VTF file (see command DEFINE FATIGUE-RESULTS-VTF-FILE) and presented as contour plots by Xtract or printed to the dump file (see command DEFINE FATIGUE-RESULTS-DUMP) which gives detailed information of the fatigue results.

In the print table of results, coordinates of the point at which the usage factor is calculated is printed. The coordinates may be printed in *current (1. level) superelement system* or *in top level superelement system*.

**EXAMPLES:**

```
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-STRESS-POINTS BOTH-SIDES
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-SURFACES -Z-SIDE
TOP-LEVEL-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-CORNERS +Z-SIDE
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-MIDDLE-PLANE
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-MEMBRANE
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK CENTRE-SURFACE-POINTS BOTH-SIDES
CURRENT-SUPERELEMENT
```

## 5.21 CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK

SUBCOMMAND:

<table>
<tr><td rowspan="3">...</td><td rowspan="3">HOTSPOT-CHECK</td><td>ONLY</td><td rowspan="3">name</td><td rowspan="3">txt</td><td rowspan="3">...</td></tr>
<tr><td>INCLUDE</td></tr>
<tr><td>EXCLUDE</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td colspan="2">NODE</td><td colspan="2">nodhot</td><td colspan="3">elhot</td><td rowspan="3">...</td></tr>
<tr><td colspan="2">COORDINATES</td><td colspan="2">xhot</td><td>yhot</td><td>zhot</td><td>elhot</td></tr>
<tr><td>ELEMENT-COORDINATES</td><td>ELEMENT</td><td>elhot</td><td>COORDINATES</td><td>xihot</td><td>yihot</td><td>yihot</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td colspan="2">NODE</td><td colspan="2">nodt/2</td><td colspan="3">elt/2</td><td rowspan="3">...</td></tr>
<tr><td colspan="2">COORDINATES</td><td colspan="2">xt/2</td><td>yt/2</td><td>zt/2</td><td>elt/2</td></tr>
<tr><td>ELEMENT-COORDINATES</td><td>ELEMENT</td><td>elt/2</td><td>COORDINATES</td><td>xit/2</td><td>yit/2</td><td>zit/2</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td colspan="2">NODE</td><td colspan="2">nod3t/2</td><td colspan="3">el3t/2</td><td rowspan="3">...</td></tr>
<tr><td colspan="2">COORDINATES</td><td colspan="2">x3t/2</td><td>y3t/2</td><td>z3t/2</td><td>el3t/2</td></tr>
<tr><td>ELEMENT-COORDINATES</td><td>ELEMENT</td><td>el3t/2</td><td>COORDINATES</td><td>xi3t/2</td><td>yi3t/2</td><td>zi3t/2</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td colspan="5">SKIP</td><td rowspan="3">...</td><td>CURRENT-SUPERELEMENT</td></tr>
<tr><td rowspan="2">ENTER</td><td>NODE</td><td colspan="3">nodaux</td><td rowspan="2">TOP-LEVEL-SUPERELEMENT</td></tr>
<tr><td>COORDINATES</td><td>xaux</td><td>yaux</td><td>zaux</td></tr>
</table>

**PURPOSE:**
To create hotspot fatigue check points.
Three points have to be created: *hotspot*, *interpolation point t/2* and *interpolation point 3t/2*. Stresses of interpolation points t/2 and 3t/2 are interpolated to the hotspot whereupon the fatigue damage is calculated.

The location of the three points may be identified by 1) *node numbers*, 2) *x-, y-, z-coordinates*, or 3) *local normalized element coordinates*. Node numbers may be applied when the point is located at nodal points of the element model.

Use of normalized element coordinates require knowledge of the normalized coordinate system of the elements. The normalized element coordinates xi, yi, zi, describing the position of the hotspot and interpolation points t/2 and 3t/2 inside the element, consist of the neutral element coordinates ($\alpha$, $\beta$, $\gamma$) for quadrilateral shaped elements and the area and volume coordinates (L1, L2, L3) for triangles and tetrahedrons, see parameter description below and figures in D.2.

The orientation of the neutral element coordinate axes is related to the orientation of the local xyz-coordinate axes of the elements as shown in D.2. The local xyz-coordinate axes of the elements can be displayed by opening the SIN file from Xtract. The orientation of the local xyz-coordinate system may also be found by relating the local numbering of the element nodes to the external numbering of the nodes. The external numbering may be found by viewing the model data from Xtract or by viewing the element data on the vtf file (see command DEFINE FATIGUE-RESULTS-VTF-FILE for print of element results to the vtf file). The external node numbers of an element are listed in the order of the local element nodes. The order of the local element node numbering applied in Xtract differs from the order applied in Sesam and Stofat for some elements, see D.2.

Element number must be entered along with the point identification. The element number is used to identify correct element stresses when the point is connected to more than one element (at an element node or along an element border). When 0 (zero) is entered as element number, the program search through the model and prints the elements that are connected to the point (not applicable for the element coordinates option). The user must then re-enter the input and specify an element number.

A point located inside an element may be moved to the surface of the element by the program. In this regard an *auxiliary point* has to be entered. The auxiliary point may be located anywhere inside or outside the element model. The point is moved to the element surface that is closest to the auxiliary point. The program prints the coordinates of the new point. If the position of the new point is accepted by the user, the hotspot must be re-entered, where the coordinates of the old point is replaced with the coordinates of the new point and the auxiliary point is skipped.

The hotspot and the interpolation points must be located inside or at the border of the elements. When the user creates a point that is located outside an element, the program does not accept the point and prints a message along with the location of the point projected to the element border. Input must then be re-entered with a position that is not outside the element.

*Note that input of a hotspot has to be accepted by the program before fatigue damage of the point is calculated in the run execution.*

Coordinates may be entered in *current (1. level) superelement system* or in *top level superelement system*. Default is current superelement.

Element stresses of the Results Interface File (R#.SIN) may be transformed to a global system, which may be the coordinate system of the current superelement or the top level superelement.

Further details are given in D.3.

**PARAMETERS:**

| | |
|---|---|
| ONLY | Include the hotspot and its interpolation points (if new) and make the hotspot active (if inactive). All other created hotspots are made inactive and not available for use. Inactive hotspots are made active by the INCLUDE parameter. A hotspot may be deleted by the DELETE HOTSPOT command. |
| INCLUDE | Include the hotspot and its interpolation points (if new) or make the hotspot active (if inactive). Original data are kept when a hotspot is made active. |
| EXCLUDE | Exclude the hotspot and its interpolation points. The excluded hotspot is made inactive and not available for use. Inactive hotspots are made active by the INCLUDE parameter. A hotspot may be deleted by the DELETE HOTSPOT command. |
| name | Name of the hotspot. |
| txt | Descriptive text. |
| NODE | Enter node number for identification of the point. |
| COORDINATES | Enter coordinates for identification of the point. |
| ELEMENT-COORDINATES | Enter normalised element coordinates for identification of the point. |
| ELEMENT | Enter element number for identification of the point by normalised element coordinates. |

| | |
|---|---|
| COORDINATES | Enter coordinates for identification of the point by normalised element coordinates. |
| nodhot | External node number identifying the hotspot. |
| elhot | External element number identifying the hotspot. |
| xhot | X-coordinate of the hotspot. |
| yhot | Y-coordinate of the hotspot. |
| zhot | Z-coordinate of the hotspot. |
| xihot | Normalised element coordinate of the hotspot: |
| | Quadrilateral shell and solids: Xi or $\alpha$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L1 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L1 $(0 \leq \alpha \leq 1)$. |
| yihot | Normalised element coordinate of the hotspot: |
| | Quadrilateral shell and solids: Eta or $\beta$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L2 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L2 $(0 \leq \alpha \leq 1)$. |
| zihot | Normalised element coordinate of the hotspot: |
| | Quadrilateral shell and solids: Zeta or $\gamma$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: Zeta or $\gamma$ coordinate $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L3 $(0 \leq \alpha \leq 1)$. |
| nodt/2 | External node number identifying interpolation point t/2. |
| elt/2 | External element number identifying interpolation point t/2. |
| xt/2 | X-coordinate of interpolation point t/2. |
| yt/2 | Y-coordinate of interpolation point t/2. |
| zt/2 | Z-coordinate of interpolation point t/2. |
| xit/2 | Normalised element coordinate of interpolation point t/2: |
| | Quadrilateral shell and solids: Xi or $\alpha$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L1 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L1 $(0 \leq \alpha \leq 1)$. |
| yit/2 | Normalised element coordinate of interpolation point t/2: |
| | Quadrilateral shell and solids: Eta or $\beta$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L2 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L2 $(0 \leq \alpha \leq 1)$. |
| zit/2 | Normalised element coordinate of interpolation point t/2: |
| | Quadrilateral shell and solids: Zeta or $\gamma$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: Zeta or $\gamma$ coordinate $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L3 $(0 \leq \alpha \leq 1)$. |
| nod3t/2 | External node number identifying interpolation point 3t/2. |
| el3t/2 | External element number identifying interpolation point 3t/2. |
| x3t/2 | X-coordinate of interpolation point 3t/2. |
| y3t/2 | Y-coordinate of interpolation point 3t/2. |
| z3t/2 | Z-coordinate of interpolation point 3t/2. |
| xi3t/2 | Normalised element coordinate of interpolation point 3t/2: |

| | |
|---|---|
| | Quadrilateral shell and solids: Xi or $\alpha$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L1 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L1 $(0 \leq \alpha \leq 1)$. |
| yi3t/2 | Normalised element coordinate of interpolation point 3t/2: |
| | Quadrilateral shell and solids: Eta or $\beta$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L2 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L2 $(0 \leq \alpha \leq 1)$. |
| zi3t/2 | Normalised element coordinate of interpolation point 3t/2: |
| | Quadrilateral shell and solids: Zeta or $\gamma$ coordinate $(-1 \leq \alpha \leq 1)$, |
| | Triangles and prisms: area coordinate L3 $(0 \leq \alpha \leq 1)$, |
| | Tetrahedrons: volume coordinate L3 $(0 \leq \alpha \leq 1)$. |
| SKIP | Don't use the auxiliary point. |
| ENTER | Create the auxiliary point. |
| nodaux | External node number identifying the auxiliary point. |
| xaux | X-coordinate of the auxiliary point. |
| yaux | Y-coordinate of the auxiliary point. |
| zaux | Z-coordinate of the auxiliary point. |
| CURRENT-SUPERELEMENT | Coordinates and global system refer to current superelement. |
| TOP-LEVEL-SUPERELEMENT | Coordinates and global system refer to top level superelement. |

**EXAMPLES:**

```
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT1 'Hotspot 1'
COORDINATES 1.89375 -0.014071 0.29 510
COORDINATES 1.888321 -0.014071 0.29 510
COORDINATES 1.88125 -0.014071 0.29 664 SKIP
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT2 'Hotspot 2'
NODE 128 510
COORDINATES 1.888321 -0.014071 0.29 510
COORDINATES 1.88125 -0.014071 0.29 664 SKIP
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT3 'Hotspot 3'
ELEMENT-COORDINATES ELEMENT 666 COORDINATES 0.0 0.0 -0.5051258
ELEMENT-COORDINATES ELEMENT 666 COORDINATES 0.5 0.0 -0.5051258
ELEMENT-COORDINATES ELEMENT 664 COORDINATES 1.0 1.0 -0.5051258 SKIP
CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK EXCLUDE HOT1 'Hotspot 1'
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK ONLY HOT2 'Hotspot 2'
```

## 5.22 CREATE SN-CURVE

<table>
<tr><td rowspan="3">...</td><td rowspan="3">SN-CURVE</td><td rowspan="3">name</td><td>USER</td><td rowspan="3">txt</td><td>m0</td><td colspan="2">s0</td><td>logN0</td><td rowspan="3">...</td></tr>
<tr><td>LOGA</td><td>m0</td><td colspan="2">logA0</td><td>logN0</td></tr>
<tr><td>STOCHASTIC</td><td>m0</td><td>logK0</td><td>s</td><td>logN0</td></tr>
</table>

<table>
<tr><td rowspan="6">...</td><td colspan="5">DEFAULT-TAIL</td></tr>
<tr><td colspan="5">ALIGNED-WITH-FIRST</td></tr>
<tr><td colspan="5">HORISONTAL-TAIL</td></tr>
<tr><td rowspan="3">ARBITRARY-TAIL</td><td rowspan="3">m1</td><td colspan="3">ALIGNED-WITH-SECOND</td></tr>
<tr><td>HORISONTAL-TAIL</td><td colspan="2">logN1</td></tr>
<tr><td>ARBITRARY-TAIL</td><td>logN1</td><td>m2</td></tr>
</table>

**PURPOSE:**

To create a SN-curve with up to 3 segments.

**PARAMETERS:**

| | |
|---|---|
| name | Name of the SN-curve. |
| USER | Option where stress level s0 at end of first segment is given. |
| LOGA | Option where the intercept of logN-axis and SN-curve, logA0, is given. |
| STOCHASTIC | Option where the intercept of logN-axis and mean SN-curve, logK0 and the standard deviation of logK0, std, are given. |
| txt | Descriptive text of the SN-curve. |
| m0 | Slope of first segment. |
| s0 | Stress level at end first segment. |
| logN0 | Log cycles to failure at end first segment. |
| logA0 | Intercept of logN-axis and SN-curve. |
| logK0 | Intercept of logN-axis and mean SN-curve. |
| sdk | Standard deviation of logK0. Note: $\log A0 = \log K0 - 2 \cdot sdk$. |
| DEFAULT-TAIL | Second segment continues with $m1 = 2 \cdot m0 - 1$. |
| ALIGNED-WITH-FIRST | Second segment continues with $m1 = m0$. |
| HORISONTAL-TAIL | Second segment is horizontal. |
| ARBITRARY-TAIL | Second segment is arbitrary. |
| m1 | Slope of second segment. |
| ALIGNED-WITH-SECOND | Third segment continues with $m2 = m1$. |
| HORISONTAL-TAIL | Third segment is horizontal. |
| logN1 | Log cycles to failure at end second segment. |
| m2 | Slope of third segment. |

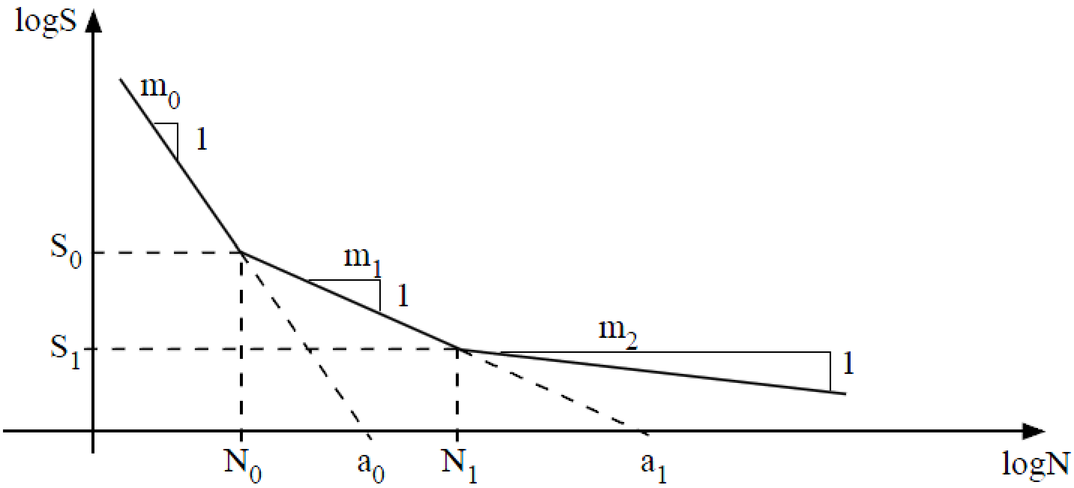


Figure 5.2: Create SN-curve

The number of cycles to failure (N) for a given stress range (S) is computed according to the following formula:

$$N \cdot S^m - a$$

$$\log N = \begin{cases} \log a_0 - m_0 \cdot \log S, & \text{for } S > S_0. \\ \log a_1 - m_1 \cdot \log S, & \text{for } S_1 < S < S_0. \\ \log a_1 - m_2 \cdot \log S, & \text{for } S_2 < S_1 \end{cases} \quad (5.3)$$

**EXAMPLES:**

```
CREATE SN-CURVE USE-X USER NONE 3.0 3.40 7.0 ARBITRARY-TAIL 5.0 ARBITRARY-TAIL
8.301 7.0
CREATE SN-CURVE USE-Y USER NONE 3.0 3.40E6 7.0 ARBITRARY-TAIL 5.0 HORISONTAL-TAIL
8.301
```

## 5.23 CREATE WAVE-SPREADING-FUNCTION

<table>
<tr><td rowspan="2">...</td><td rowspan="2">WAVE-SPREADING-FUNCTION</td><td rowspan="2">name</td><td rowspan="2">txt</td><td>COSINE-POWER</td><td colspan="7">power</td></tr>
<tr><td>USER-DEFINED</td><td>(</td><td>ONLY</td><td>{</td><td>dir</td><td>fact</td><td>}*</td><td>)</td></tr>
</table>

**PURPOSE:**

To create energy spreading for elementary wave directions by a cosine of power $n$ or with user defined weights on each direction. The sum of the user defined weights does not need to be equal to 1 since the program will normalize the weights when using the spreading function.

**PARAMETERS:**

| | |
|---|---|
| name | Name of the spreading function. |
| txt | Descriptive text of the spreading function. |
| COSINE-POWER | Cosine power spreading function. |
| power | Power of the cosine function given as an integer value. Default is 2. |
| USER-DEFINED | User defined spreading function. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |
| dir | Relative direction to the main wave direction in use. The range is, if spanning over 180 degrees, from -90 degrees to 90 degrees. |
| fact | Weight for each elementary wave direction relative to the main wave direction. |

**EXAMPLES:**

```
CREATE WAVE-SPREADING-FUNCTION COS2 Continuous COSINE-POWER 2
CREATE WAVE-SPREADING-FUNCTION USER1 ' ' USER-DEFINED ( ONLY 180.0 0.1666 210.0
0.1666 240.0 0.1666 270.0 0.1666 300.0 0.1666 330.0 0.1666 )
```

## 5.24 CREATE WAVE-STATISTICS

| | | | | | |
|---|---|---|---|---|---|
| ... | WAVE-STATISTICS | name | text | SCATTER-DIAGRAM | ... |
| | | | | ISSC-SCATTER-DIAGRAM | ... |
| | | | | ALL-PARAM-SCATTER | ... |
| | | | | NORDENSTROM | parameters |

with the subsequent input data for SCATTER-DIAGRAM:

| | | |
|---|---|---|
| ... | PROBABILITY | {Hs,Tz,prob}* |
| | OCCURRENCE | {Hs,Tz,occr}* |

with the subsequent input data for ISSC-SCATTER-DIAGRAM:

| | | |
|---|---|---|
| ... | PROBABILITY | {Hs,T1,prob}* |
| | OCCURRENCE | {Hs,T1,occr}* |

with the subsequent input data for ALL-PARAM-SCATTER:

| | | | |
|---|---|---|---|
| ... | OCHI-HUBBLE | PROBABILITY | {Hss,Tps,Ls,Hsw,Tpw,Lw,prob}* |
| | | OCCURRENCE | {Hss,Tps,Ls,Hsw,Tpw,Lw,occr}* |

**PURPOSE:**
To create a wave scatter diagram.

**PARAMETERS:**

| | |
|---|---|
| name | Name of wave statistics. |
| text | Text associated with the wave statistics. |
| ALL-PARAM-SCATTER | The wave statistics and spectrum shape are defined through a all parameter scatter diagram. |
| SCATTER-DIAGRAM | The wave statistics is a scatter diagram. |
| NORDENSTROM | The wave statistics is the Nordenstrøm model. |
| OCHI-HUBBLE | The wave spectrum is a 6 parameter Ochi-Hubble spectrum. |
| PROBABILITY | The scatter diagram shall be defined in terms of probability for each set of Hs Tz values. |
| OCCURRENCE | The scatter diagram shall be defined in terms of occurrence for each set of hs tz values. |
| Hss | Significant wave height, swell part. |
| Tps | Peak spectral period, swell part. |
| Ls | Shape factor (Lambda), swell part. |
| Hsw | Significant wave height, wind (sea) part. |
| Tpw | Peak spectral period, wind (sea) part. |
| Lw | Shape factor (Lambda), wind (sea) part. |
| prob | Probability of occurrence for one sea state. |

| | |
|---|---|
| occr | Number of occurrences for one sea state. |
| Hs | Significant wave height of one sea state. |
| Tz | Zero up-crossing period for one sea state. |
| T1 | Mean period for one sea state. |

**NOTES:**
If the sea states of the scatter diagram are defined in terms of probability then the sum of all probabilities must be 1.0.

When all parameters are given through the CREATE WAVE-STATISTICS command, a wave spectrum shape shall not be assigned to the wave statistics.

Scatter points with zero probabilities or zero occurrences should be omitted. All scatter points, zero points as well, are included as sea states in the analysis. The zero scatter points do not contribute to the fatigue damage but will, however, slow down the speed of computation and occupy unnecessary saving space in the data base for saving zero analysis results.

The Nordenstrøm model may NOT be used for fatigue analysis.

See also:

```
ASSIGN WAVE-STATISTICS...
PRINT WAVE-STATISTICS...
```

**EXAMPLES:**

```
CREATE WAVE-STATISTICS WS1 'Scatter diagram for SESAM field'
SCATTER PROBABILITY
( 5.0 7.0 0.1
  7.0 6.0 0.3
  6.0 6.0 0.5
  8.0 5.0 0.1 )
```

## 5.25 CREATE WELD-NORMAL-LINE

<table>
<tr><td rowspan="3">...</td><td rowspan="3">WELD-NORMAL-LINE</td><td>ONLY</td><td rowspan="3">name</td><td rowspan="3">txt</td><td rowspan="3">...</td></tr>
<tr><td>INCLUDE</td></tr>
<tr><td>EXCLUDE</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td>NODES</td><td>nod1</td><td colspan="6">nod2</td><td rowspan="3">alpha</td></tr>
<tr><td rowspan="2">COORDINATES</td><td>CURRENT-SUPERELEMENT</td><td rowspan="2">x1</td><td rowspan="2">y1</td><td rowspan="2">z1</td><td rowspan="2">x2</td><td rowspan="2">y2</td><td rowspan="2">z2</td></tr>
<tr><td>TOP-LEVEL-SUPERELEMENT</td></tr>
</table>

**PURPOSE:**
To create a Weld Normal (WN) line and define the stress sector related to the WN line.

**PARAMETERS:**

| | |
|---|---|
| ONLY | Include the WN line (if new) and make the WN line active (if inactive). All other created WN lines are made inactive and not available for use. Inactive WN lines are made active by the INCLUDE parameter. A WN line may be deleted by the DELETE command. |
| INCLUDE | Include the WN line (if new) or make the WN line active (if inactive). Original data are kept when a WN line is made active. |
| EXCLUDE | Exclude the WN line. The excluded line is made inactive and not available for use. Inactive WN lines are made active by the INCLUDE parameter. A WN line may be deleted by the DELETE command. |
| name | Name of the WN line. |
| txt | Text associated with the WN line (max 132 characters). |
| NODES | WN line is defined by two nodes of the model. |
| COORDINATES | WN line is defined by coordinates of two points. |
| nod1 | Node number of point 1 on the WN line. The node must be a nodal point number of current superelement. |
| nod2 | Node number of point 2 on the WN line. The node must be a nodal point number of current superelement. |
| CURRENT-SUPERELEMENT | Input coordinates of the points refer to current superelement. |
| TOP-LEVEL-SUPERELEMENT | Input coordinates of the points refer to top level superelement. |
| x1, y1, z1 | XYZ-coordinates of point 1 on the WN line. |
| x2, y2, z2 | XYZ-coordinates of point 2 on the WN line. |
| alpha | Angle defining the stress sector related to the WN line. It is counted from the WN line to the border of the stress sector. The total stress sector is $2 \cdot$ alpha. Unit is degrees and legal values are in the range of $0°$ to $+90°$. Default value is $45°$. |

**NOTES:**
A WN line has the purpose of identifying the maximum principal stress within a given stress sector connected to the WN line.

The two points defining the WN line can not be located at same position. The order the two points are entered as input is not of importance.

Principal stresses and principal directions are calculated on basis of the component stresses at the fatigue check points. The axes of the principal stresses are tested to be inside or outside the stress sector. The maximum stress component of the principal axes inside the sector is applied in the fatigue analysis.

A sector of alpha = $90°$ includes the whole area around the fatigue check point. All three principal stress axes will be inside the sector and the first principal stress component is always used. This gives the same fatigue damage as when not using the WN line.

A sector of alpha < $90°$ includes necessarily not all three principal stress axes. The principal stress components of the axes outside the sector are disregarded when the maximum principal stress component is searched for.

A sector of alpha = $0°$ may not include one or none of the principal stress axes. In this case the stress component of the principal axis closest in direction to the WN line is used. The three principal axes are projected orthogonal on the WN line and the axis with the largest length component along the WN line is selected.

A WN line must be assigned to an element or a hotspot to be applied in the fatigue analysis. The WN line applies to all fatigue check points of the element and to the interpolation points of the hotspot as well as the hotspot itself. WN lines are assigned to individual elements and hotspots by the command ASSIGN WELD-NORMAL-LINE.

When an active WN line is made inactive and not available for use, assignments of the line are also made inactive. When an inactive line is made active and available for use, all assignments of the line are made active.

Use the command PRINT RUN-OVERVIEW WELD-NORMAL-LINES or press the Show button in the dialogue box to see current status on defined weld normal lines and assignments to elements and hotspots.

Weld normal lines and weld normal line assignments may be deleted by the commands DELETE WELD-NORMAL-LINE DELETE-LINE and DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT.

**EXAMPLES:**

```
CREATE WELD-NORMAL-LINE INCLUDE WNL1 'Line defined by nodes' NODES 179 134 45.0
CREATE WELD-NORMAL-LINE INCLUDE WNL2 'Line defined by coordinates'
COORDINATES CURRENT-SUPERELEMENT -9.5 -14.36 12.495 27.36 20.91 20.505 60.0
```

## 5.26 DEFINE

| | | |
|---|---|---|
| DEFINE | FATIGUE-DAMAGE-TO-FILE | ... |
| | FATIGUE-RAINFLOW-COUNTING | |
| | FATIGUE-RESULTS-DUMP | |
| | FATIGUE-RESULTS-VTF-FILE | |
| | LONG-TERM-PROBABILITY | |
| | LONG-TERM-RETURN-PERIOD | |
| | LONG-TERM-STRESS | |
| | SHELL-FATIGUE-CONSTANTS | |
| | TIME-HISTORY-FATIGUE-TIME | |
| | STATIC-LOAD-CASE | |
| | WEIBULL-PARAMETERS | |
| | WIDE-BAND-CORRECTION-FACTOR | |

**PURPOSE:**
The define command is used to define fatigue constants, print dump of detailed fatigue results and on/off switch of fatigue calculation by rainflow counting, calculation of Weibull parameters, print of fatigue results to VTF file, probabilities and accounting for static load case.

Note that settings made by this command are applied when next fatigue analysis is executed by the RUN command.

## 5.27 DEFINE FATIGUE-RAINFLOW-COUNTING

<table>
<tr><td rowspan="2">...</td><td rowspan="2">FATIGUE-RAINFLOW-COUNTING</td><td colspan="4">OFF</td></tr>
<tr><td>ON</td><td>timstp</td><td>stpexp</td><td>seed</td></tr>
</table>

**PURPOSE:**
To switch between:

a) Damage calculations based on closed form solution from spectral moments assuming Rayleigh distribution. This is the default option.

b) Damage calculations based on generation of stress time series by FFT (Fast Fourier Transform) from stress auto spectrum, i.e. rainflow cycle counting in time domain.

**PARAMETERS:**

| | |
|---|---|
| OFF/OFF | OFF/ON switch for Rainflow counting (default is OFF). |
| timstp | Time step (default = $0.2$ sec.). |
| stpexp | Time steps exponent in generating stress time series (default = $14$, i.e. $2^{14}$ steps). |
| seed | Seed for generation of random phase angles (default = $123456$). |

**NOTES:**
Damage calculation based on rainflow counting requires considerable more computer time than solution from spectral moments. Care should therefore be taken in using this option on large element selections.

The rainflow counting option applies element stress point stresses. Extrapolated stresses to element surfaces and element corners are currently not available for this option.

**EXAMPLES:**

```
DEFINE FATIGUE-RAINFLOW-COUNTING ON 0.2 14 123456
```

## 5.28 DEFINE FATIGUE-RESULTS-DUMP

<table>
<tr><td rowspan="20">...</td><td rowspan="20">FATIGUE-RESULTS-DUMP</td><td>FILE-NAME</td><td colspan="2">name</td></tr>
<tr><td rowspan="2">FILE-STATUS</td><td colspan="2">NEW</td></tr>
<tr><td colspan="2">OLD</td></tr>
<tr><td>HOTSPOT-STRESS-TRANSFER-FUNCTION</td><td rowspan="6">...</td><td rowspan="3">ON</td></tr>
<tr><td>MOMENTS-OF-RESPONSE-SPECTRUM</td></tr>
<tr><td>DAMAGE-PER-SEA-STATE</td></tr>
<tr><td>DAMAGE-PER-DIRECTION</td><td rowspan="3">OFF</td></tr>
<tr><td>DAMAGE-PER-HOTSPOT</td></tr>
<tr><td>WEIBULL-PARAMETERS</td></tr>
<tr><td rowspan="2">EXCEEDENCE-PROBABILITY</td><td>ON</td><td>exclev</td></tr>
<tr><td colspan="2">OFF</td></tr>
<tr><td rowspan="2">STRESS-RANGE-DISTRIBUTION</td><td>ON</td><td>strlev</td></tr>
<tr><td colspan="2">OFF</td></tr>
<tr><td>TIME-FATIGUE-DAMAGE</td><td colspan="2">status</td></tr>
<tr><td rowspan="3">FATIGUE-STRESS-TIME-SERIES</td><td colspan="2">OFF</td></tr>
<tr><td colspan="2">WORST-HOTSPOT</td></tr>
<tr><td colspan="2">ALL-HOTSPOTS</td></tr>
<tr><td rowspan="3">TIME-SERIES-STRESS-RANGES</td><td colspan="2">OFF</td></tr>
<tr><td colspan="2">SORTED</td></tr>
<tr><td colspan="2">UNSORTED</td></tr>
</table>

**PURPOSE:**

Turn on dump parameters for detailed print of fatigue analysis result. Dump print is executed by the command PRINT FATIGUE-RESULTS-DUMP after run executions.

Two dump files, depending on options set, are generated when the print command is executed:

| | |
|---|---|
| nameDmp.lis: | Contains hotspot stress transfer functions, moments of response spectrum, damage per sea state, damage per direction and damage per hotspot (damage per position for element fatigue checks). |
| namePex.lis: | Contains exceedence probabilities and stress range distributions. |

**PARAMETERS:**

| | |
|---|---|
| FILE-NAME | name Enter name of dump print files. |
| FILE-STATUS | Enter status of dump print files (NEW or OLD). |
| NEW | New file(s) (nameDmp.lis and/or namePex.lis) is opened for dump print. |
| OLD | Print is added to existing file(s) (nameDmp.lis and/or namePex.lis). If the file(s) does not exist new file(s) is opened for dump print. |
| HOTSPOT-STRESS-TRANSFER-FUNCTION | Dump print of hotspot transfer function. |

| | |
|---|---|
| MOMENTS-OF-RESPONSE-SPECTRUM | Dump print moments of response spectrum. |
| DAMAGE-PER-SEASTATE | Dump print of damage per sea state. |
| DAMAGE-PER-DIRECTION | Dump print of damage per direction. |
| DAMAGE-PER-HOTSPOT | Dump print of damage per hotspot/position. |
| EXCEEDENCE-PROBABILITY | Dump print of exceedence probabilities. |
| STRESS-RANGE-DISTRIBUTION | Dump print of stress range distribution. |
| WEIBULL-PARAMETERS | Dump print of Weibull parameters. Requires that exceedance- or stress levels are defined, i.e. the exceedance probability or the stress range distribution attribute must have be turned on. |
| FATIGUE-STRESS-TIME-SERIES | Print time series of hotspot fatigue stresses. |
| Options OFF, WORST-HOTSPOT (worst damaged hotspot of each member position) or ALL-HOTSPOTS of members checked. | |
| TIME-SERIES-STRESS-RANGES | Print stress ranges of executed time series. Options OFF, SORTED (in decreasing order) or UNSORTED. |
| TIME-FATIGUE-DAMAGE | Print time fatigue damage results per hotspot checked. |
| OFF | Turn off attribute. |
| ON exclev strlev | Turn on attribute and enter number of exceedance levels exclev and stress levels strlev. The number of levels printed is the maximum of exclev and strlev (default = 11). |
| status | Print status. ON / OFF. |

**NOTES:**
The stress transfer functions printed is the maximum principal stresses at the user defined fatigue positions of the elements forming the response spectra which are applied in the fatigue damage calculation. The spectral moments printed are those found by integrating the response spectra. The spectral moments are scaled with the square of the element thickness factor (shell elements) and the static stress reduction factor (if included). The spectral band widths printed (resEps) are applied when the Wirsching correction factor for broad band stress processes is requested, see section C.3 and command DEFINE WIDE-BAND-CORRECTION-FACTOR.

The stress range distribution is divided into exclev (or strslev) exceedance levels. The maximum stress range of all wave directions for a stress point are applied when calculating the exceedance levels. The exceedance levels are numbered from 1 to exclev (or strslev). Level 1 is the level of maximum stress range and level exclev is the level of lowest stress range. Exceedances (stress cycles) for all stress levels are calculated for each individual wave direction. Accumulated exceedances and probabilities of exceedances for all wave directions are also calculated and in addition stress ranges and exceedances related to probability levels $10^{-8}$, $10^{-7}$ .... $10^{-0}$ are given. These probability levels are found by linear interpolation of the stress distribution in logarithmic scale. Note that the total number of stress cycles is given as the accumulated exceedances for exceedance probability level $10^{-0}$ (=1 and stress range = 0.0).

The maximum stress range (level 1) is applied in the fatigue damage calculations. If the accumulated exceedance of this level is larger than 1.0 an uppermost level (level 0) with an accumulated exceedance of 1.0, is printed. Level 0 is calculated by extrapolating the stress distribution by a Weibull curve fitting stress range level 1 and 2. Exceedances of level 0 for the individual wave directions are taken as the wave direction exceedances relative to the accumulated exceedance of level 1. I.e. exc0(j) = exc1(j)/exc1(all) where exc1(j) is the exceedance of wave direction j and exc1(all) is the accumulated exceedance of all wave directions. Wave direction exceedances of level 0 sums to 1.0.

If print of Weibull parameters is turned on, the Weibull scale and shape parameters are calculated and printed for each part range of the distribution. The Weibull parameters are calculated by fitting the two levels forming the part range of the distribution (level i and i+1). Weibull parameters calculated during the run execution is also printed when the command DEFINE WEIBULL-PARAMETERS is turned on. These parameters are average values of the stress range distribution calculated by fitting the Weibull function by a least square technique using 10 levels for the stress range distribution.

**EXAMPLES:**

```
DEFINE FATIGUE-RESULTS-DUMP FILE-NAME STOFAT
DEFINE FATIGUE-RESULTS-DUMP FILE-STATUS NEW
DEFINE FATIGUE-RESULTS-DUMP HOTSPOT-STRESS-TRANSFER-FUNCTION OFF
DEFINE FATIGUE-RESULTS-DUMP MOMENTS-OF-RESPONSE-SPECTRUM OFF
DEFINE FATIGUE-RESULTS-DUMP DAMAGE-PER-SEASTATE OFF
DEFINE FATIGUE-RESULTS-DUMP DAMAGE-PER-DIRECTION OFF
DEFINE FATIGUE-RESULTS-DUMP DAMAGE-PER-HOTSPOT ON
DEFINE FATIGUE-RESULTS-DUMP EXCEEDENCE-PROBABILITY ON 11
DEFINE FATIGUE-RESULTS-DUMP STRESS-RANGE-DISTRIBUTION ON 11
DEFINE FATIGUE-RESULTS-DUMP WEIBULL-PARAMETERS ON
```

## 5.29 DEFINE FATIGUE-RESULTS-VTF-FILE

<table>
<tr><td rowspan="4">...</td><td rowspan="4">FATIGUE-RESULTS-VTF-FILE</td><td colspan="6">NO</td></tr>
<tr><td rowspan="3">YES</td><td rowspan="3">vtfnam</td><td>NEW</td><td rowspan="3">...</td><td>ELEMENT-RESULTS</td><td>...</td></tr>
<tr><td rowspan="2">OLD</td><td>ELEMENT-FATIGUE-POINT-RESULTS</td><td>...</td></tr>
<tr><td>LONG-TERM-RESPONSE</td><td>...</td></tr>
</table>

<table>
<tr><td>...</td><td colspan="6"></td><td colspan="2">...</td></tr>
<tr><td rowspan="3">...</td><td colspan="6">ACCUMULATED-DAMAGE</td><td colspan="2">...</td></tr>
<tr><td rowspan="2">PART-DAMAGE</td><td colspan="2">WAVE-DIRECTION</td><td colspan="3">wavdir+</td><td colspan="2">...</td></tr>
<tr><td colspan="2">SEA-STATE</td><td colspan="2">wavdir+</td><td>seastat+</td><td colspan="2">...</td></tr>
<tr><td rowspan="2">...</td><td>ELEMENT-RESULTS</td><td rowspan="2">...</td><td>PROBABILITY-EXPONENT</td><td>log-Q</td><td rowspan="2">...</td><td rowspan="2">wavdir+</td><td rowspan="2">strcmp+</td><td rowspan="2">param+</td></tr>
<tr><td>ELEMENT-FATIGUE-POINT-RESULTS</td><td>RETURN-PERIOD</td><td>rtnprd</td></tr>
</table>

<table>
<tr><td rowspan="7">...</td><td colspan="3">MAX-USAGE-FACTOR</td></tr>
<tr><td>FATIGUE-LIFE</td><td colspan="2">uplim</td></tr>
<tr><td colspan="3">THICKNESS-CORRECTION</td></tr>
<tr><td colspan="3">AXIAL-STRESS-K-FACTOR</td></tr>
<tr><td colspan="3">BENDING-STRESS-K-FACTOR</td></tr>
<tr><td colspan="3">SHEAR-STRESS-K-FACTOR</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
<tr><td rowspan="3">...</td><td colspan="3">USAGE-FACTOR</td></tr>
<tr><td>FATIGUE-LIFE</td><td colspan="2">uplim</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
<tr><td rowspan="4">...</td><td colspan="3">USAGE-FACTOR</td></tr>
<tr><td colspan="3">DAMAGE-FRACTION</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
<tr><td>PRINCIPAL-STRESS</td><td>WAVE-FREQUENCY</td><td>wavfrq+</td></tr>
<tr><td rowspan="3">...</td><td colspan="3">USAGE-FACTOR</td></tr>
<tr><td colspan="3">DAMAGE-FRACTION</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
</table>

**PURPOSE:**
To write element fatigue analysis results to a VTF file for graphic presentation of the results by Xtract. Note that hotspot fatigue check results are not written to the VTF file.

This command prints results to the VTF file during the run execution and must be applied prior to each new run. By the command PRINT FATIGUE-RESULTS-VTF-FILE fatigue results may be printed for selected runs after the runs have been executed and results saved.

**PARAMETERS:**

| | |
|---|---|
| NO | Fatigue results are not written to the VTF file (default). |
| YES | Fatigue results are written to the VTF file. |
| vtfnam | Name of the VTF file. The default name is Stofat. The extension of the file is.vtf and the full name is vtfnam.vtf. |
| NEW | A new file with name vtfnam.vtf is opened for print. |
| OLD | Results are appended to existing VTF file with name vtf-nam.vtf. If the file does not exist, a new file is opened for print. |
| ELEMENT-RESULTS | Write one result per element of current element selection. The fatigue check point with maximum usage factor is printed. |
| ELEMENT-FATIGUE-POINT-RESULTS | Write results of all element fatigue check points of current element selection. |
| LONG-TERM-RESPONSE | Write response results. Availability of this option requires that a stress component is defined, see command DEFINE LONGTERM-STRESS. |
| PROBABILITY-EXPONENT | Write results for given probability exponent. Availability of this option requires that probability levels are defined, see command DEFINE LONG-TERM PROBABILITY. |
| RETURN-PERIOD | Write results for given return period. Availability of this option requires that return periods are defined, see command DEFINE LONG-TERM-RETURN-PERIOD. |
| ACCUMULATED-DAMAGE | Write accumulated damage results of the element fatigue check points. |
| PART-DAMAGE | Write part damage results of the element fatigue check points. |
| WAVE-DIRECTION | Write part damage results for wave direction. |
| SEA-STATE | Write part damage results for sea state. |
| MAX-USAGE-FACTOR | Write maximum usage factor of the element. |
| USAGE-FACTOR | Write usage factor. |
| FATIGUE-LIFE | Write fatigue life. |
| THICKNESS-CORRECTION | Write thickness correction applied to the element. |
| AXIAL-STRESS-K-FACTOR | Write K-factor applied to axial stress components. |
| BENDING-STRESS-K-FACTOR | Write K-factor applied to bending stress components. |
| SHEAR-STRESS-K-FACTOR | Write K-factor applied to shear stress components. |
| STRESS-CYCLES | Write the number of stress cycles. |
| DAMAGE-FRACTION | Write fraction of damage of part damage result. |
| PRINCIPAL-STRESS | Write maximum principal stress. |
| WAVE-FREQUENCY | Write maximum principal stress for wave frequency. |
| wavdir+ | Wave direction. |
| seastat+ | Sea state. |
| wavfrq+ | Wave frequency. |
| log-Q+ | Probability exponent, as an absolute real number, defining the probability level Q, i.e. $Q = 10^{-(\log(-Q))}$. |
| rtnprd+ | Return period in years. |
| strcmp+ | Stress component to be applied in response calculation. Valid components: ‘Sp1’, ‘Seq’, ‘Sxx’, ‘Syy’, ‘Szz’, ‘Sxy’, ‘Sxz’, ‘Syz’, ‘Sp2’, ‘Sp3’. |

| | |
|---|---|
| param+ | Response parameter to be written for the given probability level or return period. Valid parameters: ‘Max Stress’, ‘Min Stress’, ‘Stress Amplitude’, ‘StaDyn factor’, ‘Probability Level’ or ‘Return Period’, ‘Exceedance’, ‘Weibull Scale’, ‘Weibull Shape’, ‘Static Stress’ and ‘Max Amplitude Point’. |
| uplim | Upper limit of fatigue life applied in vtf plot. Fatigue life above this limit will take the limit value when printed to the vtf file. No limit is applied when uplim = 0.0 (Default). |

**NOTES:**
See D.2.3 for comments related to the parameters ELEMENT-RESULTS and ELEMENT-FATIGUE-POINT-RESULTS.

Only one type of fatigue result is written to the VTF file during a Stofat run. The result case must be selected by the present command before the run command is executed. Results are written for the element selection applied in the run. The element selection as well as the type of fatigue results written to the vtf file may vary from one run to the next. Xtract may present many run cases from a Stofat session, case by case, which may contain different fatigue results and different selection of elements applied in the Stofat runs.

Results are written (appended) to the same vtf file (vtfnam.vtf) for all Stofat runs as long as Old is chosen for the append option and the file exists. If the file does not exists a new file with name vtfnam.vtf is opened and results are written to this file. If New is chosen for the append option, a new file with name vtfnam.vtf is opened and results are written to this file.

If data are appended to an existing vtf file, the file must end with the following sequence lines:

```
4
*GLVIEWGEOMETRY 1
\%NAME "Superelement 30"
\%DESCRIPTION "Fatigue check model"
\%ELEMENTS
1, 2, 3
```

The first line (4) gives the identification of last result case written to the vtf file. The last line (1, 2, 3) gives the number of prints directed to the file. If the more than 10 prints have previously been directed to the vtf file, the file will end with more than one line of numbers. In such a case the last lines except the last one will have 10 numbers, while the last line will have 10 or less numbers.

Coordinates of all nodal points of the superelement are written to the VTF file. These are the first level superelement coordinates read from the SIN file. If the superelement is a mirrored position of a basis superelement, the coordinates on the SIN file are those of the basis superelement, i.e. the un-mirrored position of the superelement.

**EXAMPLES:**

```
DEFINE FATIGUE-RESULTS-VTF-FILE YES Stofat NEW ELEMENT-RESULTS MAX-USAGE-FACTOR
DEFINE FATIGUE-RESULTS-VTF-FILE YES Stofat OLD ELEMENT-FATIGUE-POINT-RESULTS
ACCUMULATED-DAMAGE FATIGUE-LIFE
DEFINE FATIGUE-RESULTS-VTF-FILE YES Stofat OLD ELEMENT-FATIGUE-POINT-RESULTS
PART-DAMAGE WAVE-DIRECTION 135.0 PRINCIPAL-STRESS WAVE-FREQUENCY 0.698062
DEFINE FATIGUE-RESULTS-VTF-FILE YES Stofat NEW ELEMENT-FATIGUE-POINT-RESULTS
PART-DAMAGE SEA-STATE 1 DAMAGE-FRACTION
DEFINE FATIGUE-RESULTS-VTF-FILE YES Stofat NEW LONG-TERM-RESPONSE
ELEMENT-RESULTS PROBABILITY-EXPONENT 4.0 ALL Sp1 'Max Stress'
DEFINE FATIGUE-RESULTS-VTF-FILE YES Stofat OLD LONG-TERM-RESPONSE
ELEMENT-RESULTS RETURN-PERIOD 1.0 45.0 Seq 'Stress Amplitude'
```

## 5.30 DEFINE LONG-TERM-PROBABILITY

<table>
<tr><td rowspan="3">...</td><td rowspan="3">LONG-TERM-PROBABILITY</td><td colspan="7">OFF</td></tr>
<tr><td rowspan="2">ON</td><td rowspan="2">necclev</td><td rowspan="2">(</td><td rowspan="2">ONLY</td><td rowspan="2">{log-Q}</td><td rowspan="2">)</td><td>WEIBULL-FIT</td></tr>
<tr><td>NUMERICAL-FIT</td></tr>
</table>

**PURPOSE:**
To define probability levels for print of the response parameters.

**PARAMETERS:**

| | |
|---|---|
| OFF/ON | OFF/ON switch for definition of probabilities (default is OFF). |
| necclev | The number of eccedance levels the stress amplitude is divide into (default = 10). |
| log-Q | The probability given as an absolute integer exponent, i.e $Q(x) = 10^{-\log(-Q)}$. Range of legal values 0 < log-Q < 16. A maximum of 5 values may be given (default values are 2, 4, 6, 7, 8). |
| WEIBULL-FIT | Responses of the log-Q probability levels are calculated analytically by a two parameters Weibull function. The Weibull function is calculated by fitting probability points of the stress amplitude distribution by a least square technique (default). |
| NUMERICAL-FIT | Responses of the log-Q probability levels are calculated numerically by interpolating probabilities of the two nearest levels of the stress amplitude distribution to the current probability level. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
Table print of responses for the probability levels is obtained by the command PRINT LONG-TERM-RESPONSE. Results may also be printed to a vtf file and displayed in Xtract by the commands DEFINE FATIGUE-RESULTS-VTF-FILE and PRINT FATIGUE-RESULTS-VTF-FILE.

Note that this command must be applied to get access to the ‘Probability Levels’ and ‘Probability Exponent’ options in the above print commands. New settings of this command prior to print execution is accounted for when results are printed.

**EXAMPLES:**

```
DEFINE LONG-TERM-PROBABILITY 10 ON ( ONLY 2 4 6 7 8 ) NUMERICAL-FIT
DEFINE LONG-TERM-PROBABILITY 10 ON ( ONLY 1 5 7 9 ) WEIBULL-FIT
```

## 5.31 DEFINE LONG-TERM-RETURN-PERIOD

<table>
<tr><td rowspan="3">...</td><td rowspan="3">LONG-TERM-RETURN-PERIOD</td><td colspan="6">OFF</td></tr>
<tr><td rowspan="2">ON</td><td rowspan="2">(</td><td rowspan="2">ONLY</td><td rowspan="2">{rtnprdr}</td><td rowspan="2">)</td><td>WEIBULL-FIT</td></tr>
<tr><td>NUMERICAL-FIT</td></tr>
</table>

**PURPOSE:**
To define return periods for print of the response parameters.

**PARAMETERS:**

| | |
|---|---|
| OFF/ON | OFF/ON switch for definition of return periods (default is OFF). |
| rtnprd | Return periods in years. A maximum of 5 values may be given (default values are 0.5, 1.0, 5.0, 20.0, 50.0). |
| WEIBULL-FIT | Responses of the rtnprd return periods are calculated analytically by a two parameters Weibull function. Corresponding probability points are calculated for the return periods and the Weibull function is found by fitting the probability points to the amplitude stress distribution by a least square technique (default). |
| NUMERICAL-FIT | Responses of the rtnprd return periods are calculated numerically by interpolating corresponding probabilities of the two nearest levels of the stress amplitude distribution to the probability level corresonding to current return period. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
Table print of responses for the return periods is obtained by the command PRINT LONG-TERM-RESPONSE. Results may also be printed to a vtf file and displayed in Xtract by the commands DEFINE FATIGUE-RESULTS-VTF-FILE and PRINT FATIGUE-RESULTS-VTF-FILE.

Note that this command must be applied to get access to the ‘Return Period’ option in the above print commands. New settings of this command prior to print execution is accounted for when results are printed.

**EXAMPLES:**

```
DEFINE LONG-TERM-RETURN-PERIODS ON ( ONLY 0.5 1.0 5.0 20. 50.0 ) NUMERICAL-FIT
DEFINE LONG-TERM-RETURN-PERIODS ON ( ONLY 0.5 1.0 5.0 20. 50.0 ) WEIBULL-FIT
```

## 5.32 DEFINE LONG-TERM-STRESS

<table>
<tr><td rowspan="3">...</td><td rowspan="3">LONG-TERM-STRESS</td><td colspan="11">OFF</td></tr>
<tr><td rowspan="2">ON</td><td rowspan="2">(</td><td rowspan="2">ONLY</td><td rowspan="2">{strcmp+}</td><td rowspan="2">)</td><td rowspan="2">.</td><td>SCF-NO</td><td rowspan="2">.</td><td>LOCAL</td><td rowspan="2">.</td><td>STATIC-NO</td></tr>
<tr><td>SCF-YES</td><td>GLOBAL</td><td>STATIC-YES</td></tr>
</table>

**PURPOSE:**
To define stress components for which responses may be calculated. This command must be turned on and stress components selected prior to run execution in order to postprocess responses after the run.

**PARAMETERS:**

| | |
|---|---|
| OFF/ON | OFF/ON switch for definition of stress components for the response calculation (default is OFF). |
| strcmp+ | Stress component for which responses may be calculated. Valid components:<br>Sp1 = First principal stress<br>Seq = von Mises equivalent stress<br>Sxx = Normal stress component in x-direction<br>Syy = Normal stress component in y-direction<br>Szz = Normal stress component in z-direction<br>Sxy = Shear stress component in xy-plane<br>Szx = Shear stress component in zx-plane<br>Syz = Shear stress component in yz-plane<br>Sp2 = Second principal stress<br>Sp3 = Third principal stress |
| SCF-NO | Stress concentrator factors (Scf) are not applied to the stresses (default). |
| SCF-YES | Stress concentrator factors (Scf) are applied to the stresses. |
| LOCAL | Local coordinate system (SIN-file reference system) is applied for the stresses. |
| GLOBAL | Global coordinate system (Superelement system) is applied for the stresses. |
| STATIC-NO | Static stresses are not accounted for when max and min stresses are calculated. |
| STATIC-YES | Static stresses are accounted for when max and min stresses are calculated (default).<br>Maximum stress = static stress + stress amplitude.<br>Minimum stress = static stress - stress amplitude. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
The stress components must be defined prior to the run since spectral moments of the stress components are required in calculation of responses and must be calculated during the run execution. Defined stress components are made available in stress component lists of the response print in the commands DEFINE

FATIGUE-RESULTS-VTF-FILE, PRINT FATIGUE-RESULTS-VTF-FILE and PRINT LONG-TERM-PROBABILIIES.

The CPU-time consumption may increase by a factor of 2-4 when stresses are selected for the run, depending on the number of stress components included. Care should therefore be given to include only relevant components in order to keep the CPU-time as low as possible.

Note that in order to account for static stress in the response calculation the command DEFINE STATIC-LOAD-CASE must have been turned on and load case number given prior to run execution.

The options SCF-NO/SCF-YEA and LOCAL/GLOBAL must be set prior to run execution. The option STATIC-NO/STATIC-YES may be set prior to each print execution.

Note that inclusion of static stresses applies to the calculation of maximum and minimum stresses only. The spectral moments are not scaled with a static stress reduction factor in the long term response analysis as performed in the fatigue damage calculation. The stress amplitude calculated by the spectral moments is accordingly not affected by the static stresses.

Depending on the user input, static stresses are then added to maximum and minimum stresses in accordance with:

Maximum stress = static stress + stress amplitude

Minimum stress = static stress - stress amplitude

The above expression helds except in case of von Mises stress is selected, therefore minimum and maximum stresses coincide.

**EXAMPLES:**

```
DEFINE LONG-TERM-STRESS ON ( ONLY Sp1 Seq Sxx Syy Szz Sxy Syz Szx Sp2 Sp3 )
SCF-NO LOCAL STATIC-NO
DEFINE LONG-TERM-STRESS ON ( ONLY Seq Sxx Syy ) SCF-YES GLOBAL STATIC-YES
```

## 5.33 DEFINE LONG-TERM-STRESS-AMPLITUDE

| | | |
|---|---|---|
| ... | LONG-TERM-STRESS-AMPLITUDE | INDIVIDUAL-WAVE-DIRECTIONS |
| | | MAX-ALL-WAVE-DIRECTIONS |

**PURPOSE:**
Define stress amplitude to used when printing long term response results.

**PARAMETERS:**

| | |
|---|---|
| INDIVIDUAL-WAVE-DIRECTIONS | Maximum amplitude for each individual direction is applied (default). |
| MAX-ALL-WAVE-DIRECTIONS | Maximum amplitude for all wave direction is applied. |

**NOTES:**
The above two options have neglectible effect on the long term response results for given probability levels and return periods. However, for the ‘Original stress amplitude’ table results reported, exceedances, probability levels and return periods are affected by the choice of option.

The MAX-ALL-WAVE-DIRECTIONS option relates exceedances, probability levels and return periods to the same stress amplitude (maximum of all wave directions) for all wave directions in same manner as exceedances and stress range distributions are reported in the dump file print (<runname>Pex.lis), see command DEFINE FATIGUE-RESULTS-DUMP. Exceedances and exceedance probabilities of maximum stress stress range level (level 1) in the dump file may be directly comparable with the ‘Original stress amplitude’ results of the long term response in cases when 1) SCF factors are accounted for in the long term response results, 2) SN-curves with no thickness corrections are applied and 3) static stresses are not accounted for in the dump file results. Otherwise differences in maximum stress amplitudes may be expected. Note that stress amplitudes are reported in the long term responses results while stress ranges (twice the stress amplitudes) are reported in the dump file results.

The INDIVIDUAL-WAVE-DIRECTIONS option applies the maximum stress amplitudes of each individual wave direction and reports related exceedances, probability levels and return periods to these amplitude values.

**EXAMPLES:**

```
DEFINE LONG-TERM-STRESS-AMPLITUDE MAX-ALL-WAVE-DIRECTIONS
DEFINE LONG-TERM-STRESS-AMPLITUDE INDIVIDUAL-WAVE-DIRECTIONS
```

## 5.34 DEFINE SHELL-FATIGUE-CONSTANTS

| | | | |
|---|---|---|---|
| ... | SHELL-FATIGUE-CONSTANTS | DEFAULT-SN-CURVE | sndef |
| | | TARGET-FATIGUE-LIFE | fatlif |
| | | FAILURE-LEVEL | failev |
| | | EXCEEDENCE-PROBABILITY-LEVELS | excpro |
| | | GEOMETRIC-STRESS-CONCENTRATION | gstrco |
| | | WELD-STRESS-CONCENTRATION | wstrco |
| | | ECCENTRICITY-STRESS-CONCENTRATION | estrco |
| | | ANGULAR-MISMATCH-FACTOR | anmfac |
| | | LATERAL-PANEL-LOAD-FACTOR | lplfac |
| | | UNIT-LENGTH-FACTOR | unlfac |
| | | STRESS-SCALING-FACTOR | strfac |

**PURPOSE:**
To define fatigue constants for use in the program.

**PARAMETERS:**

| | |
|---|---|
| DEFAULT-SN-CURVE sndef | Default SN-curve. |
| TARGET-FATIGUE-LIFE fatlif | Target fatigue life. |
| FAILURE-LEVEL failev | Failure level. |
| EXCEEDENCE-PROBABILITY-LEVELS excpro | Exceedence probability levels. |
| GEOMETRIC-STRESS-CONCENTRATION gstrco | Geometric stress concentration factor. |
| WELD-STRESS-CONCENTRATION wstrco | Welded stress concentration factor. |
| ECCENTRICITY-STRESS-CONCENTRATION estrco | Eccentricity stress concentration factor. |
| ANGULAR-MISMATCH-FACTOR anmfac | Angular mismatch factor. |
| LATERAL-PANEL-LOAD-FACTOR lplfac | Lateral panel load factor. |
| UNIT-LENGTH-FACTOR unlfac | Unit length factor. |
| STRESS-SCALING-FACTOR strfac | Stress scaling factor. |

**NOTES:**
When the default SN-curve is changed, the new default SN-curve is applied to all elements and supersedes all previous SN-curve assignments (see command ASSIGN SN-CURVE).

The resulting K-factor to be used in the fatigue calculation is derived by multiplying the five factors gstrco, wdtrco, estrco, anmfac and lplfac, see B.3.2. These factors will be set to 1.0 if they have values equal to or less than zero.

The UNIT-LENGTH-FACTOR is used in connection with thickness correction of library SN curves. Predefined thickness corrections of the library SN curves are given in SI unit meters. The purpose of the UNIT-LENGTH-FACTOR is to convert thickness corrections to the length unit of the current analysis. E.g. if the unit mm is used in the analysis and thickness corrections are given in meters, a unit length factor of 1000 should be used. Default value is 1.0.

Hard coded scatter diagrams, DNV-NA and DNV-WW will also be updated according the UNIT-LENGTH-FACTOR. They are originally in meters and will be updated accordingly.

Note that the unit length factor is only applied to thickness corrections of build-in library SN-curves and not to user defined SN-curves. Thickness corrections of user defined SN-curves must be given in same length unit as applied in the analysis, see command ASSIGN THICKNESS-CORRECTION.

The STRESS-SCALING-FACTOR can be used to scale stresses or to update them relative to different dimensions. Analysis can be run in other units than $N/m^2$ an then transformed into $N/m^2$ by using this parameter in accordance with the SN curve defined and other relevant data.

**EXAMPLES:**
Default options when Stofat starts up with a new database:

```
DEFINE SHELL-FATIGUE-CONSTANTS DEFAULT-SN-CURVE NS-F2-SE
DEFINE SHELL-FATIGUE-CONSTANTS TARGET-FATIGUE-LIFE 20.0
DEFINE SHELL-FATIGUE-CONSTANTS FAILURE-LEVEL 1.0
DEFINE SHELL-FATIGUE-CONSTANTS EXCEEDENCE-PROBABILITY-LEVELS 11
DEFINE SHELL-FATIGUE-CONSTANTS GEOMETRIC-STRESS-CONCENTRATION 1.0
DEFINE SHELL-FATIGUE-CONSTANTS WELD-STRESS-CONCENTRATION 1.5
DEFINE SHELL-FATIGUE-CONSTANTS ECCENTRICITY-STRESS-CONCENTRATION 1.0
DEFINE SHELL-FATIGUE-CONSTANTS ANGULAR-MISMATCH-FACTOR 1.0
DEFINE SHELL-FATIGUE-CONSTANTS LATERAL-PANEL-LOAD-FACTOR 1.0
DEFINE SHELL-FATIGUE-CONSTANTS UNIT-LENGTH-FACTOR 1.0
DEFINE SHELL-FATIGUE-CONSTANTS STRESS-SCALING-FACTOR 1.0
```

## 5.35 DEFINE STATIC-LOAD-CASE

| ... | STATIC-LOAD-CASE | OFF | | | | |
|---|---|---|---|---|---|---|
| | | ON | stlc | lcfac | rcfac | rtfac |

**PURPOSE:**
To switch OFF/ON inclusion of static stresses of still water load case in the fatigue calculation.

**PARAMETERS:**

| | |
|---|---|
| OFF | Switch off inclusion of static load case (default). |
| ON | Switch on inclusion of static load case. |
| stlc | Static load case number. |
| lcfac | Load factor applied to the static load case. |
| rcfac | Limit reduction factor in compression. |
| rtfac | Limit reduction factor in tension. |

**NOTES:**

Stresses of the static load case to be applied in the fatigue analysis must be present on result interface file containing the stress transfer functions of the wave loading before being read by Stofat.

If the static load case is a combination of basic static load cases, Stofat will combine stresses of the basic load cases provided they are present on the interface file together with data type records defining the load case combination. The load factor lcfac is applied to the final static load case, stlc, and comes in addition to factors applied when combining the basic load cases into the resulting static load case.

The effect of the static stresses on the fatigue is calculated according to procedure described in [30] DNV Classification Note No. 30.7. A reduction factor is calculated and applied to the principal stress component before entering the SN-curve. The limits of the reduction factor may be decided upon by the user through the input parameters rcfac and rtfac. For further details see Appendix B.6 .

```
DEFINE STATIC-LOAD-CASE OFF
DEFINE STATIC-LOAD-CASE ON 1 1.0 0.6 1.0
```

## 5.36 DEFINE TIME-HISTORY-FATIGUE-TIME

<table>
<tr><td rowspan="5">...</td><td rowspan="5">TIME-HISTORY-FATIGUE-TIME</td><td colspan="2">UNIT-TIME</td><td rowspan="5">...</td><td>tstart</td></tr>
<tr><td colspan="2">TIME-SERIES-DURATION</td><td>tend</td></tr>
<tr><td colspan="2">UNIT-YEAR</td><td>tintv</td></tr>
<tr><td colspan="2">TARGET-FATIGUE-LIFE</td><td>tintv</td></tr>
<tr><td>USER-TIME</td><td>years</td><td>strslev</td></tr>
</table>

**PURPOSE:**

Define time duration of the fatigue exposure for time history fatigue damage calculation.

**PARAMETERS:**

| | |
|---|---|
| UNIT-TIME | Damage is calculated for a time length of 1 second. (Default) |
| TIME-SERIES-DURATION | Damage is calculated for a time length equal to the duration of the fatigue load time history. |
| UNIT-YEAR | Damage is calculated for a time length of one year. |
| TARGET-FATIGUE-LIFE | Damage is calculated for a time length equal to the target fatigue life, see command DEFINE FATIGUE-CONSTANTS. |
| USER-TIME | Damage is calculated for the user time length years. |
| years | User defined fatigue exposure time in years. |
| tstart | Time start of selected time range in seconds. |
| tend | Time end of selected time range in seconds. Time end is larger than the time start value. |
| tintv | Time step interval given as integer 1, 2, 3 etc. Time step used = tintv $\times$ time step of time series. |
| strslev | Threshold stress level. Threshold limit for reporting stress ranges to TMS files. Applies to both tensile and compressive stresses. |

**NOTES:**

This command is applicable for time history fatigue analysis only.

Time range start and time range end values should be within the total range of the time series. Values outside the total range will be adjusted to the start or end point of the time series. If the start or end values do not coincide with the time values of the time series, they are adjusted to the time serie values that ate closest but not above to the input values. A message is printed when input values are adjusted.

Previously to Stofat version 4.1-00, strslev parameter was not included. Using old scripts, prior to version 4.1, will lead to incompatible scripting information. Users should update this command in accordance with Stofat version in use.

**EXAMPLES:**

```
DEFINE TIME-HISTORY-FATIGUE-TIME UNIT-TIME 0.0 595.0 1 1.E1
DEFINE TIME-HISTORY-FATIGUE-TIME TIME-SERIES-DURATION 0.0 595.0 3 1.E1
DEFINE TIME-HISTORY-FATIGUE-TIME UNIT-YEAR 110.0 595.0 1 1.E1
DEFINE TIME-HISTORY-FATIGUE-TIME TARGET-FATIGUE-LIFE 110.0 450.0 2 1.E1
```

```
DEFINE TIME-HISTORY-FATIGUE-TIME USER-TIME 0.5 0.0 300.0 1 1.E1
```

## 5.37 DEFINE WEIBULL-PARAMETERS

| | | |
|---|---|---|
| ... | WEIBULL-PARAMETERS | OFF |
| | | ON |

**PURPOSE:**

To switch OFF/ON calculation of the scale and shape parameters of the Weibull function during run executions. The parameters are printed in the fatigue results table of the run only when calculation is switched on.

**PARAMETERS:**

| | |
|---|---|
| OFF | Switch off calculation of the Weibull parameters (default). |
| ON | Switch on calculation of the Weibull parameters. |

**NOTES:**

The Weibull parameters are calculated by fitting the Weibull function to stress range distributions consisting of ten range levels by a least square technique.

**EXAMPLES:**

```
DEFINE WEIBULL-PARAMETERS ON
```

## 5.38 DEFINE WIDE-BAND-CORRECTION-FACTOR

| | | |
|---|---|---|
| ... | WIDE-BAND-CORRECTION-FACTOR | OFF |
| | | ON |

**PURPOSE:**
To switch OFF/ON Wirsching correction factor for wide banded stress processes. The correction factor is given in C.3.

**PARAMETERS:**

| | |
|---|---|
| OFF | Switch off Wirsching correction factor (default). |
| ON | Switch on Wirsching correction factor. |

**EXAMPLES:**

```
DEFINE WIDE-BAND-CORRECTION-FACTOR ON
```

## 5.39 DELETE

| | | |
|---|---|---|
| DELETE | HOTSPOT | ... |
| | RUN | |
| | SN-CURVE | |
| | WAVE-SPREADING-FUNCTION | |
| | WAVE-STATISTICS | |
| | WELD-NORMAL-LINE | |

**PURPOSE:**
To delete items previously created.
The program will ask for the name of the item and delete all data stored under this name.

## 5.40 DELETE HOTSPOT

| | | | | | |
|---|---|---|---|---|---|
| ... | HOTSPOT | ( | ONLY | name+ | ) |

**PURPOSE:**
To delete a hotspot created by the user.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the hotspot. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**EXAMPLES:**

```
DELETE HOTSPOT ( ONLY BOT1249 TOP1249 MID1249 )
```

## 5.41 DELETE RUN

| | | | | | |
|---|---|---|---|---|---|
| ... | RUN | ( | ONLY | name+ | ) |

**PURPOSE:**

To delete an executed run case and fatigue results related to the run.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the run. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**EXAMPLES:**

```
DELETE RUN ( ONLY RUN1 )
```

## 5.42 DELETE SN-CURVE

| ... | SN-CURVE | ( | ONLY | name+ | ) |
|---|---|---|---|---|---|

**PURPOSE:**
To delete a user specified SN-curve.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the user specified SN-curve. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**EXAMPLES:**

```
DELETE SN-CURVE ( ONLY USE-X USE-Y )
```

## 5.43 DELETE WAVE-SPREADING-FUNCTION

| ... | WAVE-SPREADING-FUNCTION | ( | ONLY | name+ | ) |
|---|---|---|---|---|---|

**PURPOSE:**

To delete a wave energy spreading function.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the function. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**EXAMPLES:**

```
DELETE WAVE-SPREADING-FUNCTION ( ONLY USER1 )
```

## 5.44 DELETE WAVE-STATISTICS

| | | | | | |
|---|---|---|---|---|---|
| ... | WAVE-STATISTICS | ( | ONLY | name+ | ) |

**PURPOSE:**

To delete a wave statistics model.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the model. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**EXAMPLES:**

```
DELETE WAVE-STATISTICS ( ONLY NRD SCATTER )
```

## 5.45 DELETE WELD-NORMAL-LINE

<table>
<tr><td rowspan="4">...</td><td rowspan="4">WELD-NORMAL-LINE</td><td>DELETE-LINE</td><td>(</td><td>ONLY</td><td>wnlnam+</td><td colspan="2">)</td></tr>
<tr><td rowspan="3">DELETE-ASSIGNMENT</td><td colspan="5">ALL</td></tr>
<tr><td>ELEMENT</td><td colspan="4">elmnam</td></tr>
<tr><td>HOTSPOT</td><td>(</td><td>ONLY</td><td>hotnam+</td><td>)</td></tr>
</table>

**PURPOSE:**
To delete weld normal lines and assignments of weld normal lines.

**PARAMETERS:**

| | |
|---|---|
| DELETE-LINE | Delete weld normal lines. |
| DELETE-ASSIGNMENT | Delete assignments of weld normal lines. |
| ALL | Delete all assignments of weld normal lines. |
| ELEMENT | Delete assignment of weld normal lines to elements. |
| HOTSPOT | Delete assignment of weld normal lines to hotspots. |
| wnlnam+ | Names of weld normal lines which shall be deleted. |
| elmnam | Name of element or element set to which assignment of weld normal lines shall be deleted. |
| hotnam+ | Names of hotspots to which assignment of weld normal lines shall be deleted. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
Use the command PRINT RUN-OVERVIEW WELD-NORMAL-LINES or press the Show button in the dialogue box to see current status on defined weld normal lines and assignments to elements and hotspots.

**EXAMPLES:**

```
DELETE WELD-NORMAL-LINE DELETE-LINE ( ONLY WNL4 )
DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT ELEMENT 86
SELECT ELEMENTS INCLUDE CURRENT
DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT ELEMENT DEFAULT
DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT HOTSPOT ( ONLY HOT2 HOT3 )
DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT ALL
```

## 5.46 DISPLAY

| | | |
|---|---|---|
| DISPLAY | FATIGUE-CHECK-RESULTS | ... |
| | LABEL | ... |
| | PLOT | |
| | PRESENTATION | ... |
| | REFRESH | |
| | SN-CURVE | ... |
| | SN-CURVE-SORTED | ... |
| | STRESS-TRANSFER-FUNCTION | ... |
| | SUPERELEMENT | |
| | WAVE-SPREADING-FUNCTION | ... |

**PURPOSE:**

To display selected functions or spectra on a graphical screen or to a file. The device may be altered by the SET DISPLAY DEVICE command.

**PARAMETERS:**

| | |
|---|---|
| PLOT | Plot last display on hard copy device. This command is also available as the main command PLOT in line mode. |
| REFRESH | To refresh the display on screen. The previous commands and selection are used in the refreshing. The user may change some presentation options, like the x-axis required, colour setting, grid on/off etc. |
| SUPERELEMENT | To display current superelement. This command requires access to a database produced by Stofat or a R#.SIN file. |

**EXAMPLES:**

```
DISPLAY PLOT
DISPLAY REFRESH
DISPLAY SUPERELEMENT
```

## 5.47 DISPLAY FATIGUE-CHECK-RESULTS

<table>
<tr><td rowspan="10">...</td><td rowspan="10">FATIGUE-CHECK-RESULTS</td><td rowspan="10">name+</td><td>MAX-USAGE-FACTORS</td><td rowspan="10">...</td><td rowspan="3">ABOVE</td><td rowspan="3" colspan="2">minval</td></tr>
<tr><td>USAGE-FACTOR</td></tr>
<tr><td>FATIGUE-LIFE</td></tr>
<tr><td>CYCLES</td><td rowspan="4">BELOW</td><td rowspan="4" colspan="2">maxval</td></tr>
<tr><td>WEIBULL-SCALE-Q</td></tr>
<tr><td>WEIBULL-SCALE-H</td></tr>
<tr><td>THICKNESS-CORRECTION</td></tr>
<tr><td>AXIAL-STRESS-K-FACTOR</td><td rowspan="3">BETWEEN</td><td rowspan="3">minval</td><td rowspan="3">maxval</td></tr>
<tr><td>BENDING-STRESS-K-FACTOR</td></tr>
<tr><td>SHEAR-STRESS-K-FACTOR</td></tr>
</table>

**PURPOSE:**
Select fatigue check results to be displayed and set various options. Applies to both element fatigue check and hotspot fatigue check.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the fatigue check run. |
| MAX-USAGE-FACTOR | Display maximum usage factor. |
| USAGE-FACTOR | Display usage factor. |
| FATIGUE-LIFE | Display fatigue life. |
| CYCLES | Display number of fatigue cycles. |
| WEIBULL-SCALE-Q | Display Weibull scale parameter of the fatigue check run. |
| WEIBULL-SHAPE-H | Display Weibull shape parameter of the fatigue check run. |
| THICKNESS-CORRECTION | Display thickness corrections. Available for element fatigue check runs. |
| AXIAL-STRESS-K-FACTOR | Display the K-factor applied for axial stress components. Available for element fatigue check runs. |
| BENDING-STRESS-K-FACTOR | Display the K-factor applied for bending stress components.Available for element fatigue check runs. |
| SHEAR-STRESS-K-FACTOR | Display the K-factor applied for shear stress components. Available for element fatigue check runs. |
| ABOVE minval | Print parameter values above the minimum value minval. |
| BELOW maxval | Print parameter values below the maximum value maxval. |
| BETWEEN minval maxval | Print parameter values between the minimum and maximum value minval, maxval. |

**NOTES:**
The shell elements have two result points in the thickness direction (-z and +z points) for each result position in the local xy-plane of the element. Only one value is printed in the Stofat plot for each xy-result position and parameter value of the z point with highest damage value is printed. The result plot may thus show values of both the -z and +z point for an element.

The extension of the displayed elements is currently fitted to the display window for each run displayed.

Elements and hotspots are displayed in four different colours depending on calculated values of the displayed parameters:

- Red colour is used when damage of an element/hotspot is equal to or above 1.0.
- Yellow colour is used when damage of an element/hotspot is below 1.0 and displayed parameter is inside specified range values of minval and maxval.
- Green colour is used when damage of an element/hotspot is below 1.0 and displayed parameter is outside specified range values of minval and maxval.
- Anti-background colour is applied to elements possessing hotspot points in the display of hotspot results.

**EXAMPLES:**

```
DISPLAY FATIGUE-CHECK-RESULTS RUN1 MAX-USAGE-FACTOR ABOVE 0.8
DISPLAY FATIGUE-CHECK-RESULTS RUN1 USAGE-FACTOR ABOVE 0.5
DISPLAY FATIGUE-CHECK-RESULTS RUN1 FATIGUE-LIFE BELOW 20.0
DISPLAY FATIGUE-CHECK-RESULTS RUN1 CYCLES ABOVE 5.E7
DISPLAY FATIGUE-CHECK-RESULTS RUN1 WEIBULL-SCALE-Q ABOVE 1.E7
DISPLAY FATIGUE-CHECK-RESULTS RUN1 WEIBULL-SCALE-H ABOVE 0.95
DISPLAY FATIGUE-CHECK-RESULTS RUN1 THICKNESS-CORRECTION ABOVE 1.0
DISPLAY FATIGUE-CHECK-RESULTS RUN1 BENDING-STRESS-K-FACTOR ABOVE 1.0
```

## 5.48 DISPLAY LABEL

| | | |
|---|---|---|
| ... | LABEL | ELEMENT-NUMBERS |
| | | MATERIAL-NAMES |
| | | NODE-NUMBERS |

**PURPOSE:**

This command is used for display of labels on element mesh plots.

**PARAMETERS:**

| | |
|---|---|
| ELEMENT-NUMBERS | Element number label. |
| MATERIAL-NAMES | Material name label. |
| NODE-NUMBERS | Node number label. |

**EXAMPLES:**

```
DISPLAY LABEL ELEMENT-NUMBERS ON
DISPLAY LABEL MATERIAL-NAMES OFF
DISPLAY LABEL NODE-NUMBERS ON
```

## 5.49 DISPLAY PRESENTATION

| | | | |
|---|---|---|---|
| ... | PRESENTATION | WIREFRAME | |
| | | HIDDEN-SURFACE | resol |

**PURPOSE:**
To set presentation mode for display of superelement plot.

**PARAMETERS:**

| | |
|---|---|
| WIREFRAME | Line display. |
| HIDDEN-SURFACE resol | Hidden surface display. The numeric factor resol defines resolution for the hidden display (default value is 1.0, a value of 0.1 will give a coarse resolution). |

**EXAMPLES:**

```
DISPLAY PRESENTATION WIREFRAME
DISPLAY PRESENTATION HIDDEN-SURFACE 0.5
```

## 5.50 DISPLAY SN-CURVE

| ... | SN-CURVE | ( | ONLY | snname+ | ) |
|---|---|---|---|---|---|

**PURPOSE:**
To display one or several SN-curves.

**PARAMETERS:**

| | |
|---|---|
| snname+ | Name of the SN-curve. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
This SN-curves will always be shown in a log-log scale.

**EXAMPLES:**

```
DISPLAY SN-CURVE ( ONLY USE-X USE-Y )
```

## 5.51 DISPLAY SN-CURVE-SORTED

<table>
<tr><td rowspan="11">...</td><td rowspan="11">SN-CURVE</td><td colspan="2">ABS</td><td rowspan="11">(</td><td rowspan="11">ONLY</td><td rowspan="11">snname+</td><td rowspan="11">)</td></tr>
<tr><td colspan="2">API</td></tr>
<tr><td rowspan="3">DNV</td><td>OLDER</td></tr>
<tr><td>RP-C203-2010</td></tr>
<tr><td>CN-30.7-2010</td></tr>
<tr><td colspan="2">DOE</td></tr>
<tr><td colspan="2">HSE</td></tr>
<tr><td colspan="2">NORSOK</td></tr>
<tr><td colspan="2">NS</td></tr>
<tr><td colspan="2">USER</td></tr>
<tr><td colspan="2">ALL</td></tr>
</table>

**PURPOSE:**
To display SN-curves.

**PARAMETERS:**

| | |
|---|---|
| ABS | Selection of ABS SN-curves. |
| API | Selection of API SN-curves. |
| DNV | Selection of DNV SN-curves. |
| OLDER | Selection of DNV SN-curves older than 2010. |
| RP-C203-2010 | Selection of DNV SN-curves of Recommended Practice DNV-RP-C203, April 2010. |
| CN-30.7-2010 | Selection of DNV SN-curves of Classification Notes No. 30.7, June 2010. |
| DOE | Selection of DOE SN-curves. |
| HSE | Selection of HSE SN-curves. |
| NORSOK | Selection of NORSOK SN-curves. |
| NS | Selection of Norwegian Standard NS 3472 SN-curves. |
| USER | Selection of user defined SN-curves. |
| ALL | Selection of all available SN-curves. |
| snname+ | Name of SN-curve. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
This SN-curves will always be displayed in a log-log scale.

**EXAMPLES:**

```
DISPLAY SN-CURVE-SORTED DNV OLDER ( ONLY DNV-X DNVC-I DNVC-II )
DISPLAY SN-CURVE-SORTED ALL ( ONLY ABS-B-A DNV-X DNV2010_B1-AIR HSE-C-CP )
```

## 5.52 DISPLAY STRESS-TRANSFER-FUNCTION

<table>
<tr><td rowspan="2">...</td><td rowspan="2">STRESS-TRANSFER-FUNCTION</td><td rowspan="2">XTRACT</td><td rowspan="2">filnam</td><td>NEW</td><td rowspan="2">...</td></tr>
<tr><td>OLD</td></tr>
</table>

<table>
<tr><td rowspan="6">...</td><td rowspan="2">ANGULAR-FREQUENCY</td><td>SIN-FILE</td><td colspan="4">elem</td><td rowspan="6">...</td></tr>
<tr><td rowspan="4">ELEMENT</td><td rowspan="4">elem</td><td>RESULT-POINT</td><td rowspan="4"></td><td rowspan="2">LOCAL</td></tr>
<tr><td rowspan="2">FREQUENCY</td><td>SURFACE</td></tr>
<tr><td>CORNER</td><td rowspan="2">GLOBAL</td></tr>
<tr><td rowspan="2">PERIOD</td><td>MIDDLE-PLANE</td></tr>
<tr><td>HOTSPOT</td><td>(</td><td>ONLY</td><td>hotnam+</td><td>)</td></tr>
</table>

| ... | SELECTION | ( | ONLY | strpnt+ | ) | ( | ONLY | strcmp+ | ) | ( | ONLY | wavdir+ | ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

**PURPOSE:**
To display one or several curve plots of stress transfer functions. The stress transfer functions are written to a vtf file for 2D curve plot display in Xtract.

**PARAMETERS:**

| | |
|---|---|
| XTRACT | Print data to vtf file for display in Xtract. |
| filnam | Name of vtf file. |
| NEW | A new file with name filnam.vtf is opened for print. |
| OLD | Results are appended to existing VTF file with name filnam.vtf. If the file does not exist, a new file is opened for print. |
| ANGULAR-FREQUENCY | Transfer function absissa values in radians per seconds |
| FREQUENCY | Transfer function absissa values in hertz. |
| PERIOD | Transfer function absissa values in seconds. |
| SIN-FILE | SIN file stresses (results points stresses in element coordinate system). |
| ELEMENT | Element stresses at selected positions. |
| HOTSPOT | Hotspot stresses (in global coordinate system). |
| RESULT-POINT | Stresses of element result points. |
| SURFACE | Stresses extrapolated to element surface points. |
| CORNER | Element stresses extrapolated to element corner points. |
| MIDDLE-PLANE | Element stresses interpolated middle plane points of shell element. |
| LOCAL | Stresses in local element coordinate system. |
| GLOBAL | Stresses in global coordinate system. |
| elem | Element number. |
| hotnam+ | Name of hotspot. Selected from list. |
| strpnt+ | Element stress points (1, 2,.... 10) or hotspot stress points (hotspot, t/2, 3t/2). Selected from list. |

| | |
|---|---|
| strcmp+ | Stress components selected from list. Valid components:<br>- Principal stresses (Sp1, Sp2, Sp3)<br>- von Mises equivalent stress (Seq)<br>- Real part of stress components (SxxRe, SyyRe, SzzRe, SxyRe, SxzRe,SyzRe)<br>- Imaginary part of stress components (SxxIm, SyyIm, SzzIm, SxyIm, SxzIm, SyzIm)<br>- Phase angle in complex stress plane of the stress components (PhaSp1, PhaSeq,PhaSxx, PhaSyy, PhaSzz, PhaSxy, PhaSxz, PhaSyz) |
| wavdir+ | Wave directions. Selected from list. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**

Print of stress transfer functions to the vtf file by this command and display in Xtract may be performed without executing any fatigue run in Stofat.

Stresses and phase angles are plotted as functions of the angular frequencies contained on the SIN file for selected elements and hotspots, stress points, stress components and wave directions.

One function is established for each combination of selected elements, hotspots, stress points, stress components and wave directions. I.e. the number of functions printed to the vtf file is the product of the numbers of selected items.

The current vtf file is opened in Xtract by the GRAPH VTF-FILE command. To open a 2D plot file requires that a geometry model is displayed in Xtract. The present vtf file does not contain any geometry data. Thus, prior to open the present vtf file, a file containing geometry data must be opened and displayed. This may be a SIN file or any other file containing geometry data.

**EXAMPLES:**

```
DISPLAY STRESS-TRANSFER-FUNCTION XTRACT StfHp NEW ANGULAR-FREQUENCY HOTSPOT ( ONLY CUI BOT969 )
SELECTION ( ONLY Hotspot 1t/2 ) ( ONLY SYYRE SZZRE PHSP1 ) ( ONLY 165.0 )
DISPLAY STRESS-TRANSFER-FUNCTION XTRACT StfEl NEW FREQUENCY ELEMENT 1249 RESULT-POINTS LOCAL
SELECTION ( ONLY 5 ) ( ONLY SP1 SXXRE SYYRE PHASXX PHASYY ) ( ONLY 180.0 )
DISPLAY STRESS-TRANSFER-FUNCTION XTRACT StfEl OLD PERIOD ELEMENT 1249 CORNER LOCAL
SELECTION ( ONLY 8 ) ( ONLY SP2 SXYRE SXYIM ) ( ONLY 180.0 )
DISPLAY STRESS-TRANSFER-FUNCTION XTRACT StfEl OLD FREQUENCY ELEMENT 1249 MIDDLE-PLANE LOCAL
SELECTION ( ONLY 3 ) ( ONLY SP1 SP2 SP3 ) ( ONLY 165.0 180.0 )
DISPLAY STRESS-TRANSFER-FUNCTION XTRACT StfEl OLD ANGULAR-FREQUENCY SIN-FILE 1249
SELECTION (ONLY 3 4 ) ( ONLY SP1 PHASP1 ) ( ONLY 165.0 180.0 )
```

## 5.53 DISPLAY WAVE-SPREADING-FUNCTION

| ... | WAVE-SPREADING-FUNCTION | name+ | [space] |
|---|---|---|---|

**PURPOSE:**

To display energy spreading for elementary wave directions created by the user.

**PARAMETERS:**

| | |
|---|---|
| name+ | User given name of the function. |
| space | User input space between each wave direction angle for which the energy spreading function will be displayed. This space is independent of what the program will use in calculating the response spectra. Only asked for if the name of the function corresponds to a cosine power function. |

**EXAMPLES:**

```
DISPLAY WAVE-SPREADING-FUNCTION COS2 30.0
```

## 5.54 FILE

| | | |
|---|---|---|
| FILE | EXIT | |
| | OPEN | ... |
| | PLOT | |
| | SELECT PRINTER | |
| | TRANSFER | ... |

**PURPOSE:**
This command is used for file handling control, or to terminate the program execution.

**PARAMETERS:**

| | |
|---|---|
| EXIT | To exit from Stofat. The termination of Stofat is also available as the main command EXIT in line mode. Note that EXIT cannot be abbreviated. |
| PLOT | Plot last display on hard copy device. This command is also available as the main command PLOT in line mode. |
| SELECT PRINTER | Select printer and set print properties. This command is not available in line mode. |

## 5.55 FILE OPEN

| | | | | |
|---|---|---|---|---|
| ... | OPEN | SIN-DIRECT-ACCESS | prefix | name |

**PURPOSE:**

This command opens and reads the Results Interface File containing the superelement model and the stress transfer functions for the fatigue damage calculation.

**PARAMETERS:**

| | |
|---|---|
| SIN-DIRECT-ACCESS | Results Interface File on direct access format. |
| prefix | Results file prefix. |
| name | Results file name. |

**EXAMPLES:**

```
FILE OPEN SIN-DIRECT-ACCESS ‘ ’ R211
```

## 5.56 FILE TRANSFER

| ... | TRANSFER | superel | name | loaset | txt |
|---|---|---|---|---|---|

**PURPOSE:**
To transfer geometry and loads of a superelement to Stofat’s database.

**PARAMETERS:**

| | |
|---|---|
| superel | Superelement to be transferred. |
| name | Superelement name. |
| loaset | Load set name. |
| txt | Description. |

**NOTES:**
This command should only be issued after a FILE OPEN command.

**EXAMPLES:**

```
FILE TRANSFER 2 DECK LOADS None
```

## 5.57 PLOT

PLOT

**PURPOSE:**
Plot last display on hard copy device. The previous commands and selection are used in the plotting. The user may change some presentation options, like the x-axis required, colour setting, grid on/off etc. This command *is not* available from the menu bar in graphics mode. Use FILE PLOT or DISPLAY PLOT instead.

## 5.58 PRINT

| | | |
|---|---|---|
| PRINT | FATIGUE-CHECK-RESULTS | ... |
| | FATIGUE-RESULTS-DUMP | ... |
| | FATIGUE-RESULTS-VTF-FILE | ... |
| | LONG-TERM-RESPONSE | ... |
| | RUN | |
| | RUN-OVERVIEW | ... |
| | SIN-FILE-LOAD-CASES | |
| | SN-CURVE | ... |
| | SN-CURVE-SORTED | ... |
| | SUPERELEMENT | |
| | WAVE-SPREADING-FUNCTION | ... |
| | WAVE-STATISTICS | ... |

**PURPOSE:**
This command is used to print selected information on the terminal or on a print file.

**PARAMETERS:**

| | |
|---|---|
| RUN | To print on screen or file names of the runs that have been executed Elements/hotspots that have been checked for fatigue damage and the number that have failed are also printed. |
| SUPERELEMENT | To print name of current superelement. |

**EXAMPLES:**

```
PRINT RUN
PRINT SUPERELEMENT
```

## 5.59 PRINT FATIGUE-CHECK-RESULTS

<table>
<tr><td rowspan="3">...</td><td rowspan="3">FATIGUE-CHECK-RESULTS</td><td rowspan="3">name+</td><td rowspan="2">HOTSPOT</td><td>HOTSPOTS</td><td rowspan="2">...</td></tr>
<tr><td>HOTSPOTS-AND-INTERPOLATION-POINTS</td></tr>
<tr><td colspan="2">ELEMENTS</td><td>...</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td>WORST-USAGE-FACTOR</td><td rowspan="3">...</td><td>SUMMARY</td><td rowspan="3">...</td><td>ABOVE</td><td colspan="2">minval</td></tr>
<tr><td>SELECTED-HOTSPOTS</td><td rowspan="2">FULL</td><td>BELOW</td><td colspan="2">maxval</td></tr>
<tr><td>WORST-SEA-STATE</td><td>BETWEEN</td><td>minval</td><td>maxval</td></tr>
</table>

<table>
<tr><td rowspan="3">...</td><td>WORST-USAGE-FACTOR</td><td rowspan="3">...</td><td>SUMMARY</td><td rowspan="3">...</td><td>ABOVE</td><td colspan="2">minval</td></tr>
<tr><td>SELECTED-ELEMENTS</td><td rowspan="2">FULL</td><td>BELOW</td><td colspan="2">maxval</td></tr>
<tr><td>WORST-SEA-STATE</td><td>BETWEEN</td><td>minval</td><td>maxval</td></tr>
</table>

**PURPOSE:**
To print fatigue check results.

**PARAMETERS:**

| | |
|---|---|
| name+ | Name of the fatigue check run. |
| HOTSPOT | Print hotspot fatigue check results. |
| ELEMENT | Print element fatigue check results. |
| HOTSPOTS | Results of the hotspots. |
| HOTSPOTS-AND-INTERPOLATION-POINTS | Results of the hotspots and interpolation points. |
| WORST-USAGE-FACTOR | Print results in order of worst usage factor. |
| SELECTED-ELEMENTS | Print results in order of selected elements. |
| SELECTED-HOTSPOTS | Print results in order of defined hotspots. |
| WORST-SEA-STATE | Print sea state results in order of worst sea state. |
| SUMMARY | Summary table print. |
| FULL | Full table print. |
| ABOVE minval | Print usage factors above minimum value minval. |
| BELOW maxval | Print usage factors below maximum value maxval. |
| BETWEEN minval maxval | Print usage factors between minimum and maximum values minval, maxval. |

**EXAMPLES:**

```
PRINT FATIGUE-CHECK-RESULTS RUN1 ELEMENT SELECTED-ELEMENTS SUMMARY ABOVE 0.8
PRINT FATIGUE-CHECK-RESULTS RUN2 HOTSPOT HOTSPOTS-AND-INTERPOLATION-POINTS
SELECTED-HOTSPOTS FULL BETWEEN 0.2 0.8
```

## 5.60 PRINT FATIGUE-RESULTS-DUMP

| ... | FATIGUE-RESULTS-DUMP | runam+ | ELEMENT | elnam | | | |
|---|---|---|---|---|---|---|---|
| | | | HOTSPOT | ( | ONLY | hotnam+ | ) |

**PURPOSE:**
Print a detailed dump of fatigue calculation results after a run has been executed.
Two dump files, depending on print options set, are generated for the dump print:

| | |
|---|---|
| nameDmp.lis: | Contains hotspot stress transfer functions, moments of response spectrum, damage per sea state, damage per direction and damage per hotspot (damage per position for element fatigue checks). |
| namePex.lis: | Contains exceedence probabilities and stress range distributions. |

The dump file name and the print options are set by command DEFINE FATIGUE-RESULTS-DUMP.

**PARAMETERS:**

| | |
|---|---|
| runam+ | Name of run from which results shall be printed. |
| ELEMENT | Select elements. |
| HOTSPOT | Select hotspots. |
| elnam | Name of element or element selection. |
| hotnam+ | Name of hotspot. |
| ONLY | Mandatory attribute. |
| () | Mandatory parentheses. |

**NOTES:**
Fatigue results of the run must have been saved to perform dump print by the present command. Only run names of runs with saved fatigue results are available for selection in the run name list (runam+). To save fatigue results see the RUN command.

**EXAMPLES:**

```
PRINT FATIGUE-RESULTS-DUMP BRACE-TE ELEMENT Current
PRINT FATIGUE-RESULTS-DUMP FT4 HOTSPOT ( ONLY CUI CDY CDI )
```

## 5.61 PRINT FATIGUE-RESULTS-VTF-FILE

<table>
<tr><td rowspan="3">...</td><td>FATIGUE-RESULTS-VTF-FILE</td><td rowspan="3">vtfnam</td><td>NEW</td><td rowspan="3">runam+</td><td>ELEMENT-RESULTS</td><td>...</td></tr>
<tr><td></td><td rowspan="2">OLD</td><td>ELEMENT-FATIGUE-POINT-RESULTS</td><td>...</td></tr>
<tr><td></td><td>STRESS-RANGE-DISTRIBUTION</td><td>...</td></tr>
</table>

<table>
<tr><td colspan="11"></td><td>...</td></tr>
<tr><td rowspan="3">...</td><td colspan="10">ACCUMULATED-DAMAGE</td><td>...</td></tr>
<tr><td rowspan="2">PART-DAMAGE</td><td colspan="2">WAVE-DIRECTION</td><td colspan="7">wavdir+</td><td>...</td></tr>
<tr><td colspan="2">SEA-STATE</td><td colspan="2">wavdir+</td><td colspan="5">seastat+</td><td></td></tr>
<tr><td rowspan="2">...</td><td>ELEMENT-RESULTS</td><td rowspan="2">...</td><td>PROBABILITY-EXPONENT</td><td>log-Q</td><td rowspan="2">...</td><td rowspan="2">wavdir+</td><td rowspan="2">strcmp+</td><td rowspan="2">(</td><td rowspan="2">ONLY</td><td rowspan="2">param+</td><td rowspan="2">)</td></tr>
<tr><td>ELEMENT-FATIGUE-POINT-RESULTS</td><td>RETURN-PERIOD</td><td>rtnprd</td></tr>
</table>

<table>
<tr><td rowspan="7">...</td><td colspan="3">MAX-USAGE-FACTOR</td></tr>
<tr><td>FATIGUE-LIFE</td><td colspan="2">uplim</td></tr>
<tr><td colspan="3">THICKNESS-CORRECTION</td></tr>
<tr><td colspan="3">AXIAL-STRESS-K-FACTOR</td></tr>
<tr><td colspan="3">BENDING-STRESS-K-FACTOR</td></tr>
<tr><td colspan="3">SHEAR-STRESS-K-FACTOR</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
<tr><td rowspan="3">...</td><td colspan="3">USAGE-FACTOR</td></tr>
<tr><td>FATIGUE-LIFE</td><td colspan="2">uplim</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
<tr><td rowspan="4">...</td><td colspan="3">USAGE-FACTOR</td></tr>
<tr><td colspan="3">DAMAGE-FRACTION</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
<tr><td>PRINCIPAL-STRESS</td><td>WAVE-FREQUENCY</td><td>wavfrq+</td></tr>
<tr><td rowspan="3">...</td><td colspan="3">USAGE-FACTOR</td></tr>
<tr><td colspan="3">DAMAGE-FRACTION</td></tr>
<tr><td colspan="3">STRESS-CYCLES</td></tr>
</table>

**PURPOSE:**

To write element fatigue analysis results of executed runs to a VTF file for graphic presentation of the results by Xtract. Note that hotspot fatigue check results are not written to the VTF file. The command is executed after the run executions and for those runs where results are saved.

**PARAMETERS:**

| | |
|---|---|
| vtfnam | Name of the VTF file. The default name is Stofat. The extension of the file is.vtf and the full name is vtfnam.vtf. |
| NEW | A new file with name vtfnam.vtf is opened for print. |

| | |
|---|---|
| OLD | Results are appended to existing VTF file with name vtfnam.vtf. If the file does not exist, a new file is opened for print. |
| runam+ | Name of executed run from which fatigue results are printed. |
| ELEMENT-RESULTS | Write one result per element of current element selection. The fatigue check point with maximum usage factor is printed. |
| ELEMENT-FATIGUE-POINT-RESULTS | Write results of all element fatigue check points of current element selection. |
| LONG-TERM-RESPONSE | Write response results. Availability of this option requires that a stress component has been defined prior to the run, see command DEFINE LONG-TERM-STRESS. |
| PROBABILITY-EXPONENT | Write results for given probability exponent. Availability of this option requires that probability levels are defined, see command DEFINE LONG-TERM PROBABILITY. |
| RETURN-PERIOD | Write results for given return period. Availability of this option requires that return periods are defined, see command DEFINE LONG-TERM-RETURN-PERIOD. |
| ACCUMULATED-DAMAGE | Write accumulated damage results of the element fatigue check points. |
| PART-DAMAGE | Write part damage results of the element fatigue check points. |
| WAVE-DIRECTION | Write part damage results for wave direction. |
| SEA-STATE | Write part damage results for sea state. |
| MAX-USAGE-FACTOR | Write maximum usage factor of the element. |
| USAGE-FACTOR | Write usage factor. |
| FATIGUE-LIFE | Write fatigue life. |
| THICKNESS-CORRECTION | Write thickness correction applied to the element. |
| AXIAL-STRESS-K-FACTOR | Write K-factor applied to axial stress components. |
| BENDING-STRESS-K-FACTOR | Write K-factor applied to bending stress components. |
| SHEAR-STRESS-K-FACTOR | Write K-factor applied to shear stress components. |
| STRESS-CYCLES | Write the number of stress cycles. |
| DAMAGE-FRACTION | Write fraction of damage of part damage result. |
| PRINCIPAL-STRESS | Write maximum principal stress. |
| WAVE-FREQUENCY | Write maximum principal stress for wave frequency. |
| wavdir+ | Wave direction. |
| seastat+ | Sea state. |
| wavfrq+ | Wave frequency. |
| log-Q+ | Probability exponent, as an absolute real number, defining the probability level Q, i.e. $Q = 10^{-(\log(-Q))}$. |
| rtnprd+ | Return period in years. |
| strcmp+ | Stress component to be applied in response calculation. Valid components: 'Sp1', 'Seq', 'Sxx', 'Syy', 'Szz', 'Sxy', 'Sxz', 'Syz', 'Sp2', 'Sp3'. |
| uplim | Upper limit of fatigue life applied in vtf plot. Fatigue lives above this limit will take the limit value when printed to the vtf file. No limit is applied when uplim = 0.0 (Default). |
| ONLY | Mandatory attribute. |
| () | Mandatory parentheses. |

**NOTES:**
See D.2.3 for comments related to the parameters ELEMENT-RESULTS and ELEMENT-FATIGUE-POINT-RESULTS.

Only one type of fatigue result is written to the VTF file during a Stofat run. The result case must be selected by the present command before the run command is executed. Results are written for the element selection applied in the run. The element selection as well as the type of fatigue results written to the vtf file may vary from one run to the next. Xtract may present many run cases from a Stofat session, case by case, which may contain different fatigue results and different selection of elements applied in the Stofat runs.

Results are written (appended) to the same vtf file (vtfnam.vtf) for all Stofat runs as long as Old is chosen for the append option and the file exists. If the file does not exists a new file with name vtfnam.vtf is opened and results are written to this file. If New is chosen for the append option, a new file with name vtfnam.vtf is opened and results are written to this file.

If data are appended to an existing vtf file, the file must end with the following sequence lines:

```
4
*GLVIEWGEOMETRY 1
\%NAME "Superelement 30"
\%DESCRIPTION "Fatigue check model"
\%ELEMENTS
1, 2, 3
```

The first line (4) gives the identification of last result case written to the vtf file. The last line (1, 2, 3) gives the number of prints directed to the file. If the more than 10 prints have previously been directed to the vtf file, the file will end with more than one line of numbers. In such a case the last lines except the last one will have 10 numbers, while the last line will have 10 or less numbers.

Coordinates of all nodal points of the superelement are written to the VTF file. These are the first level superelement coordinates read from the SIN file. If the superelement is a mirrored position of a basis superelement, the coordinates on the SIN file are those of the basis superelement, i.e. the un-mirrored position of the superelement.

**EXAMPLES:**

```
PRINT FATIGUE-RESULTS-VTF-FILE Stofat NEW RUN1 ELEMENT-RESULTS MAX-USAGE-FACTOR
PRINT FATIGUE-RESULTS-VTF-FILE Stofat OLD RUN2 ELEMENT-FATIGUE-POINT-RESULTS
ACCUMULATED-DAMAGE FATIGUE-LIFE
PRINT FATIGUE-RESULTS-VTF-FILE Stofat YES ELEMENT-FATIGUE-POINT-RESULTS
PART-DAMAGE WAVE-DIRECTION 135.0 PRINCIPAL-STRESS WAVE-FREQUENCY 0.698062
PRINT FATIGUE-RESULTS-VTF-FILE Stofat NO ELEMENT-FATIGUE-POINT-RESULTS
PART-DAMAGE SEA-STATE 1 DAMAGE-FRACTION
PRINT FATIGUE-RESULTS-VTF-FILE Stofat NEW OFF1 LONG-TERM-RESPONSE
ELEMENT-RESULTS PROBABILITY-EXPONENT 4.0 ALL Sp1 ( ONLY 'Max Stress'
'Stress Amplitude' 'StaDyn Factor' 'Return Period' 'Static Stress' )
PRINT FATIGUE-RESULTS-VTF-FILE Stofat OLD OFF1 LONG-TERM-RESPONSE
ELEMENT-FATIGUE-POINT-RESULTS RETURN-PERIOD 20.0 ALL Seq ( ONLY
'Max Stress' 'Stress Amplitude' 'StaDyn Factor' 'Weibull Shape'
'Static Stress' )
```

## 5.62 PRINT LONG-TERM-RESPONSE

<table>
<tr><td>...</td><td rowspan="3">LONG-TERM-RESPONSE</td><td rowspan="3">filnam</td><td rowspan="2">NEW</td><td rowspan="3">runam+</td><td rowspan="2">ELEMENT</td><td>ELEMENT-RESULTS</td><td rowspan="3">...</td></tr>
<tr><td></td><td>ELEMENT-FATIGUE-POINT-RESULTS</td></tr>
<tr><td></td><td>OLD</td><td colspan="2">HOTSPOT</td></tr>
</table>

<table>
<tr><td rowspan="2">...</td><td>PROBABILITY-LEVELS</td><td rowspan="2">wavdir+</td><td rowspan="2">strcmp+</td><td rowspan="2">(</td><td rowspan="2">ONLY</td><td rowspan="2">param+</td><td rowspan="2">)</td></tr>
<tr><td>RETURN-PERIODS</td></tr>
</table>

**PURPOSE:**

To print values of response parameters for given probability levels or return periods. The probability levels and return periods are defined by the commands DEFINE LONG-TERM PROBABILITY and DEFINE LONG-TERM RETURN-PERIOD, respectively.

The command is executed after the run executions. Only runs with saved results are available for print.

**PARAMETERS:**

| | |
|---|---|
| filnam | Name of the file. The default name is StofatLtr. The extension of the file is.lis and the full name is filnam.lis. |
| NEW | A new file with name filnam.lis is opened for print. |
| OLD | Results are appended to existing file with name filnam.lis. If the file does not exist, a new file is opened for print. |
| runam+ | Name of executed run from which responses are printed ELEMENT Write results for elements. |
| HOTSPOT | Write results for hotspots. |
| ELEMENT-RESULTS | Write one result per element of current element selection. The fatigue check point with maximum usage factor is printed. |
| ELEMENT-FATIGUE-POINT-RESULTS | Write results of all element fatigue check points of current element selection. |
| PROBABILITY-LEVELS | Write results for probability levels. |
| RETURN-PERIODS | Write results for return periods. |
| wavdir+ | Wave direction. |
| strcmp+ | Stress component to be applied in response calculation. One of the following stress components may be selected from list: ‘Sp1’, ‘Seq’, ‘Sxx’, ‘Syy’, ‘Szz’, ‘Sxy’, ‘Sxz’, ‘Syz’, ‘Sp2’, ‘Sp3’. |
| param+ | Parameter to be written for the given probability level or return period. One or more of the following parameters may be selected from list: ‘Max Stress’, ‘Min Stress’, ‘Stress Amplitude’, ‘StaDyn factor’, ‘Probability Level’ or ‘Return Period’, ‘Exceedance’, ‘Weibull Scale’, ‘Weibull Shape’, ‘Static Stress’ and ‘Max Amplitude Point’. |
| ONLY | Mandatory attribute. |
| () | Mandatory parentheses. |

**EXAMPLES:**

```
PRINT LONG-TERM-RESPONSE Stofat NEW RUN1 ELEMENT-RESULTS ALL ( ONLY
'Stress Range' 'Return Period' Exceedance)
```

```
PRINT LONG-TERM-RESPONSE Stofat NEW RUN1 ELEMENT-FATIGUE-POINT-RESULTS 0.0 ( ONLY
'Weibull Scale q' )
```

## 5.63 PRINT RUN-OVERVIEW

| | | |
|---|---|---|
| ... | RUN-OVERVIEW | ALL |
| | | APPLIED-K-FACTORS |
| | | ELEMENT MATERIAL DATA |
| | | ELEMENTS |
| | | HOTSPOTS |
| | | LONG-TERM-PROBABILITIES |
| | | NAMED-ELEMENT-SETS |
| | | RUNS |
| | | WAVE-DIRECTION-DATA |
| | | WELD-NORMAL-LINES |

**PURPOSE:**

To print on screen or file overview of fatigue check runs, created hotspots, current element selection, probabilities of executed runs, named element sets, applied K-factors and current weld normal lines and assignments made to elements and hotspots.

**PARAMETERS:**

| | |
|---|---|
| ALL | Prints overview of executed runs, created hotspots, current element selection and named element sets. |
| APPLIED-K-FACTORS | Prints K-factors of executed runs and current assigned K-factors of current element selection. |
| ELEMENT MATERIAL DATA | Prints overview of material data for current element selection. |
| ELEMENTS | Prints overview of current element selection. |
| HOTSPOTS | Prints overview of created hotspots and the positions of the hotspots and related interpolation points. |
| LONG-TERM-PROBABILITIES | Prints overview of user defined probabilities of executed runs. |
| NAMED-ELEMENT-SETS | Prints overview of current element sets (set names and elements of the sets). |
| RUNS | Prints overview of executed runs. |
| WAVE-DIRECTION-DATA | Prints overview of wave direction data of executed runs. |
| WELD-NORMAL-LINES | Prints overview of current weld normal lines and assignments made to elements and hotspots. |

**EXAMPLES:**

```
PRINT RUN-OVERVIEW ALL
PRINT RUN-OVERVIEW APPLIED-K-FACTORS
PRINT RUN-OVERVIEW ELEMENTS
PRINT RUN-OVERVIEW LONG-TERM-PROBABILITIES
PRINT RUN-OVERVIEW HOTSPOTS
PRINT RUN-OVERVIEW NAMED-ELEMENT-SETS
PRINT RUN-OVERVIEW RUNS
PRINT RUN-OVERVIEW WAVE-DIRECTION-DATA
PRINT RUN-OVERVIEW WELD-NORMAL-LINES
```

# 5.64 PRINT SIN-FILE-LOAD-CASES

| ... | SIN-FILE-LOAD-CASES |
|---|---|

**PURPOSE:**
The command prints an overview of the load cases defined on the SIN file.

**NOTES:**
Load cases defined on the RDRESREF cards and WDRESREF cards (if present) are printed. External and internal load case numbers are printed together with load type and load type identification number. Wave directions and frequencies are printed for wave loads.
The print command may be applied after SIN file has been open data transferred to Stofat.
The command may be used to identify the local load case of the static load case to be enter in the command DEFINE STATIC-LOAD-CASE. In print example below the local load case number of the static load case is 253.

**EXAMPLES:**
Load case print example:

```
Load cases on SIN file RDRESREF cards:
**************************************
ILC : Internal Load Case Number
ELC : External Load Case Number
RNO : Run Number (separates results from different analysis)
ILC ELC RNO Wave Direction Frequency Value Analysis Type (ICALTY)
-----------------------------------------------------------------------
1 1 1 1 0.000 1 -9.7138E-03 6 Quasi-static linear
2 1 1 1 0.000 2 1.6776E-01 6 Quasi-static linear
3 1 1 1 0.000 3 2.5152E-01 6 Quasi-static linear
4 1 1 1 0.000 4 2.9072E-01 6 Quasi-static linear
5 1 1 1 0.000 5 3.0731E-01 6 Quasi-static linear
6 1 1 1 0.000 6 3.1171E-01 6 Quasi-static linear
7 1 1 1 0.000 7 3.0957E-01 6 Quasi-static linear
8 1 1 1 0.000 8 3.0373E-01 6 Quasi-static linear
9 1 1 1 0.000 9 2.9600E-01 6 Quasi-static linear
10 1 1 1 0.000 10 2.8727E-01 6 Quasi-static linear
........
ILC ELC RNO Load Case Value Analysis Type (ICALTY)
-----------------------------------------------------------------------
253 1 2 1 0.000 0 Static linear
```

## 5.65 PRINT SN-CURVE

| ... | SN-CURVE | ( | ONLY | snname+ | ) |
|---|---|---|---|---|---|

**PURPOSE:**

To print data related to an SN-curve.

**PARAMETERS:**

| | |
|---|---|
| snname+ | Name of the SN-curve. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**EXAMPLES:**

```
PRINT SN-CURVE (ONLY USE-X USE-Y )
```

## 5.66 PRINT SN-CURVE-SORTED

<table>
<tr><td rowspan="11">...</td><td rowspan="11">SN-CURVE</td><td colspan="2">ABS</td><td rowspan="11">(</td><td rowspan="11">ONLY</td><td rowspan="11">snname+</td><td rowspan="11">)</td></tr>
<tr><td colspan="2">API</td></tr>
<tr><td rowspan="3">DNV</td><td>OLDER</td></tr>
<tr><td>RP-C203-2010</td></tr>
<tr><td>CN-30.7-2010</td></tr>
<tr><td colspan="2">DOE</td></tr>
<tr><td colspan="2">HSE</td></tr>
<tr><td colspan="2">NORSOK</td></tr>
<tr><td colspan="2">NS</td></tr>
<tr><td colspan="2">USER</td></tr>
<tr><td colspan="2">ALL</td></tr>
</table>

**PURPOSE:**
To print data related the SN-curves.

**PARAMETERS:**

| | |
|---|---|
| ABS | Selection of ABS SN-curves. |
| API | Selection of API SN-curves. |
| DNV | Selection of DNV SN-curves. |
| OLDER | Selection of DNV SN-curves older than 2010. |
| RP-C203-2010 | Selection of DNV SN-curves of Recommended Practice DNV-RP-C203, April 2010. |
| CN-30.7-2010 | Selection of DNV SN-curves of Classification Notes No. 30.7, June 2010. |
| DOE | Selection of DOE SN-curves. |
| HSE | Selection of HSE SN-curves. |
| NORSOK | Selection of NORSOK SN-curves. |
| NS | Selection of Norwegian Standard NS 3472 SN-curves. |
| USER | Selection of user defined SN-curves. |
| ALL | Selection of all available SN-curves. |
| snname+ | Name of SN-curve. |
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |

**NOTES:**
This SN-curves will always be displayed in a log-log scale.

**EXAMPLES:**

```
PRINT SN-CURVE-SORTED DNV OLDER ( ONLY DNV-X DNVC-I DNVC-II )
PRINT SN-CURVE-SORTED ALL ( ONLY ABS-B-A DNV-X DNV2010_B1-AIR HSE-C-CP )
```

## 5.67 PRINT WAVE-SPREADING-FUNCTION

| | | | |
|---|---|---|---|
| ... | WAVE-SPREADING-FUNCTION | name+ | [space] |

**PURPOSE:**
To print energy spreading for elementary wave directions created by the user.

**PARAMETERS:**

| | |
|---|---|
| name+ | User name of the function. |
| space | User input space between each wave direction angle for which the energy spreading function will be printed. This space is independent of what the program will use in calculating the response spectra. Only asked for if one of the names selected corresponds to a cosine power function. |

**EXAMPLES:**

```
PRINT WAVE-SPREADING-FUNCTION COS2 30.0
```

## 5.68 PRINT WAVE-STATISTICS

| ... | WAVE-STATISTICS | ( | ONLY | name+ | ) |
|---|---|---|---|---|---|

**PURPOSE:**

To print wave statistics defined.

**PARAMETERS:**

| | |
|---|---|
| ONLY | Mandatory attribute. |
| ( ) | Mandatory parentheses. |
| name+ | Name of the wave statistics. |

**EXAMPLES:**

```
DISPLAY WAVE-STATISTICS BMT
```

## 5.69 RUN

<table>
<tr><td rowspan="2">RUN</td><td rowspan="2">FATIGUE-CHECK</td><td rowspan="2">name</td><td rowspan="2">txt</td><td>ELEMENT-FATIGUE-CHECK</td><td rowspan="2">...</td><td rowspan="2">ALL</td><td>YES</td></tr>
<tr><td>HOTSPOT-FATIGUE-CHECK</td><td>NO</td></tr>
</table>

**PURPOSE:**
The command starts execution of a fatigue check run.

**PARAMETERS:**

| | |
|---|---|
| name | Name of the run. |
| txt | Run description. |
| ELEMENT-FATGUE-CHECK | Execute an element fatigue check calculation. |
| HOTSPOT-FATGUE-CHECK | Execute a hotspot fatigue check calculation. |
| ALL | Include all wave directions. |
| YES | Save fatigue results in data base for postprocessing. |
| NO | Do not save fatigue results in dada base for postprocessing. |

**NOTES:**
Names of runs for which results are saved (when YES attribute is applied) are made available in the run name lists of the PRINT FATIGUE-RESULTS-DUMP and PRINT FATIGUE-RESULTS-VTF-FILE and these commands may be applied after the runs have been executed. If results are not saved (the NO attribute is applied) the run names are not made available in the run name list of these commands and the commands can not be applied for such runs.

Saving of results puts restriction on the size of the model (number of elements) that may be treated in a run due to saving limitation of the database Stofat applies. For further details see 3.7.

**EXAMPLES:**

```
RUN FATIGUE-CHECK RUN1 'Hotspot Fatigue Check' HOTSPOT-FATIGUE-CHECK ALL YES
RUN FATIGUE-CHECK RUN2 'Element Fatigue Check' ELEMENT-FATIGUE-CHECK ALL NO
```

## 5.70 SELECT

<table>
<tr><td rowspan="11">SELECT</td><td rowspan="6">SET</td><td rowspan="6">ELEMENTS</td><td rowspan="6">selnam</td><td rowspan="11">...</td><td rowspan="4">ONLY</td><td rowspan="11">...</td><td colspan="7">elnam</td></tr>
<tr><td colspan="7">CURRENT</td></tr>
<tr><td colspan="7">ALL</td></tr>
<tr><td>SET</td><td colspan="6">setn+</td></tr>
<tr><td rowspan="7">INCLUDE<br><br>EXCLUDE</td><td>GROUP</td><td>fstel</td><td>lstel</td><td colspan="4">step</td></tr>
<tr><td>PLANE</td><td>nod1</td><td>nod2</td><td>nod3</td><td colspan="3">tol</td></tr>
<tr><td colspan="3" rowspan="5">ELEMENTS</td><td>VOLUME</td><td>lwx</td><td>hgx</td><td>lwy</td><td>hgy</td><td>lwz</td><td>hgz</td></tr>
<tr><td colspan="4">ELEMENT-TYPE</td><td colspan="3">eltyp+</td></tr>
<tr><td colspan="4">WITH-MATERIAL</td><td colspan="3">mat+</td></tr>
<tr><td colspan="4">WITH-THICKNESS</td><td colspan="3">thck+</td></tr>
<tr><td colspan="4">WITH-SN-CURVE</td><td colspan="3">sncrv+</td></tr>
</table>

**PURPOSE:**
To select elements among the elements of the superelement. Elements must be selected prior to the element fatigue check analysis.

**PARAMETERS:**

| | |
|---|---|
| SET ELEMENTS selnam | Select SET ELEMENTS option with element selection name selnam. |
| ELEMENTS | Select ELEMENTS option. |
| ONLY | Only current element selection. |
| INCLUDE | Include current elements selection. |
| EXCLUDE | Exclude current elements selection. |
| elnam | Element name. |
| CURRENT | Current element. |
| ALL | All elements. |
| SET setn+ | Element set setn. The set may be predefined in Prefem. An element set is generated for each element fatigue check run execution, with set name equal to the run name. |
| GROUP fstel lstel step | Element group. The group is defined by entering first and last elements of the group and the step in elements. |
| PLANE nod1 nod2 nod3 tol | Select the elements contained in the plane formed by the nodes nod1, nod2, nod3 and the tolerance tol. |
| VOLUME | Select the elements contained in the volume limited by the low and high values of the X-, Y- and Z-coordinates. |
| lwx | Low X-coordinate. |
| hgx | High X-coordinate. |
| lwy | Low Y-coordinate. |
| hgy | High Y-coordinate. |
| lwz | Low Z-coordinate. |
| hgz | High Z-coordinate. |
| ELEMENT-TYPE eltyp+ | All elements of element type eltyp shall be selected. |
| WITH-MATERIAL mat+ | All elements with material mat shall be selected. |

| | |
|---|---|
| WITH-THICKNESS thck+ | All elements with thickness thck shall be selected. Applicable for shell elements only. |
| WITH-SN-CURVE sncrv+ | All elements with SN curve sncrv shall be selected. |

**EXAMPLES:**

```
SELECT SET ELEMENTS DEFAULT INCLUDE 34
SELECT SET ELEMENTS DEFAULT INCLUDE ALL
SELECT SET ELEMENTS DEFAULT EXCLUDE 666
SELECT SET ELEMENTS DEFAULT ONLY 665
SELECT SET ELEMENTS DEFAULT INCLUDE SET RUN1
SELECT SET ELEMENTS DEFAULT EXCLUDE GROUP 1 10 1
SELECT SET ELEMENTS PLANE1 INCLUDE PLANE 162 185 186 1.0
SELECT SET ELEMENTS VOLUME1 INCLUDE VOLUME -35.81 35.81 -35.81 35.81 10.5 22.5
SELECT SET ELEMENTS DEFAULT ONLY ELEMENT-TYPE FTRS25
SELECT SET ELEMENTS DEFAULT INCLUDE WITH-MATERIAL 2
SELECT ELEMENTS INCLUDE WITH-THICKNESS 0.01
SELECT ELEMENTS INCLUDE WITH-SN-CURVE DNVC-I
```

## 5.71 SET

| | | |
|---|---|---|
| SET | COMPANY-NAME | ... |
| | DISPLAY | |
| | DRAWING | |
| | GRAPH | |
| | PLOT | |
| | PRINT | |
| | TITLE | |

**PURPOSE:**

Set options that apply generally to print and display/plot.

## 5.72 SET COMPANY-NAME

| | | |
|---|---|---|
| ... | COMPANY-NAME | name |

**PURPOSE:**
Set the company name for use with result presentation.

**PARAMETERS:**

| | |
|---|---|
| name | The name of the company. |

**NOTES:**
The name is used at the top of a framed display/plot (see SET DRAWING FRAME). It is not used with printed results.

**EXAMPLES:**

```
SET COMPANY-NAME 'DNV GL'
```

## 5.73 SET DISPLAY

<table>
<tr><td rowspan="7">...</td><td rowspan="7">DISPLAY</td><td rowspan="2">COLOUR</td><td colspan="4">ON</td></tr>
<tr><td colspan="4">OFF</td></tr>
<tr><td rowspan="2">DESTINATION</td><td colspan="4">SCREEN</td></tr>
<tr><td colspan="4">FILE</td></tr>
<tr><td>DEVICE</td><td colspan="4">device</td></tr>
<tr><td>WORKSTATION-WINDOW</td><td>left</td><td>right</td><td>bottom</td><td>top</td></tr>
</table>

**PURPOSE:**
Set options that affect the display of data.

**PARAMETERS:**

| | |
|---|---|
| COLOUR | Turn colour ON/OFF in the display. Note that display and plot colour options may be different. |
| DESTINATION | Show the display on the SCREEN or send it to a FILE. |
| DEVICE | Device Set the display device. If the device is not correct, the display will appear as a lot of strange characters on the screen and probably demand that a 'Return' is typed before it appears. The display device is ignored if the display destination is to file. The actual list of available devices depend on the installation. Current available are:<br>WINDOW, DUMMY<br>The DUMMY device is used to do a display command without generating a display. |
| WORKSTATION-WINDOW | Set the size of the display window. This command will only work when running under X-windows and on an Apollo workstation. In addition, the window size must be set before the window is opened. |
| left | Left edge of the window. Must be in the range from 1 to 120. |
| right | Right edge of the window. Must be in the range from 1 to 120. |
| bottom | Bottom edge of the window. Must be in the range from 1 to 100. |
| top | Top edge of the window. Must be in the range from 1 to 100. |

**NOTES:**
The DESTINATION FILE option is useful for making a journal file run in batch mode. Edit the setting into the top of the file, and all displays will be written to file instead of shown on the screen. No other changes need be made. Another possibility is to set the device to DUMMY, which will make all display commands execute without generating displays.

The DESTINATION is always set to SCREEN when Stofat starts up, regardless of the status it may have been set to in a previous run.

**EXAMPLES:**
The following options are default when Stofat starts up with a new database:

```
SET DISPLAY COLOUR ON
```

```
SET DISPLAY DESTINATION SCREEN
SET DISPLAY DEVICE DUMMY (if running line mode)
SET DISPLAY DEVICE WINDOWS (if running graphics mode)
SET DISPLAY WORKSTATION-WINDOW 49 120 1 70
```

## 5.74 SET DRAWING

<table>
<tr><td rowspan="9">...</td><td rowspan="9">DRAWING</td><td rowspan="2">CHARACTER-TYPE</td><td colspan="2">HARDWARE</td></tr>
<tr><td colspan="2">SOFTWARE</td></tr>
<tr><td rowspan="5">FONT-TYPE</td><td colspan="2">SIMPLE</td></tr>
<tr><td colspan="2">GROTESQUE</td></tr>
<tr><td colspan="2">ROMAN-NORMAL</td></tr>
<tr><td colspan="2">ROMAN-ITALIC</td></tr>
<tr><td colspan="2">ROMAN-BOLD</td></tr>
<tr><td>FRAME</td><td rowspan="2">...</td><td>ON</td></tr>
<tr><td>GRID</td><td>OFF</td></tr>
</table>

**PURPOSE:**
Set attributes of drawings.

**PARAMETERS:**

| | |
|---|---|
| CHARACTER-TYPE | The character type can be SOFTWARE (scalable) or HARDWARE (fixed). |
| FONT-TYPE | Select the font to be used. The list of fonts may be machine dependent. |
| FRAME | Turn the frame of the display and plot ON/OFF. The framed plot is roughly A4 size on paper, while the unframed plot is somewhat smaller. On the screen they will fit into the same window, so the framed display will be smaller than the unframed plot. The titles and company name will only appear when the frame is on. |
| GRID | Turn the drawing of a dotted grid ON/OFF in an xy-plot. Not valid for pie chart plots. |

**EXAMPLES:**
The following options are default when Stofat starts up with a new database:

```
SET DRAWING CHARACTER-TYPE SOFTWARE
SET DRAWING FONT-TYPE SIMPLE
SET DRAWING FRAME OFF
SET DRAWING GRID ON
```

## 5.75 SET GRAPH

<table>
<tr><td rowspan="4">...</td><td rowspan="4">GRAPH</td><td>LINE-OPTIONS</td><td rowspan="4">...</td></tr>
<tr><td>XAXIS-ATTRIBUTES</td></tr>
<tr><td>YAXIS-ATTRIBUTES</td></tr>
<tr><td>ZAXIS-ATTRIBUTES</td></tr>
</table>

**PURPOSE:**
Set options that apply to graphs.

**SUBCOMMNADS:**

| | |
|---|---|
| LINE-OPTIONS | Set options controlling how lines are drawn and marked. |
| XAXIS-ATTRIBUTES | Set options controlling the drawing and scale of the x-axis. |
| YAXIS-ATTRIBUTES | Set options controlling the drawing and scale of the y-axis. |
| ZAXIS-ATTRIBUTES | Set options controlling the drawing and scale of the z-axis. |

## 5.76 SET GRAPH LINE-OPTIONS

<table>
<tr><td rowspan="17">...</td><td rowspan="17">LINE-OPTIONS</td><td rowspan="7">LINE-TYPE</td><td rowspan="7"></td><td>BLANK</td></tr>
<tr><td>END-POINT</td></tr>
<tr><td>DASHED</td></tr>
<tr><td>DASH-DOT</td></tr>
<tr><td>DEFAULT</td></tr>
<tr><td>DOTTED</td></tr>
<tr><td>SOLID</td></tr>
<tr><td rowspan="2">MARKER</td><td rowspan="2">...</td><td>ON</td></tr>
<tr><td>OFF</td></tr>
<tr><td rowspan="7">MARKER-TYPE</td><td rowspan="7">line</td><td>CROSS</td></tr>
<tr><td>DEFAULT</td></tr>
<tr><td>DELTA</td></tr>
<tr><td>DIAMOND</td></tr>
<tr><td>NABLA</td></tr>
<tr><td>PLUS</td></tr>
<tr><td>SQUARE</td></tr>
<tr><td>MARKER-SIZE</td><td colspan="2">size</td></tr>
</table>

**PURPOSE:**
Set options controlling how lines are drawn and marked.

**PARAMETERS:**

| | |
|---|---|
| LINE-TYPE | Controls how lines are drawn. Only six lines can be controlled. |
| line | A line number, from 1 to 6. |
| MARKER | Turn usage of markers ON/OFF. |
| MARKER-TYPE | Control the marker type for up to six lines. |
| MARKER-SIZE | Set the size of the markers. |
| size | The size of the markers. |

**EXAMPLES:**
Default options when Stofat starts up with a new database:

```
SET GRAPH LINE-OPTIONS LINE-TYPE 1 DEFAULT
SET GRAPH LINE-OPTIONS MARKER ON
SET GRAPH LINE-OPTIONS MARKER-TYPE 1 DEFAULT
SET GRAPH LINE-OPTIONS MARKER-SIZE 2.0
```

## 5.77 SET GRAPH XAXIS-ATTRIBUTES

<table>
<tr><td rowspan="10">...</td><td rowspan="10">XAXIS-ATTRIBUTES</td><td rowspan="4">DECIMAL-FORMAT</td><td colspan="3">EXPONENTIAL</td></tr>
<tr><td colspan="3">FIXED</td></tr>
<tr><td colspan="3">GENERAL</td></tr>
<tr><td colspan="3">INTEGER</td></tr>
<tr><td rowspan="2">LIMITS</td><td colspan="3">FREE</td></tr>
<tr><td>FIXED</td><td>xmin</td><td>xmax</td></tr>
<tr><td rowspan="2">SPACING</td><td colspan="3">LINEAR</td></tr>
<tr><td colspan="3">LOGARITHMIC</td></tr>
<tr><td rowspan="2">TITLE</td><td colspan="3">DEFAULT</td></tr>
<tr><td colspan="2">SPECIFIED</td><td>xtitle</td></tr>
</table>

**PURPOSE:**
Set options controlling the attributes of the x axis in a graph.

**PARAMETERS:**

| | |
|---|---|
| DECIMAL-FORMAT | Controls the presentation of numbers labelling the x axis. The numbers can be presented in EXPONENTIAL format, in FIXED format, as INTEGERs or in GENERAL (free) format. |
| LIMITS | Controls the limits of the x axis. These can either be FREE (i.e. determined by the data that are being presented) or FIXED to the minimum value xmin and the maximum value xmax. |
| SPACING | Controls the spacing of numbers along the axis. The axis can have a LINEAR spacing or be LOGARITHMIC with base 10. |
| TITLE | The title at the x axis can be specified by Stofat (DEFAULT) or overridden with a SPECIFIED text: xtitle. |

**EXAMPLES:**
The following options are default when Stofat starts up with a new database:

```
SET GRAPH XAXIS-ATTRIBUTES DECIMAL-FORMAT GENERAL
SET GRAPH XAXIS-ATTRIBUTES LIMITS FREE
SET GRAPH XAXIS-ATTRIBUTES SPACING LINEAR
SET GRAPH XAXIS-ATTRIBUTES TITLE DEFAULT
```

## 5.78 SET GRAPH YAXIS-ATTRIBUTES

<table>
<tr><td rowspan="10">...</td><td rowspan="10">YAXIS-ATTRIBUTES</td><td rowspan="4">DECIMAL-FORMAT</td><td colspan="3">EXPONENTIAL</td></tr>
<tr><td colspan="3">FIXED</td></tr>
<tr><td colspan="3">GENERAL</td></tr>
<tr><td colspan="3">INTEGER</td></tr>
<tr><td rowspan="2">LIMITS</td><td colspan="3">FREE</td></tr>
<tr><td>FIXED</td><td>ymin</td><td>ymax</td></tr>
<tr><td rowspan="2">SPACING</td><td colspan="3">LINEAR</td></tr>
<tr><td colspan="3">LOGARITHMIC</td></tr>
<tr><td rowspan="2">TITLE</td><td colspan="3">DEFAULT</td></tr>
<tr><td colspan="2">SPECIFIED</td><td>ytitle</td></tr>
</table>

**PURPOSE:**
Set options controlling the attributes of the y axis in a graph.

**PARAMETERS:**

| | |
|---|---|
| DECIMAL-FORMAT | Controls the presentation of numbers labelling the y axis. The numbers can be presented in EXPONENTIAL format, in FIXED format, as INTEGERs or in GENERAL (free) format. |
| LIMITS | Controls the limits of the y axis. These can either be FREE (i.e. determined by the data that are being presented) or FIXED to the minimum value ymin and the maximum value ymax. |
| SPACING | Controls the spacing of numbers along the axis. The axis can have a LINEAR spacing or be LOGARITHMIC with base 10. |
| TITLE | The title at the y axis can be specified by Stofat (DEFAULT) or overridden with a SPECIFIED text: ytitle. |

**EXAMPLES:**
The following options are default when Stofat starts up with a new database:

```
SET GRAPH YAXIS-ATTRIBUTES DECIMAL-FORMAT GENERAL
SET GRAPH YAXIS-ATTRIBUTES LIMITS FREE
SET GRAPH YAXIS-ATTRIBUTES SPACING LINEAR
SET GRAPH YAXIS-ATTRIBUTES TITLE DEFAULT
```

## 5.79 SET GRAPH ZAXIS-ATTRIBUTES

<table>
<tr><td rowspan="10">...</td><td rowspan="10">ZAXIS-ATTRIBUTES</td><td rowspan="4">DECIMAL-FORMAT</td><td colspan="3">EXPONENTIAL</td></tr>
<tr><td colspan="3">FIXED</td></tr>
<tr><td colspan="3">GENERAL</td></tr>
<tr><td colspan="3">INTEGER</td></tr>
<tr><td rowspan="2">LIMITS</td><td colspan="3">FREE</td></tr>
<tr><td>FIXED</td><td>zmin</td><td>zmax</td></tr>
<tr><td rowspan="2">SPACING</td><td colspan="3">LINEAR</td></tr>
<tr><td colspan="3">LOGARITHMIC</td></tr>
<tr><td rowspan="2">TITLE</td><td colspan="3">DEFAULT</td></tr>
<tr><td colspan="2">SPECIFIED</td><td>ztitle</td></tr>
</table>

**PURPOSE:**
Set options controlling the attributes of the z axis in a graph.

**PARAMETERS:**

| | |
|---|---|
| DECIMAL-FORMAT | Controls the presentation of numbers labelling the z axis. The numbers can be presented in EXPONENTIAL format, in FIXED format, as INTEGERs or in GENERAL (free) format. |
| LIMITS | Controls the limits of the z axis. These can either be FREE (i.e. determined by the data that are being presented) or FIXED to the minimum value zmin and the maximum value zmax. |
| SPACING | Controls the spacing of numbers along the axis. The axis can have a LINEAR spacing or be LOGARITHMIC with base 10. |
| TITLE | The title at the z axis can be specified by Stofat (DEFAULT) or overridden with a SPECIFIED text: ztitle. |

**EXAMPLES:**
The following options are default when Stofat starts up with a new database:

```
SET GRAPH ZAXIS-ATTRIBUTES DECIMAL-FORMAT GENERAL
SET GRAPH ZAXIS-ATTRIBUTES LIMITS FREE
SET GRAPH ZAXIS-ATTRIBUTES SPACING LINEAR
SET GRAPH ZAXIS-ATTRIBUTES TITLE DEFAULT
```

## 5.80 SET PLOT

| | | | | |
|---|---|---|---|---|
| ... | PLOT | COLOUR | ... | ON |
| | | | | OFF |
| | | FILE | prefix | name |
| | | FORMAT | format | |
| | | PAGE-SIZE | | A1 |
| | | | | A2 |
| | | | | A3 |
| | | | | A4 |
| | | | | A5 |

**PURPOSE:**
Set options that affect the writing of plot to file.

**PARAMETERS:**

| | |
|---|---|
| COLOUR | Turn colour ON/OFF in the plot. Note that display and plot colour options may be different. |
| FILE prefix name | Set the plot file name and prefix. The total file name is the concatenation of prefix and name and an extension determined by the plot format. |
| FORMAT format | Set the plot format. The actual list of available devices depend on the installation. Some, but not necessarily all, of these could be available: SESAM-NEUTRAL, POSTSCRIPT, HPGL-7550, WINDOWS-PRINTER, CGM-BINARY. |
| PAGE-SIZE | Set the size of the plot. |

**NOTES:**
The command SET DISPLAY DESTINATION FILE should be used together with a following DISPLAY command.

**EXAMPLES:**
Default options when Stofat starts up with a new database:

```
SET PLOT COLOUR OFF
SET PLOT FILE ‘ ‘ R21 (prefix and name of database and journal file are defaults)
SET PLOT FORMAT SESAM-NEUTRAL
SET PLOT PAGE-SIZE A4
```

## 5.81 SET PRINT

<table>
<tr><td rowspan="9">...</td><td rowspan="9">PRINT</td><td colspan="2" rowspan="3">DESTINATION</td><td>SCREEN</td></tr>
<tr><td>FILE</td></tr>
<tr><td>CSV-FILE</td></tr>
<tr><td>FILE</td><td>prefix</td><td>name</td></tr>
<tr><td colspan="2">PAGE-HEIGHT</td><td>plines</td></tr>
<tr><td colspan="2">SCREEN-HEIGHT</td><td>nlines</td></tr>
<tr><td colspan="2" rowspan="3">PAGE-ORIENTATION</td><td>LANDSCAPE</td></tr>
<tr><td>PORTRAIT</td></tr>
<tr><td>WIDEANDLONG</td></tr>
</table>

**PURPOSE:**
Set options that affect print.

**PARAMETERS:**

| | |
|---|---|
| DESTINATION | Print destination. |
| SCREEN | Show print on screen. |
| FILE | Show print on file with extension .lis. |
| CSV-FILE | Show print on file with extension .csv. Table results are printed with semicolons between table fields. |
| FILE prefix name | Set the print file name and prefix. The total file name is the concatenation of prefix and name and the extension '.lis'. |
| PAGE-HEIGHT plines | Set the number of lines per file print page to plines. Applies when print destination is FILE. Initially set to 60. |
| SCREEN-HEIGHT nlines | Set the number of lines per screen print page to nlines. Applies when print destination is SCREEN. Initially set to 24. |
| PAGE-ORIENTATION | Set the orientation of the print in the print file. PORTRAIT will use at most 80 characters horizontally. LANDSCAPE will use up to 132 characters horizontally. WIDEANDLONG will display all fields sequencially on the same line. |

**NOTES:**
The purpose of the CSV-FILE option is to print the results in a more proper format for spread sheets. The semicolons between the table fields serve as column delimiter when the file is opened in spreadsheet. The number of lines per file print page is set to 100000, which means that page shift and print of page- and table headers take place for every 100000 printed lines.

The PAGE-HEIGHT and SCREEN-HEIGHT numbers are reset every time Stofat starts up, even if it had been set to another value in a previous run. When running in graphics mode the print in the print window may look cleaner if the SCREEN-HEIGHT is set large, eg. to 100. To avoid page shifts and print of page and table headings the numbers should be set larger than the number of lines to be printed.

The DESTINATION is reset to SCREEN and the PAGE-ORIENTATION to PORTRAIT every time Stofat starts up, even if other values are used in a previous run. When print destination is changed from FILE to CSV-FILE, or vice versa, during a run, the current file is closed and a new file is opened. When print destination is switched between SCREEN and file (FILE or CSV-FILE) the current print file is maintained opened and new print is appended to this file when going from screen print and back to the current file print option (same file prefix, name and file option). Otherwise, the current print file is closed and a new print file is opened.

**EXAMPLES:** Default options when Stofat starts up with a new database:

```
SET PRINT DESTINATION SCREEN
SET PRINT FILE ‘ ‘ R21 (prefix and name of database and journal file are defaults)
SET PRINT SCREEN-HEIGHT 24 (see NOTES above)
SET PRINT PAGE-ORIENTATION PORTRAIT
```

Print to .lis file in landscape format:

```
SET PRINT DESTINATION FILE
SET PRINT FILE ‘ ‘ STOFAT
SET PRINT PAGE-HEIGHT 60
SET PRINT PAGE-ORIENTATION LANDSCAPE
```

Print to .csv file:

```
SET PRINT DESTINATION CSV-FILE
SET PRINT FILE ‘ ‘ STOFAT
SET PRINT PAGE-ORIENTATION PORTRAIT
```

## 5.82 SET TITLE

| ... | TITLE | title | title | title | title |
|---|---|---|---|---|---|

**PURPOSE:**
Set user defined titles to be used with print and display/plot.

**PARAMETERS:**

| | |
|---|---|
| title | A title text. The display layout will not accept more than 40 characters in each title. Four titles are available to the user. |

**NOTES:**
The user titles are blank when Stofat starts up with a new database.

**EXAMPLES:**

```
SET TITLE 'Line 1' 'Line 2' 'Line 3' 'Line 4'
```

## 5.83 VIEW

| | | |
|---|---|---|
| VIEW | FRAME | ... |
| | PAN | |
| | POSITION | |
| | ROTATE | |
| | ZOOM | |

**PURPOSE:**
To control the appearance of the 3D view, by specification of angles, zoom and pan.

**PARAMETERS:**

| | |
|---|---|
| FRAME | Performs an automatic zoom to fit the current view within the frame of the display. |
| PAN | Pan (shift) the current view in the plane of the screen. |
| POSITION | Define the view angles by specifying a point in space which, together with the centre of the model's coordinate system, defines the direction of the user's observation. |
| ROTATE | Rotate view by specifying rotation angles. |
| ZOOM | Zoom in or out. |

**NOTES:**

1 All subcommands and data are fully explained subsequently as each command is described in detail.

2 This command is not logged.

3 The VIEW command works differently in the graphics user interface. The manipulations are performed by typing in the relevant numbers, then clicking on the buttons in the dialogue box, see Figure 5.3 below.

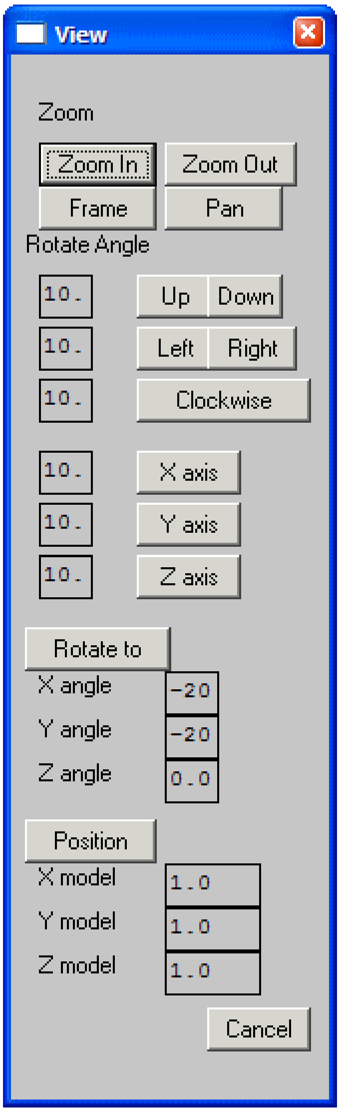


Figure 5.3: The graphics user interface View dialog

## 5.84 VIEW FRAME

| ... | FRAME |
|---|---|

**PURPOSE:**

Perform an automatic zoom to fit the current view within the frame of the display.

**PARAMETERS:**

None

**NOTES:**

1 This command is not logged.

## 5.85 VIEW PAN

| | | | |
|---|---|---|---|
| ... | PAN | pick_from | pick_to |

**PURPOSE:**

Pan (shift) the current view in the plane screen. The view is shifted by defining a vector in the plane of the screen. The vector is defined by picking the ‘from’ and the ‘to’ position, see below.

**PARAMETERS:**

| | |
|---|---|
| pick_from | Pick (using mouse or cross-hair) a point on the screen to define the ‘from’ position. |
| pick_to | Pick (using mouse or cross-hair) a point on the screen to define the ‘to’ position. |

**NOTES:**

1 This command is not logged.

## 5.86 VIEW POSITION

| ... | POSITION | x-model | y-model | z-model |
|---|---|---|---|---|

**PURPOSE:**

Define the view angles by specifying a point in space. The imaginary line from this point towards the origin of the model's coordinate system defines the direction of the user's observation.

**PARAMETERS:**

| | |
|---|---|
| x-model | x-coordinate in the model's coordinate system. |
| y-model | y-coordinate in the model's coordinate system. |
| z-model | z-coordinate in the model's coordinate system. |

**NOTES:**

1. This command is not logged.
2. This command is independent of any previously entered rotations and can therefore be used to 'reset' the viewing direction.

## 5.87 VIEW ROTATE

<table>
<tr><td rowspan="9">...</td><td rowspan="9">ROTATE</td><td rowspan="6">[</td><td>TO</td><td>angle-x</td><td>angle-y</td><td>angle-z</td><td rowspan="6">]</td><td rowspan="6">Screen mode<br>(Relative to screen)</td></tr>
<tr><td>UP</td><td colspan="3">angle-x-screen</td></tr>
<tr><td>DOWN</td><td colspan="3">angle-x-screen</td></tr>
<tr><td>LEFT</td><td colspan="3">angle-y-screen</td></tr>
<tr><td>RIGHT</td><td colspan="3">angle-y-screen</td></tr>
<tr><td>CLOCKWISE</td><td colspan="3">angle-z-screen</td></tr>
<tr><td rowspan="3">[</td><td>X-AXIS</td><td colspan="3">angle-x-model</td><td rowspan="3">]</td><td rowspan="3">Space mode<br>(Relative to model)</td></tr>
<tr><td>Y-AXIS</td><td colspan="3">angle-y-model</td></tr>
<tr><td>Z-AXIS</td><td colspan="3">angle-z-model</td></tr>
</table>

**PURPOSE:**

Rotate view by specifying rotation angles. Note that this command operates in two basic modes; screen mode and space mode.

Screen mode (TO, UP, DOWN, LEFT, RIGHT, CLOCKWISE alternatives): Here, all angles are relative to the screen axes, which remain fixed, no matter how many rotations are entered. The angles should be interpreted such that it is the observer (the user) that revolves around a stationary model.

The origin of the screen axis system lies in the centre of the screen. The x-axis is horizontal and points from the origin towards the right hand side of the screen. The y-axis is vertical and points from the origin towards the top of the screen. The z-axis is horizontal and points from the origin and out of the screen (towards the user).

Space mode (X-AXIS, Y-AXIS, Z-AXIS alternatives). Here, all angles are relative to the model axes, which follow the rotations. The angles should be interpreted such that it is the model coordinate system that rotates relative to the observer.

**PARAMETERS:**

| | |
|---|---|
| TO angle-x angle-y angle-z | The alternative is independent of all previously entered rotations. At the execution of this command, the program first re-initializes the rotations, such that the model and screen axes overlap. Then, the x, y and z rotations specified by the user are applied, in the same order. |
| UP angle-x-screen | Rotate the view position angle-x-screen degrees UP, relative to the screen x-axis, from the current position. |
| DOWN angle-x-screen | Rotate the view position angle-x-screen degree DOWN, relative to the screen x-axis, from the current position. |
| LEFT angle-y-screen | Rotate the view position angle-y-screen degrees LEFT, relative to the screen y-axis, from the current position. |
| RIGHT angle-y-screen | Rotate the view position angle-y-screen degrees RIGHT, relative to the screen y-axis, from the current position. |
| CLOCKWISE angle-z-screen | Rotate the view position angle-z-screen degrees CLOCKWISE, relative to the screen z-axis, from the current position. |
| X-AXIS angle-x-model | Rotate the model coordinate system angle-x-model around the model x-axis. |

| | |
|---|---|
| Y-AXIS angle-y-model | Rotate the model coordinate system angle-y-model around the model y-axis. |
| Z-AXIS angle-y-model | Rotate the model coordinate system angle-z-model around the model z-axis. |

**NOTES:**

1 This command is not logged.

## 5.88 VIEW ZOOM

<table>
<tr><td rowspan="2">...</td><td rowspan="2">ZOOM</td><td>IN</td><td rowspan="2">pick</td><td rowspan="2">pick</td></tr>
<tr><td>OUT</td></tr>
</table>

**PURPOSE:**

To zoom the current view in or out.

**PARAMETERS:**

| | |
|---|---|
| IN | Zoom in by pointing to two diagonal corners in a square on the screen. The part of the view within the square will then be enlarged and fitted within the whole screen, causing an illusion of movement towards the model. |
| OUT | Zoom out by pointing on two diagonal corners in a square on the screen. The current view will then be compressed and fitted within the smaller square, causing an illusion of movement away from the model. |

**NOTES:**

1 This command is not logged.

# A Tutorial Examples

The purpose of this appendix is to show the most common features of Stofat by examples of line mode commands for some Stofat applications. The examples illustrate the use Stofat.

Prior to running Stofat a direct access Results Interface File (R#.SIN) containing the model data of the structure and the stress transfer functions from the loading must be available. Only one Results Interface File can be opened at a time in Stofat and only one superelement can be transferred to the database. Several independent fatigue check runs may however be executed and input parameters may be reset between each run. The results of the runs may be displayed and printed on screen and written to files.

Stofat makes extensive use of default values for parameters and command options. The required amount of command and parameter specifications may thus be reduced if default values are applied. Defaults are specified in *Chapter 5 COMMAND DESCRIPTION.*

Comments may be inserted anywhere between the command lines in the command input file. A comment line start with '%' in first position. A comment line with '%' in second position is not printed in the log journal file (.jnl) of the input.

## A.1 Double Bottom Stiffener Connection of a Ship Hull

In the present example fatigue check is performed for a double bottom stiffener connection in a ship hull. The element model is shown in Figure A.1 and consists of 1251 elements of which 858 are eight node shell elements checked for fatigue by Stofat. The usage factors of the most stressed stiffener area are displayed in Figure A.2 Line commands for the Stofat analysis are given below the Figure A.2.

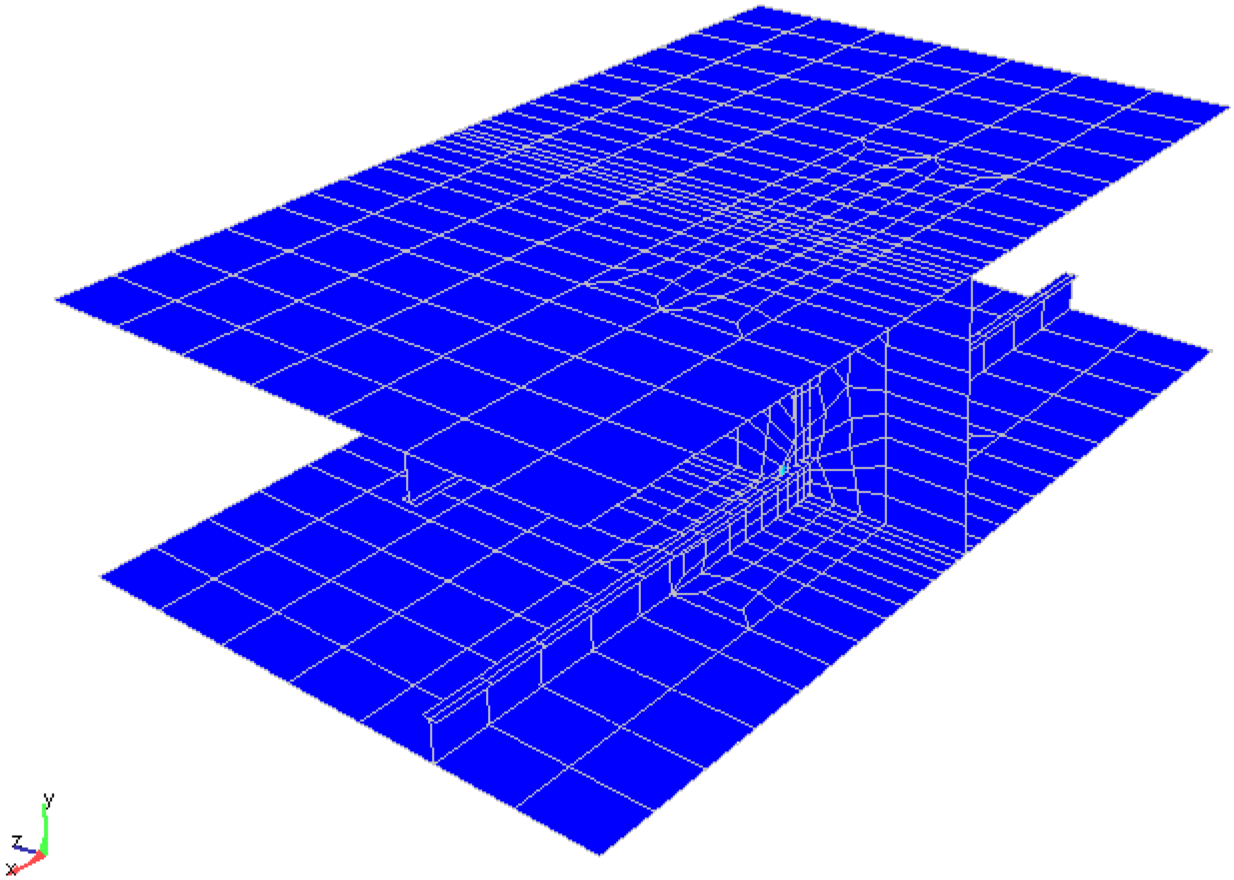


Figure A.1: Element model of the double bottom stiffener connection

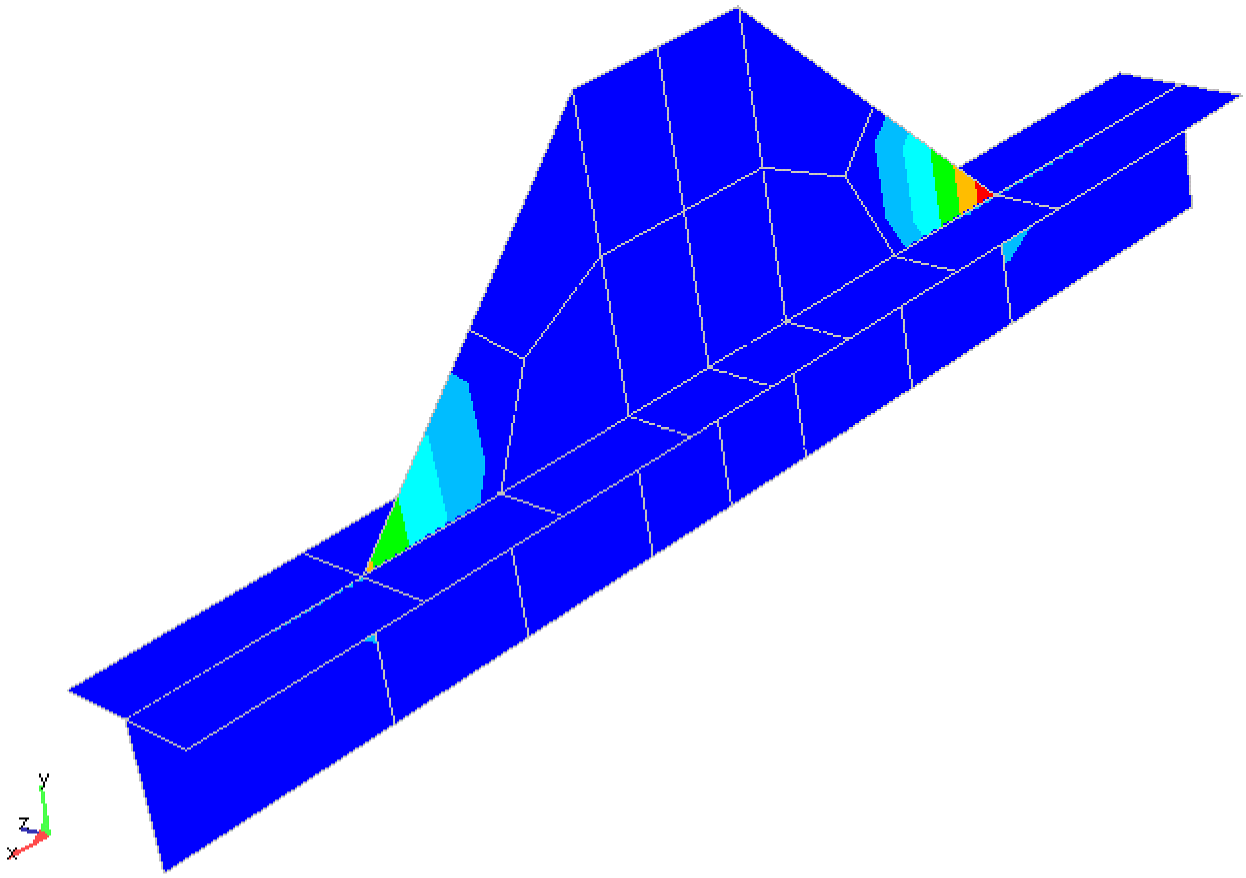


Figure A.2: Contour plot of usage factors of critical stiffener area

Line Commands:

```
%
%----------------------------------------
% Read .SIN fil and transfer superelement
%---------------------------------------
FILE OPEN SIN-DIRECT-ACCESS ' ' R5
FILE TRANSFER 1 BRACKET LOADS stringerjoint
%
% Display superelement model
%---------------------------
%%DISPLAY SUPERELEMENT
%
% Create wave statistics
%-----------------------
CREATE WAVE-STATISTICS SCATTER 'Scatter Diagram' SCATTER-DIAGRAM PROBABILITY (
    ONLY
%   HS  TZ   PROB.
    0.5   2.5 0.00126
    0.5   3.5 0.00517
    0.5   4.5 0.00383
    0.5   5.5 0.00190
    0.5   6.5 0.00084
    0.5   7.5 0.00043
    0.5   8.5 0.00019
    0.5   9.5 0.00013
    0.5  10.5 0.00010
```

```
0.75  2.5 0.00298
0.75  3.5 0.05385
0.75  4.5 0.05369
0.75  5.5 0.01825
0.75  6.5 0.00581
0.75  7.5 0.00220
0.75  8.5 0.00075
0.75  9.5 0.00023
0.75 10.5 0.00008
0.75 11.5 0.00001
0.75 12.5 0.00001
1.25  2.5 0.00011
1.25  3.5 0.02795
1.25  4.5 0.10198
1.25  5.5 0.04466
1.25  6.5 0.01290
1.25  7.5 0.00279
1.25  8.5 0.00063
1.25  9.5 0.00030
1.25 10.5 0.00006
1.25 11.5 0.00002
1.25 12.5 0.00001
1.75  3.5 0.00250
1.75  4.5 0.07835
1.75  5.5 0.06895
1.75  6.5 0.01693
1.75  7.5 0.00354
1.75  8.5 0.00063
1.75  9.5 0.00017
1.75 10.5 0.00005
1.75 11.5 0.00000
1.75 12.5 0.00001
2.25  3.5 0.00006
2.25  4.5 0.02199
2.25  5.5 0.09021
2.25  6.5 0.02647
2.25  7.5 0.00608
2.25  8.5 0.00102
2.25  9.5 0.00022
2.25 10.5 0.00007
2.75  3.5 0.00002
2.75  4.5 0.00185
2.75  5.5 0.06327
2.75  6.5 0.03641
2.75  7.5 0.00715
2.75  8.5 0.00146
2.75  9.5 0.00026
2.75 10.5 0.00001
3.25  4.5 0.00011
3.25  5.5 0.02244
3.25  6.5 0.04447
3.25  7.5 0.00809
3.25  8.5 0.00163
3.25  9.5 0.00033
3.25 10.5 0.00006
3.75  4.5 0.00002
3.75  5.5 0.00323
3.75  6.5 0.03882
3.75  7.5 0.01088
```

```
3.75  8.5 0.00175
3.75  9.5 0.00028
3.75 10.5 0.00007
4.25  4.5 0.00002
4.25  5.5 0.00021
4.25  6.5 0.02008
4.25  7.5 0.01496
4.25  8.5 0.00188
4.25  9.5 0.00028
4.25 10.5 0.00002
4.75  5.5 0.00002
4.75  6.5 0.00540
4.75  7.5 0.01496
4.75  8.5 0.00193
4.75  9.5 0.00015
5.25  5.5 0.00002
5.25  6.5 0.00090
5.25  7.5 0.00975
5.25  8.5 0.00255
5.25  9.5 0.00023
5.25 10.5 0.00004
5.75  5.5 0.00001
5.75  6.5 0.00006
5.75  7.5 0.00493
5.75  8.5 0.00342
5.75  9.5 0.00033
5.75 10.5 0.00002
6.25  6.5 0.00002
6.25  7.5 0.00176
6.25  8.5 0.00318
6.25  9.5 0.00037
6.25 10.5 0.00002
6.25 11.5 0.00001
6.75  6.5 0.00001
6.75  7.5 0.00056
6.75  8.5 0.00248
6.75  9.5 0.00059
6.75 10.5 0.00003
7.25  7.5 0.00006
7.25  8.5 0.00139
7.25  9.5 0.00057
7.25 10.5 0.00002
7.75  7.5 0.00002
7.75  8.5 0.00083
7.75  9.5 0.00067
7.75 10.5 0.00002
8.25  7.5 0.00002
8.25  8.5 0.00023
8.25  9.5 0.00048
8.25 10.5 0.00006
8.25 11.5 0.00001
8.75  8.5 0.00013
8.75  9.5 0.00032
8.75 10.5 0.00013
9.25  8.5 0.00003
9.25  9.5 0.00024
9.25 10.5 0.00013
9.25 11.5 0.00005
9.75  8.5 0.00001
```

```
    9.75  9.5 0.00007
    9.75 10.5 0.00009
    9.75 11.5 0.00005
   10.25  8.5 0.00001
   10.25  9.5 0.00002
   10.25 10.5 0.00006
   10.25 11.5 0.00004
   10.75  9.5 0.00002
   10.75 10.5 0.00004
   10.75 11.5 0.00002
   11.25 10.5 0.00002
   11.25 11.5 0.00001 )
%
%  Assign wave data
%------------------
ASSIGN WAVE-SPECTRUM-SHAPE SCATTER PIERSON-MOSKOWITZ ALL
ASSIGN WAVE-DIRECTION-PROBABILITY 165.0 0.3
ASSIGN WAVE-DIRECTION-PROBABILITY 180.0 0.7
ASSIGN WAVE-STATISTICS 165.0 SCATTER
ASSIGN WAVE-STATISTICS 180.0 SCATTER
%
% Fatigue points at element surface points
%
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-SURFACES
    CURRENT-SUPERELEMENT
%
% Calculate Weibeull parameters
%
DEFINE WEIBULL-PARAMETERS ON
%
% Select some elements in an interesting part of the model
%---------------------------------------------------------
SELECT SET ELEMENTS DEFAULT ONLY 1234
SELECT SET ELEMENTS DEFAULT INCLUDE 1235
SELECT SET ELEMENTS DEFAULT INCLUDE 1240
SELECT SET ELEMENTS DEFAULT INCLUDE 1241
SELECT SET ELEMENTS DEFAULT INCLUDE 1246
SELECT SET ELEMENTS DEFAULT INCLUDE 1247
SELECT SET ELEMENTS DEFAULT INCLUDE 1248
SELECT SET ELEMENTS DEFAULT INCLUDE 1249
SELECT SET ELEMENTS DEFAULT INCLUDE 1250
SELECT SET ELEMENTS DEFAULT INCLUDE 1251
SELECT SET ELEMENTS DEFAULT INCLUDE 964
SELECT SET ELEMENTS DEFAULT INCLUDE 969
SELECT SET ELEMENTS DEFAULT INCLUDE 970
SELECT SET ELEMENTS DEFAULT INCLUDE 975
SELECT SET ELEMENTS DEFAULT INCLUDE 976
SELECT SET ELEMENTS DEFAULT INCLUDE 981
SELECT SET ELEMENTS DEFAULT INCLUDE 982
SELECT SET ELEMENTS DEFAULT INCLUDE 989
SELECT SET ELEMENTS DEFAULT INCLUDE 1020
SELECT SET ELEMENTS DEFAULT INCLUDE 1023
SELECT SET ELEMENTS DEFAULT INCLUDE 1024
SELECT SET ELEMENTS DEFAULT INCLUDE 1025
SELECT SET ELEMENTS DEFAULT INCLUDE 1026
SELECT SET ELEMENTS DEFAULT INCLUDE 1027
SELECT SET ELEMENTS DEFAULT INCLUDE 1028
SELECT SET ELEMENTS DEFAULT INCLUDE 1029
SELECT SET ELEMENTS DEFAULT INCLUDE 1030
```

```
SELECT SET ELEMENTS DEFAULT INCLUDE 1031
SELECT SET ELEMENTS DEFAULT INCLUDE 1032
SELECT SET ELEMENTS DEFAULT INCLUDE 1033
SELECT SET ELEMENTS DEFAULT INCLUDE 1034
SELECT SET ELEMENTS DEFAULT INCLUDE 1036
SELECT SET ELEMENTS DEFAULT INCLUDE 1039
SELECT SET ELEMENTS DEFAULT INCLUDE 1033
SELECT SET ELEMENTS DEFAULT INCLUDE 1035
%
% Set print results to file
%-------------------------
SET PRINT DESTINATION FILE
SET PRINT SCREEN-HEIGHT 36
SET PRINT FILE ' ' STOFAT_A1
SET PRINT PAGE-ORIENTATION PORTRAIT
%
% Run the fatigue check on the selected elements
%----------------------------------------------
RUN FATIGUE-CHECK FT1 None ELEMENT-FATIGUE-CHECK ALL
%
% Print table in display window
%-----------------------------
PRINT FATIGUE-CHECK-RESULTS FT1 ELEMENT SELECTED-ELEMENTS FULL ABOVE 0.7
PRINT FATIGUE-CHECK-RESULTS FT1 ELEMENT WORST-USAGE-FACTOR SUMMARY ABOVE 0.2
```

## A.2 Floater Deck Structure

In present example the hull of an floater deck structure has been modelled by 232 four and three noded shell elements, see Figure A.3. The line commands for the Stofat fatigue check analysis are given below.

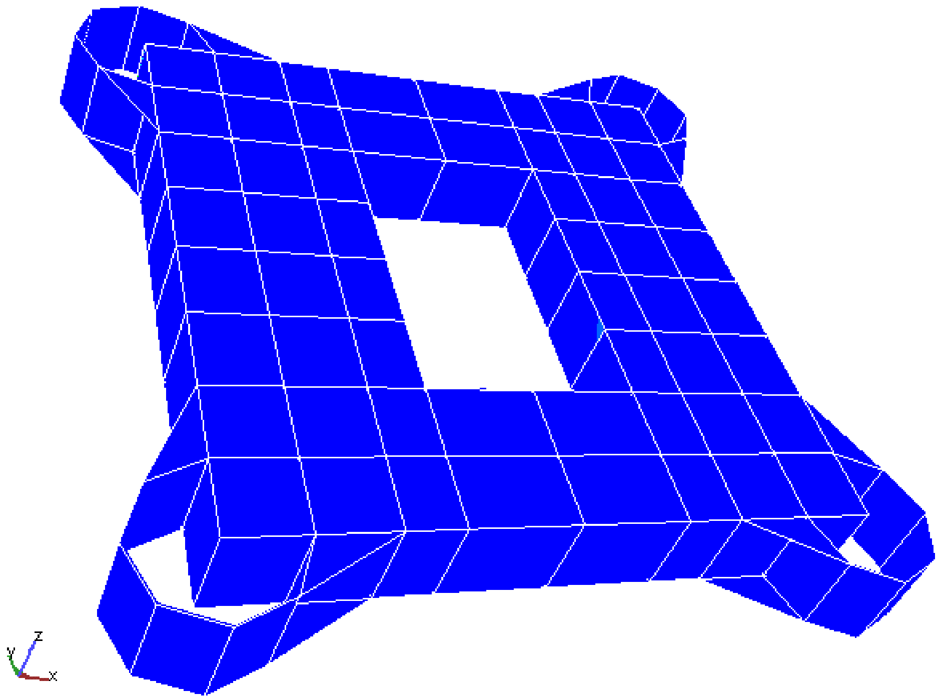


Figure A.3: Element model of floater deck structure

Line Commands:

```
%
% Open .SIN file and transfer superelement 2
```

```
%-------------------------------------------
FILE OPEN SIN-DIRECT-ACCESS x230f R121
FILE TRANSFER 2 DECK LOADS None
%
% Create: wave statistics, wave spreading function,
%        SN curves, Hotspot fatigue check points
%--------------------------------------------------
CREATE WAVE-STATISTICS SCATTER 'Scatter Diagram' SCATTER-DIAGRAM PROBABILITY (
       ONLY
        2.75  4.75 0.249
        7.75 17.75 0.086
       12.25 18.25 0.236
       14.25 20.25 0.206
       17.75 25.75 0.223 )
%
CREATE WAVE-SPREADING-FUNCTION COS2 Continous COSINE-POWER 2
%
CREATE SN-CURVE USE-X USER NONE 3.0 3.40 7.0
       ARBITRARY-TAIL 5.0 ARBITRARY-TAIL 8.301 7.0
CREATE SN-CURVE USE-Y USER NONE 3.0 3.40E6 7.0
       ARBITRARY-TAIL 5.0 HORISONTAL-TAIL 8.301
%
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT1 'Point inside element'
       COORDINATES 27.36  7.18 20.4975 39
       COORDINATES 27.36 14.36 20.503  35
       COORDINATES 27.40 20.0  20.4975  1 SKIP CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT2 'Point at top surface'
       COORDINATES 27.36  7.18 20.4975 42
       COORDINATES 27.36 14.36 20.503  39
       COORDINATES 27.36 20.91 20.4975  1
       ENTER COORDINATES 20.0  20.0  30.0 CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT3
       'Point defined by element coordinates'
       ELEMENT-COORDINATES ELEMENT 42 COORDINATES -1.0 -1.0 -0.5
       ELEMENT-COORDINATES ELEMENT 39 COORDINATES -1.0 -1.0  0.6
       ELEMENT-COORDINATES ELEMENT 1  COORDINATES  1.0  0.0  0.5
       ENTER COORDINATES 20.0 20.0 30.0 CURRENT-SUPERELEMENT
%
% Assign wave data
%-----------------
ASSIGN WAVE-SPREADING-FUNCTION SCATTER COS2 ALL
ASSIGN WAVE-SPECTRUM-SHAPE SCATTER PIERSON-MOSKOWITZ ALL
ASSIGN WAVE-DIRECTION-PROBABILITY 0.0 0.1
ASSIGN WAVE-DIRECTION-PROBABILITY 45.0 0.6
ASSIGN WAVE-DIRECTION-PROBABILITY 90.0 0.2
ASSIGN WAVE-DIRECTION-PROBABILITY 135.0 0.1
ASSIGN WAVE-STATISTICS 0.0 SCATTER
ASSIGN WAVE-STATISTICS 45.0 SCATTER
ASSIGN WAVE-STATISTICS 90.0 SCATTER
ASSIGN WAVE-STATISTICS 135.0 SCATTER
%
% Display SN curves
%------------------
DISPLAY SN-CURVE ( ONLY DNV-X USE-X )
DISPLAY SN-CURVE ( ONLY DNV-X USE-X USE-Y )
%
% Set print parameters
%---------------------
SET PRINT DESTINATION FILE
```

```
SET PRINT SCREEN-HEIGHT 41
SET PRINT FILE ' ' STOFAT_A2
SET PRINT PAGE-ORIENTATION LANDSCAPE
%
% Peform hotspot fatigue check
%----------------------------
RUN FATIGUE-CHECK RUN1 None HOTSPOT-FATIGUE-CHECK ALL
%
% Print hotspot results
% --------------------
PRINT FATIGUE-CHECK-RESULTS RUN1 HOTSPOT HOTSPOTS WORST-USAGE-FACTOR FULL
    ABOVE 0.0
```

## A.3 Stiffener Connection of a Ship Hull

A connection of transverse web frame and longitudinal stiffener in a ship hull is shown in Figure A.4. The model consists of two first level superelements, of which one superelement has been investigated for fatigue damage. The model consists of 666 20-node and 15-node solid elements. Contour plots of element fatigue usage factors in the fatigue critical area are displayed in Figure A.5. Figure A.6 shows hotspot usage factors in the same area. Line commands for the Stofat analysis are given below.

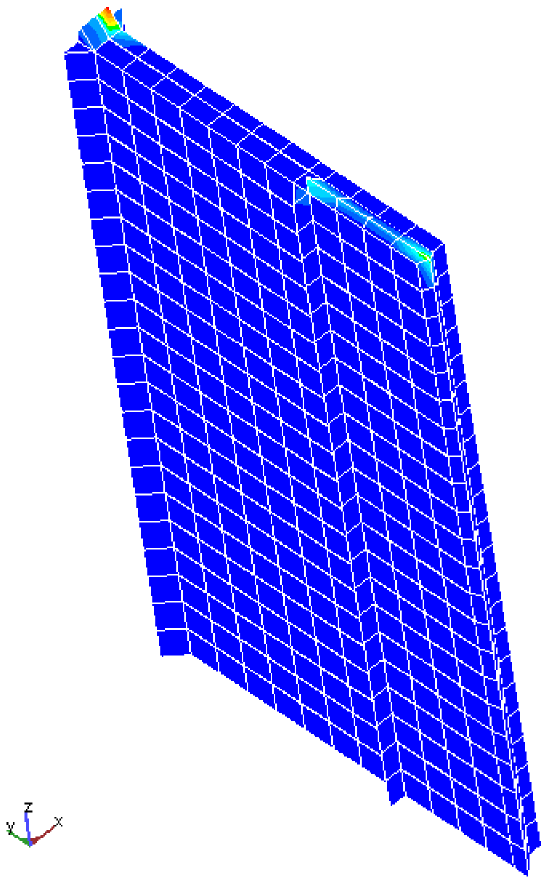


Figure A.4: Superelement model of stiffener connection

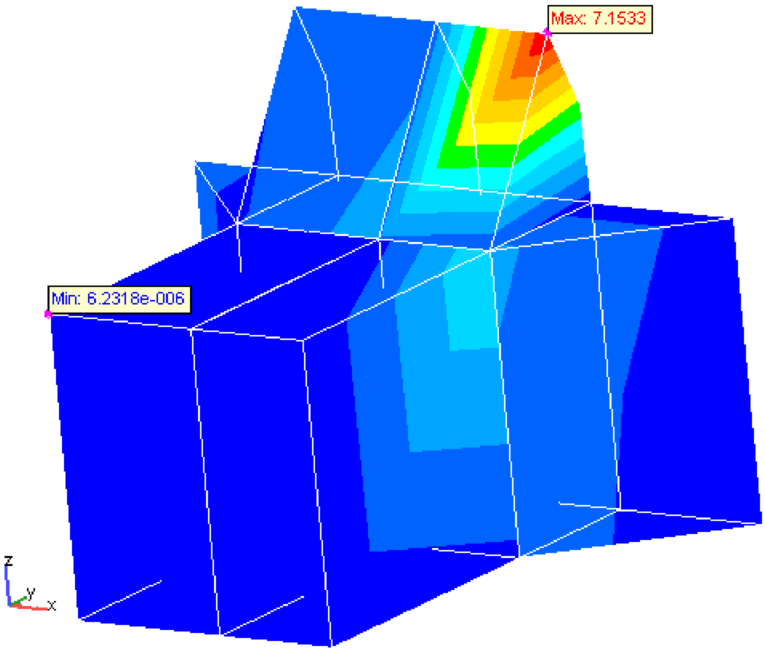


Figure A.5: Contour plot of elementt usage factors in Fatigue critical area

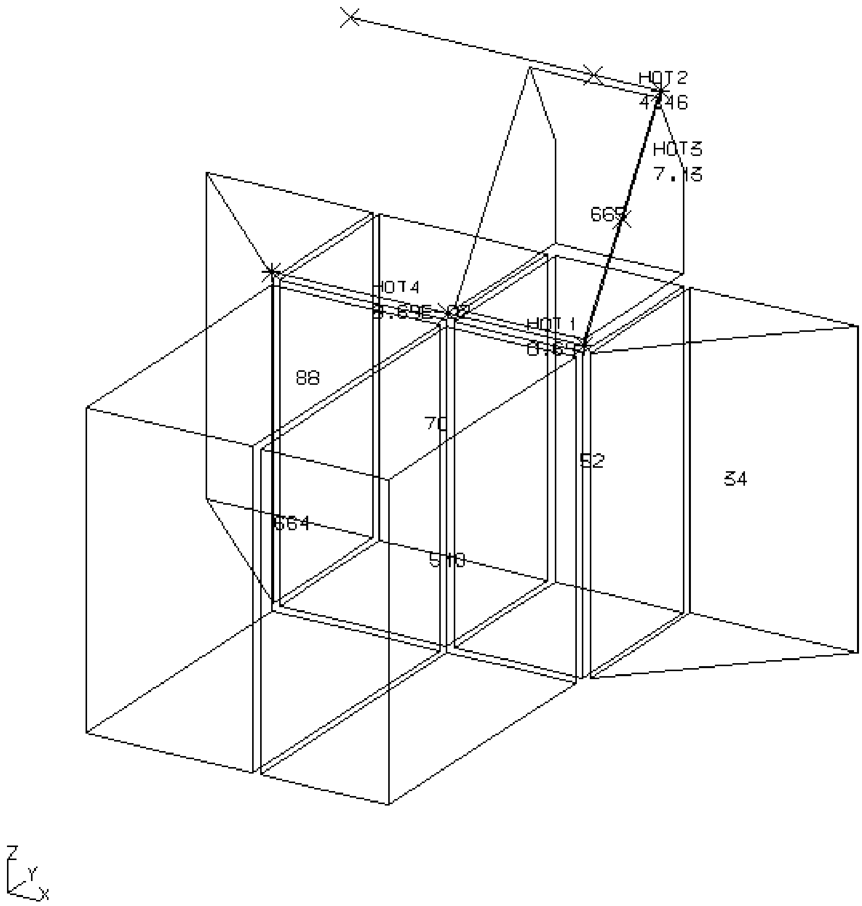


Figure A.6: Hotspot usage factors in fatigue critical area

Line Commands:

```
%
%-------------------------------------------
% Open .SIN file and transfer superelement 2
%-------------------------------------------
FILE OPEN SIN-DIRECT-ACCESS ' ' R211
FILE TRANSFER 2 22 LOADS None
%
% Define SN-default curve and target fatigue life
%------------------------------------------------
DEFINE SHELL-FATIGUE-CONSTANTS DEFAULT-SN-CURVE NS-F2-SE
DEFINE SHELL-FATIGUE-CONSTANTS TARGET-FATIGUE-LIFE 10.0
DEFINE SHELL-FATIGUE-CONSTANTS WELD-STRESS-CONCENTRATION 1.0
%
%---------------------
% Create wave-spectrum
%----------------------
CREATE WAVE-STATISTICS BMT 'GLAS DOWR' SCATTER-DIAGRAM PROBABILITY
    ( INCLUDE
%   HS  TZ   PROB.
    0.5    2.5 0.00126
    0.5    3.5 0.00517
    0.5    4.5 0.00383
    0.5    5.5 0.00190
    0.5    6.5 0.00084
    0.5    7.5 0.00043
    0.5    8.5 0.00019
    0.5    9.5 0.00013
    0.5   10.5 0.00010
    0.75   2.5 0.00298
    0.75   3.5 0.05385
    0.75   4.5 0.05369
    0.75   5.5 0.01825
    0.75   6.5 0.00581
    0.75   7.5 0.00220
    0.75   8.5 0.00075
    0.75   9.5 0.00023
    0.75  10.5 0.00008
    0.75  11.5 0.00001
    0.75  12.5 0.00001
    1.25   2.5 0.00011
    1.25   3.5 0.02795
    1.25   4.5 0.10198
    1.25   5.5 0.04466
    1.25   6.5 0.01290
    1.25   7.5 0.00279
    1.25   8.5 0.00063
    1.25   9.5 0.00030
    1.25  10.5 0.00006
    1.25  11.5 0.00002
    1.25  12.5 0.00001
    1.75   3.5 0.00250
    1.75   4.5 0.07835
    1.75   5.5 0.06895
    1.75   6.5 0.01693
    1.75   7.5 0.00354
    1.75   8.5 0.00063
    1.75   9.5 0.00017
    1.75  10.5 0.00005
    1.75  11.5 0.00000
```

```
1.75  12.5 0.00001
2.25   3.5 0.00006
2.25   4.5 0.02199
2.25   5.5 0.09021
2.25   6.5 0.02647
2.25   7.5 0.00608
2.25   8.5 0.00102
2.25   9.5 0.00022
2.25  10.5 0.00007
2.75   3.5 0.00002
2.75   4.5 0.00185
2.75   5.5 0.06327
2.75   6.5 0.03641
2.75   7.5 0.00715
2.75   8.5 0.00146
2.75   9.5 0.00026
2.75  10.5 0.00001
3.25   4.5 0.00011
3.25   5.5 0.02244
3.25   6.5 0.04447
3.25   7.5 0.00809
3.25   8.5 0.00163
3.25   9.5 0.00033
3.25  10.5 0.00006
3.75   4.5 0.00002
3.75   5.5 0.00323
3.75   6.5 0.03882
3.75   7.5 0.01088
3.75   8.5 0.00175
3.75   9.5 0.00028
3.75  10.5 0.00007
4.25   4.5 0.00002
4.25   5.5 0.00021
4.25   6.5 0.02008
4.25   .5 0.01496
4.25   8.5 0.00188
4.25   9.5 0.00028
4.25  10.5 0.00002
4.75   5.5 0.00002
4.75   6.5 0.00540
4.75   7.5 0.01496
4.75   8.5 0.00193
4.75   9.5 0.00015
5.25   5.5 0.00002
5.25   6.5 0.00090
5.25   7.5 0.00975
5.25   8.5 0.00255
5.25   9.5 0.00023
5.25  10.5 0.00004
5.75   5.5 0.00001
5.75   6.5 0.00006
5.75   7.5 0.00493
5.75   8.5 0.00342
5.75   9.5 0.00033
5.75  10.5 0.00002
6.25   6.5 0.00002
6.25  7.5 0.00176
6.25   8.5 0.00318
6.25   9.5 0.00037
```

```
    6.25  10.5 0.00002
    6.25   11.5 0.00001
    6.75   6.5 0.00001
    6.75   7.5 0.00056
    6.75   8.5 0.00248
    6.75   9.5 0.00059
    6.75  10.5 0.00003
    7.25   7.5 0.00006
    7.25   8.5 0.00139
    7.25   9.5 0.00057
    7.25  10.5 0.00002
    7.75   7.5 0.00002
    7.75   8.5 0.00083
    7.75   9.5 0.00067
    7.75  10.5 0.00002
    8.25   7.5 0.00002
    8.25   8.5 0.00023
    8.25   9.5 0.00048
    8.25  10.5 0.00006
    8.25  11.5 0.00001
    8.75   8.5 0.00013
    8.75   9.5 0.00032
    8.75  10.5 0.00013
    9.25   8.5 0.00003
    9.25   9.5 0.00024
    9.25  10.5 0.00013
    9.25  11.5 0.00005
    9.75   8.5 0.00001
    9.75   9.5 0.00007
    9.75  10.5 0.00009
    9.75  11.5 0.00005
   10.25   8.5 0.00001
   10.25   9.5 0.00002
   10.25  10.5 0.00006
   10.25  11.5 0.00004
   10.75   9.5 0.00002
   10.75  10.5 0.00004
   10.75  11.5 0.00002
   11.25  10.5 0.00002
   11.25  11.5 0.00001 )
%
% Assign wave data
%-----------------
ASSIGN WAVE-SPECTRUM-SHAPE BMT PIERSON-MOSKOWITZ ALL
ASSIGN WAVE-DIRECTION-PROBABILITY 180.0 1.0
ASSIGN WAVE-STATISTICS 180.0 BMT
%
% Calculate Weibull parameters
% ---------------------------
%
DEFINE WEIBULL-PARAMETERS ON
%
% Select elements for element fatigue check
%-----------------------------------------
SELECT SET ELEMENTS DEFAULT INCLUDE 34
SELECT SET ELEMENTS DEFAULT INCLUDE 52
SELECT SET ELEMENTS DEFAULT INCLUDE 70
SELECT SET ELEMENTS DEFAULT INCLUDE 88
SELECT SET ELEMENTS DEFAULT INCLUDE 510
```

```
SELECT SET ELEMENTS DEFAULT INCLUDE 664
SELECT SET ELEMENTS DEFAULT INCLUDE 665
SELECT SET ELEMENTS DEFAULT INCLUDE 666
%
% Create hotspots
%----------------
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT1 'Hotspot 1'
   COORDINATES 1.8937500  -0.01407100  0.2900000 510
   COORDINATES 1.8883210  -0.01407100  0.2900000 510
   COORDINATES 1.8812500  -0.01407100  0.2900000 664
   SKIP  CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT2 'Hotspot 2'
   NODE 3813 665 NODE 3818 665 NODE 3820 666
   SKIP  CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT3 'Hotspot 3'
   NODE 3813  665 NODE 3812  665
   COORDINATES 1.8937500  -0.01407100  0.2900000 510
   SKIP  CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT4 'Hotspot 4'
   COORDINATES 1.8812500  -0.01407100  0.2900000 664
   COORDINATES 1.8883210  -0.01407100  0.2900000 510
   COORDINATES 1.8937500  -0.01407100  0.2900000 510
   SKIP  CURRENT-SUPERELEMENT
CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK INCLUDE HOT6 'Hotspot 6'
   ELEMENT-COORDINATES ELEMENT 666 COORDINATES 0.0 0.0 -0.5051258
   ELEMENT-COORDINATES ELEMENT 666 COORDINATES 0.5 0.0 -0.5051258
   ELEMENT-COORDINATES ELEMENT 664 COORDINATES 1.0 1.0 -0.5051258
   SKIP  CURRENT-SUPERELEMENT
%
% Run hotspot fatigue check
%--------------------------
RUN FATIGUE-CHECK RUN1 None HOTSPOT-FATIGUE-CHECK ALL
%
% Set print options and print hotspot fatigue results to file
%-------------------------------------------------------------
SET PRINT DESTINATION FILE
SET PRINT SCREEN-HEIGHT 64
SET PRINT FILE ' ' STOFAT_A3Hot
SET PRINT PAGE-ORIENTATION PORTRAIT
PRINT FATIGUE-CHECK-RESULTS RUN1 HOTSPOT HOTSPOTS WORST-USAGE-FACTOR
      FULL ABOVE 0.8
PRINT FATIGUE-CHECK-RESULTS RUN1 HOTSPOT HOTSPOTS-AND-INTERPOLATION-POINTS
      SELECTED-HOTSPOTS SUMMARY ABOVE 0.0
%
% Perform element fatigue check at element corner points
%-------------------------------------------------------
CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK ELEMENT-CORNERS CURRENT-SUPERELEMENT
%
% Open for print of results to VTF file
% ------------------------------------
%
DEFINE FATIGUE-RESULTS-VTF-FILE YES STOFAT_A3 ELEMENT-FATIGUE-POINT-RESULTS
    ACCUMULATED-DAMAGE USAGE-FACTOR
%
% Run element fatigue check
% ------------------------
%
RUN FATIGUE-CHECK RUN2 None ELEMENT-FATIGUE-CHECK ALL
%
```

```
% Display superelement and fatigue check results
%-----------------------------------------------
DISPLAY SUPERELEMENT
DISPLAY FATIGUE-CHECK-RESULTS RUN2 MAX-USAGE-FACTOR ABOVE 0.8
%
% Set print options and print element fatigue results to file
%------------------------------------------------------------
SET PRINT SCREEN-HEIGHT 64
SET PRINT FILE ' ' STOFAT_A3Ele
SET PRINT PAGE-ORIENTATION PORTRAIT
PRINT FATIGUE-CHECK-RESULTS RUN2 ELEMENT WORST-USAGE-FACTOR FULL ABOVE 0.0
```

## A.4 Tabulated Prints of Fatigue Check Results

Examples of tabulated print results are presented in this section. Print of results are created by the command PRINT FATIGUE-CHECK-RESULTS. The user may select between several print options which are shown in the next sections:

- *Hotspots and element* fatigue check results. The run assigned must be compatible with the fatigue check type to be printed.
- *Full* and *summary* tabulated print. The summary option prints one line of information per fatigue point.
- Order of print according to *worst usage factor* and *selected hotspots/elements*. Selected elements are printed in the order of the element numbers. Selected hotspots are printed in the order as they are created. *Sorting* of hotspot results may be performed among *hotspots* or among *hotspots and interpolation points*.
- Printing range *above* a minimum value, below a maximum value or *between* two values
- *Landscape* and *portrait* tabulated print.

### A.4.1 Hotspot Fatigue Check Results

Hotspot fatigue check results of the example described in Section A.3 are printed in the present section.

#### A.4.1.1 Full Print Portrait Format

Options used:

- Print of hotspot fatigue check results.
- Results printed in order of worst usage factor. Sorting performed among hotspots.
- Hotspots with usage factors above 0.8 are printed.
- Full print.
- Portrait format.

```
  ******      ******       ******       ******      ** ***  ****
 ********    ********     ********     ********     *************
**      **  **      **   **      **   **      **    **    **    **
**          **      **   **                   **    **    **    **
 *******    **********    *******      *********    **    **    **
  *******   *********      *******    **********    **    **    **
        **  **                   **   **      **    **    **    **
**      **  **      **   **      **   **      **    **    **    **
 ********    ********     ********     *********    **    **    **
  ******      ******       ******       ****** **   **    **    **
```

```
               ***********************************************
               *                                             *
               *                S T O F A T                  *
               *                                             *
               *    Postprocessor for stochastic fatigue     *
               *                                             *
               ***********************************************


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 Program id   : 3.5-07                  Computer         : 586
 Release date : 24-FEB-2016             Impl. update     :
 Access time  : 20-APR-2016 13:13:50    Operating system : Win NT 6.1 [7601]
 User id      : aarn                    CPU id           : 1337246785
                                        Installation     : , OSLLP110507


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20-APR-2016 13:13 PROGRAM: SESAM    STOFAT    3.5-07  24-FEB-2016  PAGE:     1


                  STOCHASTIC     HOTSPOT fatigue check results
                  Run: RUN1      Superelement 22
                  Priority.....: Worst Usage Factor. Hotspots
                  Usage factor : Above  0.80
                  Design Fatigue Life: 10.0   Years            SUB PAGE:     1


NOMENCLATURE:

HotName          Name of hotspot
FatPnt           Fatigue Point: Hotspot, interpolation points (HotS, t/2, 3t/2
Stat             = PASS or FAIL: *FAIL = UsageFactor >   1.0
UsageFac         Accumulated damage (Usage factor)
Element          Name of element
AccFatLif        Design fatigue life/usage factor (year)
 StrCycle        Total number of stress cycles
 SNCurve         SN curve name.
atNode           Input node defining the point
EleType          Element type
 X-coord.        X coordinate of fatigue check point
 Y-coord.        Y coordinate of fatigue check point
Z-coordinate     Z coordinate of fatigue check point
atSide           Element side (see manual).
AxialScf         Resulting Axial stress K-factor (SCF factor)
 BendScf         Resulting Bending stress K-factor (SCF factor)
 ShearScf        Resulting Shear stress K-factor (SCF factor)
 ElThick         Thickness of element
 RefSyst         Coordinate reference system
```

```
DistanceToHot    Distance of interpolation point to hotspot.
 WeiScale        Scale parameter of Weibull distribution
 WeiShape        Shape parameter of Weibull distribution
StressRange      Maximum Stress Range of principal stress

Hotspot name                 : HOT3
Description of hotspot       : Hotspot 3
Coordinate reference system  : Current superelement
Hotspot name                 : HOT2
Description of hotspot       : Hotspot 2
Coordinate reference system  : Current superelement
Hotspot name                 : HOT6
Description of hotspot       : Hotspot 6
Coordinate reference system  : Current superelement
Hotspot name                 : HOT1
Description of hotspot       : Hotspot 1
Coordinate reference system  : Current superelement
Hotspot name                 : HOT4
Description of hotspot       : Hotspot 4
Coordinate reference system  : Current superelement

Status on failure            : *FAIL* when UsageFactor > 1.0
Design fatigue life          : 10.0 years


20-APR-2016 13:13 PROGRAM: SESAM    STOFAT    3.5-07  24-FEB-2016  PAGE:     2


                  STOCHASTIC     HOTSPOT fatigue check results
                  Run: RUN1      Superelement 22
                  Priority.....: Worst Usage Factor. Hotspots
                  Usage factor : Above  0.80
                  Design Fatigue Life: 10.0   Years            SUB PAGE:     2

HotName  FatPnt  Stat  UsageFac Element  AccFatLif  StrCycle  SNCurve
         atNode                 EleType   X-coord.  Y-coord.   Z-coordinate
                                atSide   AxialScf   BendScf   ShearScf
                                          ElThick   RefSyst   DistanceToHot
                                          WeiScale  WeiShape   StressRange
------------------------------------------------------------------------------
HOT3     HotS    *FAIL 9.79E+00 665       1.02E+00  5.13E+07  NS-F2-SE
         3813                   IPRI30    1.89E+00 -8.86E-03       2.9762E-01
                                          1.0       1.0       1.0
                                                    CurrSupE       0.0000E+00
                                          2.38E+07  1.00E+00       3.6366E+08
HOT3     t1/2    *FAIL 3.22E+00 665       3.10E+00  5.13E+07  NS-F2-SE
         3812                   IPRI30    1.89E+00 -1.15E-02       2.9381E-01
                                          1.0       1.0       1.0
                                                    CurrSupE       4.6170E-03
                                          1.65E+07  1.01E+00       2.5165E+08
HOT3     t3/2    *FAIL 3.30E+00 510       3.03E+00  5.13E+07  NS-F2-SE
                                IHEX20    1.89E+00 -1.41E-02       2.9000E-01
                                          1.0       1.0       1.0
                                                    CurrSupE       9.2340E-03
                                          1.66E+07  1.00E+00       2.5356E+08

HOT2     HotS    *FAIL 4.68E+00 665       2.13E+00  5.13E+07  NS-F2-SE
         3813                   IPRI30    1.89E+00 -8.86E-03       2.9762E-01
                                          1.0       1.0       1.0
```

```
                                                CurrSupE       0.0000E+00
                                      1.87E+07  1.00E+00       2.8475E+08
HOT2     t1/2    *FAIL 3.23E+00 665   3.10E+00  5.13E+07  NS-F2-SE
         3818                   IPRI30 1.89E+00 -8.86E-03      2.9762E-01
                                      1.0       1.0       1.0
                                                CurrSupE       2.7144E-03
                                      1.65E+07  1.01E+00       2.5191E+08
HOT2     t3/2     PASS 6.15E-01 666   1.63E+01  5.13E+07  NS-F2-SE
         3820                   IPRI30 1.88E+00 -8.86E-03      2.9762E-01
                                      1.0       1.0       1.0
                                                CurrSupE       1.2500E-02
                                      9.65E+06  1.01E+00       1.4726E+08

HOT6     HotS    *FAIL 1.67E+00 666   6.00E+00  5.13E+07  NS-F2-SE
                                IPRI30 1.88E+00 -8.86E-03      2.9762E-01
                                      1.0       1.0       1.0
                                                CurrSupE       0.0000E+00
                                      1.33E+07  1.00E+00       2.0292E+08
HOT6     t1/2     PASS 4.82E-01 666   2.08E+01  5.13E+07  NS-F2-SE
                                IPRI30 1.88E+00 -1.15E-02      2.9381E-01
                                      1.0       1.0       1.0
                                                CurrSupE       4.6170E-03
                                      8.94E+06  1.00E+00       1.3645E+08


                  STOCHASTIC     HOTSPOT fatigue check results
                  Run: RUN1      Superelement 22
                  Priority.....: Worst Usage Factor. Hotspots
                  Usage factor : Above  0.80
                  Design Fatigue Life: 10.0   Years            SUB PAGE:     3

HotName  FatPnt  Stat  UsageFac Element  AccFatLif  StrCycle  SNCurve
         atNode                 EleType   X-coord.  Y-coord.   Z-coordinate
                                atSide   AxialScf   BendScf   ShearScf
                                          ElThick   RefSyst   DistanceToHot
                                          WeiScale  WeiShape   StressRange
------------------------------------------------------------------------------
HOT6     t3/2     PASS 4.59E-01 664   2.18E+01  5.13E+07  NS-F2-SE
                                IHEX20 1.88E+00 -1.41E-02      2.9000E-01
                                      1.0       1.0       1.0
                                                CurrSupE       9.2340E-03
                                      8.81E+06  1.00E+00       1.3439E+08

HOT1     HotS    *FAIL 1.19E+00 510   8.41E+00  5.14E+07  NS-F2-SE
                                IHEX20 1.89E+00 -1.41E-02      2.9000E-01
                                      1.0       1.0       1.0
                                                CurrSupE       0.0000E+00
                                      1.19E+07  1.01E+00       1.8163E+08
HOT1     t1/2     PASS 7.51E-01 510   1.33E+01  5.13E+07  NS-F2-SE
                                IHEX20 1.89E+00 -1.41E-02      2.9000E-01
                                      1.0       1.0       1.0
                                                CurrSupE       5.4290E-03
                                      1.03E+07  1.01E+00       1.5679E+08
HOT1     t3/2     PASS 4.13E-01 664   2.42E+01  5.12E+07  NS-F2-SE
                                IHEX20 1.88E+00 -1.41E-02      2.9000E-01
                                      1.0       1.0       1.0
                                                CurrSupE       1.2500E-02
                                      8.52E+06  1.00E+00       1.3011E+08
Number of hotspots printed          : 4
```

```
Number of hotspots failed           : 4
Number of interpolation points failed: 3
********************************************************************************
```

#### A.4.1.2 Summary Print Portrait Format

Options used:

- Print of hotspot fatigue check results.
- Results printed in order of selected hotspots.
- Hotspots with usage factors above 0.0 are printed.
- Summary print.
- Portrait format.

```
                  STOCHASTIC     HOTSPOT fatigue check results
                  Run: RUN1      Superelement 22
                  Priority.....: Selected Hotspots
                  Usage factor : Above  0.00
                  Design Fatigue Life: 10.0   Years            SUB PAGE:     1



NOMENCLATURE:

HotName      Name of hotspot
FatPnt       Fatigue Point: Hotspot, interpolation points (HotS, t/2, 3t/2)
Stat         = PASS or FAIL: *FAIL = UsageFactor >   1.0
UsageFac     Accumulated damage (Usage factor)
Element      Name of element
AccFatLif    Design fatigue life/usage factor (year)
 StrCycle    Total number of stress cycles
 SNCurve     SN curve name.

Hotspot name                  : HOT1
Description of hotspot        : Hotspot 1
Coordinate reference system   : Current superelement
Hotspot name                  : HOT2
Description of hotspot        : Hotspot 2
Coordinate reference system   : Current superelement
Hotspot name                  : HOT3
Description of hotspot        : Hotspot 3
Coordinate reference system   : Current superelement
Hotspot name                  : HOT4
Description of hotspot        : Hotspot 4
Coordinate reference system   : Current superelement
Hotspot name                  : HOT6
Description of hotspot        : Hotspot 6
Coordinate reference system   : Current superelement

Status on failure             : *FAIL* when UsageFactor > 1.0
Design fatigue life           : 10.0 years



                  STOCHASTIC     HOTSPOT fatigue check results
                  Run: RUN1      Superelement 22
                  Priority.....: Selected Hotspots
                  Usage factor : Above  0.00
```

```
                   Design Fatigue Life: 10.0   Years           SUB PAGE:     2

HotName  FatPnt  Stat  UsageFac Element  AccFatLif  StrCycle  SNCurve
------------------------------------------------------------------------------
HOT1     HotS    *FAIL 1.19E+00 510       8.41E+00  5.14E+07  NS-F2-SE
HOT1     t1/2     PASS 7.51E-01 510       1.33E+01  5.13E+07  NS-F2-SE
HOT1     t3/2     PASS 4.13E-01 664       2.42E+01  5.12E+07  NS-F2-SE

HOT2     HotS    *FAIL 4.68E+00 665       2.13E+00  5.13E+07  NS-F2-SE
HOT2     t1/2    *FAIL 3.23E+00 665       3.10E+00  5.13E+07  NS-F2-SE
HOT2     t3/2     PASS 6.15E-01 666       1.63E+01  5.13E+07  NS-F2-SE

HOT3     HotS    *FAIL 9.79E+00 665       1.02E+00  5.13E+07  NS-F2-SE
HOT3     t1/2    *FAIL 3.22E+00 665       3.10E+00  5.13E+07  NS-F2-SE
HOT3     t3/2    *FAIL 3.30E+00 510       3.03E+00  5.13E+07  NS-F2-SE

HOT4     HotS     PASS 6.58E-02 664       1.52E+02  5.12E+07  NS-F2-SE
HOT4     t1/2     PASS 7.51E-01 510       1.33E+01  5.13E+07  NS-F2-SE
HOT4     t3/2    *FAIL 3.30E+00 510       3.03E+00  5.13E+07  NS-F2-SE

HOT6     HotS    *FAIL 1.67E+00 666       6.00E+00  5.13E+07  NS-F2-SE
HOT6     t1/2     PASS 4.82E-01 666       2.08E+01  5.13E+07  NS-F2-SE
HOT6     t3/2     PASS 4.59E-01 664       2.18E+01  5.13E+07  NS-F2-SE
Number of hotspots printed          : 5
Number of hotspots failed           : 4
Number of interpolation points failed: 4
*******************************************************************************
```

### A.4.2 Element Fatigue Check Results

Element fatigue check results of the example described in A.1 are printed in this section.

#### A.4.2.1 Full Print of Results for Element Surface Points

Options used:

- Element fatigue check at element surface points.
- Results printed in order of selected elements.
- Elements with usage factors above 0.7 are printed.
- Full print.
- Portrait format.

```
  ******      ******       ******       ******      ** ***  ****
 ********    ********     ********     ********    *************
**      **  **      **   **      **   **      **    **    **    **
**          **      **   **                   **    **    **    **
 *******    **********    *******      *********    **    **    **
  *******   *********      *******    **********    **    **    **
        **  **                   **   **      **    **    **    **
**      **  **      **   **      **   **      **    **    **    **
 ********    ********     ********     *********    **    **    **
  ******      ******       ******       ****** **   **    **    **
```

```
                ***********************************************
                *                                             *
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                *                                             *
                *    Postprocessor for stochastic fatigue     *
                *                                             *
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                     Marketing and Support by DNV GL - Software


  Program id   : 3.5-07                     Computer          : 586
  Release date : 24-FEB-2016                Impl. update      :
  Access time  : 20-APR-2016 12:41:05       Operating system : Win NT 6.1 [7601]
  User id      : aarn                       CPU id            : 1337246785
                                            Installation      : , OSLLP110507


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                  STOCHASTIC     ELEMENT fatigue check results
                  Run: FT1       Superelement BRACKET
                  Priority.....: Selected Elements
                  Usage factor : Above  0.70
                  Design Fatigue Life: 20.0   Years            SUB PAGE:     1


 NOMENCLATURE:

 Element        Name of element
 Stat           = PASS or FAIL: *FAIL = UsageFactor >   1.0
 UsageFact      Accumulated damage (Usage factor)
 ChkPnt         Fatigue check point number of element
 ChkPlc         Stress/surface/corner/mid-plane/membrane or centre points
  AccFatLif     Design fatigue life/usage factor (year)
  StrsCycle     Total number of stress cycles
  SNCurve       SN curve name.
 atSide         -z side or +z side of shell element
 ElType         Element type
  X-coord.      X coordinate of fatigue check point
  Y-coord.      Y coordinate of fatigue check point
 Z-coord.       Z coordinate of fatigue check point
 ElThck         Element thickness
  AxialScf      Resulting Axial stress K-factor (SCF factor)
  BendScf       Resulting Bending stress K-factor (SCF factor)
  ShearScf      Resulting Shear stress K-factor (SCF factor)
  WeibScale     Scale parameter of Weibull distribution
  WeibShape     Shape parameter of Weibull distribution
 StressRange    Maximum Stress Range of principal stress

 Coordinate reference system    : Current superelement
 Status on failure              : *FAIL when UsageFactor > 1.0
 Design fatigue life            : 20.0 years
```

```
Fatigue calculation based on   : Spectral moments of maximum principal stresses
Wave spectrum                  : Pierson Moskowitz




                  STOCHASTIC     ELEMENT fatigue check results
                  Run: FT1       Superelement BRACKET
                  Priority.....: Selected Elements
                  Usage factor : Above  0.70
                  Design Fatigue Life: 20.0   Years            SUB PAGE:     2

Element Stat  UsageFact ChkPnt  ChkPlc  AccFatLif  StrsCycle  SNCurve
                        atSide  ElType  X-coord.   Y-coord.   Z-coord.
                                ElThck  AxialScf   BendScf    ShearScf
                                        WeibScale  WeibShape StressRange
------------------------------------------------------------------------------
964     *FAIL 1.012E+00 4 (-z)  SurfPt  1.977E+01  9.450E+07  DNVC-I
                        -zSide  SCQS28 -2.160E+01 -2.062E+01  1.0275E+01
                                .01     1.5        1.5        1.5
                                        2.189E+07  9.911E-01  3.6272E+08
969      PASS 9.605E-01 7 (+z)  SurfPt  2.082E+01  9.498E+07  DNVC-I
                        +zSide  SCQS28 -2.151E+01 -2.062E+01  1.0285E+01
                                .01     1.5        1.5        1.5
                                        2.164E+07  9.934E-01  3.5607E+08
982      PASS 7.292E-01 4 (-z)  SurfPt  2.743E+01  9.671E+07  DNVC-I
                        -zSide  SCQS28 -2.077E+01 -2.062E+01  1.0275E+01
                                .01     1.5        1.5        1.5
                                        1.986E+07  9.906E-01  3.2960E+08
989      PASS 8.898E-01 3 (-z)  SurfPt  2.248E+01  9.516E+07  DNVC-I
                        -zSide  SCQS28 -2.069E+01 -2.062E+01  1.0275E+01
                                .01     1.5        1.5        1.5
                                        2.107E+07  9.899E-01  3.5016E+08
1024     PASS 7.626E-01 3 (-z)  SurfPt  2.623E+01  9.387E+07  DNVC-I
                        -zSide  SCQS28 -2.151E+01 -2.058E+01  1.0264E+01
                                .016    1.5        1.5        1.5
                                        2.024E+07  9.890E-01  3.3707E+08
1026     PASS 7.456E-01 1 (-z)  SurfPt  2.682E+01  9.350E+07  DNVC-I
                        -zSide  SCQS28 -2.151E+01 -2.058E+01  1.0296E+01
                                .016    1.5        1.5        1.5
                                        2.017E+07  9.894E-01  3.3524E+08
1248    *FAIL 2.533E+00 4 (-z)  SurfPt  7.895E+00  9.601E+07  DNVC-I
                        -zSide  SCQS28 -2.080E+01 -2.056E+01  1.0274E+01
                                .012    1.5        1.5        1.5
                                        2.848E+07  9.918E-01  4.7079E+08
1249    *FAIL 3.685E+00 5 (+z)  SurfPt  5.427E+00  9.482E+07  DNVC-I
                        +zSide  SCQS28 -2.148E+01 -2.056E+01  1.0286E+01
                                .012    1.5        1.5        1.5
                                        3.211E+07  9.930E-01  5.2812E+08
1251     PASS 7.005E-01 1 (-z)  SurfPt  2.855E+01  9.568E+07  DNVC-I
                        -zSide  SCQS28 -2.133E+01 -2.050E+01  1.0274E+01
                                .012    1.5        1.5        1.5
                                        1.984E+07  9.949E-01  3.2486E+08
Number of elements printed : 9
Number of elements failed  : 3
******************************************************************************
```

### A.4.2.2 Summary Print of Results for Element Corner Points

Options used:

- Element fatigue check at element corner points.
- Results printed in order of worst usage factor.
- Elements with usage factors above 0.2 are printed.
- Summary print.
- Portrait format.

```
   ******      ******      ******      ******      ** ***  ****
  ********    ********    ********    ********    ************
 **      **  **      **  **      **  **      **   **    **    **
 **          **      **  **                  **   **    **    **
  *******    **********   *******     *********   **    **    **
   *******   *********     *******   **********   **    **    **
         **  **                  **  **      **   **    **    **
 **      **  **      **  **      **  **      **   **    **    **
  ********    ********    ********    *********   **    **    **
   ******      ******      ******      ****** **  **    **    **



               ***********************************************
               *                                             *
               *                 S T O F A T                 *
               *                                             *
               *    Postprocessor for stochastic fatigue     *
               *                                             *
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                    Marketing and Support by DNV GL - Software


  Program id   : 3.5-07                   Computer         : 586
  Release date : 24-FEB-2016              Impl. update     :
  Access time  : 20-APR-2016 12:41:05     Operating system : Win NT 6.1 [7601]
  User id      : aarn                     CPU id           : 1337246785
                                          Installation     : , OSLLP110507


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                  STOCHASTIC     ELEMENT fatigue check results
                  Run: FT1       Superelement BRACKET
                  Priority.....: Worst Usage Factor
                  Usage factor : Above  0.20
                  Design Fatigue Life: 20.0   Years            SUB PAGE:     1


 NOMENCLATURE:
```

```
Element       Name of element
Stat          = PASS or FAIL: *FAIL = UsageFactor >   1.0
UsageFact     Accumulated damage (Usage factor)
ChkPnt        Fatigue check point number of element
ChkPlc        Stress/surface/corner/mid-plane/membrane or centre points
 AccFatLif    Design fatigue life/usage factor (year)
 StrsCycle    Total number of stress cycles
 SNCurve      SN curve name.

Coordinate reference system    : Current superelement
Status on failure              : *FAIL when UsageFactor > 1.0
Design fatigue life            : 20.0 years
Fatigue calculation based on   : Spectral moments of maximum principal stresses
Wave spectrum                  : Pierson Moskowitz



                  STOCHASTIC     ELEMENT fatigue check results
                  Run: FT1       Superelement BRACKET
                  Priority.....: Worst Usage Factor
                  Usage factor : Above  0.20
                  Design Fatigue Life: 20.0   Years            SUB PAGE:     2

Element Stat  UsageFact ChkPnt  ChkPlc  AccFatLif  StrsCycle  SNCurve
-------------------------------------------------------------------------------
1249    *FAIL 3.685E+00 5 (+z)  SurfPt  5.427E+00  9.482E+07  DNVC-I
1248    *FAIL 2.533E+00 4 (-z)  SurfPt  7.895E+00  9.601E+07  DNVC-I
964     *FAIL 1.012E+00 4 (-z)  SurfPt  1.977E+01  9.450E+07  DNVC-I
969      PASS 9.605E-01 7 (+z)  SurfPt  2.082E+01  9.498E+07  DNVC-I
989      PASS 8.898E-01 3 (-z)  SurfPt  2.248E+01  9.516E+07  DNVC-I
1024     PASS 7.626E-01 3 (-z)  SurfPt  2.623E+01  9.387E+07  DNVC-I
1026     PASS 7.456E-01 1 (-z)  SurfPt  2.682E+01  9.350E+07  DNVC-I
982      PASS 7.292E-01 4 (-z)  SurfPt  2.743E+01  9.671E+07  DNVC-I
1251     PASS 7.005E-01 1 (-z)  SurfPt  2.855E+01  9.568E+07  DNVC-I
1250     PASS 6.851E-01 1 (-z)  SurfPt  2.919E+01  9.723E+07  DNVC-I
1247     PASS 6.608E-01 7 (+z)  SurfPt  3.027E+01  1.133E+08  DNVC-I
1020     PASS 5.432E-01 4 (-z)  SurfPt  3.682E+01  9.386E+07  DNVC-I
1023     PASS 5.211E-01 2 (-z)  SurfPt  3.838E+01  9.349E+07  DNVC-I
1033     PASS 5.001E-01 4 (-z)  SurfPt  3.999E+01  9.344E+07  DNVC-I
1035     PASS 4.720E-01 2 (-z)  SurfPt  4.237E+01  9.315E+07  DNVC-I
1030     PASS 4.207E-01 3 (-z)  SurfPt  4.754E+01  9.334E+07  DNVC-I
1234     PASS 4.026E-01 6 (+z)  SurfPt  4.967E+01  9.821E+07  DNVC-I
1246     PASS 3.847E-01 8 (+z)  SurfPt  5.198E+01  9.878E+07  DNVC-I
1036     PASS 3.750E-01 3 (-z)  SurfPt  5.334E+01  9.336E+07  DNVC-I
1039     PASS 3.649E-01 1 (-z)  SurfPt  5.481E+01  9.318E+07  DNVC-I
970      PASS 3.588E-01 7 (+z)  SurfPt  5.574E+01  9.492E+07  DNVC-I
981      PASS 3.410E-01 4 (-z)  SurfPt  5.866E+01  9.939E+07  DNVC-I
1025     PASS 3.345E-01 2 (-z)  SurfPt  5.979E+01  9.565E+07  DNVC-I
1235     PASS 3.163E-01 5 (+z)  SurfPt  6.323E+01  1.022E+08  DNVC-I
1240     PASS 2.938E-01 4 (-z)  SurfPt  6.807E+01  9.775E+07  DNVC-I
1241     PASS 2.644E-01 3 (-z)  SurfPt  7.565E+01  9.925E+07  DNVC-I
1027     PASS 2.586E-01 4 (-z)  SurfPt  7.734E+01  9.247E+07  DNVC-I
976      PASS 2.470E-01 4 (-z)  SurfPt  8.098E+01  1.019E+08  DNVC-I
1029     PASS 2.016E-01 2 (-z)  SurfPt  9.923E+01  9.614E+07  DNVC-I
Number of elements printed : 29
Number of elements failed  : 3
*******************************************************************************
```

## A.5 Dump Print of fatigue Results

Example of dump print of fatigue results are given in the present section. Dump print is generated by the command PRINT FATIGUE-RESULTS-DUMP. Prior to this command, dump print options must be set by the command DEFINE FATIGUE-RESULTS-DUMP. Two dump print files are generated; <*name*>Dmp.lis and <*name*>Pex.lis. The <*name*> is given by the command DEFINE FATIGUE-RESULTS-DUMP FILENAME, default name is *Stofat*. Dump print may be generated both for element and hotspots fatigue check results. Note that the dump print files may be excessive big for dump print of all elements of large models. Dump print should therefor be executed with care and limited to a restricted number of elements.

Results are printed to the nameDmp.lis file when one of the following commands are ticked ON.

DEFINE FATIGUE-RESULTS-DUMP HOTSPOT-STRESS-TRANSFER-FUNCTION ON
DEFINE FATIGUE-RESULTS-DUMP MOMENTS-OF-RESPONSE-SPECTRUM ON
DEFINE FATIGUE-RESULTS-DUMP DAMAGE-PER-SEASTATE ON
DEFINE FATIGUE-RESULTS-DUMP DAMAGE-PER-DIRECTION ON
DEFINE FATIGUE-RESULTS-DUMP DAMAGE-PER-HOTSPOT ON

Results are printed to the namePex.lis file when one of the following commands are ticked ON.

DEFINE FATIGUE-RESULTS-DUMP EXCEEDENCE-PROBABILITY ON 11
DEFINE FATIGUE-RESULTS-DUMP STRESS-RANGE-DISTRIBUTION ON 11
DEFINE FATIGUE-RESULTS-DUMP WEIBULL-PARAMETERS ON

The following data are printed in the nameDmp.lis file:

- Stress transfer functions
- Spectral moments, mean zero-up crossing periods and spectral band width per sea state
- Damages and stress cycles per sea state
- Damages and stress cycles per wave direction
- Damage and stress cycles per element position or hotspot

The stress transfer functions printed is the maximum principal stresses at the user defined fatigue positions of the elements forming the response spectra which are applied in the fatigue damage calculation. The spectral moments printed are those found by integrating the response spectra. The spectral moments are scaled with the square of the element thickness factor (shell elements) and the static stress reduction factor (if included). The spectral band widths printed (resEps) are applied when the Wirsching correction factor for broad band stress processes is requested, see section Appendix C.3 and command DEFINE WIDE-BAND-CORRECTION-FACTOR.

Only results of position 1 for one element are shown in present example and static stresses are not included.

nameDmp.lis file:

```
*****************************************************************
**                                                             **
**                        S T O F A T                          **
**                                                             **
**          F A T I G U E   C H E C K   R E S U L T S          **
**                            O F                              **
**                      E L E M E N T S                        **
**                                                             **
**          RUN      : DMP1                                    **
**          DATE/TIME: 2016-04-20 13:49:56                     **
**                                                             **
*****************************************************************

PRINT OF:
```

```
- STRESS TRANSFER FUNCTIONS (SIN FILE STRESSES)
- MOMENTS OF RESPONSE SPECTRUM
- DAMAGES
STRESSES OF ELEMENT STRESS POINTS ARE USED
MOMENTS ARE SCALED WITH THICKNESS AND STATIC REDUCTION FACTORS
(NOTE! WAVE DIRECTIONS WITH NON-ZERO PROBABILITY ARE PRINTED)
***************************************************************


********************** Element      35 **********************


Stress Transfer Function (Maximum Principal Stress)
---------------------------------------------------
Element:       35 Position:  1

Omega   Wave Direction
           0.000     45.000     90.000    135.000
0.2094  1.841E+05  3.891E+05  3.032E+05  2.067E+05
0.2205  2.050E+05  4.413E+05  2.536E+05  1.194E+05
0.2327  2.358E+05  5.225E+05  2.808E+05  1.142E+05
0.2417  3.407E+05  6.027E+05  3.079E+05  2.313E+05
0.2513  1.044E+06  1.005E+06  3.437E+05  7.979E+05
0.2618  6.874E+05  8.346E+05  3.937E+05  6.025E+05
0.2792  4.422E+05  1.036E+06  5.408E+05  3.710E+05
0.2856  5.255E+05  1.182E+06  6.540E+05  3.596E+05
0.2922  7.210E+05  1.447E+06  8.983E+05  3.551E+05
0.2992  1.040E+06  1.602E+06  1.250E+06  9.675E+05
0.3065  3.762E+05  7.932E+05  3.828E+05  9.284E+05
0.3110  2.385E+05  8.801E+05  2.371E+05  8.281E+05
0.3307  2.205E+05  1.305E+06  3.053E+05  8.186E+05
0.4189  4.371E+05  3.157E+06  7.386E+05  2.020E+06
0.5464  6.570E+05  7.301E+06  1.655E+06  5.401E+06
0.5984  7.242E+05  9.140E+06  2.162E+06  7.040E+06
0.6283  7.424E+05  1.003E+07  2.441E+06  7.906E+06
0.6616  7.332E+05  1.076E+07  2.696E+06  8.697E+06
0.6981  6.816E+05  1.114E+07  2.868E+06  9.260E+06
0.7854  4.547E+05  1.006E+07  2.653E+06  8.805E+06

- Moments of response spectrum m0, m1, m2
- Mean zero up-crossing period, resTz = 2*pi*sqrt(m0/m2)
- Mean zero up-crossing period / mean wave period, resTz/T1 = m1/sqrt(m0*m2)
- Spectral band width, resEps = sqrt(1-m2*m2/m0*m4)
----------------------------------------------------------------------------
Element:       35 Position:  1

Sea Dir        m0        m1        m2        m4     resTz  resTz/T1    resEps
  1   1 5.128E+12 4.840E+12 4.789E+12 5.671E+12 6.502E+00 9.768E-01 4.599E-01
  2   1 8.720E+12 4.747E+12 2.883E+12 1.401E+12 1.093E+01 9.468E-01 5.653E-01
  3   1 2.014E+13 1.079E+13 6.503E+12 3.143E+12 1.106E+01 9.429E-01 5.760E-01
  4   1 2.083E+13 1.032E+13 6.001E+12 2.835E+12 1.171E+01 9.233E-01 6.247E-01
  5   1 2.047E+13 7.681E+12 3.891E+12 1.710E+12 1.441E+01 8.606E-01 7.534E-01
  6   2 1.023E+13 9.666E+12 9.568E+12 1.135E+13 6.498E+00 9.768E-01 4.598E-01
  7   2 1.613E+13 9.048E+12 5.592E+12 2.763E+12 1.067E+01 9.527E-01 5.463E-01
  8   2 3.704E+13 2.051E+13 1.260E+13 6.197E+12 1.077E+01 9.493E-01 5.556E-01
  9   2 3.746E+13 1.939E+13 1.156E+13 5.585E+12 1.131E+01 9.315E-01 6.007E-01
 10   2 3.514E+13 1.398E+13 7.391E+12 3.363E+12 1.370E+01 8.671E-01 7.333E-01
 11   3 9.973E+12 9.455E+12 9.394E+12 1.121E+13 6.474E+00 9.769E-01 4.593E-01
 12   3 1.375E+13 7.899E+12 4.991E+12 2.565E+12 1.043E+01 9.535E-01 5.420E-01
```

```
 13   3 3.154E+13 1.788E+13 1.124E+13 5.751E+12 1.053E+01 9.501E-01 5.514E-01
 14   3 3.185E+13 1.686E+13 1.029E+13 5.180E+12 1.105E+01 9.313E-01 5.982E-01
 15   3 3.022E+13 1.215E+13 6.562E+12 3.115E+12 1.348E+01 8.629E-01 7.366E-01
 16   4 1.243E+13 1.183E+13 1.181E+13 1.421E+13 6.446E+00 9.770E-01 4.586E-01
 17   4 1.401E+13 8.456E+12 5.546E+12 3.013E+12 9.985E+00 9.595E-01 5.208E-01
 18   4 3.187E+13 1.908E+13 1.246E+13 6.753E+12 1.005E+01 9.572E-01 5.274E-01
 19   4 3.090E+13 1.767E+13 1.134E+13 6.073E+12 1.037E+01 9.443E-01 5.613E-01
 20   4 2.534E+13 1.186E+13 7.041E+12 3.642E+12 1.192E+01 8.879E-01 6.803E-01

Damage per seastate
-------------------
Element:       35 Position:  1

 Sea        Hs         Tz        Prob     Damage   Fraction     Cycles
   1 2.750E+00  4.750E+00  0.249E+00  1.531E-04  3.152E-02  2.421E+07
   2 7.750E+00  1.775E+01  0.860E-01  8.581E-05  1.766E-02  5.130E+06
   3 1.225E+01  1.825E+01  0.236E+00  1.859E-03  3.828E-01  1.394E+07
   4 1.425E+01  2.025E+01  0.206E+00  1.577E-03  3.246E-01  1.161E+07
   5 1.775E+01  2.575E+01  0.223E+00  1.183E-03  2.435E-01  1.040E+07

Damage per direction
--------------------
Element:       35 Position:  1

  Dir       Angle        Prob     Damage   Fraction     Cycles
    1       0.000   0.100E+00  1.306E-04  2.689E-02  6.344E+06
    2      45.000   0.600E+00  3.514E-03  7.233E-01  3.889E+07
    3      90.000   0.200E+00  8.127E-04  1.673E-01  1.316E+07
    4     135.000   0.100E+00  4.009E-04  8.253E-02  6.894E+06

Damage per position
-------------------
Element:       35  Position:  1

      Damage       Cycles
 4.85771E-03  6.52887E+07

*************************************************************************************
```

The following data are printed in the namePex.lis file: Stress range levels. Maximum stress range divided into equally spaces levels. The same levels are applied to all wave directions.

- Exceedance (stress cycles) for each individual wave direction and accumulated exceedance for all wave directions
- Exceedance probabilities for all wave directions
- Accumulated exceedance for exceedance probabilities levels $10^{-8}$, $10^{-7}$, ..... $10^{-0}$
- Total damage and stress cycles per element position and hotspot
- Averange Weibull parameters of the stress range distribution using a least square fit of 10 stress levels
- Weibull parameters for each part of the stress range distribution fitting two and two stress range levels

The stress range distribution is divided into exclev (or strslev) exceedance levels. The maximum stress range of all wave directions for a stress point are applied when calculating the exceedance levels. The exceedance levels are numbered from 1 to exclev (or strslev). Level 1 is the level of maximum stress range and level exclev is the level of lowest stress range. Exceedance (stress cycles) for all stress levels are calculated for each individual wave direction. Accumulated exceedance and probabilities of exceedance for all wave directions are also calculated and in addition stress ranges and exceedance related to probability levels $10^{-8}$, $10^{-7}$ .... $10^{-0}$ are given. These probability levels are found by linear interpolation of the stress distribution in logarithmic scale. Note that the total number of stress cycles is given as the accumulated exceedance for exceedance probability level $10^{-0}$ (=1 and stress range = 0.0).

The maximum stress range (level 1) is applied in the fatigue damage calculations. If the accumulated exceedance of this level is larger than 1.0 an uppermost level (level 0) with an accumulated exceedance of 1.0, is printed. Level 0 is calculated by extrapolating the stress distribution by a Weibull curve fitting stress range level 1 and 2. Exceedance of level 0 for the individual wave directions are taken as the wave direction exceedance relative to the accumulated exceedance of level 1. I.e. exc0(j) = exc1(j)/exc1(all) where exc1(j) is the exceedance of wave direction j and exc1(all) is the accumulated exceedance of all wave directions. Wave direction exceedance of level 0 sums to 1.0.

If print of Weibull parameters is turned on, the Weibull scale- and shape parameters are calculated and printed for each part range of the distribution. The Weibull parameters are calculated by fitting the two levels forming the part range of the distribution (level $i$ and $i+1$). Weibull parameters calculated during the run execution is also printed when the command DEFINE WEIBULL-PARAMETERS is turned on. These parameters are average values of the stress range distribution calculated by fitting the Weibull function by a least square technique using 10 levels for the stress range distribution.

nameStofatPex.lis file:

```
***************************************************************
**                                                           **
**                        S T O F A T                        **
**                                                           **
**          F A T I G U E   C H E C K   R E S U L T S        **
**                            O F                            **
**                      E L E M E N T S                      **
**                                                           **
**          RUN      : DMP1                                  **
**          DATE/TIME: 2016-04-20 13:49:56                   **
**                                                           **
***************************************************************

PRINT OF:
- STRESS RANGES
- PROBABILITIES OF EXCEEDENCES
STRESSES OF ELEMENT STRESS POINTS ARE USED
SPECTRAL MOMENTS APPLIED IN FATIGUE DAMAGE CALCULATION ARE USED
(NOTE! WAVE DIRECTIONS WITH NON-ZERO PROBABILITY ARE PRINTED)
***************************************************************


Element      Positions    Exceedence levels   Design fatigue life
35                   8                   12           20.00 Years
-----------------------------------------------------------------

Element      Pos  Wavedir Level     Stress range        Exceedence
35             1     0.00     0   7.05443040E+07    4.64855901E-07
35             1     0.00     1   6.87062080E+07    1.10468500E-06
35             1     0.00     2   6.29806920E+07    1.08067645E-04
35             1     0.00     3   5.72551720E+07    7.12257065E-03
35             1     0.00     4   5.15296520E+07    3.15980613E-01
35             1     0.00     5   4.58041360E+07    9.42732811E+00
35             1     0.00     6   4.00786200E+07    1.89003815E+02
35             1     0.00     7   3.43531000E+07    2.54445312E+03
35             1     0.00     8   2.86275840E+07    2.29903398E+04
35             1     0.00     9   2.29020680E+07    1.39552281E+05
35             1     0.00    10   1.71765500E+07    5.74783000E+05
35             1     0.00    11   1.14510340E+07    1.71463162E+06
```

| | | | | | |
|---|---|---|---|---|---|
| 35 | 1 | 0.00 | 12 | 5.72551750E+06 | 4.20542300E+06 |
| | | | | | |
| 35 | 1 | 45.00 | 0 | 7.05443040E+07 | 9.70862389E-01 |
| 35 | 1 | 45.00 | 1 | 6.87062080E+07 | 2.30716038E+00 |
| 35 | 1 | 45.00 | 2 | 6.29806920E+07 | 2.96216888E+01 |
| 35 | 1 | 45.00 | 3 | 5.72551720E+07 | 3.05454773E+02 |
| 35 | 1 | 45.00 | 4 | 5.15296520E+07 | 2.52841187E+03 |
| 35 | 1 | 45.00 | 5 | 4.58041360E+07 | 1.67903945E+04 |
| 35 | 1 | 45.00 | 6 | 4.00786200E+07 | 8.94051797E+04 |
| 35 | 1 | 45.00 | 7 | 3.43531000E+07 | 3.81696562E+05 |
| 35 | 1 | 45.00 | 8 | 2.86275840E+07 | 1.30887462E+06 |
| 35 | 1 | 45.00 | 9 | 2.29020680E+07 | 3.63916050E+06 |
| 35 | 1 | 45.00 | 10 | 1.71765500E+07 | 8.49955800E+06 |
| 35 | 1 | 45.00 | 11 | 1.14510340E+07 | 1.76659000E+07 |
| 35 | 1 | 45.00 | 12 | 5.72551750E+06 | 3.11642280E+07 |
| | | | | | |
| 35 | 1 | 90.00 | 0 | 7.05443040E+07 | 2.07340717E-02 |
| 35 | 1 | 90.00 | 1 | 6.87062080E+07 | 4.92725112E-02 |
| 35 | 1 | 90.00 | 2 | 6.29806920E+07 | 9.85051751E-01 |
| 35 | 1 | 90.00 | 3 | 5.72551720E+07 | 1.52169981E+01 |
| 35 | 1 | 90.00 | 4 | 5.15296520E+07 | 1.81543732E+02 |
| 35 | 1 | 90.00 | 5 | 4.58041360E+07 | 1.67174854E+03 |
| 35 | 1 | 90.00 | 6 | 4.00786200E+07 | 1.18757803E+04 |
| 35 | 1 | 90.00 | 7 | 3.43531000E+07 | 6.50620703E+04 |
| 35 | 1 | 90.00 | 8 | 2.86275840E+07 | 2.75243031E+05 |
| 35 | 1 | 90.00 | 9 | 2.29020680E+07 | 9.07754188E+05 |
| 35 | 1 | 90.00 | 10 | 1.71765500E+07 | 2.42392850E+06 |
| 35 | 1 | 90.00 | 11 | 1.14510340E+07 | 5.55353700E+06 |
| 35 | 1 | 90.00 | 12 | 5.72551750E+06 | 1.03614860E+07 |
| | | | | | |
| 35 | 1 | 135.00 | 0 | 7.05443040E+07 | 8.40320718E-03 |
| 35 | 1 | 135.00 | 1 | 6.87062080E+07 | 1.99694075E-02 |
| 35 | 1 | 135.00 | 2 | 6.29806920E+07 | 3.98181409E-01 |
| 35 | 1 | 135.00 | 3 | 5.72551720E+07 | 6.15789270E+00 |
| 35 | 1 | 135.00 | 4 | 5.15296520E+07 | 7.39788208E+01 |
| 35 | 1 | 135.00 | 5 | 4.58041360E+07 | 6.91567932E+02 |
| 35 | 1 | 135.00 | 6 | 4.00786200E+07 | 5.03638184E+03 |
| 35 | 1 | 135.00 | 7 | 3.43531000E+07 | 2.85850059E+04 |
| 35 | 1 | 135.00 | 8 | 2.86275840E+07 | 1.26757430E+05 |
| 35 | 1 | 135.00 | 9 | 2.29020680E+07 | 4.45730812E+05 |
| 35 | 1 | 135.00 | 10 | 1.71765500E+07 | 1.28515625E+06 |
| 35 | 1 | 135.00 | 11 | 1.14510340E+07 | 3.06082325E+06 |
| 35 | 1 | 135.00 | 12 | 5.72551750E+06 | 5.56098250E+06 |
| | | | | | |
| | | | | | Accumulated |
| | | | | Stress range | exceedence |
| 35 | 1 | All | 0 | 7.05443040E+07 | 1.00000000E+00 |
| 35 | 1 | All | 1 | 6.87062080E+07 | 2.37640309E+00 |
| 35 | 1 | All | 2 | 6.29806920E+07 | 3.10050316E+01 |
| 35 | 1 | All | 3 | 5.72551720E+07 | 3.26836792E+02 |
| 35 | 1 | All | 4 | 5.15296520E+07 | 2.78425024E+03 |
| 35 | 1 | All | 5 | 4.58041360E+07 | 1.91631367E+04 |
| 35 | 1 | All | 6 | 4.00786200E+07 | 1.06506352E+05 |
| 35 | 1 | All | 7 | 3.43531000E+07 | 4.77888062E+05 |
| 35 | 1 | All | 8 | 2.86275840E+07 | 1.73386550E+06 |
| 35 | 1 | All | 9 | 2.29020680E+07 | 5.13219900E+06 |
| 35 | 1 | All | 10 | 1.71765500E+07 | 1.27834250E+07 |
| 35 | 1 | All | 11 | 1.14510340E+07 | 2.79948900E+07 |
| 35 | 1 | All | 12 | 5.72551750E+06 | 5.12921200E+07 |

```
                                                        Exceedence
                                          Stress range  probability
35           1       All      0   7.05443040E+07   1.53165942E-08
35           1       All      1   6.87062080E+07   3.63984043E-08
35           1       All      2   6.29806920E+07   4.74891493E-07
35           1       All      3   5.72551720E+07   5.00602664E-06
35           1       All      4   5.15296520E+07   4.26452316E-05
35           1       All      5   4.58041360E+07   2.93513993E-04
35           1       All      6   4.00786200E+07   1.63131463E-03
35           1       All      7   3.43531000E+07   7.31961755E-03
35           1       All      8   2.86275840E+07   2.65569147E-02
35           1       All      9   2.29020680E+07   7.86078125E-02
35           1       All     10   1.71765500E+07   1.95798546E-01
35           1       All     11   1.14510340E+07   4.28786367E-01
35           1       All     12   5.72551750E+06   7.85620630E-01
                       Exceedence                      Accumulated
                      probability   Stress range       exceedences
35           1     1.000000E-08   7.17800080E+07   6.52886629E-01
35           1     1.000000E-07   6.63937600E+07   6.52886629E+00
35           1     1.000000E-06   6.11111560E+07   6.52886658E+01
35           1     1.000000E-05   5.53395320E+07   6.52886597E+02
35           1     1.000000E-04   4.89166720E+07   6.52886621E+03
35           1     1.000000E-03   4.16350200E+07   6.52886680E+04
35           1     1.000000E-02   3.28696140E+07   6.52886625E+05
35           1     1.000000E-01   2.12286560E+07   6.52886650E+06
35           1     1.000000E+00   0.00000000E+00   6.52886640E+07
                                          Damage        Cycles/year
35           1                    4.85771289E-03   3.26443325E+06
Weibull parameters. Least square fit. 10 range levels. WavDir=All:
                                           Scale             Shape
                                  1.35513030E+07        1.73909724
Weibull parameters. Fitting two and two range levels. WavDir=All:
                   Fit levels              Scale             Shape
                      0 - 1       1.50085960E+07        1.86742401
                      1 - 2       1.50060490E+07        1.86721671
                      2 - 3       1.48230780E+07        1.85138214
                      3 - 4       1.46112040E+07        1.83186531
                      4 - 5       1.43590210E+07        1.80690432
                      5 - 6       1.40500640E+07        1.77364624
                      6 - 7       1.36693410E+07        1.72834957
                      7 - 8       1.32134990E+07        1.66699767
                      8 - 9       1.27439970E+07        1.59247661
                      9 - 10      1.25164710E+07        1.54499471
                     10 - 11      1.26920860E+07        1.61611986
                     11 - 12      1.25521400E+07        1.81129718

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# B Load and Response Modelling

The major time varying loads on marine structures are generally those caused by waves. An adequate description of ocean waves is therefore necessary for a fatigue analysis. When the long term stress range response distribution is assigned to be a sum of Rayleigh distributions (or for a Weibull fit of the sum of Rayleigh distributions), Stofat apply spectral fatigue analysis where only the load response caused by fluctuating wave loading is considered. For the real sea state, the wave model assumptions applied in Stofat are not exactly fulfilled. However, from an engineering point of view they are very attractive due to the simplification they imply in the structural analysis.

This chapter focus on the load and response modelling applied in Stofat when the long-term stress range distribution is assigned to be a sum of Rayleigh distributions. First the sea environment model is considered. Then the load model and the global structural analysis are described leading to transfer functions for selected forces. Finally the local stress analysis is discussed. The sources of uncertainty and their treatment is presented throughout the chapter.

## B.1 Sea State Description

The load model in Stofat is based on a description of the wave conditions into a set of stationary short term sea states. Each sea state is characterized by

- Main wave direction $\theta_0$, measured relative to a given reference direction.
- Wave spectrum model e.g. Jonswap
- Characteristic sea state parameters
  - significant wave height $H_S$, defined as the average of the upper third of the wave heights.
  - Mean zero up-crossing period $T_Z$, defined as the time between sucessive up-crossing of the still water level, averaged over the number of waves
- wave spreading function

For each sea state the long term probabilities of the different main wave directions are given along with a wave scatter diagram for each direction. A wave scatter diagram gives either the occurrence or the probability for each set of $H_S$ and $T_Z$ values. A unique wave spreading function is either assigned to all or a subset of the wave-statistics given by each assigned scatter diagram. If no wave spreading function is assigned, long crested sea is assumed.

### B.1.1 Main Wave Directions

Sets of wave observations may be sorted with respect to the corresponding main wave directions if directional buoy or hindcast data are available (or wind directions). Statistics on the observations may be made individually for each sector, or one may assume that the statistical properties for the occurrence of waves are the same in all sectors. The word 'main wave direction' denotes the middle direction for each of the sectors. The analysis may only be performed for waves in these discrete directions. In Stofat each main wave direction $i$ is defined by the angle $\bar{\theta}_i$, measured relative to a given reference direction, usually defined as the structures global x-axis. An example of sector numbering and main wave directions is shown in Figure B.1

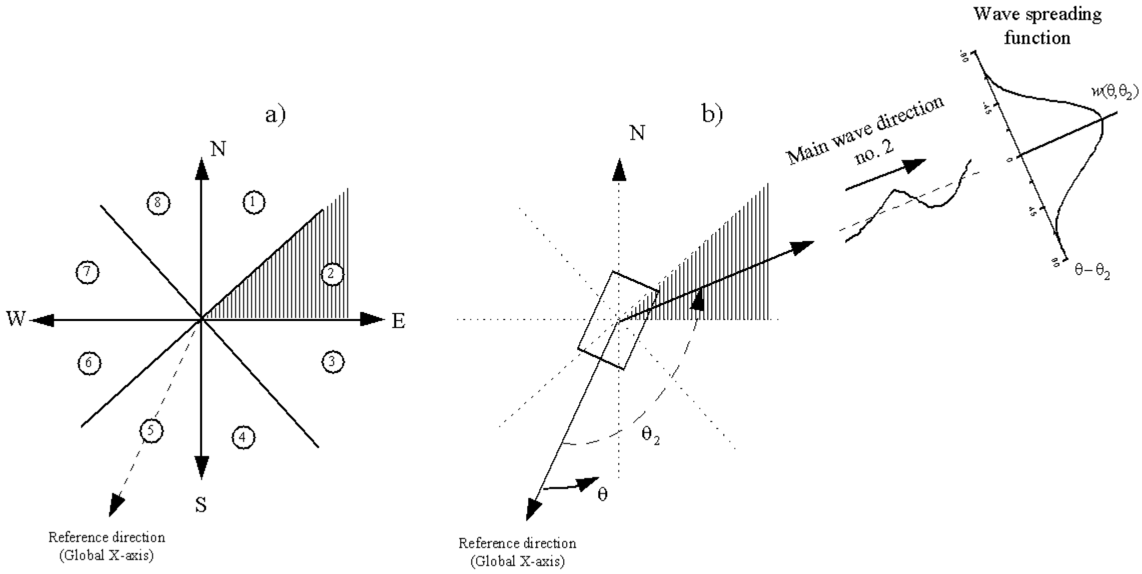



Figure B.1: a) Example of sector numbering, b) Main wave direction in structure coordinate system

In Stofat the main wave direction is assumed to be given by a set of prescribed discrete directions. The probability distribution of the main wave direction is given as a discrete distribution with

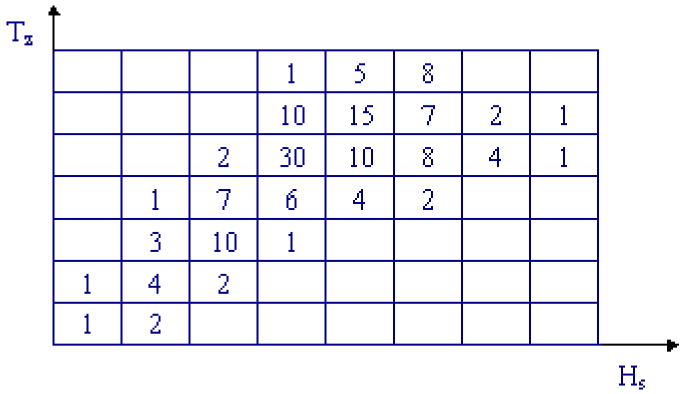
$P_{\bar{\theta}_i} \equiv$ probability that main wave direction is$\bar{\theta}_i, i = 1, 2, \ldots, N_{\bar{\theta}}$

where $N_{\bar{\theta}}$ is the number of possible main wave directions and

$$\sum_{i=1}^{N_\theta} P_{\bar{\theta}_i} = 1 \qquad \text{(B.1)}$$

## B.1.2 Main Scatter Diagram

The $H_S$ and $T_Z$ data for each sea state are usually obtained by measurements and presented as a *sea scatter diagram*.




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1 | 5 | 8 | | |
| | | | 10 | 15 | 7 | 2 | 1 |
| | | 2 | 30 | 10 | 8 | 4 | 1 |
| | 1 | 7 | 6 | 4 | 2 | | |
| | 3 | 10 | 1 | | | | |
| 1 | 4 | 2 | | | | | |
| 1 | 2 | | | | | | |

Figure B.2: Bivarite discrete ($H_S$,$T_Z$) probability density function

The bivariate discrete form of the wave scatter diagram is the basis for the Stofat programs. The sea scatter diagram gives the occurrence frequency of a discrete number of combinations of ($H_S$,$T_Z$). Typically, 60 to 150 sea states are used to describe most sea environments.

### B.1.3 Wave Energy Spreading Function

The wave energy spreading function is introduced to account for the energy spreading in different directions for short crested sea. Real sea waves are not infinitely long crested and *directional spectra* are required for a complete statistical description of the sea. The directional spectra accounts for the spreading of wave energy by direction as well as frequency. A spectrum in terms of direction $\theta$ is in Stofat assumed of the form.

$$S_\eta(\omega, \theta) = S_\eta(\omega)\, w(\theta) \tag{B.2}$$

where $w(\theta)$ is the wave energy spreading function, assumed independent of the frequency.

In Stofat it is assumed that the wave energy is spread over a set of directions in a region of $\pm n/2$ on both sides of the main direction. The function is selected in such a way that it gives higher weights to the directions $\theta_i$ closer to the main direction. The wave energy spreading function for a given main wave direction may in general depend on ($H_S$,$T_Z$). In Stofat a unique wave spreading function is either assigned to all or a subset of the wave-statistics given by each assigned scatter diagram. If no wave spreading function is assigned, long crested sea is assumed.

The wave energy spreading function applied in Stofat is a frequency independent cosine power function of the form

$$w\left(\theta, \bar{\theta}_i\right) = \frac{1}{2c\sqrt{\pi}} \frac{\Gamma\left(\frac{N}{2}+1\right)}{\Gamma\left(\frac{N}{2}+\frac{1}{2}\right)} \cos^N\left(\frac{\theta-\bar{\theta}_i}{2c}\right), \qquad |\theta-\bar{\theta}_i| < c\pi \tag{B.3}$$

and zero otherwise, $\Gamma()$ is the gamma function, $\bar{\theta}_i$ is main wave direction no. $i$, and $N$ is the exponent in the cosine function. Figure B.3 shows the directional function for different values of $N$. $c = 0.5$ is always used in Stofat. For large values of $N$, all the energy is concentrated around the main wave direction.

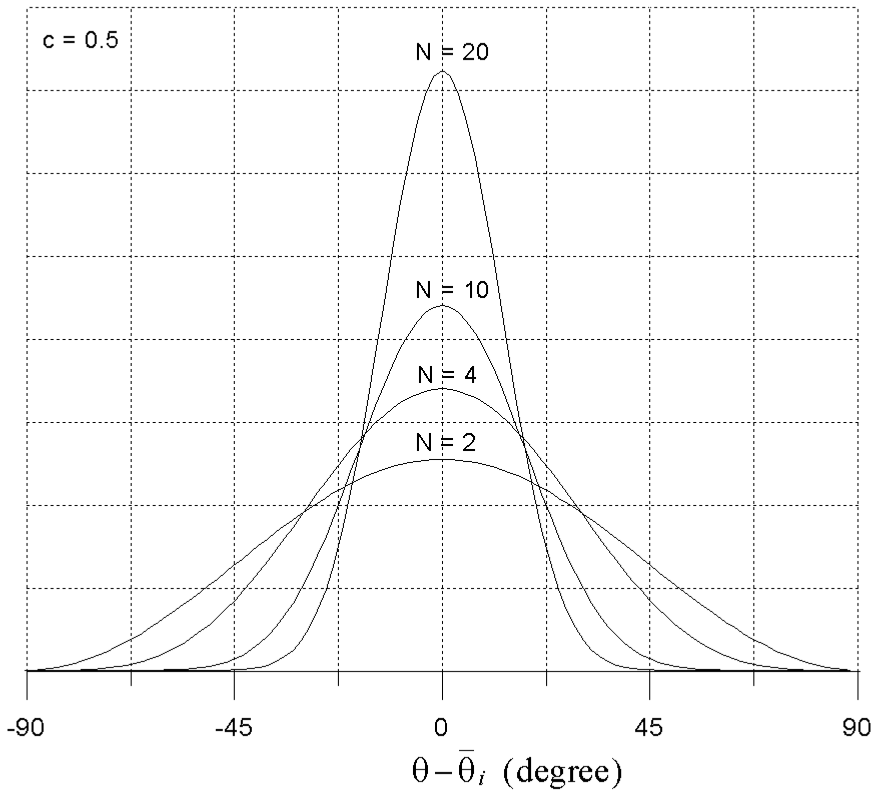



Figure B.3: The spreading function for different values of the cosine power N

The discrete directions for which the transfer functions are calculated, denoted elementary wave directions, $\bar{\theta}_e$ , are usually equivalent to the main wave directions. The squared modulus of the stress transfer func-

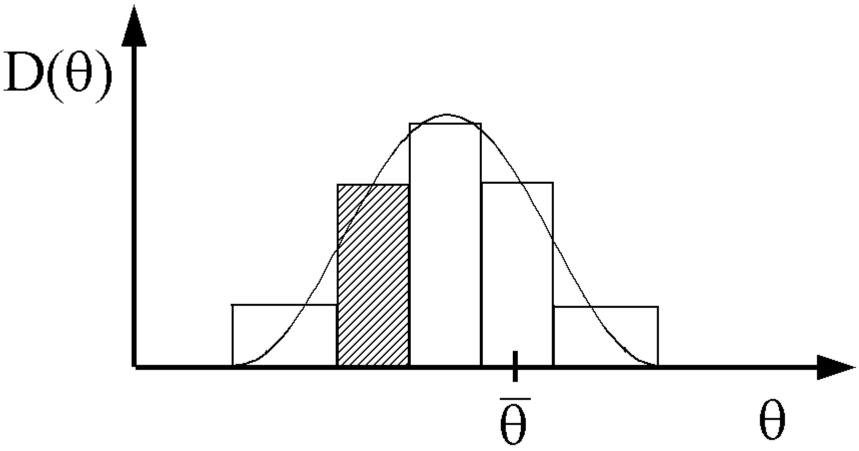



Figure B.4: Discretizing the analytical spreading function

tions for the elementary wave directions are multiplied with the spreading function weights to generate the squared modulus of the stress transfer function for each of the main wave directions.

The spreading function weights are obtained by integration of the energy spreading function over the proper ranges. The analytical spreading function is discretized. The analytical discretionality function is approximated by a histogram. The ordinate of each histogram box corresponds to the area of the analytical function over the width of the box. The procedure is illustrated in Figure B.4 where the weights are

$$w_{\theta_i\theta_e} = \int_{\theta_e-\Delta\frac{\theta}{2}}^{\theta_e+\Delta\frac{\theta}{2}} w\left(\theta,\theta_i\right) d\theta \tag{B.4}$$

For example, suppose there are $k = 8$ main wave directions, then secundary directions for the main wave direction $\theta_1$ exist, $\theta_1$, $\theta_2$, $\theta_3$, $\theta_7$ and $\theta_8$. The corresponding weights are

$$w_{\theta_1\theta_3} = w_{\theta_1\theta_7} = \int_{\theta_3-\frac{\pi}{8}}^{\frac{\pi}{2}} w\left(\theta,\theta_1\right) d\theta \tag{B.5}$$

$$w_{\theta_1\theta_2} = w_{\theta_1\theta_8} = \int_{\theta_2-\frac{\pi}{8}}^{\theta_2+\frac{\pi}{8}} w\left(\theta,\theta_1\right) d\theta \tag{B.6}$$

$$w_{\theta_1\theta_1} = \int_{\theta_1-\frac{\pi}{8}}^{\theta_1+\frac{\pi}{8}} w\left(\theta,\theta_1\right) d\theta \tag{B.7}$$

The wave spreading function can also be modelled directly as a histogram.

The sum of the spreading weights of the elementary wave directions is adjusted to always be 1.0 for a cosine wave spreading function.

If the elementary wave directions are symmetrically positioned in the range of $\pm\pi/2$ around the main wave direction, the cosine spreading function results in a symmetrical spreading of the wave energy to both sides of the main wave directions.

If transfer functions for some elementary wave directions in the range $\pm\pi/2$ on either side of the main wave direction are not available, the corresponding weights are given to the nearest available elementary wave direction and a non-symmetric wave energy spreading will take place.

To illustrate this, assume that the elementary directions $\theta_7$ and $\theta_8$ in the example above are not available. The weights of the cosine spreading functions to the available directions $\theta_1$, $\theta_2$, $\theta_3$ are given by

$$w_{\theta_1\theta_1} = \int_{-\frac{\pi}{2}}^{\theta_1+\frac{\pi}{8}} w\left(\theta,\theta_1\right) d\theta \tag{B.8}$$

$$w_{\theta_1\theta_2} = \int_{\theta_2-\frac{\pi}{8}}^{\theta_2+\frac{\pi}{8}} w\left(\theta,\theta_1\right)d\theta \tag{B.9}$$

$$w_{\theta_1\theta_3} = \int_{\theta_3-\frac{\pi}{8}}^{\frac{\pi}{2}} w\left(\theta,\theta_1\right)d\theta \tag{B.10}$$

The above weights result in a non-symmetric spreading of the wave energy around the main wave direction $\theta_1$. Note that the whole range $\pm\pi/2$ on both side of the maindirection is always integrated and the wave energy is spread to the available wave directions within this range.

If non-symmetric cosine spreading is not satisfactory, a user defined wave spreading function may be used.

Stofat tests if symmetric spreading really takes place when cosine spreading function is applied. If not, a warning together with information about the spreading are printed.

Wave spreading function applied to double-peak spectrums might be regarded differently when compared against the method applied on single peak methods. The reason is concerned with double-peak spectrums split the energy into a swell component and a wind-sea component and different wave spreading functions might have to be applied to each one of those components. Stofat cannot decompose a double-peak spectrum and therefore apply different wave spreading functions for each component. Stofat does not hold different methods for application of wave spreading methods regarding their nature, holding the same method for single or double peak spectrums.

### B.1.4 Wave Spectrum

A sea state is characterized by a *wave spectrum* (or power spectral density function). This spectrum accounts for the variation of the wave energy over the frequencies in the sea state. The most commonly used spectrum is the [25] spectrum, defined by

$$S_\eta\left(\omega\right) = H_S^2 T_Z \frac{1}{8\pi^2}\left(\frac{\omega T_Z}{2\pi}\right)^{-5} e^{-\frac{1}{\pi}\left(\frac{\omega T_Z}{2\pi}\right)} \tag{B.11}$$

In Stofat two different one-dimensional wave spectrum are available, i.e. the Jonswap spectrum and the one sided Gamma spectrum. The one sided Gamma spectrum is uniquely defined in terms of the sea state description ($H_S$,$T_Z$),

$$W_\eta\left(\omega\right) = A\omega^{-\xi}e^{-B\omega^{-\zeta}};\quad \omega > 0 \tag{B.12}$$

The gamma spectrum may have a variety of shapes depending on the values of the parameter $\xi$ giving the power of the high frequency tail and the parameter $\zeta$ describing the steepness of the low frequency part. The constants $A$ and $B$ are unequally related to $H_S$ and $T_Z$ by

$$A = \frac{1}{16}H_S^2\zeta\left(\frac{2\pi}{T_Z}\right)^{\xi-1}\frac{\Gamma\left(\frac{\xi-1}{\zeta}\right)^{\frac{\xi-3}{2}}}{\Gamma\left(\frac{\xi-3}{\zeta}\right)^{\frac{\xi-1}{2}}},\qquad B = \left(\frac{2\pi}{T_Z}\right)^{\zeta}\frac{\Gamma\left(\frac{\xi-1}{\zeta}\right)^{\frac{\zeta}{2}}}{\Gamma\left(\frac{\xi-3}{\zeta}\right)^{\frac{\zeta}{2}}} \tag{B.13}$$

The gamma spectrum formulae has the following spectra as special cases:

- For $\zeta = 4$ and $\xi = 5$ it yields the Pierson and Moskovitz spectrum.
- For $\zeta = 4$ and $\xi = 5$ and substituting the upcrossing period $T_Z$ with the mean period $T_1$ it yields ISSC (International Ship and Offshore Structure Congress) spectrum.
- For $\zeta = 4$ and $\xi$ it yields a a spectrum that has been used by Ochi and Huble (1976).
- For $\zeta = \xi - 1$ and $\xi$ it yields a spectrum that has been used by Lee and Black (1978).

The Pierson and Moskowitz spectrum applies to deep water conditions and fully developed seas.

The ISSC (International Ship and Offshore Structure Congress) spectrum, recommended by the 15th ITTC (International Towing Tank Conferences) applies to open sea conditions and fully developed seas and may be written as

$$S_\eta(\omega) = H_S^2 \frac{A}{4\omega_1} \left(\frac{\omega}{\omega_1}\right)^{-5} e^{-A\left(\frac{\omega}{\omega_1}\right)^{-4}} \tag{B.14}$$

where $H_S$ is the significant wave height and $\omega_1$ is the mean wave frequency which is related to the mean wave period $T_1$ by

$$\omega_1 = \frac{2\pi}{T_1} \tag{B.15}$$

The mean wave period $T_1$ is defined by

$$T_1 = 2\pi \frac{m_0}{m_1} \tag{B.16}$$

The mean wave period $T_1$ is related to the mean zero up-crossing period $T_Z$ by

$$\frac{T_1}{T_Z} = \frac{\sqrt{m_0 m_2}}{m_1} = \frac{\sqrt{\Gamma\left(\frac{1}{2}\right)}}{\Gamma\left(\frac{3}{4}\right)} = \frac{\sqrt[4]{\pi}}{\Gamma\left(\frac{3}{4}\right)} = \frac{\sqrt[4]{\pi}}{\pi\sqrt{2}}\Gamma\left(\frac{1}{4}\right) = 1.086435 \tag{B.17}$$

The parameter $A$ may be written as

$$A = \frac{1}{\pi}\left(\frac{T_1}{T_Z}\right)^4 = \left(\Gamma\left(\frac{3}{4}\right)\right)^{-4} = 0.44347 \tag{B.18}$$

The Jonswap spectrum applies to limited fetch area and homogeneous wind fields and may be expressed as:

$$S_\eta(\omega) = \alpha g^2 \omega^{-5} e - \frac{5}{4}\left(\frac{\omega}{\omega_p}\right)^{-4} \gamma^a \tag{B.19}$$

where

$$a = e^{\left(-\frac{1}{2}\left(\frac{\frac{\omega}{\omega_p}-1}{\sigma}\right)^2\right)} \tag{B.20}$$

$$\sigma = \begin{cases} \sigma_a & \text{if} \quad \omega \leq= \omega_p \\ \sigma_b & \text{if} \quad \omega >= \omega_p \end{cases} \tag{B.21}$$

In the above equations the following definitions are used: $\alpha$ represents the Philips constant (=0.81 for fully developed sea), $\omega_p$ represents the angular frequency of the spectral peak, $\gamma$ represents the peak enhancement factor, $\sigma_a$ represent the spectrum left width and $\sigma_b$ represents the spectrum right width.

For known $H_S$, $T_Z$, $\sigma_a$, $\sigma_b$ and $\gamma$, the spectral peak frequency $\omega_p$ and $\alpha$ are obtained by numerical integration.

A significant increase in predicted fatigue life is likely to be achieved when the spreading function is adopted.

The one-dimensional wave spectrum is given as input to the Stofat as the one sided Gamma or as the Jonswap spectrum.

- Gamma spectrum

  The Pierson and Moskowitz spectrum corresponds to $(\xi, \zeta) = (5, 4)$. While the parameter choice $\xi = 5$ can be justified from asymptotic considerations, see e.g.[19], the exponent $\zeta$ can be used to adjust the bandwidth of the spectrum. The bandwidth parameter $\delta$ is defined in terms of the three lowest spectral moments as

$$\delta = \frac{\lambda_1}{\sqrt{\lambda_0 \lambda_2}} = \frac{\Gamma\left(\frac{3}{\zeta}\right)}{\sqrt{\Gamma\left(\frac{2}{\zeta}\right)\Gamma\left(\frac{4}{\zeta}\right)}} \tag{B.22}$$

  For $\zeta = 4$, $\delta = 0.92$, and $\delta$ increases for increasing values of $\zeta$.

- Jonswap spectrum
  The Jonswap spectrum can be used to take into account the imbalance of energy flow in the wave system (e.g. when the sea is not fully developed). This will often be the case with a high wind speed. The Jonswap spectrum has a higher peak spectral value than the P-M spectrum, but is more narrow away from the peak so that energy balance is maintained.

  The frequency range of the transfer function $[\omega_1, \omega_N]$ is divided into 200 equistant frequencies. The transfer function is interpolated between the frequencies for which ordinates are given. Response spectrum ordinates are computed by multiplying squared transfer function ordinates with wave spectrum ordinates. The moments of the response spectrum is calculated using trapezoidal integration, assuming linear variation between neighbouring response spectrum ordinates.

The six parameter Ochi-Hubble spectrum consists of essentially two parts; one for the lower frequency components of the wave energy and the other covering the higher frequency components. Each component is expressed in terms of three parameters and the total spectrum is written as a linear combination of the two. Thus, double peaks present in a wave energy density can be modelled with this formulation, e.g. a low-frequency swell along with the high-frequency wind generated waves. The spectrum may be expressed by

$$S_\eta(\omega) = \frac{1}{4} \sum_{j=1}^{2} \frac{\left(\tilde{\lambda}_j \omega_{0j}^4\right)^{\lambda_j}}{\Gamma(\lambda_j)} \frac{H_{Sj}^2}{\omega^{4\lambda_j+1}} e^{-\tilde{\lambda}_j \left(\frac{\omega}{\omega_{0j}}\right)^{-4}} \tag{B.23}$$

where

$$\tilde{\lambda}_j = \frac{4\lambda_j + 1}{4} \tag{B.24}$$

and where $j = 1$ corresponds to the lower frequency components and $j = 2$ to the higher frequency components. $H_{Sj}$, $\omega_{0j}$, $\lambda_j$ are significant wave height, modal frequency of the spectral peak and shape factor of component $j$, respectively. The spectrum is illustrated in Figure B.5

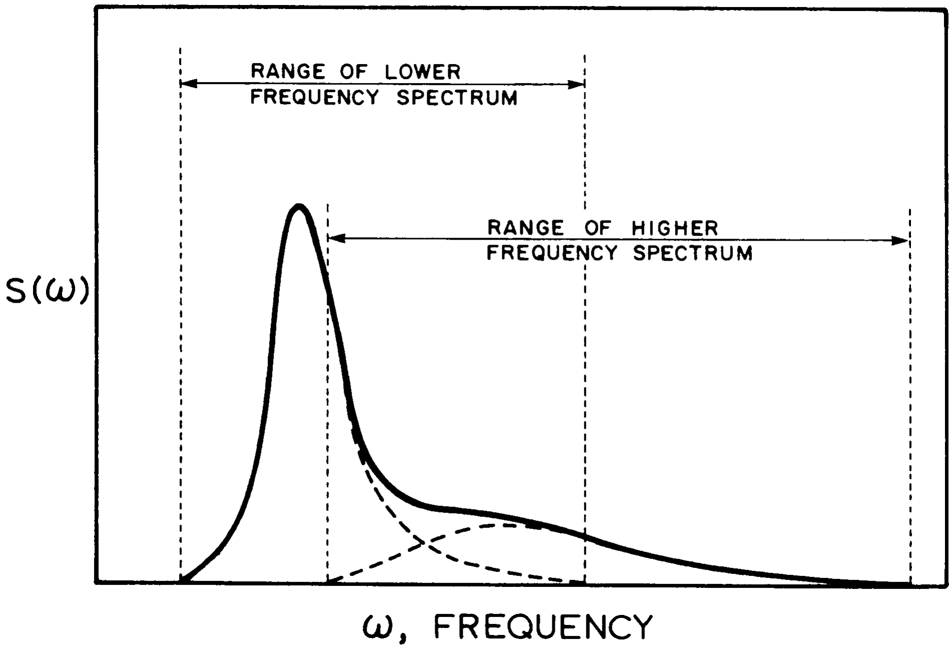



Figure B.5: Ochi-Hubble double peaks spectrum model

If in either spectral component the values of the parameters $H_{Sj}$ and $\omega_{0j}$ are held constant, $\lambda_j$ controls the shape, or, in particular the sharpness of the spectral peak. Thus, $\lambda_j$ is called the spectral shape parameter. If $\lambda_1 = 1$ and $\lambda_2 = 0$, we obtain the Pierson-Moskowitz spectrum model. In the general formulation of Equation B.23 , the equivalent significant height $H_S$ is obtained from

$$H_S = \sqrt{H_{S1}^2 + H_{S2}^2} \tag{B.25}$$

on the assumption of narrowbandedness of the entire spectrum. Generally, the value of $\lambda_1$ is much higher than that of $\lambda_2$.

## B.1.5 Torsethaugen Wave Spectrum

The sea state is described by superposing a part according to locally wind generated sea on another part according to swell. Each one of the parts are described by a generalized Jonswap spectrum. The generalized Jonswap spectrum $S$, as a function of the frequency $\omega$ has the form:

$$S(\omega) = G_0 \omega^{-N_e^{-\frac{N}{M}\left(\frac{\omega}{\omega_p}\right)^{-M}}} \gamma^a \tag{B.26}$$

where $\gamma$ denotes the peak-enhancement factor with exponent $a$ defined by

$$a = e^{-\frac{1}{2}\left(\frac{\omega - \omega_p}{\sigma \omega_p}\right)^2} \tag{B.27}$$

The parameter $\sigma$ is a measure of the width of the spectral peak, here put equal to 0.07 if $\omega \leq \omega_p$ and 0.09 if $\omega > \omega_p$ where $\omega_p$ is the peak frequency, related to peak period $T_p$, by $\omega = {}^{2\pi}/_{\omega_p}$. The normalized factor for the Pierson-Moskovitz form is denoted by $G_0$ and given by:

$$G_0 = \frac{M\left(\frac{N}{M}\right)^{\frac{N-1}{M}}}{\Gamma\left(\frac{N-1}{M}\right)} h \tag{B.28}$$

where $\Gamma$ denotes the complete gamma function. The parameter $h$ denotes a factor used to fit the spectrum to a given significant wave height. In other words:

$$h = H_S \left( \int_0^\infty \frac{M \left(\frac{N}{M}\right)^{\frac{N-1}{M}}}{\Gamma\left(\frac{N-1}{M}\right)} \omega^{-M} e^{-\frac{N}{M}\left(\frac{\omega}{\omega_p}\right)^{-M}} \gamma^a d\omega \right)^{-1} \tag{B.29}$$

It is well known the relation between Pierson-Moskovitz and Jonswap spectrums, meaning that Pierson-Moskovitz is a special case of Jonswap, the same stands between Torsethaugen spectrum and Pierson-Moskovitz and Jonswap. The ordinary Jonswap spectrum is obtained by putting M=4 and N=5. If, in addition $\gamma = 1$, we have the Pierson-Moskovitz (PM) spectrum. In many descriptions of Jonswap and PM spectra, $H_S$ is assumed to be given by Phillip's constant $\alpha$, so that $h = \alpha g^2$, where $g$ represents gravity.

$H_S$, $T_p$, $M$, $N$ and $\gamma$ are dependent of a set of semi-empiric parameters. The functional relations are different for the swell part and the wind part and are different according to whether the total sea state is regarded as wind-dominated or swell-dominated.

Stofat presents 2 options relative to the Torsethaugen spectrum: Full or the Simplified version.

**Basic Constants**

| | | | | |
|---|---|---|---|---|
| AF=6.6 | AE=2.0 | AU=25.0 | A10=0.7 | A1=0.5 |
| KG=35 | KG0=3.5 | KG1=1.0 | R=0.857 | K0=0.5 |
| K00=3.2 | M0=4.0 | B1=2.0 | A20=0.6 | A2=0.3 |
| A3=6.0 | S0=0.08 | S1=3.0 | B2=0.7 | B3=3.0 |

**Full Torsethaugen spectrum formulation:**

Definition of the sea state type:

The seastate is defined as wind dominated or swell dominated according to whether the primary peak period is below or above a value TF given by:

$$TF = AF\,(H_S)^{\frac{1}{3}} \tag{B.30}$$

Based on this, lower and upper period fractions are defined:

$$\epsilon_L = \frac{TF - TP}{TF - AE\sqrt{H_S}}, \qquad \epsilon_U = \frac{TF - TP}{TF - AU} \tag{B.31}$$

The locally fully developed sea concept is used to divide the $T_p - H_S$ space in two different types:

- wind dominated sea where $TP \leq TF$
- swell dominated sea where $TP > TF$

where $TF$ is the spectral peak period for fully developed at the actual location. This is determined by the maximum fetch given by the topography or the typical extent for low pressures in the area. It gives a relation between the maximum wind wave energy (or $H_S$ ) and the corresponding spectral peak period for the actual location, given by B.30.

**Wind dominated Sea $TP \leq TF$:**

**Primary Peak**

Significant wave height:

$$H_{Sp} = H_S \left[ (1 - A10)\, e^{-\left(\frac{\epsilon_L}{A1}\right)^2} + A10 \right] \tag{B.32}$$

Spectral period:

$$T_{pp} = T_p \tag{B.33}$$

Peak enhancement factor:

$$\gamma_p = KG \left(1 + KG0 e^{\frac{H_S}{KG1}}\right) \left(\frac{2\pi H_S}{g T_p^2}\right)^{6/7} \tag{B.34}$$

High frequency exponent:

$$N_p = K0\sqrt{H_S} + K00 \tag{B.35}$$

Spectral width exponent:

$$M_p = M0 \tag{B.36}$$

**Secondary Peak**

Significant wave height:

$$H_{Ss} = H_S\sqrt{1 - \left[(1 - A10)\, e^{-\left(\frac{\epsilon_L}{A1}\right)^2} + A10\right]^2} \tag{B.37}$$

Spectral period:

$$T_{ps} = TF + B1 \tag{B.38}$$

Peak enhancement factor:

$$\gamma_s = 1 \tag{B.39}$$

High frequency exponent:

$$N_s = N_p \tag{B.40}$$

Spectral width exponent:

$$M_s = M_p \tag{B.41}$$

**Swell Dominated Sea $TP > TF$:**

**Primary Peak**

Significant wave height:

$$H_{Sp} = H_S\left[(1 - A20)\, e^{-\left(\frac{\epsilon_U}{12}\right)^2} + A20\right] \tag{B.42}$$

Spectral period:

$$T_{pp} = T_p \tag{B.43}$$

Peak enhancement factor:

$$\gamma_p = (1 + A3\epsilon_U)\, KG \left(1 + KG0 e^{\frac{H_S}{KG1}}\right)\left(\frac{2\pi H_S}{gTF^2}\right)^{6/7} \tag{B.44}$$

High frequency exponent:

$$N_p = K0\sqrt{H_S} + K00 \tag{B.45}$$

Spectral width exponent:

$$M_p = M0 \tag{B.46}$$

**Secondary Peak**

Significant wave height:

$$H_{Ss} = H_S\sqrt{1 - \left[(1 - A20)\, e^{-\left(\frac{\epsilon_U}{A2}\right)^2} + A20\right]^2} \tag{B.47}$$

Spectral period:

$$T_{ps} = \left(\frac{16S0\left(1 - e^{\frac{H_S}{S1}}\right)\left(0.4^{N_s}\right)}{G0H_{s_s}^2}\right)^{-\frac{1}{N_s - 1}} \tag{B.48}$$

Peak enhancement factor:

$$\gamma_s = 1 \quad \text{(B.49)}$$

High frequency exponent:

$$N_s = N_p \quad \text{(B.50)}$$

Spectral width exponent:

$$M_s = M0\left(1 - B2e^{-\frac{H_S}{B3}}\right) \quad \text{(B.51)}$$

**Simplified Torsethaugen spectrum formulation:**

The simplified formulation shares the same basic constants as presented above for the Full spectrum formulation. Differences are, however, encountered in the wind dominated and swell dominated sea states equations. Equations applied for the Simplified spectrum formulation are given in the following.

Definition of the sea state type: The seastate is defined as wind dominated or swell dominated according to whether the primary peak period is below or above a value TF given by Equation B.30. Based on this, lower and upper period fractions are defined by Equation B.31 similar as for the Full spectrum formulation.

**Wind dominated Sea $TP \leq TF$:**

**Primary Peak**

Significant wave height:

$$H_{Sp} = H_S\left[(1 - A10)\, e^{-\left(\frac{\epsilon_L}{A1}\right)^2} + A10\right] \quad \text{(B.52)}$$

Spectral period:

$$T_{pp} = T_p \quad \text{(B.53)}$$

Peak enhancement factor:

$$\gamma_p = KG\left(\frac{2\pi H_S}{gT_p^2}\right)^R \quad \text{(B.54)}$$

High frequency exponent:

$$N_p = M0 \quad \text{(B.55)}$$

Spectral width exponent:

$$M_p = M0 \quad \text{(B.56)}$$

**Secondary Peak**

Significant wave height:

$$H_{Ss} = H_S\sqrt{1 - \left[(1 - A10)\, e^{-\left(\frac{\epsilon_L}{A1}\right)^2} + A10\right]^2} \quad \text{(B.57)}$$

Spectral period:

$$T_{ps} = TF + B1 \quad \text{(B.58)}$$

Peak enhancement factor:

$$\gamma_s = 1 \quad \text{(B.59)}$$

High frequency exponent:

$$N_s = M0 \quad \text{(B.60)}$$

Spectral width exponent:

$$M_s = M0 \quad \text{(B.61)}$$

**Swell Dominated Sea $TP > TF$:**

**Primary Peak**

Significant wave height:

$$H_{Sp} = H_S \left[ (1 - A20)\, e^{-\left(\frac{\epsilon_U}{12}\right)^2} + A20 \right] \tag{B.62}$$

Spectral period:

$$T_{pp} = T_p \tag{B.63}$$

Peak enhancement factor:

$$\gamma_p = KG \left( \frac{2\pi H_S}{gTF^2} \right)^{\frac{6}{7}} \tag{B.64}$$

High frequency exponent:

$$N_p = M0 \tag{B.65}$$

Spectral width exponent:

$$M_p = M0 \tag{B.66}$$

**Secondary Peak**

Significant wave height:

$$H_{Sp} = H_S \left[ (1 - A20)\, e^{-\left(\frac{\epsilon_U}{12}\right)^2} + A20 \right] \tag{B.67}$$

Spectral period:

$$T_{ps} = (H_{Ss})^{1/3} AF \tag{B.68}$$

Peak enhancement factor:

$$\gamma_s = 1 \tag{B.69}$$

High frequency exponent:

$$N_s = N_p \tag{B.70}$$

Spectral width exponent:

$$M_s = M0 \tag{B.71}$$

**The combined spectrum for wind and swell**

Thus the total doubly peaked spectrum is the sum of the generalized Jonswap spectrum for the primary peak, and the generalized Jonswap spectrum for the secondary peak, each dependent on the parameters $H_{Sp}$, $T_{pp}$, $M_p$, $N_p$ and $\gamma_p$ or $H_{Ss}$, $T_{ps}$, $M_s$, $N_s$ and $\gamma_s$. These constants are in turn functions of the basic parameters $H_S$ and $T_p$ for the total spectrum.$H_S$ is the significant wave height of the total spectrum, whereas $T_p$ is taken as the period of the primary peak. In other words the total doubly peaked spectrum $S_{dps}(\omega)$ is constructed as:

$$S_{dps}(\omega) = s\left(\omega; H_S = H_{Sp}; T_p = T_{p_p}; M = M_p; N = N_p\right) + s\left(\omega; H_S = H_{Ss}; T_p = T_{ps}; M = M_s; N = N_s\right) \tag{B.72}$$

## B.2 Global Structural Analysis

### B.2.1 Structural Response

The structural response to hydrodynamic loads can be determined by the use of the finite element method (FEM). Since fatigue damage is a localized phenomenon, the structure and its joints should be modelled to yield realistic load response. This includes modelling of structural stiffness and damping (only for dynamic analysis) and loading.

### B.2.2 Wave Load Calculation

The calculation of wave forces involves both the selection of an appropriate wave theory to describe the water particle kinematics for the given wave condition and determination of hydrodynamic forces.

The linear *Airy wave theory* is generally adopted for fatigue analysis. In the Airy theory water particle velocity and acceleration are linear with wave amplitude. Linear wave theory is based on the assumption that the wave height is much smaller than both the wave length and the water depth.

Hydrodynamic loading on structures with slender members is often calculated by *Morison's equation*, [20]. The in-line force per unit length $\mathbf{p}$ on a vertical slender cylinder in unsteady flow is,

$$\mathbf{p} = C_d \rho \frac{D}{2} \mathbf{u}_n |\mathbf{u}_n| + C_m \rho \pi \frac{D^2}{4} \dot{\mathbf{u}}_n \quad \text{(B.73)}$$

where $\rho$ is the water density, $D$ is the diameter, $\mathbf{u}_n$ and $\dot{\mathbf{u}}_n$ are respectively the water particle velocity and acceleration normal to the cylinder and $C_d$ and $C_m$ are the drag and inertia coefficients, respectively. Hydrodynamic forces calculated by use of regular waves and Morison's equation are a very simple description of a complex phenomenon.

The *drag* and *inertia* coefficients are difficult to measure under realistic flow conditions and large uncertainties are related to their magnitude, [26]. The coefficients are dependent on several factors and structural surface roughness and wave kinematics are probably the most important ones. However, to simplify the analysis these coefficients are usually assumed to be constant for all the structural force segments. Fixed values of the coefficients are normally used. Typical values for cylindrical members ranges from $0.6$ to $1.2$ for $C_d$ and from $1.3$ to $2.0$ for $C_m$, [15]. It has been a common practice to apply $C_d = 1.0$ and $C_m = 2.0$. Recent research, [26] and [2], indicates an increase in the drag coefficient and an reduction in the inertia coefficient for non-smooth circular cylinders. The choice depends on the marine growth expected. However, the specification of appropriate values of $C_d$ and $C_m$ is still a critical research issue.

### B.2.3 Structural Analysis

The major element of the frequency domain analysis is the determination of the response of the structure under sinusoidal waves as function of wave period or angular frequency. This function is called the *response transfer function*. The response transfer functions for section forces and moments in each beam end are usually developed by analysing the structure subjected to unit height waves of different angular frequencies and different directions. The number of wave periods (frequencies) selected for the computation of the transfer function should be considered carefully. A sufficient number of wave periods have to be used to adequately define the transfer function over an expected range of wave energy. Special care should be given in choosing wave periods close to the eigenperiods of the structure.

The transfer from wave height to wave force is non-linear due to the drag term in the Morison equation. To solve this problem, basically two approaches exist. One is to make the drag force *linear* and compute the response based on the linear load, i.e. *wave height linearization*. The other approach is to compute the response using the non-linear force and then linearize the response in one sea state, i.e. *stochastic linearization*, [2]. The linearization of the drag term will introduce uncertainties for members where drag load is of importance, [27]. For the major range of the waves causing fatigue, inertia forces are dominating on jacket structures and the wave height/response is approximately linear for the major part of the elements.

The linear wave theory does not account for the fluctuating water surface due to the passage of waves and is strictly applicable only up to the still water level (SWL). The use of a linear approach, therefore, can not yield realistic forces around the still water level. Various methods have been suggested to modify the linear wave theory to incorporate variable submergence effect, e.g. [5], [6] , [32], [14].

### B.2.4 Stochastic Linearization

Within a stationary sea state with significant wave height $H_S$ and mean wave period $T_Z$ the stress process is expressed as

$$\sigma(t) = aX(t)|X(t)| + \dot{X}(t) \quad \text{(B.74)}$$

where $X(t)$ is an auxiliary zero mean stationary Gaussian process, [4].

This choice covers the two limiting cases described in the previous section, i.e., a process proportional to the wave loading on one horizontal member according to the Morison formula and a Gaussian process. $X\left(t\right)$ is obtained through a linear filtering with transfer function $H_{\eta x}\left(\omega\right)$ of the sea elevation process $\eta\left(t\right)$. The variances of $X\left(t\right)$, $\dot{X}\left(t\right)$ and $\ddot{X}\left(t\right)$ are

$$\sigma_x^2 = Var\left[X\left(t\right)\right] = \int_0^\infty |H_{\eta x}\left(\omega\right)|^2 \cdot W_\eta\left(\omega\right) d\omega = H_S^2 c\left(T_Z\right) \tag{B.75}$$

$$\sigma_{\dot{x}}^2 = Var\left[\dot{X}\left(t\right)\right] = \int_0^\infty \omega^2 |H_{\eta x}\left(\omega\right)|^2 \cdot W_\eta\left(\omega\right) d\omega = H_S^2 d\left(T_Z\right) \tag{B.76}$$

$$\sigma_{\ddot{x}}^2 = Var\left[\ddot{X}\left(t\right)\right] = \int_0^\infty \omega^4 |H_{\eta x}\left(\omega\right)|^2 \cdot W_\eta\left(\omega\right) d\omega = H_S^2 e\left(T_Z\right) \tag{B.77}$$

The one-sided wave spectra density is assumed of the form

$$W_\eta\left(\omega\right) = \frac{H_S^2}{16} w\left(\omega, T_Z\right) \tag{B.78}$$

in accordance with, e.g., the Pierson-Moskowitz and Jonswap spectra, and with the following properties for $w\left(\omega, T_Z\right)$

$$\int_0^\infty w\left(\omega, T_Z\right) dw = 1 \quad ; \quad \int_0^\infty \omega^2 w\left(\omega, T_Z\right) dw = \left(\frac{2\pi}{T_Z}\right)^2 \tag{B.79}$$

The dependence on $H_S$ and $T_Z$ is thus separated. The variance of the stress process is

$$Var\left[s\left(t\right)\right] = 3a^2\sigma_x^4 + \sigma_{\dot{x}}^2 = \sigma_{\dot{x}}^2 \cdot \left(1 + K^2\right) \tag{B.80}$$

where $K$ is a measure of the importance of the nonlinearity in the drag loading leading to the non-Gaussian response

$$K = \frac{a\sigma_x^2}{\sigma_{\dot{x}}} = \frac{ac\left(T_Z\right)}{\sqrt{d\left(T_Z\right)}} H_S \tag{B.81}$$

The variance of the derivative of the response process is

$$Var\left[\dot{s}\left(t\right)\right] = Var\left[2a\dot{X}\left(t\right)|X\left(t\right)| + [\ddot{X}\left(t\right)\right] = 4a^2\sigma_x^2\sigma_{\dot{x}}^2 + \sigma_{\ddot{x}}^2 \tag{B.82}$$

The distribution of $s\left(t\right)$ is generally referred to as the Pierson and Holmes distribution, [24]. The probability density function is, see also [19].

$$f_s\left(s\right) = \frac{1}{4\pi\sqrt{K}} e^{\left(-\frac{s^2}{2}\right)} \left[I\left(\frac{1}{2K} + s\right) + I\left(\frac{1}{2K} - q\right)\right] \tag{B.83}$$

where the function $I\left(\right)$ is

$$I\left(z\right) = \sqrt{\pi} e^{\left(-\frac{z^2}{4}\right)} D_{-\frac{1}{2}}\left(z\right) \tag{B.84}$$

$I\left(\right)$ can thus be determined from the parabolic cylinder function $D_{\frac{-1}{2}}\left(z\right)$ or by direct numerical integration. The formulation given by Equation B.74 have been justified for various platform responses obtained by full scale measurements. The agreement with the Pierson and Holmes distribution is very good.

In narrow band approximation the distribution of peak values for a process of type Equation B.74 has been determined, see, e.g. [19] and [3].

$$f_{max} = \begin{cases} \frac{x}{\sigma_{\dot{x}}} e^{\left(-\frac{1}{2}\left(\frac{x}{\sigma_{\dot{x}}}\right)^2\right)} & ; \quad 0 < x < \frac{\sigma_{\dot{x}}}{2K} \\ \frac{1}{2K\sigma_{\dot{x}}} e^{\left(-\frac{1}{2K}\left(\frac{x}{\sigma_{\dot{x}}} - \frac{1}{4K}\right)^2\right)} & ; \quad \frac{\sigma_{\dot{x}}}{2K} \leq x \end{cases} \tag{B.85}$$

from which the distribution of stress range $S$ is directly determined when the stress range is taken as two times the peak value. The stress range distribution is thus determined completely in terms of the nonlinearity factor $K$ and the variance of the process, as $\sigma_{\dot{x}}$ is determined from the variance and $K$ according to Equation B.82.

$$\sigma_{\dot{x}}^2 = \frac{Var\left[\sigma\left(t\right)\right]}{1 + 3K^2} \tag{B.86}$$

In the same narrow band approximation the number of stress cycles per unit time is taken as the mean number of up-crossings of zero, i.e.

$$\nu_0 = \frac{1}{2\pi}\frac{\sigma_{\dot{x}}}{\sigma_x} = \frac{1}{2\pi}\left(\frac{d\left(T_Z\right)}{c\left(T_Z\right)}\right)^{\frac{1}{2}} \tag{B.87}$$

and the fatigue damage $D$ for an S-N curve of the form $N = A \cdot S^{-m}$ and a time period $T$ is

$$D = \frac{N}{A}E\left[S^m\right] = \nu_0\frac{T}{A}\sigma^m\left(\left(\frac{8}{3K^2+1}\right)^{\frac{m}{2}} \cdot \gamma\left(1+\frac{m}{2};\frac{1}{8K^2}\right) + e^{\left(\frac{1}{8K^2}\right)} \cdot \left(\frac{16K^2}{3K^2+1}\right)^{\frac{m}{2}} \cdot \Gamma\left(1+m;\frac{1}{4K^2}\right)\right) \tag{B.88}$$

where $\Gamma\left(\right)$ and $\gamma\left(\right)$ are the Complementary Incomplete and Incomplete Gamma functions, respectively.

Similar expressions can easily be calculated for S-N curves with an endurance limit or consisting of several piecewise as linear parts in a $\log\left(S\right) - \log\left(N\right)$ diagram.

For a given sea state the process Equation B.82 is determined by four numbers, $a$, $\sigma_x$, $\sigma_{\dot{x}}$, $\sigma_{\ddot{x}}$. Two sea states are now considered, with the same value of $T_Z$, and $H_{S1}$ and $H_{S2}$. a spectral analysis with stochastic linearization is performed for each sea state and the two variances are denoted $\sigma_1^2$ and $\sigma_2^2$, respectively.

$$\sigma_1^2 = 3a^2H_{S1}^4c\left(T_Z\right)^2 + H_{S1}^2d\left(T_Z\right) \tag{B.89}$$

$$\sigma_2^2 = 3a^2H_{S2}^4c\left(T_Z\right)^2 + H_{S2}^2d\left(T_Z\right) \tag{B.90}$$

From these equations follows

$$a^2c\left(T_Z\right)^2 = \frac{1}{3}\frac{H_{S2}^2\sigma_1^2 - H_{S1}^2\sigma_2^2}{H_{S1}^2H_{S2}^2\left(H_{S1}^2 - H_{S2}^2\right)} \tag{B.91}$$

$$d\left(T_Z\right)^2 = \frac{H_{S1}^4\sigma_2^2 - H_{S2}^2\sigma_1^2}{H_{S1}^2H_{S2}^2\left(H_{S1}^2 - H_{S2}^2\right)} \tag{B.92}$$

$$K = \frac{ac\left(T_Z\right)}{\sqrt{d\left(T_Z\right)}}H_S = \left(\frac{H_{S2}^2\sigma_1^2 - H_{S1}^2\sigma_2^2}{H_{S1}^4\sigma_2^2 - H_{S2}^2\sigma_1^2}\right)^{\frac{1}{2}} H_S \tag{B.93}$$

The variance of $\sigma\left(t\right)$ in a sea state with the same zero crossing period $T_Z$ and an arbitrary significant wave height $H_S$ is now expressed in terms of variances $H_{S1}$ and $H_{S2}$ as

$$Var\left[\sigma\left(t\right)\right] = 3a^2H_S^4c\left(T_Z\right)^2 + H_S^2d\left(T_Z\right) = \frac{\left(H_{S2}^2\sigma_1^2 - H_{S1}^2\sigma_2^2\right) \cdot H_S^4 + \left(H_{S1}^2\sigma_2^2 - H_{S2}^2\sigma_1^2\right) \cdot H_S^2}{H_{S1}^2H_{S2}^2\left(H_{S1}^2 - H_{S2}^2\right)} \tag{B.94}$$

$$\gamma_2 = \frac{105K^4 + 18K^2 + 3}{\left(3K^2 + 1\right)^2} \tag{B.95}$$

For the variances of $\dot{\sigma}(t)$ in the two selected sea states follows similarly to Equation B.89 and Equation B.90

$$\dot{\sigma}_1^2 = 4a^2 H_{S1}^4 c(T_Z) d(T_Z) + H_{S1}^2 e(T_Z) \tag{B.96}$$

$$\sigma_2^2 = 4a^2 H_{S2}^4 c(T_Z) d(T_Z) + H_{S2}^2 e(T_Z) \tag{B.97}$$

These equations permit an evaluation of $a^2$ and $e(T_Z)$. The variance on $\dot{\sigma}(t)$ in a sea state with the same zero crossing period $T_Z$ and an arbitrary significant height $H_S$ is now expressed in terms of the variances of $\dot{\sigma}(t)$ for $H_{S1} H_{S2}$ as

$$Var\left[\dot{\sigma}(t)\right] = \frac{\left(H_{S2}^2 \dot{\sigma}_1^2 - H_{S1}^2 \dot{\sigma}_2^2\right) \cdot H_S^4 + \left(H_{S1}^2 \dot{\sigma}_2^2 - H_{S2}^2 \dot{\sigma}_1^2\right) \cdot H_S^2}{H_{S1}^2 H_{S2}^2 \left(H_{S1}^2 - H_{S2}^2\right)} \tag{B.98}$$

The zero crossing frequency in the narrow band approximation becomes

$$\nu_0 = \frac{1}{2\pi} \left( \frac{3}{4} \frac{H_{S2}^2 \dot{\sigma}_1^2 - H_{S1}^2 \dot{\sigma}_2^2}{H_{S2}^2 \sigma_1^2 - H_{S1}^2 \sigma_2^2} \right)^{\frac{1}{2}} \tag{B.99}$$

A basic assumption for the above results is that very good approximations for the variances of $\sigma()$ and $\dot{\sigma}()$ are obtained by the stochastic linearization procedure. Reported experience for jacket structures comparing results of simulation and stochastic linearization confirm that such a stochastic linearization procedure is possible.

So far results have been provided for one value of $T_Z$ and an arbitrary value $H_S$. Experience shows that the linearized transfer function depends only very little on the value of $T_Z$ used in the linearization. It is therefore suggested to use the transfer functions for all values of $T_Z$. Based on the results from two sea states it is thus possible to determine the variances of the response process and its derivative as well as the parameter $K$ measuring the deviation from a Gaussian process for any sea-state. A fatigue analysis with a summation of damage over all sea states in the sea scatter diagram can then be performed. As for a traditional spectral analysis or a time domain analysis, the analysis must be repeated for each main wave direction. The inclusion of a wave energy spreading in the analysis only affects the stochastic linearization procedure, while the subsequent analysis is unaltered.

## B.3 Local Stress Calculation

Stress amplifications are classified into two types; geometric and notch. Geometric stress amplification arises from the gross geometrical configuration including the presence and size of the weld. In Stofat the geometric stress amplification is accounted for explicitly in the calculation of the hot spot stresses. The notch stress amplification arises from the local geometry at a weld toe and varies randomly along a weld and from weld to weld. It is very difficult to measure and its influence in Stofat is incorporated in the fatigue strength in terms of the S-N curves.

The spectral density of the hotspot stress is expressed as

$$W_\sigma(\omega) = \sum_{i=1}^{k-6} \sum_{j=1}^{k-6} I_i \cdot\ J_j \cdot W_{F_i W_j}(\omega) = W_\eta(\omega) \cdot \sum_{i=1}^{k-6} \sum_{j=1}^{k-6} I_i \cdot\ J_j \cdot H_{\eta F_i}(\omega) H_{\eta F_i}(\omega) \tag{B.100}$$

for long crested sea with a similar expression for short crested sea. The squared modulus of the stress transfer function is then

$$\left|H_{\eta\sigma}\right|^2 = \frac{W_\sigma(\omega)}{W_\eta(\omega)} = \sum_{i=1}^{k-6} \sum_{j=1}^{k-6} I_i \cdot\ J_j \cdot H_{\eta F_i}(\omega) H_{\eta F_i}(\omega) \tag{B.101}$$

for long crested sea, and similarly for short crested sea

$$|H_{\eta\sigma}|^2 = \frac{W_\sigma(\omega)}{W_\eta(\omega)} = \sum_{r=1}^{k-6}\sum_{i=1}^{k-6}\sum_{j=1}^{k-6} I_i \cdot\ J_j \cdot H_{\eta F_i}(\omega,\theta_r)\, H_{\eta F_i}(\omega,\theta_r) \tag{B.102}$$

The influence numbers $I_i$ or the stress concentration factors $SCF_i$ can be determined by a finite element analysis or by model testing. It is highly desirable that the stiffness of the weld is explicitly included in the finite element model or the test model. When the hot spot stresses are determined by model testing it is difficult to separate the geometric from the notch stress concentration in a unique and indisputable way. One of the procedures that may be used is that of [11].

This procedure is based on the observation that the stresses increase at a moderate rate near the weld except for the region immediate to the weld where a more rapid increase or decrease is observed due to the notch effect. The geometric stress concentration at the weld toe is obtained by a linear extrapolation of stress from a point chosen at a distance not less than 0.3 times the thickness or 4 mm from the weld toe. The former criterion (0.3 times the thickness) is at present a tentative recommendation which can be modified when more extensive test results on members with thickness exceeding 20 mm become available.

The approach of Gibstein exhibits the following significant advantages:

- It provides fatigue strength results, SN curves, with minimum scatter
- It provides results which are in good agreement with results from finite element analysis
- It gives consistent fatigue strength results independent of the type of tubular joint tested
- It is readily applicable in experimental work and is reasonably insensitive to measurement inaccuracies

### B.3.1 Hotspot Stresses for Other Welded Connections

For these joints, hot spots are defined as points adjacent to the weld toe. Traditionally these joints are treated somewhat differently than tubular joints in that both the geometric and the notch stress amplifications are incorporated in the SN curve. A joint is classified according to some rules and the appropriate SN curve is then automatically defined.

The fatigue analysis for these joints is completely based on nominal stresses therefore the stress concentration factors are thus equal to one. It is very important to include bending stresses where these will occur due to, e.g., misalignment.

### B.3.2 Hotspot Stresses for Details in Ship Structures

In [30] stress concentration factors are denoted K-factors and are defined

$$K = \frac{\sigma_{notch}}{\sigma_{nominal}} \tag{B.103}$$

The SN curves defined in the [30] and predefined in Stofat are given for smooth specimens where the notch stress is equal to the nominal stress: $K = 1.0$.

The relation between the notch stress range to be used together with the S-N curve and the nominal stress range is

$$\Delta\sigma = K \cdot \Delta\sigma_{nominal} \tag{B.104}$$

All stress risers have to be considered when evaluating the notch stress. This can be done by multiplication of K-factors arising from different causes, or by using a finite element model with sufficiently detailed mesh to represent the stress gradient. The resulting K-factor to be used for calculation of notch stress is derived as

$$K = K_g \cdot K_w \cdot K_{te} \cdot K_{ta} \cdot K_n \tag{B.105}$$

where

$K_g$ stress concentration factor due to the gross geometry of the detail considered.

$K_w$ stress concentration factor due to the weld geometry. $K_w = 1.5$ if not otherwise stated

$K_{te}$ additional stress concentration factor due to eccentricity tolerance (normally used for plate connections only)

$K_{ta}$ additional stress concentration factor due to angular mismatch (normally used for plate connections only)

$K_n$ additional stress concentration factor for unsymmetrical stiffeners on lateral loaded panels, applicable when the nominal stress is derived from simple beam analysis

Note that according to DNV Classification Notes 30.7, see [30], the lateral panel load factor, $K_n$ should only be applied to unsymmetric stiffeners on laterally loaded panels when such stiffeners are included in the Stofat model, applicable when the nominal stress is derived from simple beam analysis. [30] prescribes different factors for the web and flange. In Stofat which is based on stresses derived from finite element models, this factor should be applied with care and in accordance with rule specifcations and recommendations.

Stress type dependent K-factors ($K_{axial}$, $K_{bending}$, and $K_{shear}$) may be specified for axial-, bending- and shear stress components of the shell elements. The stress type K-factors are resulting factors from multiplication of the five K-factor components given above for each stress type, i.e.:

$$K_{axial} = (K_g \cdot K_w \cdot K_{te} \cdot K_{ta} \cdot K_n)_{axial} \tag{B.106}$$

$$K_{bending} = (K_g \cdot K_w \cdot K_{te} \cdot K_{ta} \cdot K_n)_{bending} \tag{B.107}$$

$$K_{shear} = (K_g \cdot K_w \cdot K_{te} \cdot K_{ta} \cdot K_n)_{shear} \tag{B.108}$$

Application of axial- and bending K-factors requires that the normal stresses of the shell elements are decomposed into axial- and bending stress components, see Figure B.6

$$\sigma_{axial} = \frac{(\sigma_{top} + \sigma_{bot})}{2} \tag{B.109}$$

$$\sigma_{bending} = \frac{(\sigma_{top} - \sigma_{bot})}{2} \tag{B.110}$$

where $\sigma_{axial}$, $\sigma_{top}$ are the normal components of the stress point stresses below and above the middle plan at same position within the shell element. Applying K-factor to the axial and bending stresses the scaled normal stresses of the stress points may be calculated as, see Figure B.6:

$$(\sigma_{bot}) = k_{axial} \cdot \sigma_{axial} - k_{bending} \cdot \sigma_{bending} \tag{B.111}$$

$$(\sigma_{top}) = k_{axial} \cdot \sigma_{axial} + k_{bending} \cdot \sigma_{bending} \tag{B.112}$$

Equation B.111 and Equation B.112 apply to the real and imaginary parts of the local $\sigma_x$ and $\sigma_y$ stress components of the shell elements

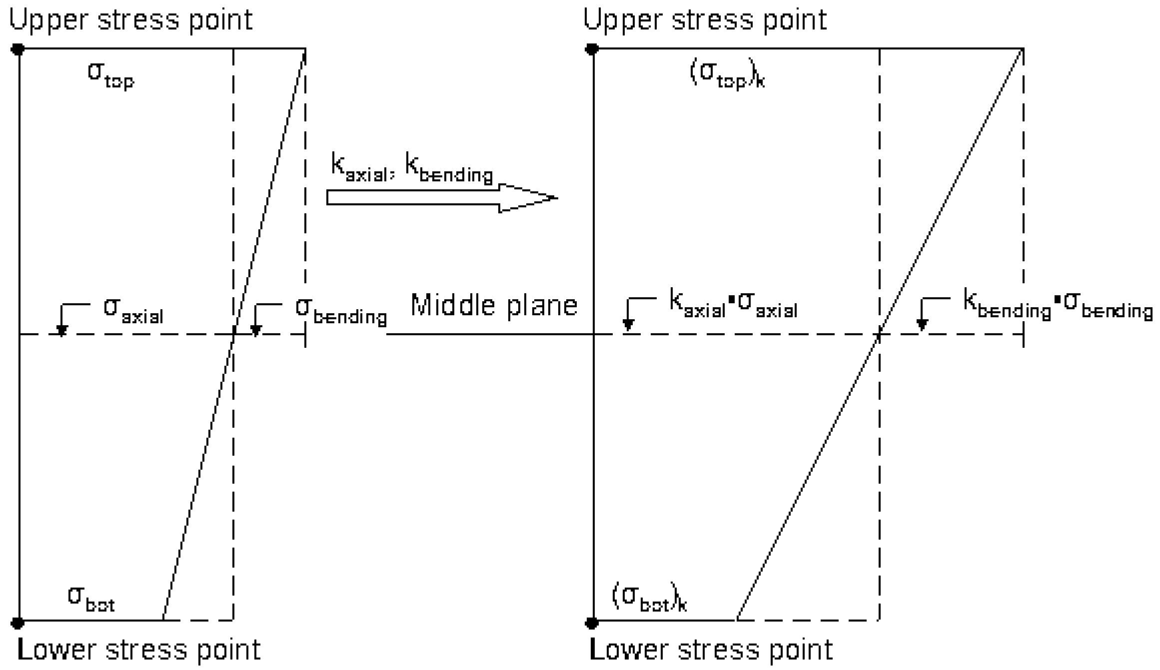



Figure B.6: Normal stress component of shell elements scaled by axial and bending stress K-factors

## B.4 Stress Ranges and Cycles

The fatigue strength is expressed in terms of the number of stress cycles $N$ of constant stress range $S$ leading to failure. Statistics for the number of stress cycles and the stress range distribution must consequently be produced from the statistical description of the hotspot stress process.

For a random stress process the definition of stress cycles is not unique and several different methods are used, including the peak counting method, the range counting method and the rain flow counting. A detailed description of the methods can be found in e.g., [19]. For a narrow band stress process there is only one maximum between two consecutive up-crossings of the mean level making the identification of stress cycles straightforward. The three mentioned counting methods also give identical results for such a process. For a wide band process or a process with a multi mode spectral density function there may be several local maxima between one up-crossing of the mean level and the following up-crossing, and the three counting methods give different results. It is generally believed that the rainflow counting method gives results which are in better agreement with experimental results than the peak counting method which tends to overestimate damage and the range counting method which tends to underestimate damage. The rain flow counting method is, however, used for time series of the stress process. The rainflow counting method is made available in Stofat and may be switched on by the command DEFINE FATIGUE-RAINFLOW-COUNTING. Time history of the stresses are generated from the frequency domain representation of the stresses by Inverse Fast Fourier Transformation (IFFT). It should be noted that use of rainflow counting in Stofat is considerable more time consuming than using the spectral density approach.

For offshore jacket structures the hot spot stress process tends to be narrow-banded. The wave loading is reasonably narrow banded and structures behaving in a quasi static manner therefore have a narrow banded response although cancellation effects may give rise to a bimodal or even multi modal spectral density of the response.

In [19] it is shown that applying the peak counting method the number of stress cycles is equal to the number of up-crossings of the mean level. The mean number of stress cycles for a stationary stress process in a time period $t$ is then

$$N_t = \nu_0 t \tag{B.113}$$

where $\nu_0$ is the mean up-crossing rate of the process.

The stress range $S$ is a random variable and its density function is obtained in connection with stress peak density function. It can be shown, see [18], that the stress peak density may be taken as

$$f_{max}(x) = -\frac{1}{\nu_0}\frac{d\nu^+(x)}{dx}; \qquad x > 0 \tag{B.114}$$

where $\nu^+$ is the mean up-crossing rate for the stress process. For a zero mean Gaussian process with variance $\sigma^2$, $f_{max}(x)$ becomes

$$f_{max}(x) = \frac{x}{\sigma^2}e^{\left(-\frac{x^2}{2\sigma^2}\right)}; \qquad x > 0 \tag{B.115}$$

i.e., a Rayleigh distribution. The probability density of minima is similar to Equation B.114

$$f_{min}(x) = \frac{1}{\nu_0}\frac{d\nu^-(x)}{dx}; \qquad x < 0 \tag{B.116}$$

where $\nu^-$ is the mean down crossing rate of level $x$. Due to symmetry $f_{max}(x) = f_{min}(-x)$ for the stress processes obtained in Stofat. The stress range is therefore taken as two times the peak value and its density function is for a Gaussian stress process

$$f_s(s) = \frac{s}{2\sigma^2}e^{\left(-\frac{s^2}{8\sigma^2}\right)}; \qquad s > 0 \tag{B.117}$$

When a steady current is introduced $f_{max}(x) \neq f_{min}(-x)$ and calculation of the stress range distribution becomes more complicated. This is described in detail in [19].

For a Gaussian stress process it is observed that the number of stress cycles and the stress range density function are given solely in terms of the mean up-crossing $\nu_0$ and the variance $\sigma^2$. These two parameters are determined from the moments of the one sided stress spectral density function. The spectral moments are denoted,

$$\lambda_i = \int_0^\infty \omega^i W_i(\omega)\, d\omega \tag{B.118}$$

The variance $\sigma^2$ and the mean up-crossing rate $\nu_0$ of the stress process $s(t)$

$$\sigma^2 = Var[s(t)] = \lambda_0 \tag{B.119}$$

$$\nu_0 = \frac{1}{2\pi}\sqrt{\frac{\lambda_2}{\lambda_0}} \tag{B.120}$$

## B.5 Effect of Forward Speed

When the structure is moving relative to the sea, both the values of the transfer function and the frequency of encounter will be affected.

It is assumed that any effects on the loading of the structure is taken care of by the wave loading programs.

A shift in frequency is taken into account by retrieving both wave frequency and frequency of encounter from the wave loading program. The wave frequency is used when computing the wave spectrum for each sea state, and when computing the response spectrum from the transfer functions. When Jonswap wave spectrum is selected, calculation of moments of the response spectrum is performed by numeric integration over a fixed number of intervals taking the frequency of encounter into account.

## B.6 Effect of Static Stresses

The procedure for the fatigue analysis is based on the assumption that it is only necessary to consider the range of cyclic principal stresses in the determining the fatigue endurance. However, some reduction in the fatigue damage accumulation can, according to DNV Classification Notes No. 30.7, see [30], be credited when parts of the stress cycle range are in compression. Static stresses present in the material from still water loads may contribute to a reduction of the fatigue damage and may be of interest to consider.

In Stofat the effect of static stresses from an input static load case is accounted for by performing a possible reduction in the cyclic stress range according to procedure described in [30]. The calculated stress range $(\Delta s)$ is multiplied by a stress reduction factor$(f_m)$ as obtained from Figure B.7 before entering the SN-curve. The size of the reduction factor depends on whether the mean cyclic stress $(s_m)$ is tension or compression. The mean cyclic stress is obtained by the normal component of the static stress and the cyclic principal stress, where static stresses of the fatigue check point are transformed to the direction of the applied principal stress. The reduction factor varies linearly between the limit values $(ft_{lim})$ in tension and $(fc_{lim})$ in compression when mean cyclic stress is less than half the stress range in tension and compression, respectively, otherwise the reduction factor is constant. [30] prescribes the limit values. Default limit values are $ft_{lim} = 1.0$ in tension and $fc_{lim} = 0.6$ in compression.

The static load case applied may be a combination of several basic load cases. Stofat combines such basic load cases provided that they are present on the interface file and the combination described by load combination records.

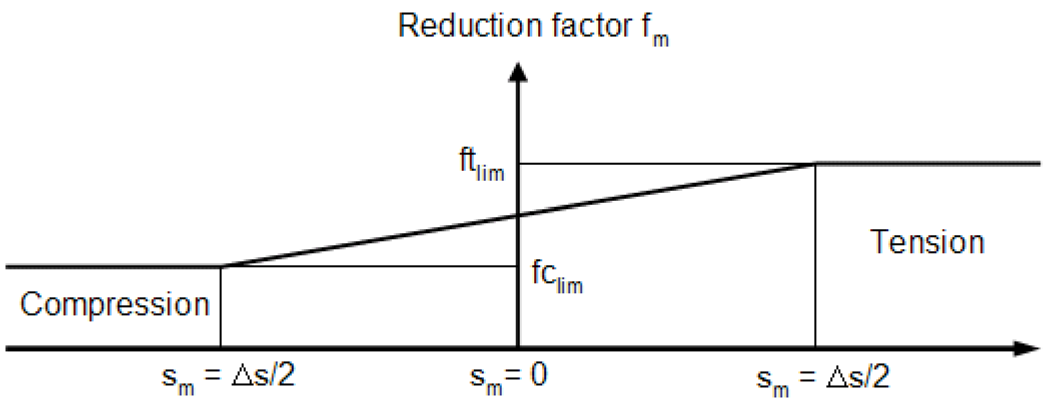



Figure B.7: Stress range reduction factor

## B.7 Weld Normal Line

DNV Classification Notes No. 30.7, see [30] , prescribes that the maximum principal stress range within a sector of $45°$ of the normal to the weld toe should be used for fatigue assessment of welded structures. Fatigue damage and crack formation at the weld toe are mainly caused by stresses within this sector. Using maximum principal stress components outside this sector may overestimate the fatigue damage taken place at the weld toe.

A stress sector for this purpose may be defined by the Weld Normal (WN) line facility of Stofat. A WN line is specified together with an angle, $\alpha$, defining the extension of the stress sector related the WN line, see Figure B.8. $\alpha$ is counted from the WN line to the border of the stress sector and may take values in the range of $\alpha = 0°$ and $\alpha = 90°$.

Principal stresses and principal directions are calculated on basis of the component stresses at the fatigue check point. The axes of the principal stresses are tested to be inside or outside the stress sector. The maximum stress component of the principal axes inside the sector is applied in the fatigue analysis. An illustration is given in Figure B.8.

Two methods are available in Stofat, see command ASSIGN WELD-NORMAL-LINE-METHOD:

1. SECTOR-STRESS method and
2. AREA-STRESS method

SECTOR-STRESS Method In this method the first (maximum) principal stress component is applied in the fatigue analysis when the axis direction of this principal stress component is located inside or along the borders of the stress sector. Otherwise, i.e when the axis direction is outside the stress sector, zero damage is enforced.

AREA-STRESS Method In this method the largest principal stress component inside the stress sector is applied in the fatigue analysis. If none of principal stresses are located inside the stress sector, the principal stress component closest to the border lines is applied in the fatigue analysis. An illustration is given in Figure B.8 where principal stress axis I is outside and principal axis II is inside the stress sector. Stress component of principal axis II is in this case used in the fatigue analysis.

A stress sector of $\alpha = 90°$ includes the whole area around the fatigue check point. All three principal stress axes will be inside the sector and the first principal stress component is always used.$\alpha = 90°$ will thus give the same fatigue damage as if not using the WN line.

If none of the principal stress components are inside the stress sector ($\alpha = 0°$ or $\alpha < 90°$), the three principal axes outside the stress sector are projected orthogonal on the WN line and the axis with the largest length component along the WN line is the one that coincide or is closest to the border lines and is selected.

A WN line must be assigned to an element or a hotspot to be actively applied. A series of WN lines may be generated and assigned to individual elements and hotspots. An element or a hotspot can be connected to only one WN line which are applied to all fatigue check points of the element and the interpolation points of the hotspot as well as the hotspot itself.

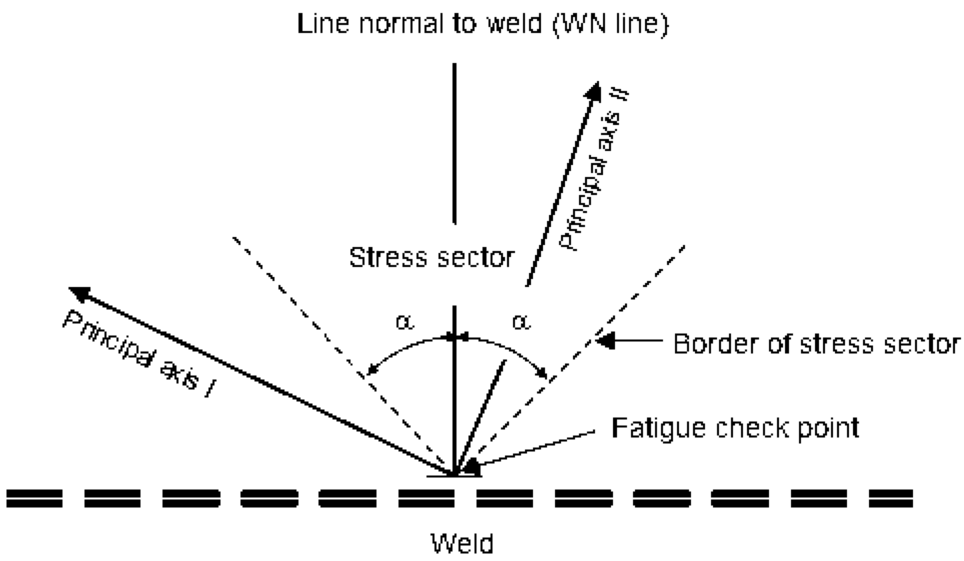



Figure B.8: Weld Normal (WN) line and related stress sector

## B.8 Calibration of Weibull Long Term Stress Range Distribution

Within each short term sea state the distribution of stress ranges has been determined as described in Section B.3. For a Gaussian stress response process, stress ranges $S$ are Rayleigh distributed under a narrow band assumption.

$$F_S(s) = 1 - e^{\left(-\frac{S^2}{8\sigma^2}\right)}; \qquad S > 0 \tag{B.121}$$

where $\sigma$ is the standard deviation of the process. When the response is non-Gaussian e.g. due to the nonlinear drag loading, stress ranges are assumed to follow the distribution, see Section B.2.4.

$$F_S = \begin{cases} 1 - e^{\left(-\frac{S^2}{8\sigma^2}\right)} & ; \quad 0 < S \le \frac{\sigma}{K} \\ 1 - e^{\left(-\frac{S - \frac{\sigma}{2K}}{4\sigma K}\right)} & ; \quad \frac{\sigma}{K} < S \end{cases} \tag{B.122}$$

The long term distribution of stress ranges is obtained as a weighted average of the short term distributions, with the weights proportional to the number of stress cycles in a specific short term sea state. Each sea state is described by the significant wave height $H_S$, the mean zero crossing period $T_Z$, and the mean wave direction $\Theta$. For a hot spot the short term stress range distribution function for the *i*-th sea state is denoted as $F_S(S, H_S, T_Z, \Theta)_i$, where $F_S()$ is given in by the equations above where the standard deviation $\sigma$ depends on $(H_S, T_Z, \Theta)$.

The fraction of sea states with the ith combination of $(H_S, T_Z, \Theta)$ is denoted by $q_i$, and the mean zero crossing frequency for the stress process with this sea state parameter combination is denoted as $\nu_{0,j}$. The long term mean zero crossing frequency is

$$\nu_{0,\textit{long term}} = \sum_{H_S} \sum_{T_Z} \sum_{\Theta_i} q_0 \cdot \nu_{0,i} \tag{B.123}$$

since the sum of the weights $q_i$ is unity. The expected number of stress cycles in a time period $t$ is obtained by multiplying $\nu_0$,long term by $t$.

The long term distribution of stress ranges may now be determined as

$$F_{S,\textit{long term}} = \frac{1}{\nu_{0,\textit{long term}}} \cdot \sum_{H_S} \sum_{T_Z} \sum_{\Theta_i} q_0 \cdot \nu_{0,i} \cdot F_S(S, H_S, T_Z, \Theta)_i \tag{B.124}$$

This long term distribution function is of a somewhat complicated form and requires considerable computation time. A fit to a simpler distribution is therefore of interest. During the 1960's research related to such distribution fitting was performed by [21]. Among the distribution types considered, the best fit was reported for a Weibull distribution and this choice has been confirmed in many later studies. The two parameter Weibull distribution has the form

$$F_S(S) = 1 - e^{\left(-\left(\frac{S}{A}\right)^B\right)} \quad ; \qquad S > 0 \tag{B.125}$$

and the task is to determine values for the scale parameter $A$ and the shape parameter $B$ which result in a close agreement between the original and fitted distribution. In this analysis the closeness of fit is judged by the difference in fatigue life from use of the two distributions.

Experience shows that the value of $B$ is typically between 0.8 and 1.2, with the lower values for drag loading dominated structures and the higher values for inertia loading dominated. The fatigue damage $D$ in a time period $t$ for a Weibull stress range distribution and an S-N curve without a threshold or change in slope is given as

$$D = \frac{\nu_{0,\textit{long term}} \cdot t}{K} \cdot E[S^m] = \frac{\nu_{0,\textit{long term}} \cdot t}{K} \cdot A \cdot \Gamma\left(1 + \frac{m}{B}\right) \tag{B.126}$$

## B.8.1 Deterministic Calibration

The two Weibull parameters can be determined by fitting at two or more fractile levels.

When two levels are used, the fractiles corresponding to these two levels determine three stress range intervals. An intuitively good choice is the levels giving the same fatigue damage contribution from stress ranges in these three intervals.

With the SN curve slope parameter $m = 3$ and $B = 1$ it turns out that the fitting should be performed at the 95th and 99th percentile levels. Let $S95$ and $S99$ denote these fractiles as obtained from the original long term distribution. The Weibull parameters $A$ and $B$ for the fitted distribution are then determined by solving the equations

$$A = e^{\left(\frac{k \ln S_{0.99} - \ln a_{0.95}}{k-1}\right)} \qquad B = \frac{\ln(-\ln 0.05)}{\ln S_{0.99} - \ln a} \tag{B.127}$$

where

$$k = \frac{\ln\left(-\ln 0.05\right)}{\ln\left(-0.01\right)} \tag{B.128}$$

Experience shows that the fit is quite stable for varying choices of the fractiles, which confirms the choice of the Weibull distribution.

More elaborate fitting procedures may involve fitting at more fractiles combined with a least square fit.

### B.8.2 Calculation of Weibull parameters in Stofat

In Stofat a least square technique fitting several fractile levels as well as a simple interpolation fitting two fractile levels are applied at different occasions.

The Weibull parameters may be calculated during a run execution and printed in the fatigue result table of the run by turning on the command DEFINE WEIBULL-PARAMETER. In this case the Weibull parameters are calculated for the overall stress range distribution fitting ten fractile levels by the least square technique. The calculated parameters may also be displayed by the DISPLAY FATIGUE-CHECK-RESULTS.

A dump print of the Weibull parameters for a user defined number of stress level may be executed by the command DEFINE FATIGUE-RESULTS-DUMP. In this case the Weibull parameters are calculated and printed for each part range of the stress distribution by fitting the two neighbouring levels forming the part range. Weibull parameters calculated during the run execution is printed as well, see 'Weibull parameters. Least square fit of range levels.' below.

```
Weibull parameters. Least square fit of range levels. WavDir=All:
                                            Scale             Shape
                                   2.13636420E+07        0.99333149
Weibull parameters. Fitting two and two range levels. WavDir=All:
                   Fit levels               Scale             Shape
                      1 - 2        2.52301560E+07        1.05685902
                      2 - 3        2.35946380E+07        1.02956617
                      3 - 4        2.26024080E+07        1.01201606
                      4 - 5        2.12439360E+07        0.98640007
                      5 - 6        2.05986160E+07        0.97331631
                      6 - 7        2.02589300E+07        0.96582323
                      7 - 8        1.98986000E+07        0.95695561
                      8 - 9        1.98709140E+07        0.95615709
                      9 - 10       2.03623640E+07        0.97501755
```

Figure B.9: Dump print of Weibull parameters for 10 stress range levels

## B.9 Long Term Response

### B.9.1 Calculation Procedure

In long term response calculation the maximum stress amplitude is established for the main wave directions in the same way as in long term fatigue calculation. Stress amplitudes for individual sea states are calculated and the maximum amplitude of these within each wave direction is taken as the stress amplitude of the wave direction. The maximum stress amplitude of the overall sea states is taken as the amplitude of all wave directions. The amplitudes are applied in calculation of the long term responses. Stress amplitudes for the individual sea states are calculated on basis of spectral moments established during the run execution for each stress component requested by the user. Note that the spectral moments are not scaled with thickness correction factors, static stress reduction factor or SCF factors (may however be requested to be accounted for, see command DEFINE LONG-TERM-STRESS) as is the case in the long term fatigiue calculation. Valid stress components are: principal stresses Sp1, Sp2, Sp3, equivalent stress (von Mises stress) Seq, normal stress components Sxx, Syy, Szz and shear components Sxy, Szx, Syz (see command DEFINE LONG-TERM-STRESS).

The stress amplitude of a sea state for a given stress point is;

$$\Delta\sigma = \sqrt{\lambda}\sqrt{2\ln(n_s)} \tag{B.129}$$

where

$$n_s = \frac{T}{2\pi}\sqrt{\frac{\lambda_2}{\lambda_0}}p_s = \frac{T \cdot Y}{dT_{Zs}} \tag{B.130}$$

$$dT_{Zs} = \frac{2\pi}{p_s}\sqrt{\frac{\lambda_0}{\lambda_2}} \tag{B.131}$$

| | |
|---|---|
| $\Delta\sigma_s$ | Stress amplitude of the sea state |
| $n_s$ | Stress cycles of the sea state |
| $dT_{Zs}$ | Mean zero up-crossing period of the sea state |
| $T$ | Duration of a year in seconds, $T = 3.1536 \times 10^7$ |
| $Y$ | Design fatigue life in years |
| $p_s$ | Probability of the sea state and current wave direction |
| $\lambda_0$ | Zero spectral moment of the sea state |
| $\lambda_2$ | Second spectral moment of the sea state |

Stress amplitude of wave direction $j$, $\Delta\sigma_j$ , is taken as maximum stress amplitude of the sea states of wave direction $j$, and stress amplitude of the stress point, $\Delta\sigma_0$ (all wave directions), is maximum stress amplitude of all wave directions (or sea states), i.e.;

Stress amplitude of wave direction $j$

$$\Delta\sigma_j = max\left(\Delta\sigma_s\right)_j \tag{B.132}$$

Stress amplitude of all wave directions

$$\Delta\sigma_0 = max\left(\Delta\sigma_j\right) \tag{B.133}$$

The stress amplitudes $\Delta\sigma_j$ and $\Delta\sigma_0$ are divided into a number of equally spaced stress levels, $nl$, decided by the user (default is 10 levels). Exceedances and probability of exceedances are calculated for each of the stress levels.

Amplitude of stress level $i$ is given by; Amplitude of stress level $i$, wave direction $j$

$$\Delta\sigma_{ji} = \Delta\sigma_j\frac{i}{nl} \tag{B.134}$$

Amplitiude of stress level $i$, all wave directions

$$\Delta\sigma_{0i} = \Delta\sigma_0\frac{i}{nl} \tag{B.135}$$

Contributions from the sea states are accumulated for each wave direction; Stress cycles, wave direction $j$

$$n_j = \sum_{seastates}^{j} ns \tag{B.136}$$

Mean zero up-crossing period, wave direction $j$

$$dT_{Zj} = \sum_{seastates}^{j} dT_{Zs} \tag{B.137}$$

Exceedance of stress level $i$, wave direction $j$

$$e_{j_i} = \sum_{seastates}^{j} e_{s_i} \tag{B.138}$$

Exceedance of stress level $i$, sea state $s$

$$e_{si} = n_s q_{si} \tag{B.139}$$

Probability of exceedance of stress level $i$, sea state $s$

$$q_{si} = \exp\left(-\frac{1}{2}\frac{\Delta\sigma_{ji}}{\sqrt{\lambda_0}}\right)^2 \tag{B.140}$$

Probability of exceedance of stress level $i$, wave direction $j$

$$q_{ji} = \frac{e_{ji}}{n_j} \tag{B.141}$$

Probability of exceedance of max amplitude, wave direction $j$

$$q_{j0} = q_{ji}\left(\Delta\sigma_j\right) = \frac{e_{j0}}{n_j} \tag{B.142}$$

Accumulated contributions with all wave directions included;

Stress cycles, all wave directions

$$n_0 = \sum_{wavedir} n_j \tag{B.143}$$

Mean zero up-crossing period, all wave directions

$$T_Z = \sum_{wavedir} dT_{Zj} \tag{B.144}$$

Exceedance of stress level $i$, all wave directions

$$e_i = \sum_{wavedir} e_{ji} \tag{B.145}$$

Probability of exceedance of stress level $i$, all wave directions

$$q_i = \frac{e_i}{n_0} \tag{B.146}$$

Probability of exceedance of max amplitude, wave direction $j$

$$q_0 = \frac{e_0}{n_0} \tag{B.147}$$

In order to have a best fit of distribution to the probability levels, an aiming probability of exceedance of the uppermost response level is established and aimed for. This is obtained through iterations in which the uppermost response level is scaled to an acceptable level fitting the aiming probability of exceedance defined as the mean of an upper- and lower bound of probability set by the program. The new uppermost stress amplitude is divided into the given number of exceedance levels and calculation of the long term response variables is related to this new distribution. The iterative scaling for an aiming stress level is performed if the probability of exceedance $(q_{j0}, q_0)$ of the maximum stress amplitudes $(\Delta\sigma_{j0}, \Delta\sigma_0)$ are outside the bounds. This approach is similar to that applied in long term response calculation of Postresp.

Upper-and lower bounds and aiming probability:

Upper bound of probability of exceedance

$$q_{upper} = 10^{-8} \tag{B.148}$$

Lower bound of probability of exceedance

$$q_{lower} = \frac{q_{upper}}{100} \tag{B.149}$$

Aiming probability of exceedance

$$q_{aim} = 0.5\left(q_{upper} + q_{lower}\right) \tag{B.150}$$

Iteractive scaling to obtain acceptable long term stress range distribution when

Aiming probability of exceedance

$$q_{lower} \geq q_0, \qquad q_0 \geq q_{upper} \tag{B.151}$$

The upper bound $q_{upper} = 10^{-8}$ corresponds to $n_0 = 10^8$ cycles over a long term wave period of 20 years exceeding the uppermost stress level with only one amplitude, i.e.$q_{upper} = 1/n_0 = 10^{-8}$.

Three cases are handled in the iteractive process:

1. when the aiming probability is in between highest and lowest exceedance stress levels, linear interpolation to the aiming probability of exceedance is performed in the logaritmic $\Delta\sigma - qplane$

$$\log(\Delta\sigma_{aim}) = \log(\Delta\sigma_{j-1}) + (\log(\Delta\sigma_j) - \log(\Delta\sigma_{j-1})) \frac{Q_{aim} - Q_{j-1}}{Q_j - Q_{j-1}} \tag{B.152}$$

   Aiming probability of exceedance

$$q_{lower} \geq q_0 \qquad q_0 \geq q_{upper} \tag{B.153}$$

   Aiming stress level

$$\Delta\sigma_{aim} = \exp(\log(\Delta\sigma_{aim})) \tag{B.154}$$

   Tray factor for iteration $k$, max $k = 5$ iterations

$$f_k = f_{k-1} \frac{\Delta\sigma_{aim}}{(\Delta\sigma_0)_{k-1}} \tag{B.155}$$

   Max stress level for scaling iteration $k$

$$(\Delta\sigma_0)_k = f_k (\Delta\sigma_0)_{k-1} \tag{B.156}$$

   Amplitude of stress level $j$ for scaling iteration $k$

$$(\Delta\sigma_j)_k = f_k (\Delta\sigma_j)_{k-1} \tag{B.157}$$

   Logarithm of aiming probability of exceedance exponent

$$Q_{aim} = \log(-\log(q_{aim})) \tag{B.158}$$

   where

   Logarithm of level $j$ probability of exceedance exponent

$$Q_j = \log(-\log(q_j)) \tag{B.159}$$

   Max stress amplitude of scaling iteration $k - 1$

$$(\Delta\sigma_0)_{k-1} \tag{B.160}$$

   Max stress amplitude in first iteration $(k = 1)$

$$(\Delta\sigma_0)_{k-1=0} = \Delta\sigma_0 \tag{B.161}$$

   Tray factor in first iteration $(k = 1)$

$$f_{k-1=0} = 1 \tag{B.162}$$

2. When the aiming probability is below lowest exceedance stress level (nexc) the scaling is:

$$\Delta\sigma_{aim} = 0.5 \cdot \exp(\log(\Delta\sigma_{nexc})) \qquad \text{for} \qquad Q_{aim} \leq Q_{nexc} \tag{B.163}$$

3. When the aiming probability is above highest exceedance stress level $(0)$ the scaling is:

$$\Delta\sigma_{aim} = 1.5 \cdot \exp\left(\log\left(\Delta\sigma_0\right)\right) \qquad \text{for} \qquad Q_{aim} \geq Q_0 \tag{B.164}$$

Iterations are performed until $q_0$ is within the bounds, i.e, $q_{lower} \leq q_0 \leq q_{upper}$. The stress amplitude obtained after maximum of 5 iterations are applied in further calculation of the long term response parameters.

The Weibull function is used to fit the stress amplitude response levels. The user may select between two fit methods:

a) A least square technique fitting all stress levels of the stress amplitude range (Weibull fit)

b) Interpolate values between the two nearest levels (above and below) to the defined probability level (Numerical fit).

The Weibull function is given by:

$$f\left(\Delta\sigma\right) = \frac{wh}{wq} \cdot \left(\frac{\Delta\sigma}{wq}\right)^{wh-1} \cdot \exp\left(\frac{\Delta\sigma}{wq}\right)^{wh} \tag{B.165}$$

where

| | |
|---|---|
| $\Delta\sigma_s$ | Stress amplitude |
| $wh$ | Weibull shape parameter |
| $wq$ | Weibull scale parameter |

The probability that the maximum stress amplitude $\Delta\sigma_0$ is exceeded for a total of $n_0$ cycles is:

$$q\left(\Delta\sigma_0\right) = 1 - \int_0^\infty f\left(\Delta\sigma_0\right) d\Delta\sigma = \exp\left(\frac{\Delta\sigma_0}{wq}\right)^{wh} = \frac{1}{n0} \tag{B.166}$$

The probability that the stress amplitude $\Delta\sigma$ is exceeded is:

$$q\left(\Delta\sigma\right) = 1 - \int_0^\infty f\left(\Delta\sigma\right) d\Delta\sigma = \exp\left(\frac{\Delta\sigma}{wq}\right)^{wh} \tag{B.167}$$

Taking the logarithm of the above equation we have:

$$Q = -\ln\left(q\left(\Delta\sigma\right)\right) = \left(\frac{\Delta\sigma}{wq}\right)^{wh} \tag{B.168}$$

This equation is used to calculate the stress amplitude for a given probability level $Q$ in the long term response analysis. The Weibull parameters are calculated on basis of the scaled stress amplitude range when scaling is required.

Since $q\left(\Delta\sigma\right)$ represents the probability that $\Delta\sigma$ is exceeded, we have for the number of stress cycles $n$ that exceeds $\Delta\sigma$:

$$q\left(\Delta\sigma\right) = \frac{n}{n_0} = \exp - \left(\frac{\Delta\sigma}{wq}\right)^{wh} = \exp - \left[\left(\frac{\Delta\sigma}{wq}\right)^{wh} \cdot \ln n_0\right] \tag{B.169}$$

From which the stress amplitude $\Delta\sigma$ may be expressed as a function of maximum stress amplitude $\Delta\sigma_0$:

$$\Delta\sigma = \Delta\sigma_0 \left[1 - \frac{\ln n}{\ln n_0}\right] \tag{B.170}$$

Calculation of the long term response parameters are based on the scaled stress range amplitude. In addition max level values of the original stress range amplitude are also calculated and printed. Printed long term response parameters are:

1. Scaled stress range amplitude. Probability of exceedance $q$ given as input:

   Probability of exceedance
   $$q = 10^{-p} \tag{B.171}$$

   Given probability exponent (input)
   $$p = -\log(q) \tag{B.172}$$

   Probability exponent in $\ln$ scale
   $$pl = p \ln(10) \tag{B.173}$$

   Return period
   $$T_R = \frac{T_Z}{T \cdot q} \tag{B.174}$$

   Stress amplitude ($\ln$ of Equation B.170)
   $$\Delta\sigma = wq\left(-\ln\left(q\left(\Delta\sigma\right)\right)\right)^{\frac{1}{wh}} = wq \cdot pl^{\frac{1}{wh}} \tag{B.175}$$

   Exceedance
   $$e = q \cdot n_0 \tag{B.176}$$

2. Scaled stress range amplitude. Return period $T_R$ given as input: The return period $T_R$ is transformed to corresponding probability of exceedance by Equation B.174 and the long term response parameters are calculated as given in above item 1), i.e.:

   Probability of exceedance corresponding to return period $T_R$
   $$q_R = \frac{T_Z}{T \cdot T_R} \tag{B.177}$$

   The exceedance of Equation B.176 may be expressed by the return period $T_R$ by combining Equation B.177, Equation B.143, Equation B.144, Equation B.130 and Equation B.131;

   Exceedance
   $$e = q_R \cdot n_0 = \frac{T_Z}{T \cdot T_R} \cdot \frac{T \cdot Y}{T_Z} = \frac{Y}{T_R} \tag{B.178}$$

   where the design fatigue life Y and the return period $T_R$ are given in years.

3. Original stress range amplitude The Weibull parameters are calculated on basis of the original stress amplitude range $(wqo, who)$. A least square technique fitting all stress levels is used.

   Max level values are calculated for

   1) each individual wave direction

   2) for all wave directions applied to all wave directions

   Stress amplitude wave direction $j$
   $$\Delta\sigma_j = wqo\left(-\ln\left(qo\left(\Delta\sigma_j\right)\right)\right)^{\frac{1}{who}} = wqo \cdot plo^{\frac{1}{who}} \tag{B.179}$$

   Overall max stress amplitude
   $$\Delta\sigma_o = wqo\left(-\ln\left(qo\left(\Delta\sigma_0\right)\right)\right)^{\frac{1}{who}} = wqo \cdot plo^{\frac{1}{who}} \tag{B.180}$$

   Probability exponent of maximum stress amplitude
   $$po = -\log(qo) \tag{B.181}$$

   Probablility exponent in $\ln$ scale
   $$plo = po \cdot \ln(10) \tag{B.182}$$

Probability of exceedance of maximum stress level

$$qo = \frac{e_o}{n_0} \tag{B.183}$$

Return period of maximum stress level

$$T_{R_o} = \frac{T_Z}{T \cdot qo} \tag{B.184}$$

where $e_o$ is the exceedance of each wave direction related to the maximum stress amplitude applied for the wave direction (Equation B.179 or Equation B.180), see Equation B.138 and Equation B.145.

It should be noted that stress amplitudes reported in the long term response table print are calculated by the spectral moments, see Equation B.129 and not by the Weibull function of Equation B.179 and Equation B.180. This is done in order to compare amplitude values directly with maximum stress range values reported in the dump file. However, stress amplitudes calculated by the Weibull function are close to the amplitude values calculated by the spectral moments.

### B.9.2 Print of Long Term Response

Results are given in form of table print of the response parameters and storage on a vtf file for graphic presentation of results in Xtract, see commands PRINT LONG-TERM-RESPONSE and PRINT FATIGUE-RESULTS-VTF-FILE STRESS-RANGE-DISTRIBUTION. Print is performed for selected response parameters, wave directions and stress components. Print to the vtf file is performed for a single probability level or return period, entered in the print command.

Table print of long term parameters is given for:

- Each stress component requested by the user, see command DEFINE LONG-TERM-STRESS
- Individual or all wave directions
- All element stress points or point with maximum stress amplitude
- Hotspots and interpolation points
- Input probability levels or return periods given by the user. One print for each.
- Exceedance, exceedance probability, return period and Weibull parameters related to original stress amplitudes applied for the wave directions
- Parameter values reported for max stress amplitude of all wave directions applied to all wave direction or using stress amplitudes of each individual wave direction. Option choice selected by the command DEFINE LONG-TERM-STRESS-AMPLITUDE

<u>Parameters printed for scaled stress amplitude range:</u>

| | |
|---|---|
| Stress Amplitude | Amplitude stress $\Delta\sigma$ for given probability levels or return periods |
| Maximum stress | Maximum stress amplitude including static stress offset for given probability levels or return periods, i.e: $\Delta\sigma_{max} = \Delta\sigma_{static} + \Delta\sigma$ Note! $\Delta\sigma_{static}$ is the static stress component of current element stress point corresponding to the long term stress component. |
| Minimum stress | Minimum stress amplitude including static stress offset for given probability levels or return periods, i.e: $\Delta\sigma_{max} = \Delta\sigma_{static} - \Delta\sigma$ |
| Peak factor | Stress peak amplification factor, $d = \frac{\lvert\Delta\sigma_{max}\rvert}{\Delta\sigma} = \frac{\lvert\Delta\sigma_{static}\rvert+\Delta\sigma}{\Delta\sigma} = 1 + \frac{\lvert\Delta\sigma_{static}\rvert}{\Delta\sigma}$ |
| Exceedance | Exceedance $e$, see Equation B.176 and Equation B.178 |
| Return period | Return period $T_R$, see Equation B.174 when probability levels are input |
| Probability level | Probability level $q_R$, see Equation B.177 when return periods are input |
| Weibull scale | Weibull scale parameter $wq$ |
| Weibull shape | Weibull shape parameter $wh$ |

Parameters printed for max level values of original stress amplitude range:

| | |
|---|---|
| Stress Amplitude | Maximum stress amplitude $\Delta\sigma_j$, $\Delta\sigma_0$, Equation B.179, Equation B.180 |
| $-\log(Q)$ | Probability exponent of maximum stress amplitude, see Equation B.181 |
| Minimum stress | Minimum stress amplitude including static stress offset for given probability levels or return periods, i.e: $\Delta\sigma_{max} = \Delta\sigma_{static} - \Delta\sigma$ |
| Exceedance | Exceedance $e_j$, $e_o$ see Equation B.138 and Equation B.145 |
| Return period | Return period $T_{R_o}$, see Equation B.184 |
| Weibull scale | Weibull scale parameter $wqo$ |
| Weibull shape | Weibull shape parameter $who$ |

Note that stress components for the long term response analysis must be selected prior to run execution. Selection of probability levels and return periods must performed prior to selection of the long term parameters to be printed. The Weibull parameters are calculated by a least square fit of the whole stress amplitude distribution divided into 10 stress levels.

### B.9.3 Long Term Response Results

The table prints below show results from a long term response analysis. The long term response parameters for given probability levels and return periods are printed in separate tables for all given response levels (max 5). Results are given shown both for the Weibull fit method, using a least square technique for all response levels, and the numerical fit method, interpolating the two nearest response levels to the current probability level. The results are based on the scaled stress amplitude range distribution.

Maximum level values of the original stress amplitude distribution are printed below the scaled amplitude results. These maximum values are the stress amplitudes calculated by the spectral moments used in the fatigue damage calculation. Stress amplitudes calculated by the Weibull function parameters, see Equation B.179 and Equation B.180, are approximate values to the spectral moment based stress amplitude values and are not printed. Two options of the stress amplitudes are possible; 1) maximum stress amplitudes of each individual wave direction and 2) overall maximum stress amplitude of all wave directions. The choice of option is performed by the command DEFINE LONG-TERM-STRESS-AMPLITUDE. The last choice applies the overall maximum stress amplitude to all wave directions and reports exceedances, exceedance probabilities, return periods and Weibull parameter according to this amplitude for each of the wave directions.

Note that spectral moments applied in the long term response calculation is not scaled with thickness correction factor of the SN-curves, static stress reduction factors from static load cases and SCF factors. Stress amplitude values reported are thus independent of these correction factors. SCF factors may be included on request, see command DEFINE LONG-TERM-STRESS.

Results below are given only for element stress point 2, however, in the print file generated results for all stress points of the elements are printed.

Note that the size of the print file may be quite big if many stress components and elements are selected for print at the same time.

Return Periods as input Scaled amplitude response distribution Weibull curve fitting method:

```
#
#
# Long Term Responses
# ===================
# Program               : STOFAT      Postprocessor for stochastic fatigue
# Program id            : 3.5-07
# Release date          : 24-FEB-2016
# Run name              : LTR1
# Run date              : 21-APR-2016  06:42:06
```

```
# Fatigue points        : At element stress points
#
# Input:
# Curve fitting method  : Weibull fit
# Return periods (years): 5.000E-01 1.000E+00 5.000E+00 2.000E+01 5.000E+01
#                       : Stress amplitude scaled to input probability levels
# Stress amplitude      : Amplitude of indiviual wave directions applied
# Exceedance levels     : 10
# Wave directions       : ALL
# Parameters printed    : MAX STRESS    (= static + stress amplitude)
#                       : MIN STRESS    (= static - stress amplitude)
#                       : STRESS AMPLITUDE
#                       : PEAK FACTOR   (PeakAmplification=1+|static|/amplitude
#                       : PROBABILITY LEVEL
#                       : EXCEEDANCE
#                       : WEIBULL SCALE
#                       : WEIBULL SHAPE
#                       : STATIC STRESS
# Stress component      : Sp1 - Maximum principal stress
# Static stress         : Sp1 - Static stress included
# SCF factors           : Applied
# Results printed for   : Element Fatigue Point Results
#
#------------------------------------------------------------------------------
#

ELEMENT: 35
===========             Return Periods in years:
Parameter   Pnt Heading 5.0000E-01 1.0000E+00 5.0000E+00 2.0000E+01 5.0000E+01
------------------------------------------------------------------------------
MaxStress     2 0.0      2.2936E+07 2.3532E+07 2.4864E+07 2.5958E+07 2.6658E+07
              2 45.0     3.1909E+07 3.2676E+07 3.4396E+07 3.5818E+07 3.6730E+07
              2 90.0     2.9296E+07 3.0044E+07 3.1716E+07 3.3094E+07 3.3976E+07
              2 135.     2.8880E+07 2.9656E+07 3.1387E+07 3.2811E+07 3.3721E+07
              2 All      3.2068E+07 3.2824E+07 3.4524E+07 3.5932E+07 3.6837E+07

MinStress     2 0.0     -1.4438E+07-1.5035E+07-1.6366E+07-1.7460E+07-1.8160E+07
              2 45.0    -2.3411E+07-2.4178E+07-2.5898E+07-2.7320E+07-2.8233E+07
              2 90.0    -2.0798E+07-2.1546E+07-2.3219E+07-2.4596E+07-2.5478E+07
              2 135.    -2.0382E+07-2.1158E+07-2.2890E+07-2.4313E+07-2.5223E+07
              2 All     -2.3570E+07-2.4326E+07-2.6027E+07-2.7435E+07-2.8340E+07

StrAmplitude  2 0.0      1.8687E+07 1.9283E+07 2.0615E+07 2.1709E+07 2.2409E+07
              2 45.0     2.7660E+07 2.8427E+07 3.0147E+07 3.1569E+07 3.2481E+07
              2 90.0     2.5047E+07 2.5795E+07 2.7467E+07 2.8845E+07 2.9727E+07
              2 135.     2.4631E+07 2.5407E+07 2.7138E+07 2.8562E+07 2.9472E+07
              2 All      2.7819E+07 2.8575E+07 3.0275E+07 3.1684E+07 3.2589E+07

PeakFactor    2 0.0      1.2274E+00 1.2203E+00 1.2061E+00 1.1957E+00 1.1896E+00
              2 45.0     1.1536E+00 1.1495E+00 1.1409E+00 1.1346E+00 1.1308E+00
              2 90.0     1.1696E+00 1.1647E+00 1.1547E+00 1.1473E+00 1.1429E+00
              2 135.     1.1725E+00 1.1672E+00 1.1566E+00 1.1488E+00 1.1442E+00
              2 All      1.1527E+00 1.1487E+00 1.1403E+00 1.1341E+00 1.1304E+00

ProbLevel     2 0.0      5.2101E+00 5.5111E+00 6.2101E+00 6.8121E+00 7.2101E+00
              2 45.0     5.9956E+00 6.2966E+00 6.9956E+00 7.5976E+00 7.9956E+00
              2 90.0     5.5230E+00 5.8240E+00 6.5230E+00 7.1250E+00 7.5230E+00
              2 135.     5.2387E+00 5.5397E+00 6.2387E+00 6.8408E+00 7.2387E+00
              2 All      6.2198E+00 6.5208E+00 7.2198E+00 7.8218E+00 8.2198E+00
```

```
Exceedance     2 0.0     4.0000E+01 2.0000E+01 4.0000E+00 1.0000E+00 4.0000E-01
               2 45.0    4.0000E+01 2.0000E+01 4.0000E+00 1.0000E+00 4.0000E-01
               2 90.0    4.0000E+01 2.0000E+01 4.0000E+00 1.0000E+00 4.0000E-01
               2 135.    4.0000E+01 2.0000E+01 4.0000E+00 1.0000E+00 4.0000E-01
               2 All     4.0000E+01 2.0000E+01 4.0000E+00 1.0000E+00 4.0000E-01

WeibullScale   2 0.0     4.6588E+06 4.6588E+06 4.6588E+06 4.6588E+06 4.6588E+06
               2 45.0    6.3909E+06 6.3909E+06 6.3909E+06 6.3909E+06 6.3909E+06
               2 90.0    6.1183E+06 6.1183E+06 6.1183E+06 6.1183E+06 6.1183E+06
               2 135.    6.1867E+06 6.1867E+06 6.1867E+06 6.1867E+06 6.1867E+06
               2 All     6.1406E+06 6.1406E+06 6.1406E+06 6.1406E+06 6.1406E+06

WeibullShape   2 0.0     1.7887E+00 1.7887E+00 1.7887E+00 1.7887E+00 1.7887E+00
               2 45.0    1.7917E+00 1.7917E+00 1.7917E+00 1.7917E+00 1.7917E+00
               2 90.0    1.8042E+00 1.8042E+00 1.8042E+00 1.8042E+00 1.8042E+00
               2 135.    1.8023E+00 1.8023E+00 1.8023E+00 1.8023E+00 1.8023E+00
               2 All     1.7618E+00 1.7618E+00 1.7618E+00 1.7618E+00 1.7618E+00

StaticStress   2         4.2489E+06
```

Probability Levels as input. Scaled amplitude response distribution. Numerical fitting method. Individual stress amplitudes for the wave directions:

```
#
#
# Long Term Responses
# ===================
# Program                : STOFAT       Postprocessor for stochastic fatigue
# Program id             : 3.5-07
# Release date           : 24-FEB-2016
# Run name               : LTR1
# Run date               : 21-APR-2016  06:42:06
# Fatigue points         : At element stress points
#
# Input:
# Curve fitting method   : Numerical fit
# Probability exponents  : 2 4 6 7 8
#                        : Stress amplitude scaled to input probability levels
# Stress amplitude       : Max amplitude of all wave directions applied
# Exceedance levels      : 10
# Wave directions        : ALL
# Parameters printed     : MAX STRESS    (= static + stress amplitude)
#                        : MIN STRESS    (= static - stress amplitude)
#                        : STRESS AMPLITUDE
#                        : PEAK FACTOR   (PeakAmplification=1+|static|/amplitude
#                        : RETURN PERIOD (= in years)
#                        : EXCEEDANCE
#                        : WEIBULL SCALE
#                        : WEIBULL SHAPE
#                        : STATIC STRESS
# Stress component       : Sp1 - Maximum principal stress
# Static stress          : Sp1 - Static stress included
# SCF factors            : Applied
# Results printed for    : Element Fatigue Point Results
#
#-----------------------------------------------------------------------------
#
```

```
ELEMENT: 35
===========
Parameter   Pnt Heading -Log(Q)=2  -Log(Q)=4  -Log(Q)=6  -Log(Q)=7  -Log(Q)=8
-----------------------------------------------------------------------------


MaxStress     2 0.0     1.5288E+07 2.0526E+07 2.4452E+07 2.6178E+07 2.7763E+07
              2 45.0    1.9344E+07 2.6517E+07 3.1906E+07 3.4276E+07 3.6452E+07
              2 90.0    1.8597E+07 2.5382E+07 3.0454E+07 3.2681E+07 3.4754E+07
              2 135.    1.8662E+07 2.5572E+07 3.0798E+07 3.3096E+07 3.5202E+07
              2 All     1.8930E+07 2.6092E+07 3.1496E+07 3.3874E+07 3.6056E+07

MinStress     2 0.0    -6.7904E+06-1.2029E+07-1.5954E+07-1.7681E+07-1.9265E+07
              2 45.0   -1.0846E+07-1.8019E+07-2.3408E+07-2.5779E+07-2.7954E+07
              2 90.0   -1.0099E+07-1.6884E+07-2.1956E+07-2.4184E+07-2.6256E+07
              2 135.   -1.0164E+07-1.7074E+07-2.2301E+07-2.4598E+07-2.6704E+07
              2 All    -1.0433E+07-1.7594E+07-2.2998E+07-2.5376E+07-2.7558E+07

StrAmplitude  2 0.0     1.1039E+07 1.6277E+07 2.0203E+07 2.1930E+07 2.3514E+07
              2 45.0    1.5095E+07 2.2268E+07 2.7657E+07 3.0028E+07 3.2203E+07
              2 90.0    1.4348E+07 2.1133E+07 2.6205E+07 2.8432E+07 3.0505E+07
              2 135.    1.4413E+07 2.1323E+07 2.6550E+07 2.8847E+07 3.0953E+07
              2 All     1.4681E+07 2.1843E+07 2.7247E+07 2.9625E+07 3.1807E+07

PeakFactor    2 0.0     1.3849E+00 1.2610E+00 1.2103E+00 1.1938E+00 1.1807E+00
              2 45.0    1.2815E+00 1.1908E+00 1.1536E+00 1.1415E+00 1.1319E+00
              2 90.0    1.2961E+00 1.2011E+00 1.1621E+00 1.1494E+00 1.1393E+00
              2 135.    1.2948E+00 1.1993E+00 1.1600E+00 1.1473E+00 1.1373E+00
              2 All     1.2894E+00 1.1945E+00 1.1559E+00 1.1434E+00 1.1336E+00

ReturnPeriod  2 0.0     3.0825E-04 3.0825E-02 3.0825E+00 3.0825E+01 3.0825E+02
              2 45.0    5.0513E-05 5.0513E-03 5.0513E-01 5.0513E+00 5.0513E+01
              2 90.0    1.4997E-04 1.4997E-02 1.4997E+00 1.4997E+01 1.4997E+02
              2 135.    2.8858E-04 2.8858E-02 2.8858E+00 2.8858E+01 2.8858E+02
              2 All     3.0144E-05 3.0144E-03 3.0144E-01 3.0144E+00 3.0144E+01

Exceedance    2 0.0     6.4883E+04 6.4883E+02 6.4883E+00 6.4883E-01 6.4883E-02
              2 45.0    3.9593E+05 3.9593E+03 3.9593E+01 3.9593E+00 3.9593E-01
              2 90.0    1.3336E+05 1.3336E+03 1.3336E+01 1.3336E+00 1.3336E-01
              2 135.    6.9306E+04 6.9306E+02 6.9306E+00 6.9306E-01 6.9306E-02
              2 All     6.6348E+05 6.6348E+03 6.6348E+01 6.6348E+00 6.6348E-01

WeibullScale  2 0.0     4.5615E+06 4.8929E+06 5.0682E+06 5.1266E+06 5.1266E+06
              2 45.0    6.2455E+06 6.6762E+06 6.9096E+06 6.9921E+06 6.9921E+06
              2 90.0    5.9412E+06 6.3556E+06 6.5809E+06 6.6555E+06 6.6555E+06
              2 135.    5.9833E+06 6.3102E+06 6.5462E+06 6.6424E+06 6.6424E+06
              2 All     5.9659E+06 6.3990E+06 6.6437E+06 6.7299E+06 6.7299E+06

WeibullShape  2 0.0     1.7201E+00 1.8448E+00 1.8967E+00 1.9119E+00 1.9119E+00
              2 45.0    1.7225E+00 1.8408E+00 1.8911E+00 1.9067E+00 1.9067E+00
              2 90.0    1.7248E+00 1.8463E+00 1.8982E+00 1.9132E+00 1.9132E+00
              2 135.    1.7287E+00 1.8210E+00 1.8734E+00 1.8922E+00 1.8922E+00
              2 All     1.6880E+00 1.8059E+00 1.8587E+00 1.8750E+00 1.8750E+00

StaticStress  2         4.2489E+06
```

Original amplitude response distribution. Individual stress amplitude values of wave directions:

```
Original stress amplitude.  Max level values:           WeibullCurveFitMethod
Pnt Heading  StressAmpl  Exceedance -log(Q)    ReturnPrd  WeibScale  WeibShape
------------------------------------------------------------------------------


  2 0.0      2.1078E+07 2.1347E+00 6.4828E+00 9.3691E+00 4.5872E+06 1.7604E+00
  2 45.0     3.0792E+07 1.8383E+00 7.3332E+00 1.0880E+01 6.3494E+06 1.7789E+00
  2 90.0     2.8107E+07 1.9522E+00 6.8345E+00 1.0245E+01 6.0534E+06 1.7844E+00
  2 135.     2.8112E+07 1.5198E+00 6.6590E+00 1.3160E+01 6.1307E+06 1.7866E+00
  2 All      3.0792E+07 2.0207E+00 7.5163E+00 9.8977E+00 6.1058E+06 1.7519E+00
```

Probability Levels as input. Scaled amplitude response distribution. Numerical fitting method. Overall maximum stress amplitude of all wave directions applied for all wave direction:

```
#
#
# Long Term Responses
# ===================
# Program               : STOFAT       Postprocessor for stochastic fatigue
# Program id            : 3.5-07
# Release date          : 24-FEB-2016
# Run name              : LTR1
# Run date              : 21-APR-2016  06:42:06
# Fatigue points        : At element stress points
#
# Input:
# Curve fitting method  : Numerical fit
# Probability exponents : 2 4 6 7 8
#                       : Stress amplitude scaled to input probability levels
# Stress amplitude      : Max amplitude of all wave directions applied
# Exceedance levels     : 10
# Wave directions       : ALL
# Parameters printed    : MAX STRESS    (= static + stress amplitude)
#                       : MIN STRESS    (= static - stress amplitude)
#                       : STRESS AMPLITUDE
#                       : PEAK FACTOR   (PeakAmplification=1+|static|/amplitude
#                       : RETURN PERIOD (= in years)
#                       : EXCEEDANCE
#                       : WEIBULL SCALE
#                       : WEIBULL SHAPE
#                       : STATIC STRESS
# Stress component      : Sp1 - Maximum principal stress
# Static stress         : Sp1 - Static stress included
# SCF factors           : Applied
# Results printed for   : Element Fatigue Point Results
#
#-------------------------------------------------------------------------------
#

ELEMENT: 35
===========
Parameter   Pnt Heading -Log(Q)=2  -Log(Q)=4  -Log(Q)=6  -Log(Q)=7  -Log(Q)=8
------------------------------------------------------------------------------
MaxStress     2 0.0     1.5288E+07 2.0526E+07 2.4452E+07 2.6178E+07 2.7763E+07
              2 45.0    1.9344E+07 2.6517E+07 3.1906E+07 3.4276E+07 3.6452E+07
              2 90.0    1.8597E+07 2.5382E+07 3.0454E+07 3.2681E+07 3.4754E+07
              2 135.    1.8662E+07 2.5572E+07 3.0798E+07 3.3096E+07 3.5202E+07
              2 All     1.8930E+07 2.6092E+07 3.1496E+07 3.3874E+07 3.6056E+07
```

```
MinStress     2 0.0    -6.7904E+06-1.2029E+07-1.5954E+07-1.7681E+07-1.9265E+07
              2 45.0   -1.0846E+07-1.8019E+07-2.3408E+07-2.5779E+07-2.7954E+07
              2 90.0   -1.0099E+07-1.6884E+07-2.1956E+07-2.4184E+07-2.6256E+07
              2 135.   -1.0164E+07-1.7074E+07-2.2301E+07-2.4598E+07-2.6704E+07
              2 All    -1.0433E+07-1.7594E+07-2.2998E+07-2.5376E+07-2.7558E+07

StrAmplitude  2 0.0     1.1039E+07 1.6277E+07 2.0203E+07 2.1930E+07 2.3514E+07
              2 45.0    1.5095E+07 2.2268E+07 2.7657E+07 3.0028E+07 3.2203E+07
              2 90.0    1.4348E+07 2.1133E+07 2.6205E+07 2.8432E+07 3.0505E+07
              2 135.    1.4413E+07 2.1323E+07 2.6550E+07 2.8847E+07 3.0953E+07
              2 All     1.4681E+07 2.1843E+07 2.7247E+07 2.9625E+07 3.1807E+07

PeakFactor    2 0.0     1.3849E+00 1.2610E+00 1.2103E+00 1.1938E+00 1.1807E+00
              2 45.0    1.2815E+00 1.1908E+00 1.1536E+00 1.1415E+00 1.1319E+00
              2 90.0    1.2961E+00 1.2011E+00 1.1621E+00 1.1494E+00 1.1393E+00
              2 135.    1.2948E+00 1.1993E+00 1.1600E+00 1.1473E+00 1.1373E+00
              2 All     1.2894E+00 1.1945E+00 1.1559E+00 1.1434E+00 1.1336E+00

ReturnPeriod  2 0.0     3.0825E-04 3.0825E-02 3.0825E+00 3.0825E+01 3.0825E+02
              2 45.0    5.0513E-05 5.0513E-03 5.0513E-01 5.0513E+00 5.0513E+01
              2 90.0    1.4997E-04 1.4997E-02 1.4997E+00 1.4997E+01 1.4997E+02
              2 135.    2.8858E-04 2.8858E-02 2.8858E+00 2.8858E+01 2.8858E+02
              2 All     3.0144E-05 3.0144E-03 3.0144E-01 3.0144E+00 3.0144E+01

Exceedance    2 0.0     6.4883E+04 6.4883E+02 6.4883E+00 6.4883E-01 6.4883E-02
              2 45.0    3.9593E+05 3.9593E+03 3.9593E+01 3.9593E+00 3.9593E-01
              2 90.0    1.3336E+05 1.3336E+03 1.3336E+01 1.3336E+00 1.3336E-01
              2 135.    6.9306E+04 6.9306E+02 6.9306E+00 6.9306E-01 6.9306E-02
              2 All     6.6348E+05 6.6348E+03 6.6348E+01 6.6348E+00 6.6348E-01

WeibullScale  2 0.0     4.5615E+06 4.8929E+06 5.0682E+06 5.1266E+06 5.1266E+06
              2 45.0    6.2455E+06 6.6762E+06 6.9096E+06 6.9921E+06 6.9921E+06
              2 90.0    5.9412E+06 6.3556E+06 6.5809E+06 6.6555E+06 6.6555E+06
              2 135.    5.9833E+06 6.3102E+06 6.5462E+06 6.6424E+06 6.6424E+06
              2 All     5.9659E+06 6.3990E+06 6.6437E+06 6.7299E+06 6.7299E+06

WeibullShape  2 0.0     1.7201E+00 1.8448E+00 1.8967E+00 1.9119E+00 1.9119E+00
              2 45.0    1.7225E+00 1.8408E+00 1.8911E+00 1.9067E+00 1.9067E+00
              2 90.0    1.7248E+00 1.8463E+00 1.8982E+00 1.9132E+00 1.9132E+00
              2 135.    1.7287E+00 1.8210E+00 1.8734E+00 1.8922E+00 1.8922E+00
              2 All     1.6880E+00 1.8059E+00 1.8587E+00 1.8750E+00 1.8750E+00

StaticStress  2         4.2489E+06
```

Original amplitude response distribution. Overall maximum stress amplitude of all wave directions applied for all wave direction:

```
Original stress amplitude.  Max level values:           WeibullCurveFitMethod
Pnt Heading  StressAmpl  Exceedance -log(Q)    ReturnPrd  WeibScale  WeibShape
-----------------------------------------------------------------------------
  2 0.0      3.0792E+07 2.3485E-07 1.3441E+01 8.5160E+07 4.8094E+06 1.8403E+00
  2 45.0     3.0792E+07 1.8383E+00 7.3332E+00 1.0880E+01 6.3494E+06 1.7789E+00
  2 90.0     3.0792E+07 9.6941E-02 8.1385E+00 2.0631E+02 6.1120E+06 1.8027E+00
  2 135.     3.0792E+07 8.5411E-02 7.9093E+00 2.3416E+02 6.1766E+06 1.7998E+00
  2 All      3.0792E+07 2.0207E+00 7.5163E+00 9.8977E+00 6.1058E+06 1.7519E+00
```

# C Fatigue Strength Based on Wöhler Curves

Stofat program will perform fatigue check calculations for shell and plate structures. It is based on spectral calculation methods.

Using the program requires previous calculation of wave loads on a finite element model and calculation of stresses caused by these loads.

Typical steps in a fatigue calculation using Stofat:

## C.1 Calculation Steps

### C.1.1 Establish Finite Element Model of the Structure

The modelling may be performed in different level of detail depending upon the details to be analysed and previous knowledge of stress concentrations in the structure. Modelling and computations in several steps of refinement may be needed.

### C.1.2 Perform Hydrodynamic Wave Load Calculation

The Wadam program will calculate hydrodynamic pressure loads on the submerged surfaces of the finite element model. Input data to the wave load calculation are wave directions and wave frequencies.

### C.1.3 Perform Finite Element Structural Calculation

Sestra program will compute stresses in the finite element model caused by the loads applied. Computation is commonly performed as static linear analysis. Linear dynamic analysis may also be performed if resonance may occur in the frequency ranges excited by the wave loads.

### C.1.4 Spectral Fatigue Damage Calculation

Input data for the fatigue damage calculations in Stofat are wave statistics, SN curve, stress concentration factors and stresses from the previous calculations. Two scatter diagrams and some SN curves available predefined in the program. Other data may be specified by the user.

Long term wave statistics data is specified to the program as a scatter diagram and a wave direction probability distribution. Short term wave statistics is specified by selecting a wave spectrum model and setting appropriate parameters. Wave spreading may be used to specify short term distribution of wave directions.

The modelling may be performed in different level of detail depending SN data are experimental data giving the number of cycles N of stress range S necessary to cause fatigue failure. These data are summarized in SN curves.

SN data are generally obtained from testing with constant amplitude sinusoidal loading. The mean loading, which is often expressed in terms of the ratio between the smallest stress and the largest stress in a stress cycle known as the R-ratio, is also fixed. For welded structures the influence of the mean stress or R-ratio is generally small since the welding procedure sets up residual stresses which are close to the yield limit. In this case only the stress range determines the number of stress cycles to failure.

The definition of the stress, used to obtain the stress range entering the SN curve, is not unique and depends on the specific application. For tubular joints, it is the geometrically amplified stress being measured or computed normal to the weld direction at a hot spot. For other welded connections it is a nominal stress. This lack of uniqueness has some influence on the presentation of code based design curves.

## C.2 Codified SN Curves

### C.2.1 SN Curve Equations

For practical fatigue design, welded joints are divided into several classes, each with a corresponding design SN curve.

The joint classification of [8] and [9] divides all joints, including tube to plate joints, into eight classes B, C, D, E, F, F2, G or W according to:

1. The geometrical arrangement of the detail
2. The direction of the fluctuanting stress relative to the detail
3. the method of fabrication and inspection of the detail

The class T curve, suggested by the Department of Energy for tubular joints (1982) for tubular joints is also relevant.

Each construction detail at which fatigue cracks may develop must, whenever possible, be placed in its relevant class in accordance with the criterion given by [8]. Details which cannot be classified according to the classification of DNV should be treated as class G, or class W for load carrying welded metal, unless a higher classification can be justified. It should be noted that in every welded joint there are several locations at which fatigue cracks may develop and each location should be classified separately.

The design SN curves are based on a statistical analysis of experimental data. They are made of linear or piece wise linear relations between $\log_{10} S$ and $\log_{10} N$ (or $\log_{10} K$). A design curve is defined as the mean curve, obtained from the data fitting, with a parallel shift of the curve (down) of two standard deviations of $\log_{10} N$ (or $\log_{10} K$). As the curves are shifted down (not left, i.e. $N_0$ is fixed), $K$ will be treated as the random variable in the following. The standard deviation is computed based on the assumption of a fixed and known slope. The design SN curves are thus of the form

$$\log_{10} N = \log_{10} K - 2\sigma_{\log_{10} K} - m \log_{10} S \tag{C.1}$$

$$\log_{10} N = \log_{10} A - m \log_{10} S \tag{C.2}$$

where

- $N$ number of cycles to failure under stress range $S$
- $K0$ intercept of mean SN curve with the $\log_{10} N$ axis
- $\sigma_{\log_{10} K}$ the standard deviation of $\log_{10} K$
- $m$ the inverse slope of the SN curve
- $s_o$ endurance limit or stress value for slope change
- $\log_{10} A \qquad \log_{10} K - 2\sigma_{\log_{10} K}$

The SN curves used for deterministic design calculations represent the relation between $S$ and $N$ resulting in a small probability of fatigue failure $(\Phi(-2) \sim 0.025)$.

$$\log_{10} N = \log_{10} K0 - m \log_{10} S \tag{C.3}$$

or

$$N = K \cdot S^{-m}, \qquad S > s_o \tag{C.4}$$

The uncertainty in fatigue lifetime applying to the SN curve is assumed to apply to the first linear segment of the curve. When the curve consists of 2 or 3 segments, or has a horizontal segment corresponding to an endurance limit, the entire curve is shifted vertically as described above, basing the shift on the values calculated for the first slope only.

The fatigue strength of welded joints is dependent on the plate thickness, $t$, with the strength decreasing with increasing thickness. For the thickness $t$ different from the reference thickness $t_{ref}$, the stress range $S$ of the S-N curve must be corrected for the thickness effect. In general, the corrected stress range may be written Equation C.4 may written:

$$S = S_0 \cdot t_c^{\text{exp}} \tag{C.5}$$

where $S_0$ is the stress range without correction of thickness effect and the thickness effect factor $t_c$ is given by

$$t_c = {}^{t}/_{t_{ref}}, \qquad t > t_{cut} \tag{C.6}$$

$$t_c = {}^{t_{cut}}/_{t_{ref}}, \qquad t \leq t_{cut} \tag{C.7}$$

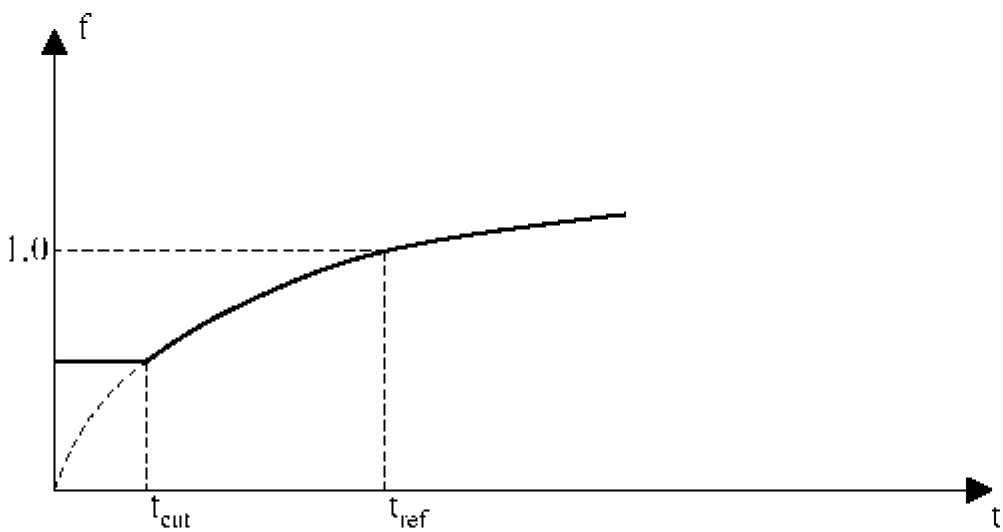
where $t_{cut}$ is the cutoff thickness. The $\log$ representation of the SN curve including correction for thickness effect may thus be written

$$\log_{10} N = \log_{10} K - m \cdot \exp \cdot \log_{10} t_c - m \log_{10} S_0, \qquad S_0 > s_o \tag{C.8}$$

Equation C.8 is the general SN curve including an arbitrary thickness correction of exponential form. The standard design T-curve has an exponent value equal to $^1/_4$ and the reference thickness is equal to the cut-off thickness. With a reference thickness of 32 mm, a modification is carried out when the actual thickness is larger than 32 mm and the T-curve becomes

$$\log_{10} N = \log_{10} K - \frac{m}{4} \log_{10} \left( \frac{t}{32} \right) - m \log_{10} S_0, \qquad S_0 > s_o \tag{C.9}$$

where $t$ is the thickness in mm through which the potential fatigue crack will grow. It is possible in the program to specify a cut-off thickness which is different from the reference thickness and an arbitrary value of the exponent, see the command ASSIGN THICKNESS-CORRECTION. When the actual thickness is smaller than the cut-off thickness, the S-N curve for the cut-off thickness is used, see Figure C.1




The SN-curve thickness correction factor is calculated as:

$f = ( t_{cut} / t_{ref} )^{exp}$ for $t \leq t_{cut}$

$f = ( t / t_{ref} )^{exp}$ for $t > t_{cut}$

Figure C.1: Thickness correction factor

### C.2.2 SN Curve Parameters

**Library SN curves:**

The SN curves calculated by the program are converted from SI base units to the current set of consistent units based on the assumption that the Young's modulus of the material corresponds to steel (with $E =$

$2.1 \cdot 10^{11} N/m^2$ ). The stress level S of the SN curve is multiplied with a factor scaling the Young's modulus of the material Em, relative to the basic Young's modulus E, i.e:

$$S = S \cdot f_E \tag{C.10}$$

$$f_E = E_m/E = E_m/2.1 \cdot 10^{11} \tag{C.11}$$

Note that when $E_m$ differs from $E$, the stress level of SN curve is scaled. Thus, using $E_m = 2.05 \cdot 10^{11} N/m^2$, the stress level is scaled with a factor of $f_E = 2.05/2.1 = 0.976$ when library SN curves are applied.

**User defined SN curves:**

When creating codified SN curves, the user must ensure that the input SN curve data are consistent with units applied elsewhere in the analysis. The user may choose between three options when creating an SN curve (see command CREATE SN-CURVE);

- USER: Stress level S0 at end of first segment is given.
- LOGA: INTERCEPT VALUE $\log A0$ of $\log N$-axis by first line segment of SN curve is given, see Figure C.2
- STOCHASTIC: Intercept $\log K0$ of $\log N$-axis by first line segment of mean SN curve is given together with standard deviation $(\sigma)$ of $\log K0$, see C.3

Input and calculated SN curve parameters for the three input options are as follows:

Table C.1: Input (I) and calculated (C) SN curve parameters

| Input Option | SN curve parameters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 | S1 | $\log_{A0}$ | $\log_{A1}$ | $\log_{A2}$ | $\log_{\bar{A}0}$ | $\sigma_{\log K}$ |
| USER | I | I | I | I | I | I | C | C | C | C | - | 0.0 |
| LOGA | I | I | I | I | I | C | C | I | C | C | - | 0.0 |
| STOCHASTIC | I | I | I | I | I | C | C | I | C | C | C | I |

**SN curve equations:**

The SN curve parameters are illustrated in Figure C.2. The SN curve Equation C.2 applies for the different line segments of the SN curve as follows:

$$\log_{10} N = \log_{10} A0 - m0 \log_{10} S, \qquad \text{for} \quad S > S0 \tag{C.12}$$

$$\log_{10} N = \log_{10} A1 - m1 \log_{10} S, \qquad \text{for} \quad S1 < S < S0 \tag{C.13}$$

$$\log_{10} N = \log_{10} A2 - m2 \log_{10} S, \qquad \text{for} \quad S < S1 \tag{C.14}$$

at the intersection points 0 and 1 of the SN curve the line segments, see Figure C.2 we have

$$\log_{10} N0 = \log_{10} A0 - m0 \log_{10} S0, \qquad \text{Intersection 0} \tag{C.15}$$

$$\log_{10} N1 = \log_{10} A1 - m1 \log_{10} S1, \qquad \text{Intersection 1} \tag{C.16}$$

For stochastic SN curve input, the $\log A$ of the deterministc SN curve is calculated as given in Figure C.3.

For stochastic (mean-minus-two-standard-deviation) SN curve input, $\log A0$, see Figure C.3, is calculated as a shift of two standard deviation $(2\sigma)$ of $\log A0$ of the mean SN curve, i.e $\log A0 = \log \bar{A}0 - 2\sigma$. The shift of the curve is vertically down with fixed $N_0$. The design SN curves of DNV,[31] , included in the SN curve library of Stofat, are based on mean-minus-two-standard-deviation curves.

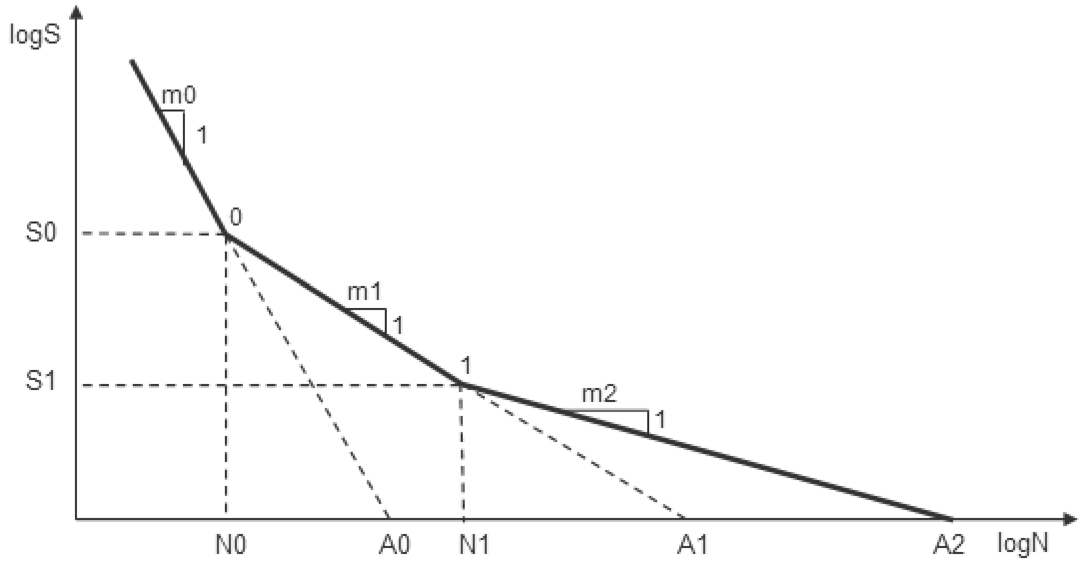



Figure C.2: SN curve parameters for a general three branch SN curve

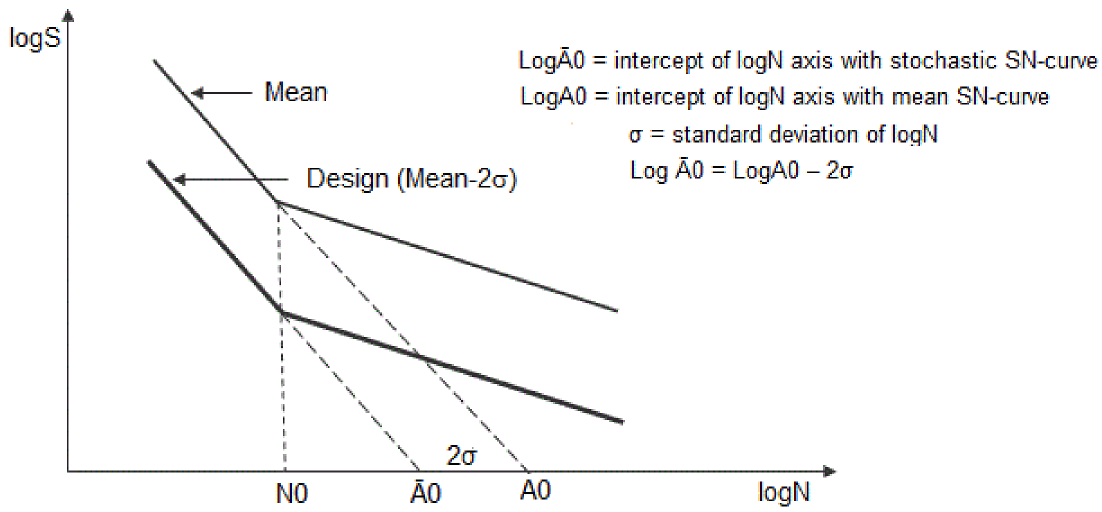



Figure C.3: Stochastic SN-curve parameters

**SN curve parameters:**

The SN curve parameters calculated by program for SN curves with of three line segments as shown in Figure C.2 and Figure C.3:

USER input option:

Input parameters: $m0$, $m1$, $m2$, $N0$, $N1$, $S0$
Calculated parameters:

$$\log_{10} A0 = \log_{10} N0 + m0 \log_{10} S0 \tag{C.17}$$

$$\log_{10} A1 = \log_{10} N0 + m1 \log_{10} S0 \tag{C.18}$$

$$\log_{10} S1 = \frac{(\log_{10} A1 - \log_{10} N1)}{m1} \tag{C.19}$$

$$\log_{10} A2 = \log_{10} N1 + m2 \log_{10} S1 \quad \text{(C.20)}$$

LOGA input option:

Input parameters: $m0$, $m1$, $m2$, $N0$, $N1$, $\log A0$

Calculated parameters:

$$\log_{10} S0 = \frac{(\log_{10} A0 - \log_{10} N0)}{m0} \quad \text{(C.21)}$$

$$\log_{10} A1 = \log_{10} N0 + m1 \log_{10} S0 \quad \text{(C.22)}$$

$$\log_{10} S1 = \frac{(\log_{10} A1 - \log_{10} N1)}{m1} \quad \text{(C.23)}$$

$$\log_{10} A2 = \log_{10} N1 + m2 \log_{10} S1 \quad \text{(C.24)}$$

STOCHASTIC input option:

Input parameters: $m0$, $m1$, $m2$, $N0$, $N1$, $\log K0$, $\sigma_{\log K}$

Calculated parameters:

$$\log_{10} \bar{A}0 = \log_{10} A_0 - 2\sigma_{\log_{10} K} \quad \text{(C.25)}$$

$$\log_{10} S0 = \frac{\left(\log_{10} \bar{A}0 - \log_{10} N0\right)}{m0} \quad \text{(C.26)}$$

$$\log_{10} \bar{A}1 = \log_{10} N_0 + m1 \log_{10} S0 \quad \text{(C.27)}$$

$$\log_{10} S1 = \frac{(\log_{10} A1 - \log_{10} N1)}{m1} \quad \text{(C.28)}$$

$$\log_{10} \bar{A}2 = \log_{10} N_1 + m2 \log_{10} S1 \quad \text{(C.29)}$$

**Units convertion of SN curve parameters:**

Use of consistent units in the fatigue analysis is required for valid analysis results. Convertion of SN curve data from one unit to another may be required. Units of parameters calculated by the program are in accordance with units of the input parameters.

When $S0$ is given as input (USER input option), the values of the calculated parameters (e.g. $\log A0$, $\log A1$) are in accordance with unit and value of $S0$. When $\log A0$ is given as input (LOGA input option) the value must be in accordance with the unit of the stresses applied in the analysis.

$\log A0$, $m1$ and $m2$ are commonly used parameters in SN curve data specifications. The value of $\log A0$ reflects the stress unit of the SN curve. The unit of the SN curve data do not always coincide with the unit applied in the analysis and a conversion of the SN curve data may be required.

A conversion rule may easily established by expressing Equation C.2 in two different stress values. A general stress value may S may be written as an exponent of 10, e.g.:

$$S = x \cdot 10^{\bar{n}} = 10^{\bar{n}} \tag{C.30}$$

which gives

$$\log_{10} S = \log_{10} x + \bar{n} = n \tag{C.31}$$

Illustrated by an example we have; $S = 7.44 \cdot 10^7 = 10^{7.872}$ which gives $\log_{10} S = 0.782 + 7 = 7.872$, Two stress values $\bar{S}_1$ and $\bar{S}_2$ may be written as:

$$\bar{S}_1 = 10^{n1} \tag{C.32}$$

$$\bar{S}_2 = 10^{n2} = 10^{c+n1} \tag{C.33}$$

where the relation between the exponent values is

$$n2 = c + n1 \tag{C.34}$$

Further we have

$$\log_{10} \bar{S}_1 = \log_{10} \left(10^{n1}\right) = n1 \tag{C.35}$$

$$\log_{10} \bar{S}_2 = \log_{10} \left(10^{n2}\right) = n2 = c + n1 \tag{C.36}$$

Applying Equation C.2 for $\bar{S}_1$ and $\bar{S}_2$ in combination with Equation C.35 and Equation C.36 we have:

$$\log_{10} \bar{A}_1 = \log_{10} N + m \log_{10} \bar{S}_1 = \log_{10} N + mn1 \tag{C.37}$$

$$\log_{10} \bar{A}_2 = \log_{10} N + m \log_{10} \bar{S}_2 = \log_{10} N + mn2 = \log_{10} N + m\left(c + n1\right) \tag{C.38}$$

Substracting Equation C.38 from Equation C.37 gives:

$$\log_{10} \bar{A}_2 = \log_{10} \bar{A}_1 + mc \tag{C.39}$$

This equation gives the $\log A$ relation for two stress values where $c$ represents the difference of the stress values expressed by their exponent values as outlined above. $\log K$ transforms in a same way as $\log A$. Equation C.34 may be applied to the various branches of the SN curve by using $m$ and $c$ related to each of the branches.

Equation C.39 may be used to transform the $\log A$ between stress values expresses in different unit. Examples are given in Table C.2

## C.3 Fatigue Damage Model and Failure Criterion

In Section B.4 the wave-induced stresses in terms of stress ranges and cycles are given in a probabilistic manner, whereas in Section C.2 the fatigue strength of offshore structures in terms of SN curves is given in a probabilistic terms. In this chapter the failure criteria corresponding to the limit state functions are described.

A distinct problem arises in defining the failure criterion due to the formulations of the wave-induced stresses and the fatigue strength. The wave-induced stresses during the expected life time of a structure are of varying ranges, whereas the fatigue strength of the structure is formulated in terms of number of cycles to failure for a fixed stress range. Therefore it is not possible to compare directly the induced stress ranges with the fatigue strength. This problem is resolved by considering the fraction of damage to the structure

Table C.2: Relations between stress values and $logA$ values

| Parameter | $S1$,$n1$, $\log A1 = \log N + mn$ | $S2$, $n2 = n1 + c$, $\log A2 = \log A1 + mc$ | | | |
|---|---|---|---|---|---|
| | $N/mm^2$ $(MPa)$ | $N/m^2$ $(Pa)$ | $kN/m^2$ | $psi$ 1 $MPa$=145.04 $psi$ | $ksi$ 1 $MPa$ =14504 $psi$ |
| $S$ | $7.44 \times 10^1$ | $7.44 \times 10^7$ | $7.44 \times 10^4$ | $1.0791 \times 10^4$ | $1.07911.0791 \times 10^1$ |
| $n$ | 1.8716 | 7.8716 | 4.8716 | 4.0331 | 1.0331 |
| $c$ | 0 | 6 | 3 | 2.1615 | −0.8385 |
| $m$ | 3 | 3 | 3 | 3 | 3 |
| $\log N$ | 7 | 7 | 7 | 7 | 7 |
| $\log A$ | 12.615 | 30.615 | 21.615 | 19.100 | 10.100 |

caused by each stress range and corresponding cycles and summing/integrating to obtain the total damage. Then the failure criterion can be given in terms of total accumulated damage. The accumulated damage is computed from the representative stress distribution and the SN relation. The accumulated damage depends on the number and magnitude of the applied stress cycles, but is assumed independent of the sequence in which the stress cycles occur. The damage $D$ can then be written as

$$D = \sum_{i=1} \frac{n_i}{N_i} \tag{C.40}$$

where $n_i = n(S_i)$ is the number of cycles of stress range in the stress history and $N_i = N(S_i)$ is the number of stress cycles of stress range necessary to cause failure. This model for damage accumulation is usually attributed to Palmgren [22], and Miner, who independly proposed that failure will occur when the sum reaches unity. Although the absolute validity of Miner's theory can be questioned, its comparative usefulness as a simple analytical criterion for comparing different designs of a system is of considerable value. This damage accumulation model is used in Stofat. The definition of failure is not unique but in a limit state design analysis a precise definition must be chosen. This definition then refers to a unique state of damage, e.g. total rupture through cracking or crack growth to a certain fraction of the circumsphere. When test results are used to estimate strength it is therefore very important to note that failure is defined by the same failure criterion used in the tests.

The failure criterion gives the value of the damage at failure. For a constant amplitude stress variation it follows directly from the damage definition above that failure occurs when $D \geq 1$.

For a variable amplitude loading the value of the Miner's sum at failure will be random due to the inherent randomness in the stress history. The Miner's summation then contains so many terms that this inherent uncertainty can be neglected and as it was stated before, the total damage at failure, defined by random variable $D$, can be represented by the expected value of $D$.

The strength modelling error of the damage at failure, the random variable $D$, is measured from random fatigue testing. Because fatigue behaviour is influenced by many factors, among them the variability inherent in the material, it is difficult to interpret the test results. However, there seems to be some coherence to published results where a slight non-conservative bias is suggested by recent tests on welded details, where uncertainties around 30-60% seem to be typical.

Fatigue stresses in offshore structures can be considered as random continuous functions. The determination of fatigue damage from the response spectra is simple in the case where the response is taken as a stationary and narrow banded Gaussian process.

With this assumptions it follows that the stress amplitudes are Rayleigh distributed. [23], [17], [18] and several others have used this distribution in fatigue damage calculations. It is believed that the assumption of a narrow banded process may not always be valid. The expression for the stress range and number of cycles with this assumption is given in Appendix B.4. The possible error in assuming a narrow banded response has been studied in, e.g. [33], by introducing a correction factor where describes the spectral width.

$$\kappa = a(m) + (1 - a(m))(1 - \epsilon)^{b(m)} \tag{C.41}$$

$$\epsilon = \sqrt{1 - \frac{\lambda_2^2}{\lambda_0 \lambda_4}} \tag{C.42}$$

where

$a(m) = 0.926 - 0.033m$
$b(m) = 1.587m - 2.323$
$\epsilon$ is the spectral band width. $\epsilon \to 0$ when the stress process is narrow banded
$\lambda_i$ is the spectral moment of order $i$

A comparison with rainflow counting on simulated stress histories of a Gaussian stress process for typical ocean structure problems, $\epsilon = 0.5$, gives $\kappa = 0.79$ for $m = 4.38$ and $\kappa = 0.86$ for $m = 3$ . This means that an assumption of a narrow banded process causes a small overestimation of the fatigue damage.

The effects of nonlinearity in the drag, nonlinearity of wave kinematics and free surface elevation, make the response of the platform non-Gaussian, especially for higher sea states and small diameter members, [**?**]. This creates a problem during the frequency domain analysis in choosing the sea state in which stochastic linearization is performed. The nonlinearity also introduces a systematic error in the fatigue damage calculation due to the non-Gaussian response process, [3], [19] and [16]. A method accounting for this type of non-Gaussian response is presented in [28]. Full scale measurements on two instrumented jackets in the North Sea (Valhall QP and Frigg DP2), [12], show that the response is widebanded and non-Gaussian. However, the measurements concluded that the fatigue damage estimation based on a narrow-banded Gaussian distribution is not significantly affected by the non-Gaussian response.

Experimental data suggest that the Miner-Palmgren rule predicts fatigue failure reasonable well. Sequence effects seem negligible for random loaded components. On welded joints it appears that the Miner-Palmgren rule is slightly non-conservative. Biases down to 0.7 to 0.8 are being observed, where bias is defined as the ratio of the predicted damage divided by the measured damage. The response in the fatigue damage calculation is assumed to be a narrow banded Gaussian process. However, fatigue stresses are typically somewhat wide banded and a rainflow correction factor $(\kappa \geq 0)$ for wide banded processes is observed. The rainflow correction factor for wide banded processes indicates a compensating bias. Therefore, the Miner-Palmgren damage is used unbiased and no rainflow correction factor is included.

For a linear SN curve, the accumulated fatigue damage in one sea state is written as

$$D = \frac{\nu_0 t}{K} E\left[S^m\right] = \frac{\nu_0 t}{K} \left(2\sqrt{2\lambda_0}\right)^m \cdot \Gamma\left(1 + \frac{m}{2}\right) \tag{C.43}$$

where $\nu_0$ is the expected zero up-crossing frequency, $t$ is the period damage is calculated for, $K$ and $m$ are parameters in the SN equation and $\lambda_0$ is the variance of the stress amplitude process. The damage is then summed over all sea states and over all wave directions. For SN curves with a threshold, bilinear or trilinear SN curves, the damage equations are slightly different.

# D Stofat Elements and Fatigue Check Points

## D.1 Fatigue Check Points

Two types of fatigue check calculations are performed by Stofat; 1) *element fatigue check* and 2) *hotspot fatigue check*. Element fatigue check is performed for individual elements selected by the used and hotspot fatigue check is performed for critical points in the structure specified by the user.

Element fatigue check points may be located at following positions within an element, 1) at the stress points (result points), 2) at the element surface points, 3) at the element corner points and 4) at the element middle plane points, 5) at element centre points, see Section D.2. The middle plane fatigue check points are applicable for shell elements and are located at the projections normal to the middle plane of the element stress points. Use of only membrane stresses in the fatigue calculation for the middle plane points is also possible. The user selects the fatigue point locations by the command CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK.

The number of fatigue check points of an element is the same as the number of stress points for the element. For the middle plane, the number of fatigue points is half the number of stress points, see D.1. Damage is calculated for all fatigue points of an element and the usage factor of the point that suffers most fatigue damage is taken as the usage factor of the element and is made available to the user in tabulated prints of the fatigue results. Usage factors of all the fatigue points may, however, be printed to a dump print file or written to the VTF file and presented as contour plots by Xtract.

Hotspots may be placed anywhere inside or at the borders of the elements. Creation of a hotspot is described in Section D.3.

Stofat interpolates stresses to element surface points, element corner points, element middle plane points and hotspots on basis of stresses of the stress points which are read from the Result Interface File (.SIN). Linear interpolation schemes are applied, see Section D.3.2.

Element fatigue check and hotspot fatigue check cannot be mixed and have to be executed in a separate runs. The user selects the fatigue check type to be executed in the RUN FATIGUE-CHECK command.

Note that fatigue calculations are not performed for element types that are not implemented in Stofat. If such elements are present in the model, Stofat neglects them and prints a message.

## D.2 Elements Implemented in Stofat

Stofat performs fatigue check calculations of structural models based on shell and solid elements. The elements implemented in Stofat are listed in D.1 which gives an overview of the nodes, stress points, stress components and fatigue point locations of the elements. Key information about the elements and specification of the fatigue point locations are described in the next sections. Node numbering applied in Xtract for Stofat elements are also given since the numbering do not coincide for the higher order elements.

### D.2.1 Shell Elements

Four types of shell elements are implemented in Stofat:

- Flat thin shell elements - quadrilateral FQUS(24) and triangular FTRS(25) elements
- Subparametric curved thick shell element - quadrilateral SCQS(28) and triangular SCTS(26) elements

#### D.2.1.1 Thin Shell Elements

The flat thin shell element FQUS and FTRS have 4 and 3 nodes, respectively. The nodes are located in the corners of the middle plane of the elements. The stress points are located at the element corners and at the centre point of the element surfaces, see Figure D.1 and Figure D.2. The elements have 10 and 8 stress points, respectively. Stress points and corner points coincide for the thin shell elements and the middle plane points coincide with the nodes of the elements.

The elements have two surfaces, numbered as 1 and 2, where surface 1 is the lower surface of the element (at $\gamma = -1$) and surface 2 is the upper surface (at $\gamma = +1$). The natural element coordinate axes $\alpha$, $\beta$, $\gamma$ and the i, j, k axes (which relates to the I, J, K planes) are shown in the figures. The stress points are numbered according to the Results Interface File numbering sequence in the order of the $i$,$j$, $k$ directions. Area coordinates of a triangular shell element is shown in Figure D.3.

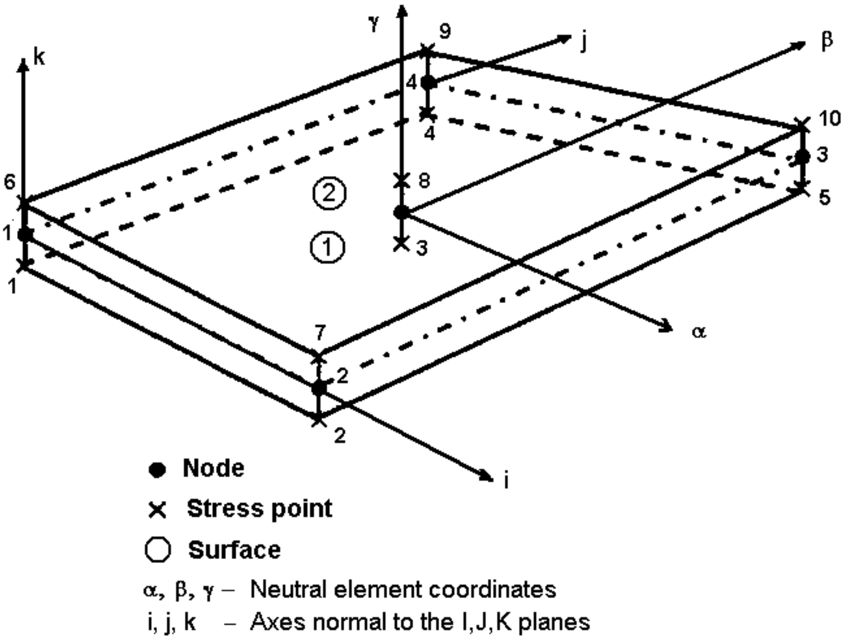
Table D.1: Sesam elements implemented in Stofat

| Element type | Element name (number) | ♯ of nodes | ♯ of stress points | Stress components | Element fatigue point locations (D/O/N = Default/Optional/Not possible) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Stress points | Element mid-plane[a] | | Surface point | Corner points | Centre str. Surf. points | Centroid |
| | | | | | | Middle plane | Membrane | | | | |
| **Shell elements** | | | | | | | | | | | |
| Flat triangular thin shell | FTRS(25) | 3 | 8[b] | $\sigma_x$, $\sigma_y$, $\tau_{xy}$ | D | O[c] | O[b] | D | D | O | O |
| Flat quadrilateral thin shell | FQUS(24) | 4 | 10[a] | $\sigma_x$, $\sigma_y$, $\tau_{xy}$ | D | O[b] | O[b] | D | D | O | O |
| Subparametric curved triangular thick shell | SCTS(26) | 6 | 6 | $\sigma_x$, $\sigma_y$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | O | N | O | O | O | O |
| | | | | $\sigma_x$, $\sigma_y$, $\tau_{xy}$ | N | N | O | N | N | N | O |
| Subparametric curved quadrilateral thick shell | SCQS(28) | 8 | 8 | $\sigma_x$, $\sigma_y$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | O | N | O | O | O | O |
| | | | | $\sigma_x$, $\sigma_y$, $\tau_{xy}$ | D | N | O | N | NO | N | O |
| **Solid elements** | | | | | | | | | | | |
| Tetrahedron | TETR(33) | 4 | 1 | $\sigma_x$, $\sigma_y$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | N | N | N | O | N | O |
| Triangular prism | TPRI(32) | 6 | 2(6) | $\sigma_x$, $\sigma_y$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | N | N | N/O[d] | O | O | O |
| Linear hexahedron | LHEX(21) | 8 | 8 | $\sigma_x$, $\sigma_y$, $\sigma_z$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | N | N | N/O[e] | O | O | O |
| Isoparametric tetrahedron | ITET(31) | 10 | 4 | $\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{zx}$ | D | N | N | N | O | N | O |
| Isoparametric triangular prism | IPRI(30) | 15 | 8 | $\sigma_x$, $\sigma_y$, $\sigma_z$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | N | N | N/O[b] | O | O | O |
| Isoparametric hexahedron | IHEX(20) | 20 | 8 | $\sigma_x$, $\sigma_y$, $\sigma_z$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ | D | N | N | N/O[f] | O | O | O |

[a] The number of fatigue points is half the number of stress points of the element
[b] Stresses of centre point of elements are not used
[c] Middle plane and membrane options are identical
[d] Triangular surfaces 4 and 5, see "Triangular prism elements" in Section D.2.2
[e] Surfaces 1 and 2 in local z-direction of element, see "Hexahedron elements" in Section D.2.2
[f] Surfaces 5 and 6 in local z-direction of element, see "Hexahedron elements" in Section D.2.2

The stress components $\sigma_x$, $\sigma_y$, $\tau_{xy}$ contain contributions from the bending and the membrane parts of the element stresses. Linear interpolation of stresses to a hotspot inside the elements is based on the corner stresses. Stresses of the centre points are not used.

The node numbering applied in Xtract and Stofat coincide for the thin shell elements.

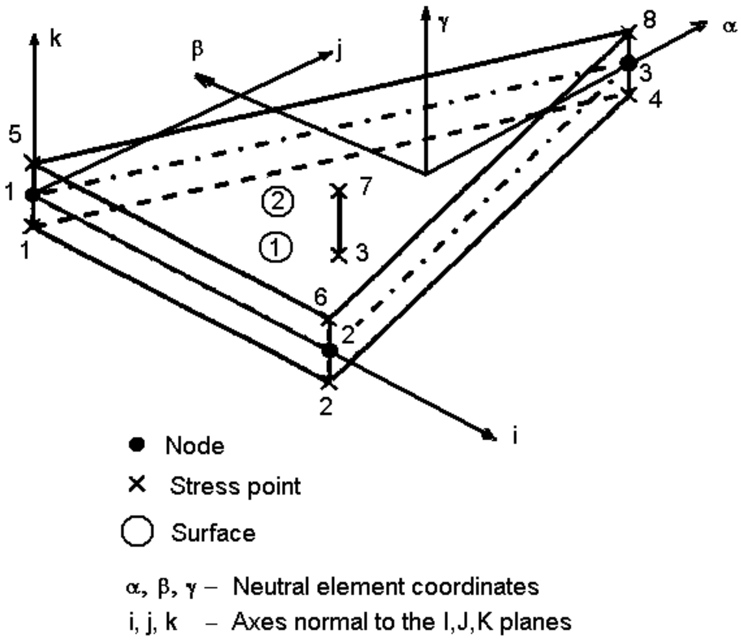



| Stress point | α | β | γ |
|---|---|---|---|
| 1 | - 1 | - 1 | - 1 |
| 2 | 1 | - 1 | - 1 |
| 3 | 0 | 0 | - 1 |
| 4 | - 1 | 1 | - 1 |
| 5 | 1 | 1 | - 1 |
| 6 | - 1 | - 1 | 1 |
| 7 | 1 | - 1 | 1 |
| 8 | 0 | 0 | 1 |
| 9 | - 1 | 1 | 1 |
| 10 | 1 | 1 | 1 |

| Surface | | | |
|---|---|---|---|
| 1 | | | -1 |
| 2 | | | 1 |

| Middle plane point | α | β | γ |
|---|---|---|---|
| 1 | - 1 | - 1 | 0 |
| 2 | 1 | - 1 | 0 |
| 3 | 0 | 0 | 0 |
| 4 | - 1 | 1 | 0 |

Figure D.1: The quadrilateral thin shell element FQUS




| Stress point | α | β | γ |
|---|---|---|---|
| 1 | -1 | 1 | -1 |
| 2 | -1 | -1 | -1 |
| 3 | -1/3 | 0 | -1 |
| 4 | 1 | 0 | -1 |
| 5 | -1 | 1 | -1 |
| 6 | -1 | -1 | -1 |
| 7 | -1/3 | 0 | -1 |
| 8 | 1 | 0 | -1 |

| Surface | | | |
|---|---|---|---|
| 1 | | | -1 |
| 2 | | | 1 |

| Middle plane point | α | β | γ |
|---|---|---|---|
| 1 | -1 | 1 | 0 |
| 2 | -1 | -1 | 0 |
| 3 | 1 | 0 | 0 |

Figure D.2: The triangular thin shell element FTRS

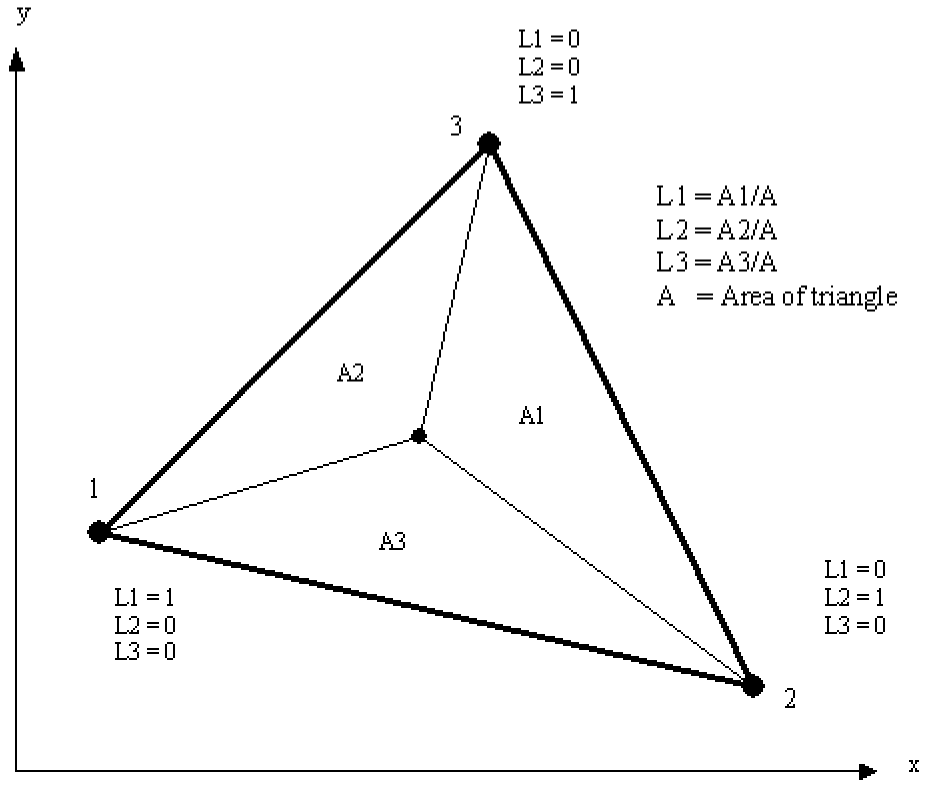



Figure D.3: Area coordinates of triangular shell element

### D.2.1.2 Thick Shell Elements

The curved thick shell elements SCQS and SCTS have 8 and 6 nodes, respectively, as shown in Figure D.4 and Figure D.5. The quadrilateral element SCQS has 8 integration points located in the 2x2x2 Gaussian integration points of the element, see Figure D.4. The triangular element SCTS has 6 stress points located in the Gaussian integration point in the thickness direction and with triangular area coordinates L1, L2 and L3, see Figure D.5.

The element surface and middle plane points are located at same positions in the $\alpha - \beta$ plane as the stress points, but at top and bottom surface of the element (surface 2 and 1, respectively) and at the middle surface. The corner points are located in corners of the element surfaces Coordinates of stress-, surface- and corner points are given in Figure D.4 and Figure D.5.

The natural element coordinate axes $\alpha$, $\beta$, $\gamma$ and the $i$, $j$, $k$ axes are shown in the figures. The stress points are numbered according to the Results Interface File numbering sequence in the order of $i$, $j$, $k$ directions.

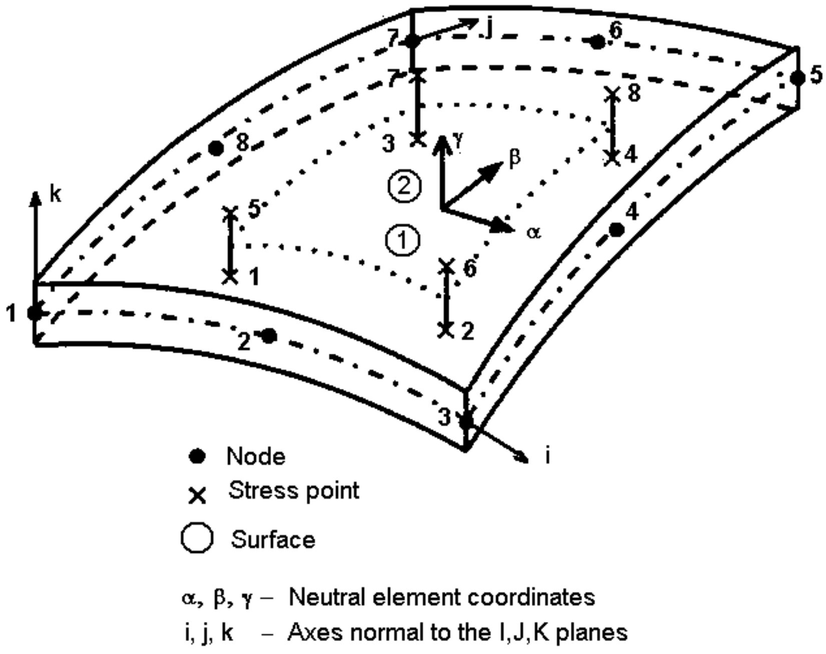
The stress components $\sigma_x$, $\sigma_y$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{zx}$ contain contributions from the bending and the membrane parts of the normal stresses and inplane- and transverse shear stresses. Linear interpolations of stresses to the surface-, corner-, middle plane- and hotspots points are performed on basis of the stress points stresses. The transverse shear stresses are interpolated through the thickness according to a parabolic stress variation with zero shear stress at the element surfaces and maximum shear stress at the element middle plane.

In case of the membrane option is applied for the element fatigue check location, the stress components $\sigma_x$, $\sigma_y$, $\tau_{xy}$ of the element middle plane are applied in the fatigue calculation. In case of centre points or centroid point option is selected, stresses of the stress points at same z-coordinate are interpolated to the centre point of the element.

The node numbering applied in Xtract and Stofat coincide for the triangular thick shell elements (SCTS), but not for the quadrilateral thick shell element (SCQS). Table D.2 shows the node numbering of Xtract related to the Stofat numbering for the SCQS element.

Table D.2: Node numbering of Xtract related to Stofat for the quadrilateral shell element, SCQS

| Program | Node Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Stofat | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Xtract | 1 | 5 | 2 | 6 | 3 | 7 | 4 | 8 |




$$a = 0.57735 = \frac{\sqrt{3}}{3}$$

Stress point

| | α | β | γ |
|---|---|---|---|
| 1 | -a | -a | -a |
| 2 | a | -a | -a |
| 3 | -a | a | -a |
| 4 | a | a | -a |
| 5 | -a | -a | a |
| 6 | a | -a | a |
| 7 | -a | a | a |
| 8 | a | a | a |

Surface point

| | α | β | γ |
|---|---|---|---|
| 1 | -a | -a | -1 |
| 2 | a | -a | -1 |
| 3 | -a | a | -1 |
| 4 | a | a | -1 |
| 5 | -a | -a | 1 |
| 6 | a | -a | 1 |
| 7 | -a | a | 1 |
| 8 | a | a | 1 |

Corner point

| | α | β | γ |
|---|---|---|---|
| 1 | -1 | -1 | -1 |
| 2 | 1 | -1 | -1 |
| 3 | -1 | 1 | -1 |
| 4 | 1 | 1 | -1 |
| 5 | -1 | -1 | 1 |
| 6 | 1 | -1 | 1 |
| 7 | -1 | 1 | 1 |
| 8 | 1 | 1 | 1 |

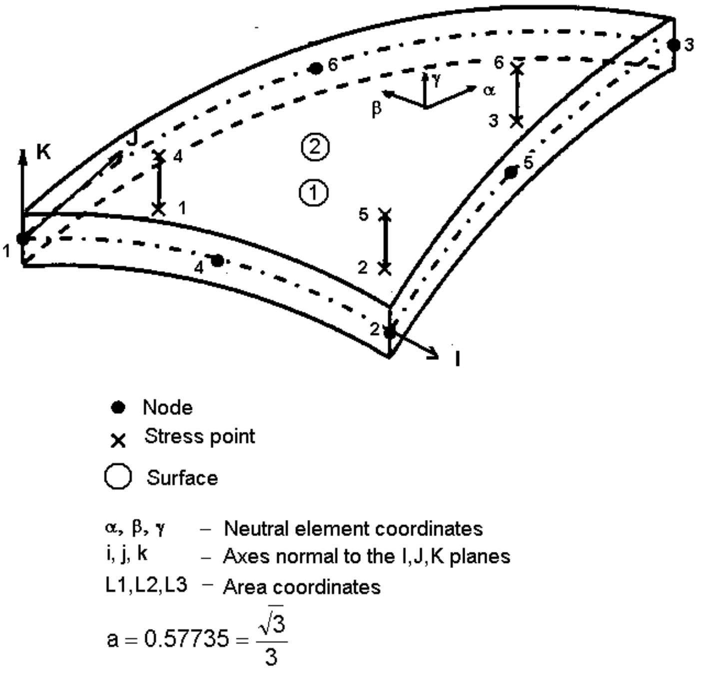
Surface

| | α | β | γ |
|---|---|---|---|
| 1 | | | -1 |
| 2 | | | 1 |

Middle plane point

| | α | β | γ |
|---|---|---|---|
| 1 | -a | -a | 0 |
| 2 | a | -a | 0 |
| 3 | -a | a | 0 |
| 4 | a | a | 0 |

Figure D.4: The quadrilateral thin shell element SCQS




| Stress point | L1 | L2 | L3 | α | β | γ |
|---|---|---|---|---|---|---|
| 1 | 2/3 | 1/6 | 1/6 | -2/3 | 1/2 | -a |
| 2 | 1/6 | 2/3 | 1/6 | -2/3 | -1/2 | -a |
| 3 | 1/6 | 1/6 | 2/3 | 1/3 | 0 | -a |
| 4 | 2/3 | 1/6 | 1/6 | -2/3 | 1/2 | a |
| 5 | 1/6 | 2/3 | 1/6 | -2/3 | -1/2 | a |
| 6 | 1/6 | 1/6 | 2/3 | 1/3 | 0 | a |
| **Surface point** | | | | | | |
| 1 | 2/3 | 1/6 | 1/6 | -2/3 | 1/2 | -1 |
| 2 | 1/6 | 2/3 | 1/6 | -2/3 | -1/2 | -1 |
| 3 | 1/6 | 1/6 | 2/3 | 1/3 | 0 | -1 |
| 4 | 2/3 | 1/6 | 1/6 | -2/3 | 1/2 | 1 |
| 5 | 1/6 | 2/3 | 1/6 | -2/3 | -1/2 | 1 |
| 6 | 1/6 | 1/6 | 2/3 | 1/3 | 0 | 1 |
| **Corner point** | | | | | | |
| 1 | 1 | 0 | 0 | -1 | 1 | -1 |
| 2 | 0 | 1 | 0 | -1 | -1 | -1 |
| 3 | 0 | 0 | 1 | 1 | 0 | -1 |
| 4 | 1 | 0 | 0 | -1 | 1 | 1 |
| 5 | 0 | 1 | 0 | -1 | -1 | 1 |
| 6 | 0 | 0 | 1 | 1 | 0 | 1 |
| **Surface** | | | | | | |
| 1 | | | | | | -1 |
| 2 | | | | | | 1 |
| **Middle plane point** | | | | | | |
| 1 | 2/3 | 1/6 | 1/6 | -2/3 | 1/2 | 0 |
| 2 | 1/6 | 2/3 | 1/6 | -2/3 | -1/2 | 0 |
| 3 | 1/6 | 1/6 | 2/3 | 1/3 | 0 | 0 |

Figure D.5: The triangular thin shell element SCTS

## D.2.2 Solid Elements

The solid elements implemented in Stofat consist of three lower order elements and three higher order elements. The lower order elements are:

- Linear haxahedron, LHEX(21)
- Triangular prism, TPRI(32)
- Tetrahedron, TETR(33)

The higher order elements are:

- Isoparametric hexahedron, IHEX(20)
- Isoparametric triangular prism, IPRI(30)
- Isoparametric tetrahedron, ITET(31)

### D.2.2.1 Hexahedron Elements

The linear hexahedron element LHEX has 8 nodes and the isoparametric hexahedron has 20 nodes. Both elements have 8 stress points located in the 2x2x2 Gaussian integration points, see Figure D.6 and Figure D.8. Numbering of nodes and stress points are given in the figures. The node numbering applied in Xtract coincides with the node numbering applied in Stofat for the hexahedron elements.

Stresses of the stress points may be extrapolated to the corners of the element (corner points) or the element surfaces (surface points). *Note that the numbering of the corner points is the same as for the stress points and does not coincide with the node numbers of the element.* The stress points are numbered according to the Results Interface File numbering sequence in the order of $i$, $j$, $k$ directions.

The numbering of the element surfaces are shown in Figure D.7 and Figure D.9. The present version of Stofat extrapolates stresses to surface 1 and 6 for the linear hexahedron and to surface 6 and 5 for the isoparametric element, i.e. the surfaces normal to the $\gamma$ - axis. The $\alpha$ - and $\beta$ - coordinates of the surface points are the same as for the stress points (2x2 Gaussian points). $\gamma$ takes the values of $\gamma = +1$ and $\gamma = -1$ for the surface points. Coordinates of the surface points are given in Figure D.7 and Figure D.9.

The elements contain all six stress components $\sigma_x$, $\sigma_y$, $\sigma_z$, $\tau_{xy}$, $\tau_{yz}$, $\tau_{xy}$. Linear interpolations of stresses to the surface points, corner points or hotspots are performed on basis of the stress points stresses. In case of centre points or centroid point option is selected, stresses of the stress points at same z-coordinate are interpolated to the centre point of the element.

The node numbering applied in Xtract and Stofat coincides for the linear hexahedron element (LHEX), but not for the isoparametric hexahedron element (IHEX). Table D.3 shows the node numbering of Xtract related to the Stofat numbering for the IHEX element.

Table D.3: Node numbering of Xtract related to Stofat for the isoparametric hexahedron, IHEX

| Program | Node Number | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stofat | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Xtract | 1 | 9 | 2 | 10 | 3 | 11 | 4 | 12 | 17 | 18 | 19 | 20 | 5 | 13 | 6 | 14 | 7 | 15 | 8 | 16 |

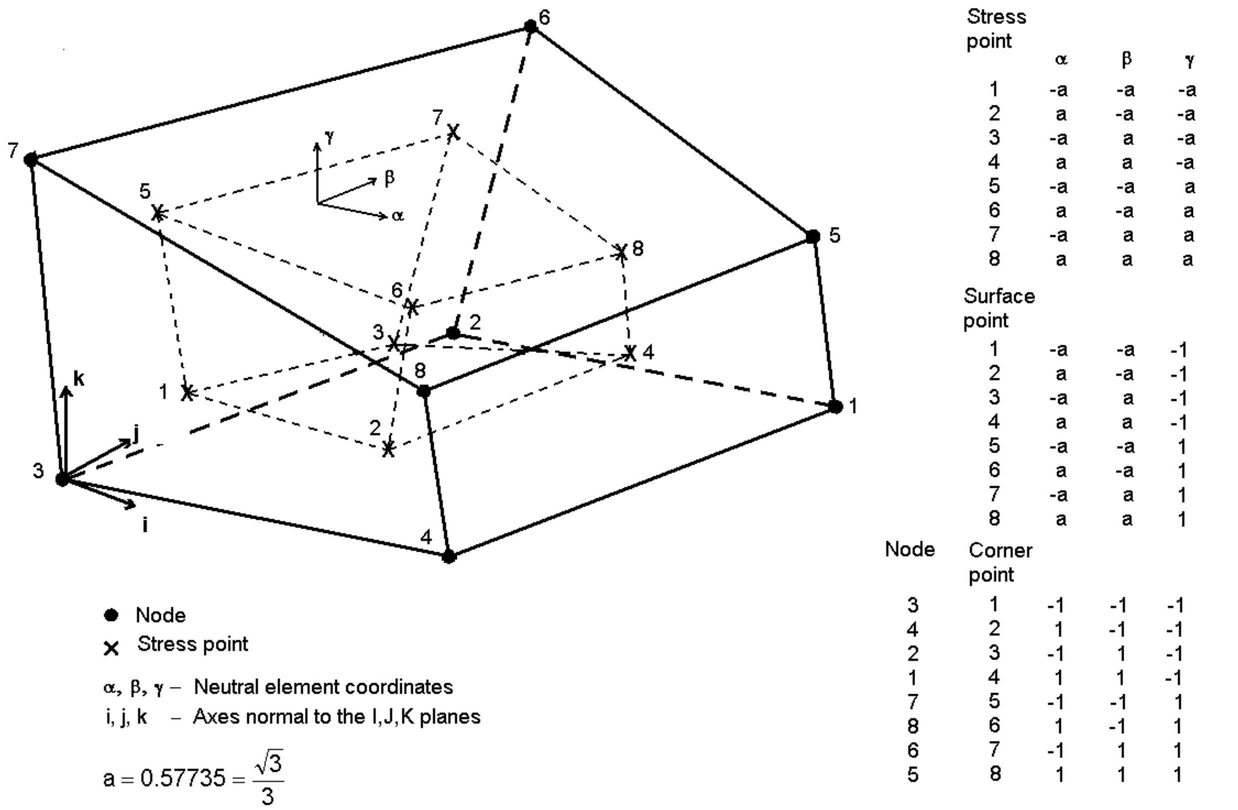
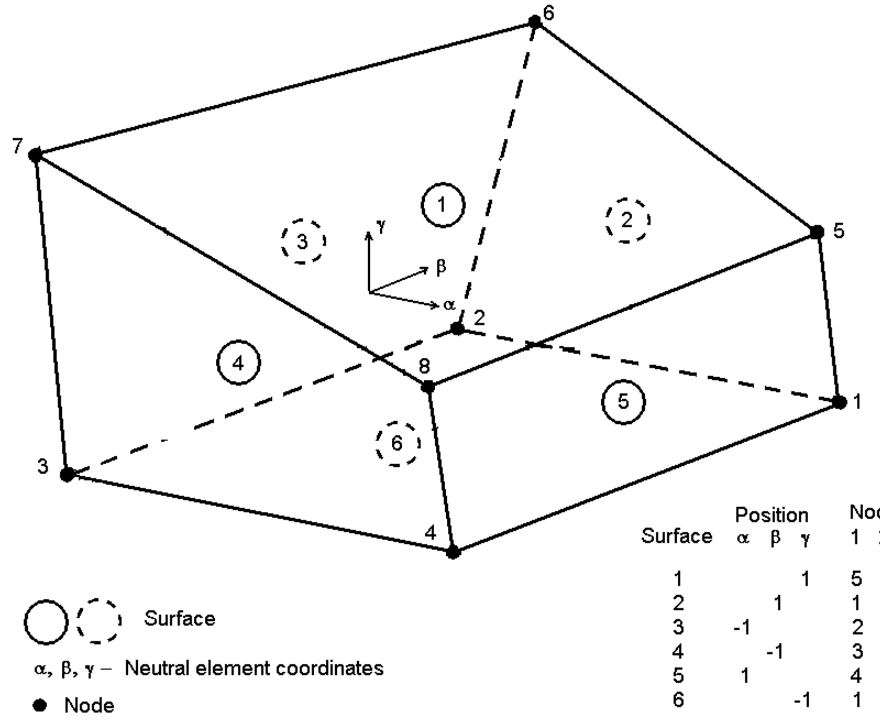
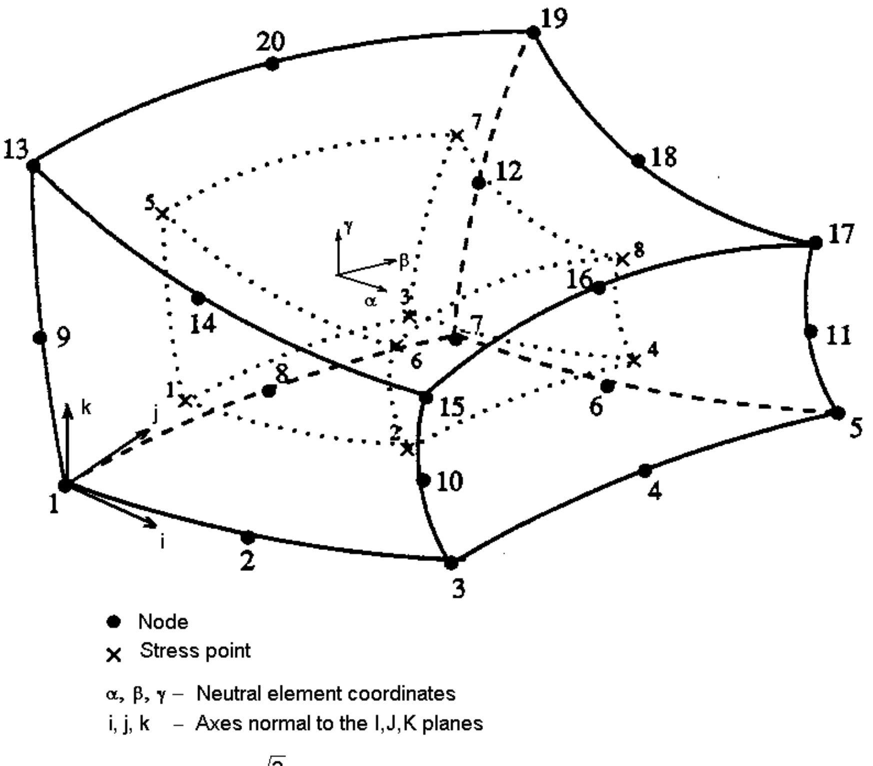



Figure D.6: The linear hexahedron element LHEX




| Surface | Position α | β | γ | Node number 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|
| 1 | | | 1 | 5 | 6 | 7 | 8 |
| 2 | | 1 | | 1 | 2 | 6 | 5 |
| 3 | -1 | | | 2 | 3 | 7 | 6 |
| 4 | | -1 | | 3 | 4 | 8 | 7 |
| 5 | 1 | | | 4 | 1 | 5 | 8 |
| 6 | | | -1 | 1 | 4 | 3 | 2 |

Figure D.7: Element surfaces of the linear hexahedron element LHEX




$$a = 0.57735 = \frac{\sqrt{3}}{3}$$

| Stress point | α | β | γ |
|---|---|---|---|
| 1 | -a | -a | -a |
| 2 | a | -a | -a |
| 3 | -a | a | -a |
| 4 | a | a | -a |
| 5 | -a | -a | a |
| 6 | a | -a | a |
| 7 | -a | a | a |
| 8 | a | a | a |

| Surface point | α | β | γ |
|---|---|---|---|
| 1 | -a | -a | -1 |
| 2 | a | -a | -1 |
| 3 | -a | a | -1 |
| 4 | a | a | -1 |
| 5 | -a | -a | 1 |
| 6 | a | -a | 1 |
| 7 | -a | a | 1 |
| 8 | a | a | 1 |

| Node | Corner point | α | β | γ |
|---|---|---|---|---|
| 1 | 1 | -1 | -1 | -1 |
| 3 | 2 | 1 | -1 | -1 |
| 7 | 3 | -1 | 1 | -1 |
| 5 | 4 | 1 | 1 | -1 |
| 13 | 5 | -1 | -1 | 1 |
| 15 | 6 | 1 | -1 | 1 |
| 19 | 7 | -1 | 1 | 1 |
| 17 | 8 | 1 | 1 | 1 |

Figure D.8: The isoparametric hexahedron element IHEX

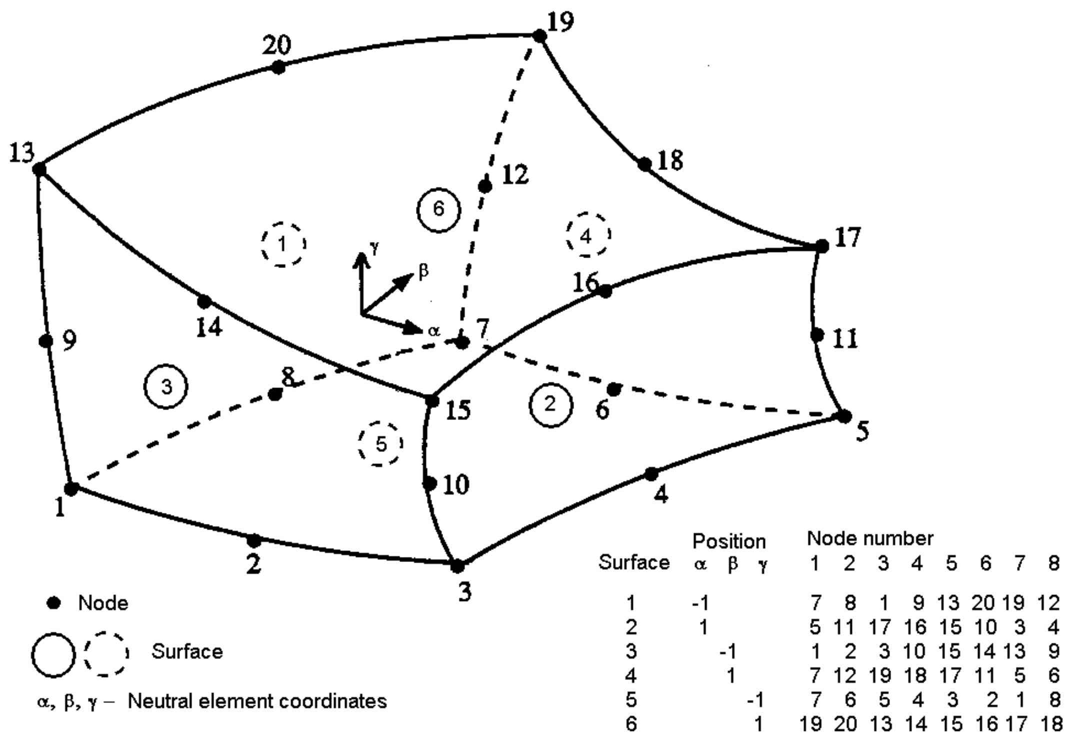



Figure D.9: Element surfaces of the isoparametric hexahedron element LHEX

### D.2.2.2 Triangular Prism Elements

The linear triangular prism TPRI has 6 nodes and may have 2 or 6 stress points, see Figure D.10. The default number of stress points are 2, located at the centre of the triangle and in the Gaussian integration points in thickness direction, see points 3 and 7 in Figure D.10. Optionally, the number of stress points may be extended to 6 (must be done in preprocessing/structural analysis phase). In this case the stress points are located in the Gaussian integration points in the thickness direction with triangular area coordinates L1, L2 and L3, see points 1, 2, 4, 5, 6 and 8.

The isoparametric triangular prism IPRI has 15 nodes 8 stress points. The stress points are located in the Gaussian integration points in the thickness direction with triangular area coordinates L1, L2 and L3, (points 1, 2, 4, 5, 6 and 8) and at the centre of the triangle (points 3 and 7), see Figure D.11.

Stresses of the stress points may be interpolated to the corners of the element (corner points) or the triangular element surfaces (surface points). Note that the numbering of the corner points is the same as for the stress points and does not coincide with the node numbers of the element. The stress points are numbered according to the Results Interface File numbering sequence in the order of $i$, $j$, $k$ directions.

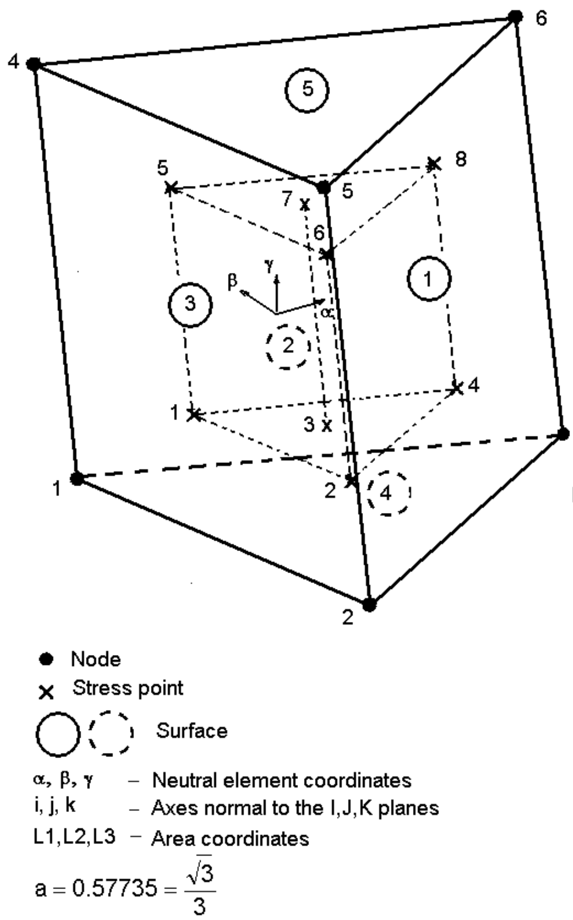
The numbering of the element surfaces are also shown in Figure D.10 and Figure D.11. Stofat extrapolates stresses only to triangular element surfaces 4 and 5, i.e. to the surface normal to the $\gamma$ - axis. The L1 and L2 coordinates of the surface points are the same as for the stress points. $\gamma$ takes the values of $\gamma = +1$ and $\gamma = -1$ for the surface points. Coordinates of the surface points are given in Figure D.10 and Figure D.11.

The elements contain all six stress components $\sigma_x$, $\sigma_y$, $\sigma_z$, $\sigma_{xy}$, $\sigma_{zx}$, $\sigma_{zx}$. Linear interpolations of stresses to the surface points, corner points or hotspots are performed on basis of the stress points stresses. Stresses of the centre points are used only when fatigue check location at the element centre points or centroid are selected.

The node numbering applied in Xtract and Stofat coincides for the linear triangular prism (TPRI), but not for the isoparametric triangular prism (IPRI) Table D.4 shows the node numbering of Xtract related to the Stofat numbering for the IPRI element.

Table D.4: Node numbering of Xtract related to Stofat for the isoparametric triangular prism, IPRI

| Program | Node Number | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stofat | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Xtract | 1 | 7 | 2 | 8 | 3 | 9 | 13 | 14 | 15 | 4 | 10 | 5 | 11 | 6 | 12 |




| Stress point | L1 | L2 | L3 | α | β | γ |
|---|---|---|---|---|---|---|
| 1 | 0.6 | 0.2 | 0.2 | -0.6 | 0.4 | -a |
| 2 | 0.2 | 0.6 | 0.2 | -0.6 | -0.4 | -a |
| 3 | 1/3 | 1/3 | 1/3 | -1/3 | 0 | -a |
| 4 | 0.2 | 0.2 | 0.6 | 0.2 | 0 | -a |
| 5 | 0.6 | 0.2 | 0.2 | -0.6 | 0.4 | a |
| 6 | 0.2 | 0.6 | 0.2 | -0.6 | -0.4 | a |
| 7 | 1/3 | 1/3 | 1/3 | -1/3 | 0 | a |
| 8 | 0.2 | 0.2 | 0.6 | 0.2 | 0 | a |

| Surface point | L1 | L2 | L3 | α | β | γ |
|---|---|---|---|---|---|---|
| 1 | 0.6 | 0.2 | 0.2 | -0.6 | 0.4 | -1 |
| 2 | 0.2 | 0.6 | 0.2 | -0.6 | -0.4 | -1 |
| 3 | 1/3 | 1/3 | 1/3 | -1/3 | 0 | -1 |
| 4 | 0.2 | 0.2 | 0.6 | 0.2 | 0 | -1 |
| 5 | 0.6 | 0.2 | 0.2 | -0.6 | 0.4 | 1 |
| 6 | 0.2 | 0.6 | 0.2 | -0.6 | -0.4 | 1 |
| 7 | 1/3 | 1/3 | 1/3 | -1/3 | 0 | 1 |
| 8 | 0.2 | 0.2 | 0.6 | 0.2 | 0 | 1 |

| Node | Corner point | L1 | L2 | L3 | α | β | γ |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 0 | -1 | 1 | -1 |
| 2 | 2 | 0 | 1 | 0 | -1 | -1 | -1 |
| 3 | 4 | 0 | 0 | 1 | 1 | 0 | -1 |
| 4 | 5 | 1 | 0 | 0 | -1 | 1 | 1 |
| 5 | 6 | 0 | 1 | 0 | -1 | -1 | 1 |
| 6 | 8 | 0 | 0 | 1 | 1 | 0 | 1 |

| Surface | Position L1 | L2 | L3 | γ | Node number 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | | | | 2 | 3 | 6 | 5 |
| 2 | | 0 | | | 3 | 1 | 4 | 6 |
| 3 | | | 0 | | 1 | 2 | 5 | 4 |
| 4 | | | | -1 | 1 | 2 | 3 | |
| 5 | | | | -1 | 6 | 5 | 4 | |

Figure D.10: The triangular prism TPRI

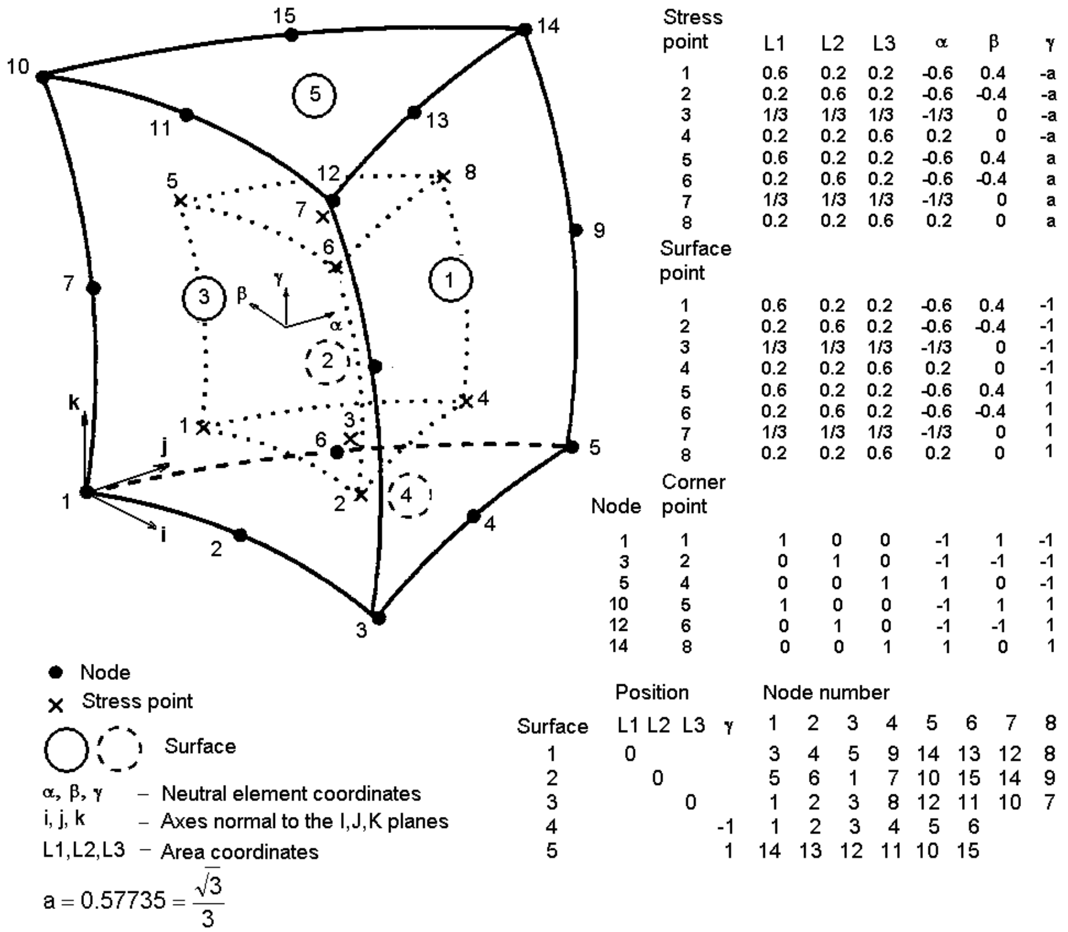



Figure D.11: The isoparametric triangular prism IPRI

## D.2.2.3 Tetrahedrons

The four node linear tetrahedron TETR and the ten node isoparametric tetrahedron ITET are shown in Figure D.12 and Figure D.13 . Both elements have 4 stress points. The positions of the stress points, expressed by the volume coordinates L1, L2, L3, L4, are given in the figures.

Stresses of the stress points may be interpolated to the element corner points. Note that the numbering of the corner points is the same as for the stress points and does not coincide with the node numbers of the element. The stress points are numbered according to the Results Interface File numbering sequence in the order of $i$, $j$, $k$ directions.

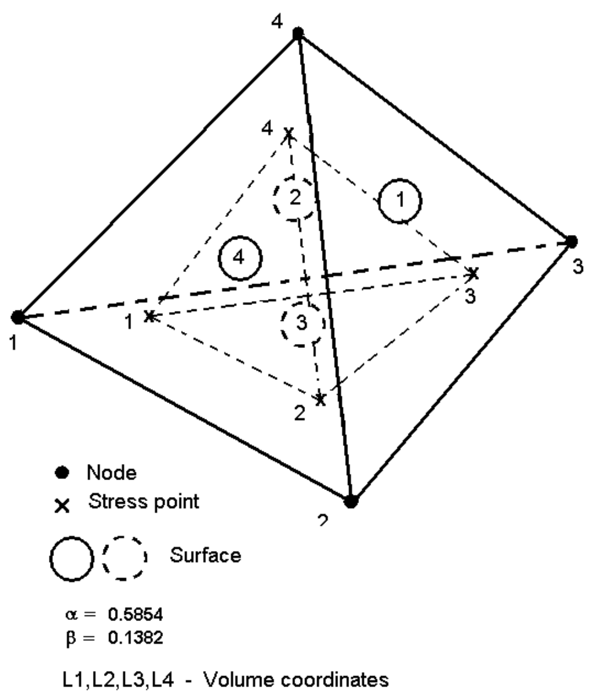
The numbering of the element surfaces are shown in Figure D.12 and Figure D.13.

The elements contain all six stress components $\sigma_x$, $\sigma_y$, $\sigma_z$, $\sigma_{xy}$, $\sigma_{zx}$, $\sigma_{zx}$. Linear interpolations of stresses to the corner points or hotspots are performed on basis of the stress points stresses. In case of centre point location is selected for the fatigue check position the centroid point is applied and stresses of the stress points are interpolated to this location.

The node numbering applied in Xtract and Stofat coincides for the linear tetrahedron (TETR), but not for the isoparametric tetrahedron (ITET). Table D.5 shows the node numbering of Xtract related to the Stofat numbering for the ITET element.

Table D.5: Node numbering of Xtract related to Stofat for the isoparametric tetrahedron, ITET

| Program | Node Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stofat | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Xtract | 1 | 5 | 2 | 6 | 3 | 7 | 8 | 9 | 10 | 4 |

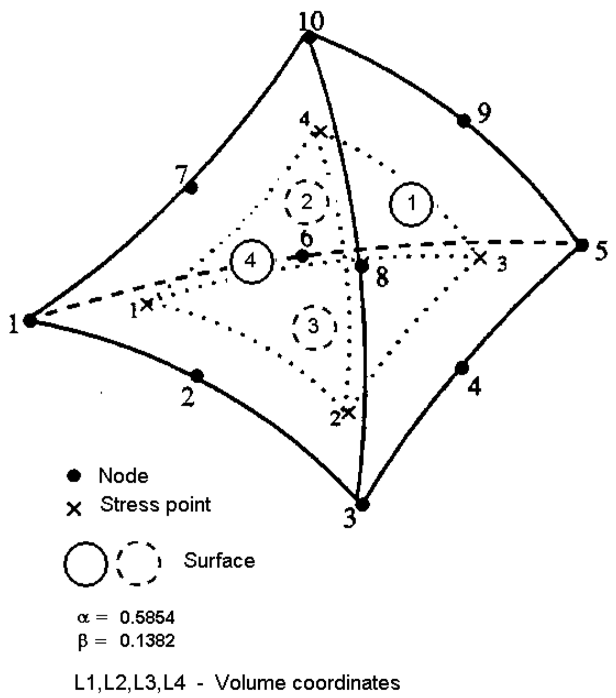



| Stress point | L1 | L2 | L3 | L4 |
|---|---|---|---|---|
| 1 | α | β | β | β |
| 2 | β | α | β | β |
| 3 | β | β | α | β |
| 4 | β | β | β | α |

| Corner point | L1 | L2 | L3 | L4 |
|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 |
| 4 | 0 | 0 | 0 | 1 |

| Surface | Position L1 | L2 | L3 | L4 | Node number 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| 1 | 0 | | | | 2 | 3 | 4 |
| 2 | | 0 | | | 3 | 1 | 4 |
| 3 | | | 0 | | 1 | 2 | 3 |
| 4 | | | | 0 | 1 | 2 | 4 |

Figure D.12: The linear tetrahedron element TETR




| Stress point | L1 | L2 | L3 | L4 |
|---|---|---|---|---|
| 1 | α | β | β | β |
| 2 | β | α | β | β |
| 3 | β | β | α | β |
| 4 | β | β | β | α |

| Corner point | L1 | L2 | L3 | L4 |
|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 |
| 3 | 0 | 0 | 1 | 0 |
| 4 | 0 | 0 | 0 | 1 |

| Surface | Position L1 | L2 | L3 | L4 | Node number 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | | | | 3 | 4 | 5 | 9 | 10 | 8 |
| 2 | | 0 | | | 5 | 6 | 1 | 7 | 10 | 9 |
| 3 | | | 0 | | 1 | 2 | 3 | 4 | 5 | 6 |
| 4 | | | | 0 | 1 | 2 | 3 | 8 | 10 | 7 |

Figure D.13: The isoparametric tethahedron element ITET

### D.2.3 Element centre point locations

Fatigue check location may be selected to be at the centre points or at the centroid of the elements. The centre points may be located at top and bottom surface of the element (centre surface points), at z-location of the stress points (centre stress points) or at centroid of the element, point $(x, y, z) = (0.0, 0.0, 0.0)$ as illustrated in Figure D.14, see also Table D.6.

Centre stress points for the flat thin shell elements (FQUS, FTRS) and the prism elements (TRI, IPRI) are available from the SIN file and accordingly used for the centre point stress points. For the other elements except the thetrahedrons, interpolation to the stress point centre location of the element stress point stresses are performed. The centre point stresses are interpolated to the centroid and extrapolated to the surface points of the element. The centre stress points and surface centre points coincide for the flat shell elements (FQUS, FTRS).

For the solid brick elements the top and bottom surfaces are the surfaces in local +z and -z direction of the element. The centre points located along the z-axis of the element and interpolation of the stress points to the centre points are according to this direction. Surface 1 and 6 are the top surfaces and surface 6 and 5 the bottom surfaces of element LHEX and IHEX, respectively, see Figure D.7 and Figure D.9.

The number fatigue check points for the centre point location are two if both side fatigue check points are selected and one if only one side fatigue check points is selected, see command CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK. For the centroid only one fatigue check point is applied.

Use of element centre points in the fatigue analysis will reduce data storage requirement and run time of execution and increase the number of elements that may be included in a run execution. However, maximum damage will not occur at the centre points and damage values obtained will normally be comparable smaller than for the stress point or element corner fatigue check locations.

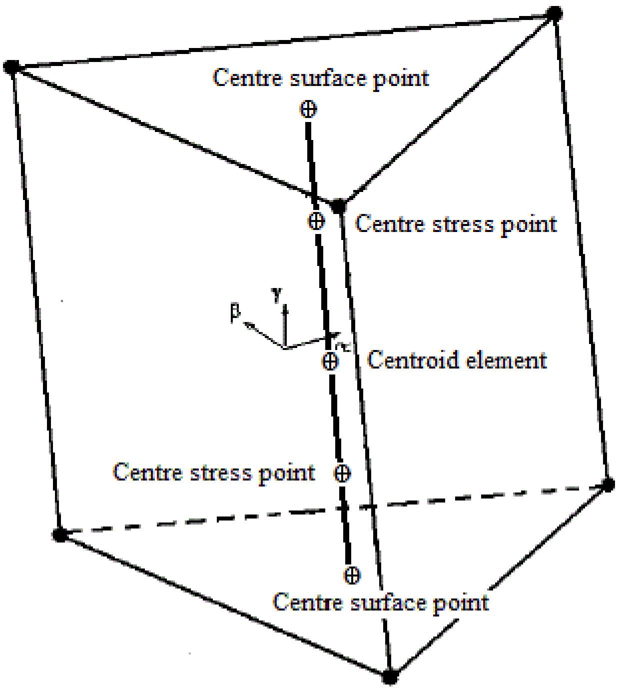



Figure D.14: Location of element centre points and centroid

Table D.6: Positions of centre points and centroid fatigue check points

| Element type | Neutral element z-coordinate of centre points | | | | |
|---|---|---|---|---|---|
| | Stress point +z | Stress point -z | Surface point +z | Surface point -z | Centroid z |
| FQUS(24) 4-node shell | +1.0 | -1.0 | +1.0 | -1.0 | 0.0 |
| FTRS(25) 3-node shell | +1.0 | -1.0 | +1.0 | -1.0 | 0.0 |
| SCQS(28) 8-node shell | +0.57735 | -0.57735 | +1.0 | -1.0 | 0.0 |
| SCTS(26) 6-node shell | +0.57735 | -0.57735 | +1.0 | -1.0 | 0.0 |
| LHEX(21) 8-node brick | +0.57735 | -0.57735 | +1.0 | -1.0 | 0.0 |
| IHEX(20) 20-node brick | +0.57735 | -0.57735 | +1.0 | -1.0 | 0.0 |
| TPRI(32) 6-node prism | +0.57735 | -0.57735 | +1.0 | -1.0 | 0.0 |
| IPRI(30) 15-node prism | +0.57735 | -0.57735 | +1.0 | -1.0 | 0.0 |
| TETR(33) 4-node tetrahedron | Not applicable | | | | 0.0 |
| ITET(31) 12-node tetrahedron | Not applicable | | | | 0.0 |

## D.2.4 Display of element fatigue results in Xtract

Element results calculated by Stofat may be printed to the vtf file and displayed as contour plots on the element model in Xtract. The user may select between the print options: ‘Element Results’ and ‘Element Fatigue Point Results’, see command PRINT FATIGUE-RESULTS-VTF-FILE.

The ‘Elements Results’ option prints results of the fatigue check point with maximum damage in the element. One point is printed for each element and Xtract displays one value for each element.

The ‘Element Fatigue Point Results’ option prints values for all fatigue check points of the elements (except element centre points if such points are present, see Appendix D.2. When values of the fatigue check points varies contour lines will appear in the result display within the elements.

Result values for the ‘Element Fatigue Point Results’ option are assigned to the node positions of the elements in Xtract. Fatigue results calculated at the stress points, surface points, corner points or middle plane points in Stofat are all assigned to the element nodes. Xtract requires one result value per node of the elements. The corner nodes of the elements are associated with the fatigue check points closest to the respective nodes, see Table D.6 and figures in Appendix D.2. The mid-side nodes of the higher order elements have, however, no associated fatigue check points. Values assigned to these nodes are taken as the middle values of their associated corner nodes. The middle values represent, however, not quite the correct results of the mid-points since the values are not calculated on basis of stresses of the points. A correct value will require that fatigue check points associated with the mid-side points also are included in the fatigue analysis.

Table D.7: Fatigue check points and associated element corner nodes in Stofat

| Element type | | Element fatigue check point | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| FTRS(25) | | 1 | 2 | | 3 | 1 | 2 | | 3 | | |
| FQUS(24) | | 1 | 2 | | 4 | 3 | 1 | 2 | | 4 | 3 |
| SCTS(26) | | 1 | 2 | 3 | 1 | 2 | 3 | | | | |
| SCQS(28) | | 1 | 3 | 7 | 5 | 1 | 3 | 7 | 5 | | |
| TETR(33) | Stofat element | 1 | 2 | | 3 | 4 | 5 | | 6 | | |
| TPRI(32) | corner node | 1 | 2 | | 3 | 4 | 5 | | 6 | | |
| LHEX(21) | | 3 | 4 | 2 | 1 | 7 | 8 | 6 | 5 | | |
| ITET(31) | | 1 | 3 | 5 | 10 | | | | | | |
| IPRI(30) | | 1 | 3 | | 5 | 10 | 12 | | 14 | | |
| IHEX(20) | | 1 | 3 | 7 | 5 | 13 | 15 | 19 | 17 | | |

For shell elements, where the nodes are located in the middle plane, two result cases are written to the vtf file; one for the fatigue points below the element middle plane (shell bottom points) and one for the fatigue point above the middle plane (shell top points). One result case is written to the vtf file when 'element-middle-plane' or 'element-membrane' option is selected for the fatigue check points of the shell elements (command CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK). One result case is also written for the solid elements.

The Stofat fatigue results are printed to the vtf file in the order of element and node numbering applied in Xtract. Fatigue results per elements (*RESULTS block and %PER _ELEMENT identifier) are written in the order of the elements printed in the *ELEMENTS block. Fatigue results per element node (*RESULTS block and %PER_ELEMENT_NODE identifier) are written in the order of elements and element nodes printed in the *ELEMENTS block. Xtract shows one *RESULTS block at the time in result plot views.

The element node numbering in Xtract coincide with the node numbering in Stofat for the lower order elements, but not for the higher order elements, see Appendix D.2. When reading the vtf file and printing display results in Xtract, the results are in the order of the node numbering of Xtract.

## D.3 Hotspots

### D.3.1 Hotspots and Interpolation Points

A hotspot is a point in the structure where fatigue damage is to be examined. Three points are necessary to create a hotspot; the hotspot itself, interpolation point $t/2$ and interpolation point $3t/2$, see Figure D.15. The hotspot and the interpolation points may be placed anywhere within the element model of the superelement investigated. Only one first level superelement can be handled at the time by Stofat. A hotspot and its interpolation points must therefore be located in the same superelement. Hotspots can not be created in elements that are not implemented in Stofat. A series of hotspots may be created and examined in the same run. A hotspot is identified by name given by the user.

The two interpolation point points should be placed in different elements. If not, a message is printed. The program tests if a line drawn through the hotspot and the two interpolation is a straight line. If the line is not straight, the program prints the out-of-line deviation $(dt/2)$ of point $t//2$, see Figure D.16, and the coordinates of point $t/2$ projected to the straight line $L_{hot} - 3t/2$. The distances of the two interpolation points to the hotspot $(L_{hot} - t/2$ and $L_{hot} - 3t/2)$ are printed in the table of analysis results.

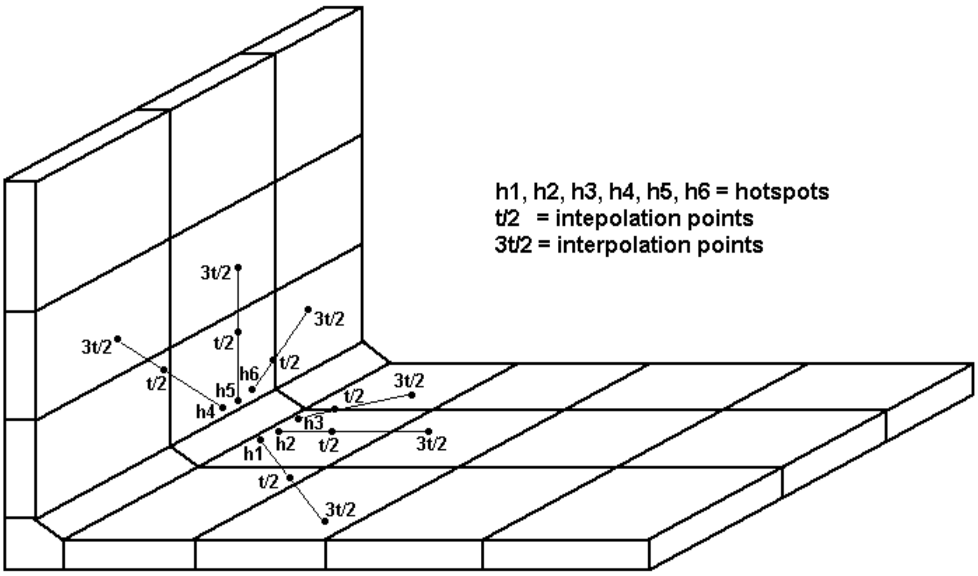



Figure D.15: Hotspot and interpolation points

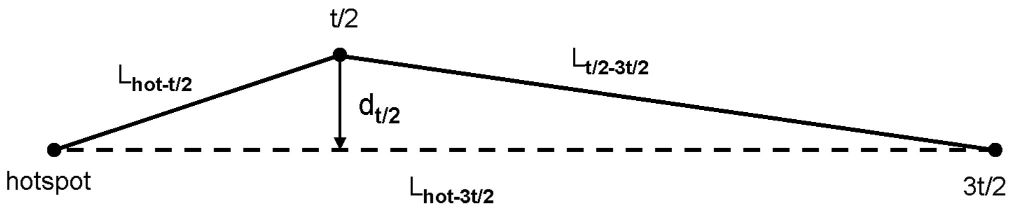



Figure D.16: Hotspot - interpolation points line

## D.3.2 Interpolation of Stresses of the Hotspot

Stresses of the interpolation points $^t/_2$ and $^{3t}/_2$ are interpolated linearly to the hotspot and applied in the calculation of fatigue damage of the hotspot, see Figure D.17. The stresses are interpolated component by component whereupon the principal stresses of the hotspot are calculated and applied in the fatigue calculation. The hotspot stress $\sigma_{hot}$ may be expressed as

$$\sigma_{hot} = \frac{\left(\sigma_{\frac{t}{2}} \cdot L_{hot-\frac{3t}{2}} - \sigma_{\frac{3t}{2}} \cdot L_{hot-\frac{t}{2}}\right)}{L_{\frac{t}{2}-\frac{3t}{2}}} \tag{D.1}$$

The interpolation point stresses are found by interpolating the element stress point stresses to the interpolation points as described in Section D.4.3.

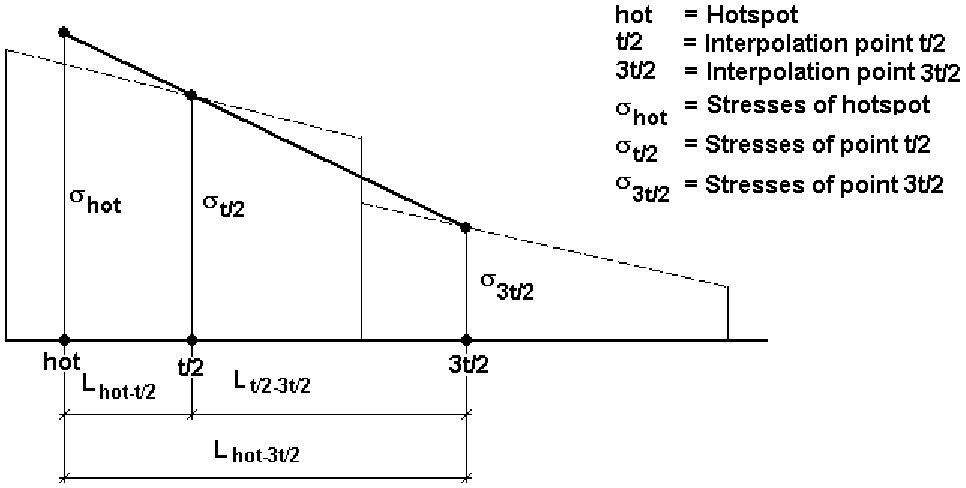



Figure D.17: Interpolation of stresses to the hotspot

Hotspots may also be used to calculate fatigue at specific element points using the element stresses of the point instead of the interpolated hotspot stresses. This is obtained by placing the hotspot and one or both interpolation points at the same spot. The hotspot stresses will then be identical to the interpolation point stresses, and since the interpolation point stresses are the element stresses of the point, the hotspot stresses will be the same.

## D.3.3 Creation of Hotspots and Interpolation Points

A hotspot and its interpolation points may be created in two ways:

1. Specification of coordinates

2. Specification of nodal point numbers

Nodal point numbers may be applied when points are placed at element nodes, otherwise coordinates must be applied. Element numbers must be specified together with the coordinates or the node numbers. In this way the user itself decides which element stresses that shall be applied if a point is placed along a mesh line or at a nodal point.

The user may enter zero as element number. The program then search through the whole model and find the element (or elements) that is connected to the given point. The user must then specify an element number and re-enter the input.

### D.3.4 Moving Points to the Element Surface

Fatigue damage often starts at the surface of a structure and surface points are of interest to examine in a fatigue damage investigation. Accurate localization of surface points by coordinates may be cumbersome for the user when the model is large and complex. A few facilities have been implemented in Stofat to ease the effort in getting the coordinates of such points.

A hotspot or interpolation point may be created inside an element and moved to the surface of the element by the program itself. An auxiliary point, specified by the user, is used to identify which element surface the point shall be moved to. The program calculates the distances of the element surfaces to the auxiliary point and moves the point to the surface that is *closest* to the auxiliary point. The distances are calculated in the neutral $\alpha$, $\beta$, $\gamma$ element coordinates. The point is moved by forcing the value of the neutral coordinate normal to the element surface to be 1.0 in absolute value. X, Y, Z coordinates of the new point are then calculated and printed together with the neutral element coordinates. Moving a point to the element surface is carried out in the preprocessing phase when an auxiliary point is specified together with the hotspot and its two interpolation points. The auxiliary point is used to move the points to the surfaces of their respective elements. If the points shall not be moved to the element surfaces, the auxiliary point *shall not* be entered (use 'skip' option for the auxiliary point). After the points have been moved, the coordinates of the new surface points must be entered *without* entering the auxiliary point.

Moving points to the element surfaces are illustrated in Figure D.18, Figure D.19 and Figure D.20. Figure D.18 shows how a point A inside the a linear hexahedron element is moved to the surface. In case 1) the auxiliary point is closest to element surface 3 (with a distance of -1 - (-0.78) = 0.12). Point A is accordingly moved to this surface (point A' with $\alpha = -1.0$). In case II) surface 1 is closest to the auxiliary point and point A is moved to point A' at surface 1 with $\gamma = +1.0$.

A point inside the hexahedron may be moved to any of the six element surfaces shown in Figure D.7 and Figure D.9, however in present version of Stofat the points are restricted to be moved only to the surfaces normal the $\gamma$-axis, i.e. to surface 1 and 6 for the linear hexahedron, and surface 6 and 5 for the isoparametric hexahedron, see Figure D.7 and Figure D.9.

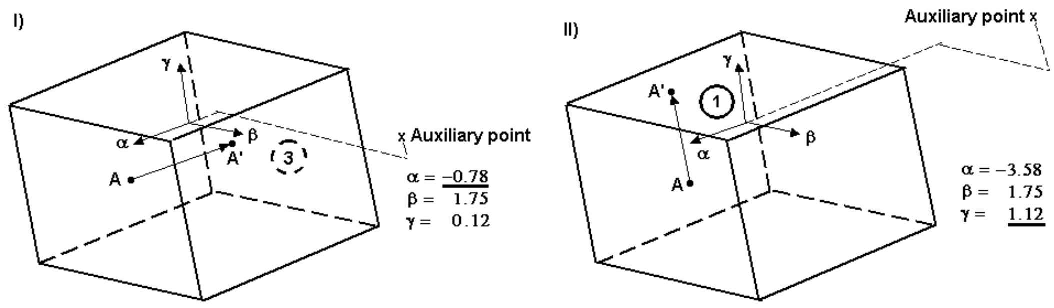



Figure D.18: Moving point A to point A' at I) surface 3 and II) surface 1 of the linear hexahedron

For the triangular prisms a point inside the element may be moved to one of the triangular surfaces, i.e. surface 4 or 5, see Figure D.10 and Figure D.11. The distance of the auxiliary point to surface 4 and 5 is measured by the $\gamma$ coordinate and a point is moved to surface 4 if $\gamma$ is negative and to surface 5 if $\gamma$ is positive, see Figure D.19.

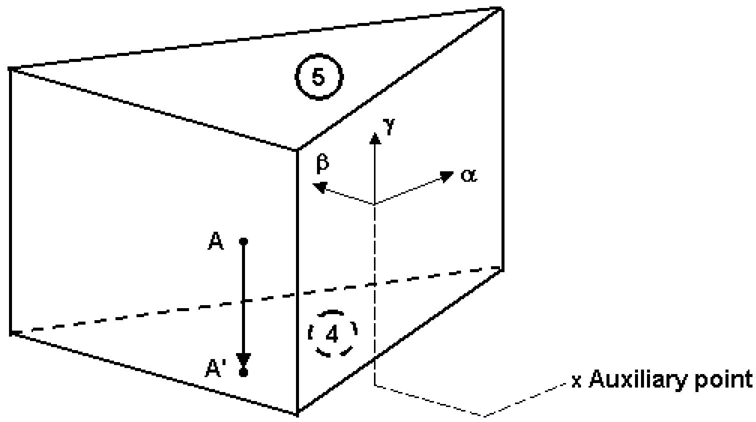



Figure D.19: Moving point A to point A' on surface 4 of the triangular prism

For the tetrahedron elements, see Figure D.12 and Figure D.13, no movement to any of the element surfaces is permitted.

The shell elements have two surfaces, surface 1 and 2, see Figure D.2 through Figure D.4. In the same way as for the triangular prism elements, the distance to the auxiliary point is measured by the $\gamma$-coordinate, i.e. in thickness direction of the element. A point is moved to surface 1 if $\gamma$ is negative and to surface 2 if $\gamma$ is positive. Moving points to the element surfaces of shell elements is illustrated in Figure D.20. The figure illustrates a cross section view of a stiffener connected to a plate. In case I) the auxiliary point is placed at the right hand side of the stiffener web and in case II) it is placed at the left side of the web. A, B, C and D are points created by the user. A', B', C' and D' are locations of the points after being moved to the surface of the elements.

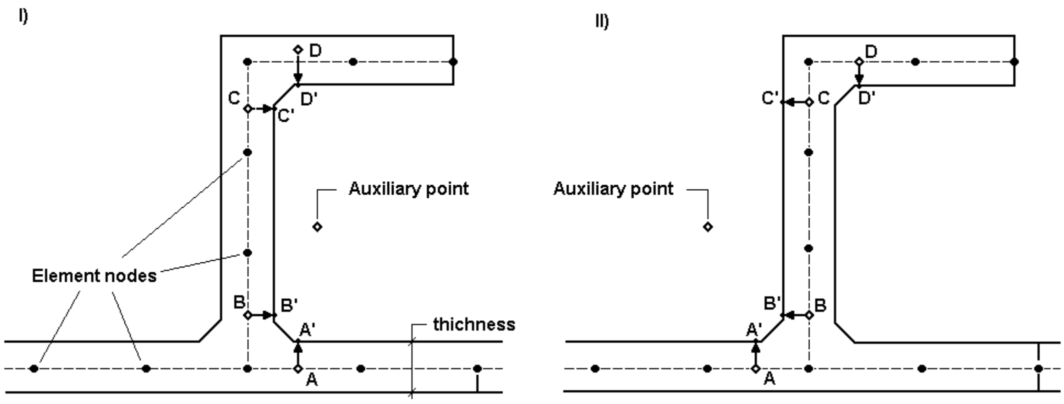



Figure D.20: Moving points to surfaces of the shell elements

## D.3.5 Points Placed Outside the Elements

A hotspot or an interpolation point has to be located inside or at the border of an element. In the preprocessing phase Stofat performs extensive checking to assure that points created by the user are not placed outside the elements and that they are connected to the right elements.

If a point is placed outside the element it shall be connected to, the program does not accept the input. Along with a message the program supply the user with coordinates of the point at the element border that is closest to the input point. The user must re-enter the input and make sure that the point is inside or at the border of the element. When accepted, the program prints a message to the user.

In the testing process, the coordinates of the point is transformed into the neutral $\alpha$, $\beta$, $\gamma$ coordinates of the element. If one of the coordinates exceeds 1.0 in absolute value, the point is outside the element and the program will put the point to the element border and calculates the coordinates of the new position of the point.

For rectangular shell and hexahedron solid elements the projection is carried out along the $\alpha$, $\beta$, $\gamma$ coordinate axes. The point at the element border is established by forcing the neutral coordinates exceeding 1.0 in absolute value is to be 1.0. This is executed in an iterative process. The $\alpha$, $\beta$, $\gamma$ coordinates of the new point are transformed to global X, Y, Z coordinates.

Figure D.21 illustrates projections to the element border of points placed outside the linear hexahedron element. Point A exceeds 1.0 in a direction and the new point A' at surface 5 is established by forcing a to be $\alpha = 1.0$. In the same way points B and C exceed 1.0 in $\beta$ and $\gamma$ direction, respectively, and points B' and C' at surface 2 and 1 are established by forcing $\beta$ and $\gamma$ to be $\gamma = 1.0$ for point B' and $\gamma = 1.0$ for point C'. Point D exceeds 1.0 in $\alpha$ and $\gamma$ directions. Point D' is established at the line between node 5 and 8 by giving $\alpha$ and $\gamma$ the values $\alpha = 1.0$ and $\gamma = 1.0$. Point E exceeds 1.0 in all three directions and point E' is established at element corner node 6.

The same operations are shown for a rectangular shell element in Figure D.22 case I). Note that point A' and B' are established at the side surfaces of the element (normal to the $\alpha$- and $\beta$ axes). If an auxiliary point are entered together with coordinates of point A and B, points A' and B' are established at the element surface normal to $\gamma$ axis as shown in case II) in Figure D.22.

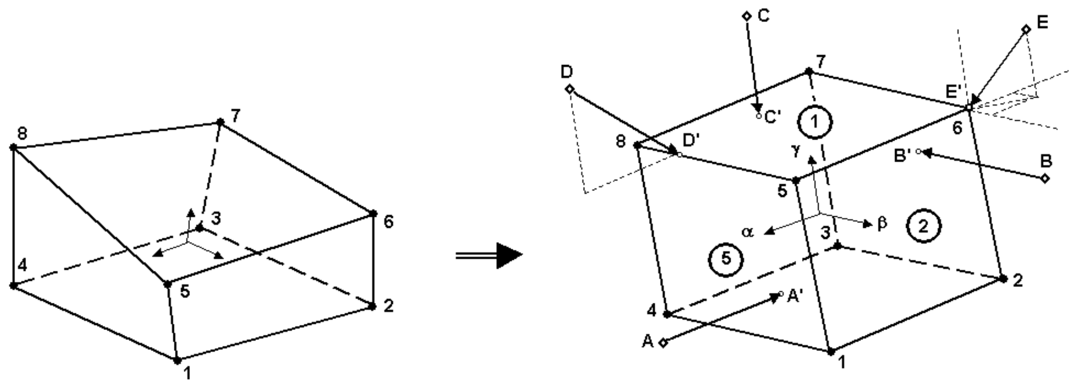


Figure D.21: Projection on points placed outside the hexahedron element

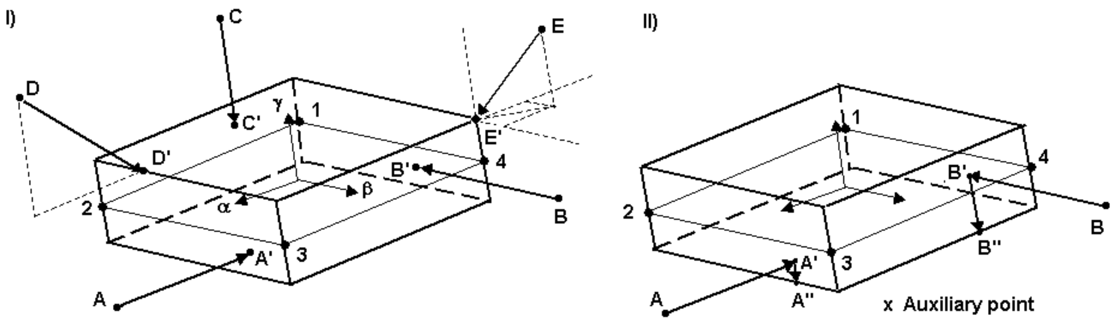



Figure D.22: Projection on points placed outside the rectangular element

Projection of a point to the border of elements with irregular shapes may cause problems for certain locations of the point. Such a location is shown in Figure D.23. At point A the element lines 1-2 and 3-4 crosses and the neutral coordinate $\beta$ is indefinite and may take any value between -1 and +1. In such a case projection of the point to the border fails and the message "Convergence is not obtained when iterating for the neutral coordinates of the point. Check if point is outside the element" is printed.

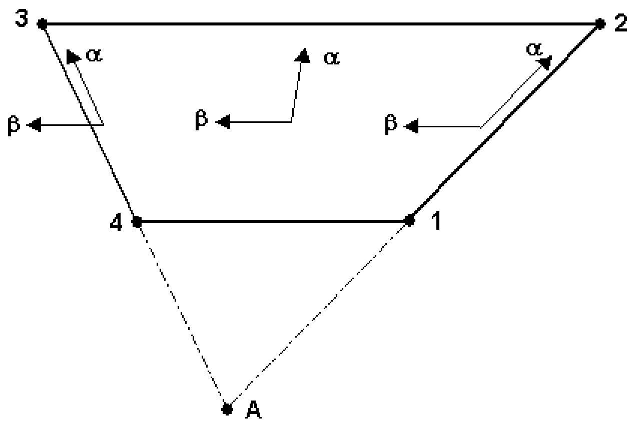



Figure D.23: Point outside element (point A) with indefinite neutral coordinate

Points inside triangular prism and shell elements are expressed by the area coordinates L1, L2, L3 in the triangular plane and by the neutral coordinate $\gamma$ in normal direction to the triangular plane, see point P in Figure D.24. The sum of the area coordinates is equal to one. Corner points 1, 2, 3 of the triangle have area coordinates (1.0, 0.0, 0.0), (0.0, 1.0, 0.0) and (0.0, 0.0, 1.0), respectively, and points along element lines 1-2, 2-3 and 3-1 have coordinates (L1, L2, 0.0), (0.0, L2, L3) and (L1, 0.0, L3), respectively. A point placed outside the element line 2-3 has a negative L1 value. Such a point will be projected to the element border along a line from the point to corner 1 of the triangle, see points A and A' in Figure D.24. The coordinates of A, (L1, L2, L3), are changed to (0.0, L'1, L'2) for A', where L'1 + L'2 = 1. If $\gamma$ exceeds 1.0 in absolute value it is changed to 1.0 in absolute value in the same way as for the hexahedron and rectangular shell elements.

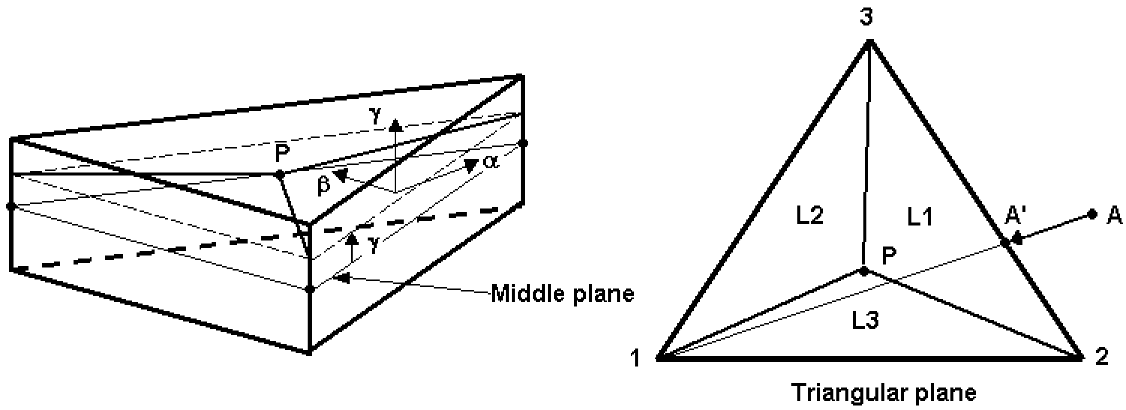



Figure D.24: Area coordinates and neutral coordinates of triangular element

Examples of projecting points to the border of triangular elements are illustrated in Figure D.25. Point A which is outside line 2-3 is projected to A' at line 2-3 along the line A - corner 1. Point B which outside both line 2-3 and line 1-3 and has $\gamma > 1.0$, is moved to B' at corner 3. Point C is outside line 1-3 and is projected to C' along line C - corner 3. Point D is inside the triangle but $\gamma$ exceeds 1.0. The point is projected to D' at the triangular top surface of the element by putting $\gamma = 1.0$.

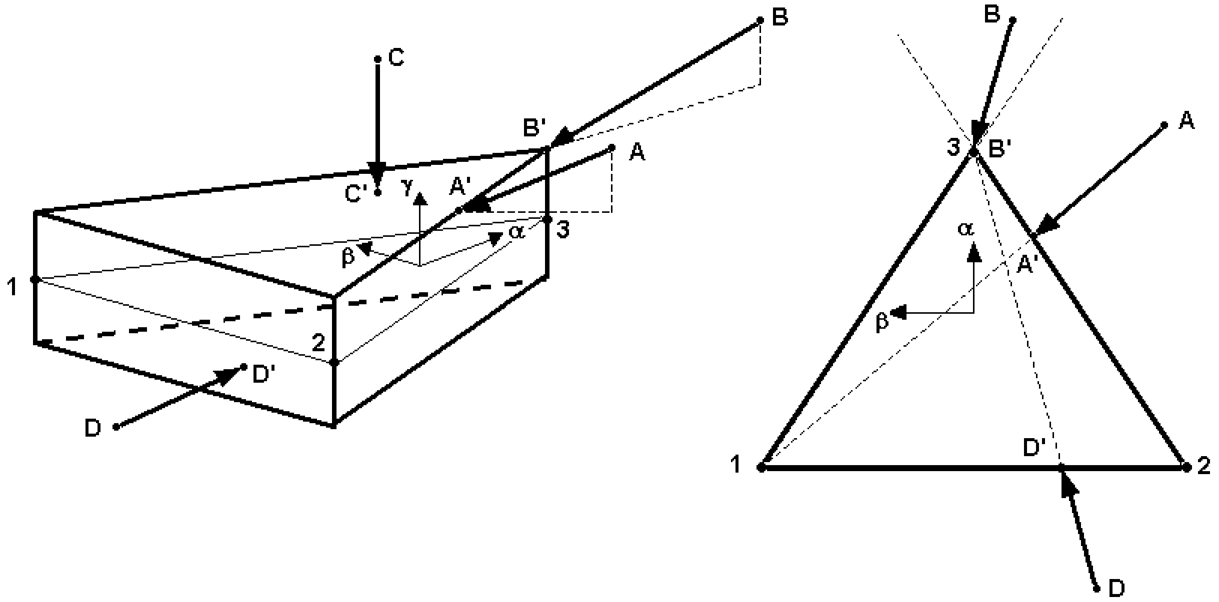



Figure D.25: Projection of points to the border of triangular elements

Points outside tetrahedrons are treated in a similar way as the triangular elements. The position of a point is expressed by the volume coordinates L1, L2, L3, L4, where the sum of volume coordinates is one. Point A in Figure D.26 is projected to A’ at element surface 1 along the line A - corner 1. At A’, L1 = 0.0. Point B which is outside surface 3 but in the plane of surface 4, is projected to B’ at line 1- 2. At B’, L3 = L4 = 0.0. Point C is outside all three surfaces 1, 2 and 3 and is projected to C’ at corner 4. At C’, L1 = VL = L3 = 0.0 and L4 = 1.0.

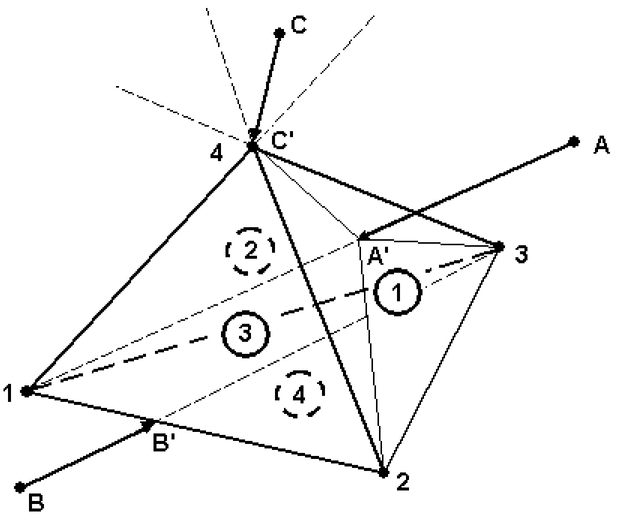



Figure D.26: Projection of points to the border of tetrahedrons

If a point is placed outside the elements and zero is given for the element number, the program searches through all elements in the model and finds the element with the shortest distance to the point. The operation is carried out in the neutral $\alpha$, $\beta$, $\gamma$ coordinate systems of the elements. The program prints the number of this element, the distance to the point and the position of a new point projected to the element border as described in previous sections. In case of irregular element shapes and with a point placed similar as point A in Figure D.23, the program may fail to calculate the distance to the point for such elements and also may fail to detect the closest element to the point.

## D.4 Reference Frame for Coordinates and Stresses

### D.4.1 Coordinates

Hotspots may be defined in one of the following two coordinate frames:

- current or 1. level superelement
- highest level superelement

Selection of coordinate frame is performed in the ‘Hotspot-check’ dialogue box. There must be correspondence between selection of the coordinate frame and the coordinate values entered when creating a hotspot and its interpolation points. The reference frame for the coordinates may be changed from one hotspot to the next when several hotspots are created.

All calculations take place in the 1. level superelement coordinate system. Hotspots given in the highest level superelement system are thus transformed to the 1. level superelement, the highest level superelement coordinates are reported together with the analysis results.

In element fatigue damage checks, no coordinate values are necessary to specify. Coordinates of the interface file refer to the 1. level superelement system. The user may, however, select the highest level superelement coordinate system as reference frame for the purpose of printing coordinates of the element fatigue points in this reference frame along with the analysis results. Selection of the coordinate system is performed in the ‘Element-check’ dialogue box.

### D.4.2 Stresses

Stresses of the Sesam Interface File may either refer to the 1. level superelement coordinate system or to local coordinate systems of the elements. If no transformation matrix is present for the result point, stresses of the point refer to the 1. level superelement system.

Stofat applies the 1. level superelement coordinate frame as reference system for the stresses, and transform stresses to this system if necessary. This ensures that the stresses refer to the same coordinate frame when components of the stresses are interpolated across element borders in hotspot fatigue calculations.

### D.4.3 Interpolation of Stresses within the Elements

Interpolation of stresses is required when fatigue damage checks are performed at points other than the stress points of the elements. Linear, bilinear and trilinear interpolation schemes are applied for interpolation along lines, surfaces and in element volumes, respectively. A stress component at point $h$ may, in the three interpolation schemes, be written:

Linear interpolation

$$\sigma_h\left(\alpha_h\right) = K_1 + \alpha_h K_2 \tag{D.2}$$

Bilinear interpolation

$$\sigma_h\left(\alpha_h, \beta_h\right) = K_1 + \alpha_h K_2 + \beta_h K_3 + \alpha_h \beta_h K_4 \tag{D.3}$$

Trilinear interpolation

$$\sigma_h\left(\alpha_h, \beta_h, \gamma_h\right) = K_1 + \alpha_h K_2 + \beta K_3 + \gamma_h K_4 + \alpha_h \beta_h K_5 + \beta_h \gamma_h K_6 + \alpha_h \gamma_h K_7 + \alpha_h \beta_h \gamma_h K_8 \tag{D.4}$$

where $\alpha_h$, $\beta_h$, $\gamma_h$ are the neutral element coordinates of $K_1$, $K_2$, ... are stress constants. In matrix notation, each of the above equations may be expressed as:

$$\sigma_h = \mathbf{A}_h \cdot \mathbf{K} \tag{D.5}$$

where $\mathbf{A}_h$ is the vector containing coordinate values of point $h$ and $\mathbf{K}$ is the vector of stress constants. Applying the equation to the element stress points may be written as:

$$\sigma_s = \mathbf{A}_s \cdot \mathbf{K} \tag{D.6}$$

where $\sigma_s$ is the vector containing the stress point stresses, $\mathbf{A}_s$ is the matrix containing coordinate values of the stresses points according to the above interpolation schemes and $\mathbf{K}$ is the vector of stress constants. $\sigma_h$ may now be written as:

$$\sigma_h = \mathbf{A}_h \cdot \mathbf{K} = \mathbf{A}_h \cdot \mathbf{A}_h^{-1} \cdot \sigma_s = \mathbf{T}_h \cdot \sigma_s \tag{D.7}$$

where $\mathbf{T}_h$ is the interpolation vector for point $h$, which interpolates stresses of the stress points to point $h$.The interpolation scheme is applied when stresses are interpolated to surface points, corner points or hotspots. When element thicknesses vary within the shell elements, interpolation of nodal point thicknesses to the stress points is an integrated part of the interpolation scheme to point $h$.

Stress variation of the 8-nodes quadrilateral thick shell element SCQS is illustrated in Figure D.27. The stress variation is linear in directions parallel with the neutral coordinate axes ($\alpha$-, $\beta$ axes) and nonlinear in other directions since the four stress ordinates $\sigma_1$, $\sigma_2$, $\sigma_3$, $\sigma_4$ of the corner points do not form a straight plane. The 20-nodes solid brick element IHEX has similar stress variations.

The stress variation of the elements should be kept in mind when hotspots and interpolation points are defined, see Section D.3.1. Since linear stress interpolation is applied to find the hotspot stresses, see Section D.3.2, the direction of interpolation may influence the hotspot stresses and accordingly the fatigue damage of the hotspot. Assume that corner point 4 in Figure D.27 is a hotspot. When points 6 and 2 along the element side 2-4 are used as interpolation points, linear interpolation gives $\sigma_4$ as hotspot stress. When points 9 and 1 along the element diagonal is used as interpolation points, linear interpolation gives $\sigma_{ed}$ as hotspot stress, which is different from $\sigma_4$. Two other interpolation points along the diagonal will give a hotspot stress different from both $\sigma_4$ and $\sigma_{ed}$, while interpolation points at placed anywhere along the element side 2-4 give $\sigma_4$ as the hotspot stress. This illustrates that interpolations performed in the direction of the $\alpha$- or $\beta$-axes or close to these, give hotspot stresses equal or close to the element stresses of the same point. Interpolations in other directions give hotspot stresses different from the element stresses.

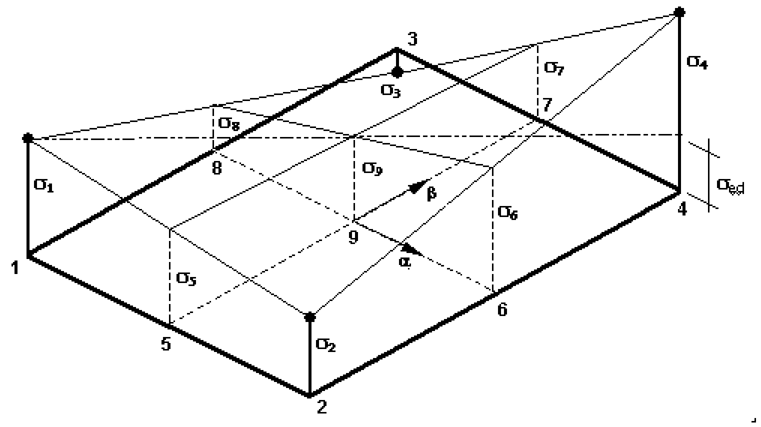



Figure D.27: Bilinear stress variation of the SCQS element

## D.5 Stress Applied in the Fatigue Damage Calculation

The maximum principal stress component of the fatigue point is applied in the fatigue damage analysis. The principal stresses are calculated on basis of the stress components given in Table D.1, and multiplied with the resulting K-factor entered by the user (see B.3.2).

The stress components in Table D.1 are formed by a real and an imaginary part of the complex stress representation. The maximum principal stress component applied is found by seeking the maximum value in the complex stress plane. A step of one degree of the phase angle around the maximum point is applied in this process.

When interpolation of stresses to the fatigue check point is performed, the interpolation is carried out for the element stress components. At the fatigue point, the principal stresses are calculated on basis of the interpolated stress components, whereupon the first (maximum) principal component is applied in the fatigue calculation.

The stresses applied in the fatigue damage calculation process may be printed to a vtf file as function of the angular frequencies for graphic presentation (2D curve plots) by the Xtract program. SIN file stresses, elements stresses and hotspot stresses may be printed for selected wave directions, stress components and positions in the elements. Principal stresses, real and complex parts of the stress components and phase angle in the complex stress plane are available for print.

## D.6 Stresses Applied in the Long Term Response Calculation

Stress components applied in long term response calcuation are selected by the user prior to run execution. Principal stresses (Sp1, Sp2, Sp3), von Mises equivalent stress (Seq), normal stress components (Sxx, Syy, Szz) and shear stress components (Sxy, Sxz, Syz) may be selected.

The stress components of the transfer functions are formed by a real and an imaginary part of the complex stress representation. For each sea state and for each fatigue point stress components are retrieved from results file. Stress components are computed for each phase angle iteration and maximum value is searched. A step of one degree phase angle around the maximum point is applied to get the stress value of each long term stress component applied in the calculation. Equivalent stress is computed for each frequency and will be used to compute spectral moments. Stress amplitude is computed from spectral moments. Static stress is calculated from static load case for any stress component or equivalent stress.

Depending on the user input, static stresses are then added to maximum and minimum stresses in accordance with:

Maximum stress = static stress + stress amplitude
Minimum stress = static stress - stress amplitude

The above expression helds except in case of von Mises stress is selected, therefore minimum and maximum stresses coincide.

The long term stresses may be transformed to global coordinates (superelement coordinate system) when applied in long term respons calculation. Stress concentration factors are applied only on request by user. Static reduction factor, applied in fatigue check, is not applied to the long term stresses. Static stresses are accounted for in the maximum and minimum stresses calculated, where the static stress is added to the positive and negative stress amplitude values, respectively.

# E SN Curves

## E.1 SN curve equations

The parameters of a general three line SN curve are shown in Figure E.1

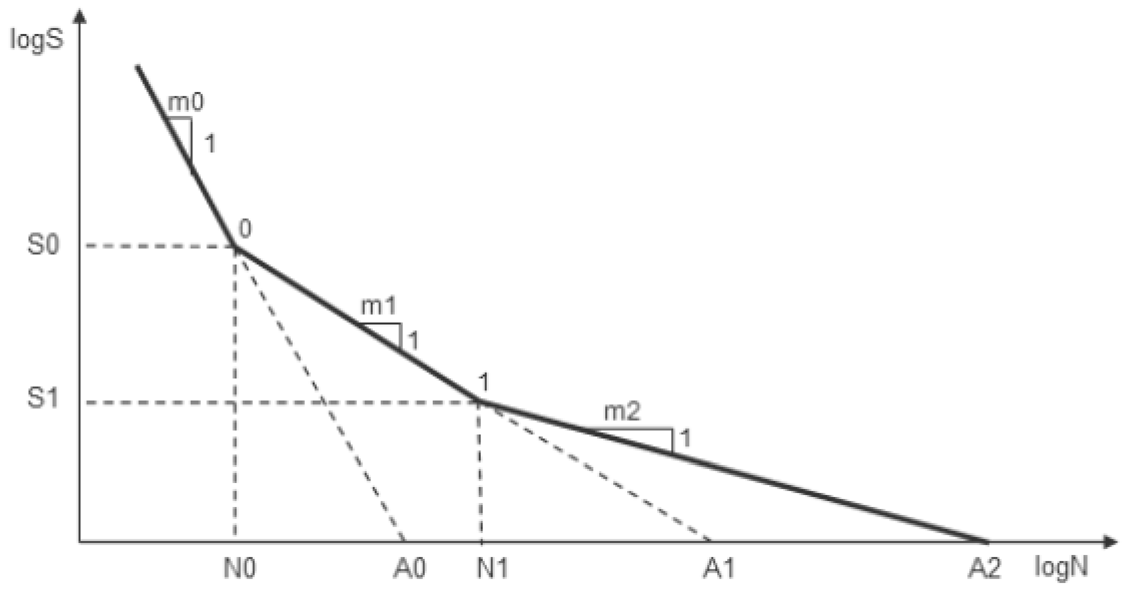



Figure E.1: Parameters for a general three line SN curve

The SN curve equations applied to the different line segments are given by:

$$\log_{10} N = \log_{10} A_0 - m_0 \log_{10} S \qquad \text{for} \quad S > S_0 \tag{E.1}$$

$$\log_{10} N = \log_{10} A_1 - m_1 \log_{10} S \qquad \text{for} \quad S_1 < S < S_0 \tag{E.2}$$

$$\log_{10} N = \log_{10} A_2 - m_2 \log_{10} S \qquad \text{for} \quad S < S_1 \tag{E.3}$$

At the intersection points 0 and 1 of the SN curve line segments, see Figure E.1, we have

$$\log_{10} N_0 = \log_{10} A_0 - m_0 \log_{10} S_0 \qquad \text{Intersection 0} \tag{E.4}$$

$$\log_{10} N_1 = \log_{10} A_1 - m_1 \log_{10} S_1 \qquad \text{Intersection 1} \tag{E.5}$$

Not all SN curves are of general type as shown in Figure E.1. A SN curve may consist of two- and three line segments with various slope conditions for segment 2 and 3. The cases are illustrated below.

**Two line SN curves:**

The slope of the second line segment of a two line SN curve may be, see Figure E.2

1) *horizontal* ($m_1 = 0$)
2) *default* ($m_1 = 2m_0 - 1$)
3) *aligned with* first line segment ($m_1 = m_0$)

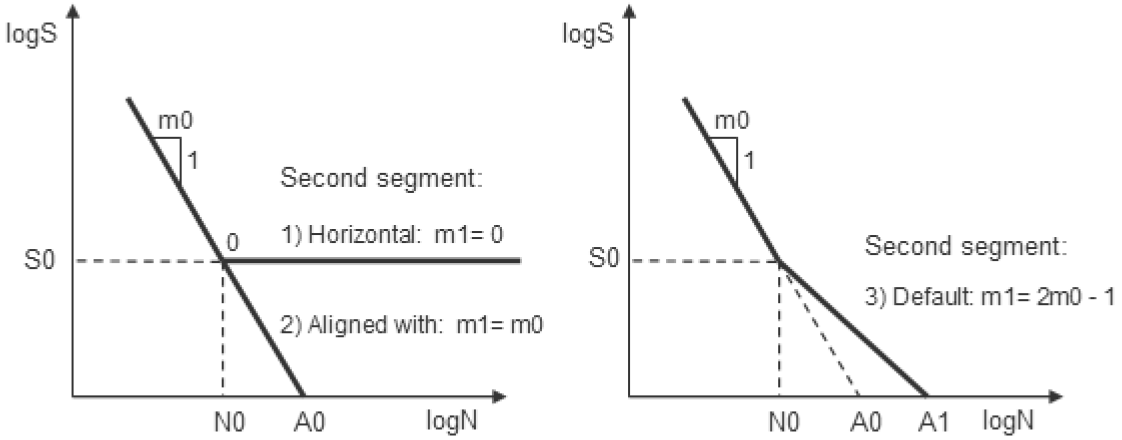



Figure E.2: Two line SN curves

**Three line SN curves:** A three line SN curve is applied when an arbtrary tail is specified for the second line segment. The slope of the third line segment may be

1) *horizontal* ($m_2 = 0$)
2) *aligned with* second line segment ($m_2 = m_1$)
3) *arbitrary* ($m_2 > m_1$)

The last option is the general case shown in Figure E.1. The first and second options are shown in E.3

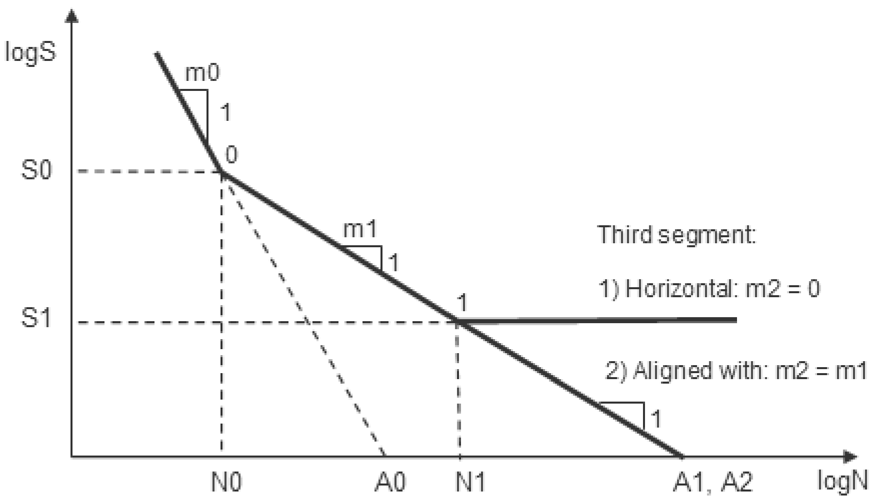



Figure E.3: Three line SN curves

## E.2 SN curve table data

Tabulated values of SN curve parameters shown in Figure E.1 are given for the library SN curves of Stofat in the following sections. Thickness correction parameters are also given. The SN curves are shown by curve plots.

The library contains subsets of ABS [1], API [15], DOE[7], DNV [30], [31], [8], HSE [13], NORSOK [29] and NS3472 [9] SN curves. Each of the subsets are given in separate sections.

## E.3 Nomenclature

Nomenclature of the SN curve table data:

**Name** Name of the SN Curve

**m0** Inverse slope of first branch of the SN-curve

**m1** Inverse slope of second branchof the SN-curve

**m2** Inverse slope of third branch of the SN-curve

**logN0** Logarithm of number of cycles at intersection between first and second branch

**logN1** Logarithm of number of cycles at instersection between second and third branch

**S0** Stress level at intersection between first and second branch (Unit: $N/m^2$)

**S1** Stress level at intersection between second and third branch (Unit: $N/m^2$)

**logA0** Intercept of logN-axis by the first branch of the SN-curve (Unit: Stress in $N/m^2$)

**logA1** Intercept of logN-axis by the second branch of the SN-curve (Unit: Stress in $N/m^2$)

**logA2** Intercept of logN-axis by the third branch of the SN-curve (Unit: Stress in $N/m^2$)

**logK0** Intercept of logN-axis by the mean of the SN-curve (Unit: Stress in $N/m^2$)

$\sigma$ Standard deviation of $\log K0$. Note. $\log A0 = \log K0 - 2\sigma$

$t_{exp}$ Exponent of thickness correction

$t_{ref}$ Reference thickness given in mm

$t_{cut}$ Cut thickness given in mm

## E.4 ABS SN curves

Paramters and plot of ABS SN curves [1]

Table E.1: ABS SN curves in air

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| ABS-B-A | 4 | 6 | 6 | 7 | 8 | 100.20 | 68.35 | 39.003 | 55.080 | 55.080 | 39.003 | 0 | 0.25 | 22 | 21.9 |
| ABS-C-A | 3.5 | 5.5 | 5.5 | 7 | 8 | 78.20 | 51.46 | 34.626 | 50.413 | 50.413 | 34.626 | 0 | 0.25 | 22 | 21.9 |
| ABS-D-A | 3 | 5 | 5 | 7 | 8 | 53.40 | 33.67 | 30.183 | 45.636 | 45.636 | 30.183 | 0 | 0.25 | 22 | 21.9 |
| ABS-E-A | 3 | 5 | 5 | 7 | 8 | 47.00 | 29.67 | 30.016 | 45.362 | 45.362 | 30.016 | 0 | 0.25 | 22 | 21.9 |
| ABS-F-A | 3 | 5 | 5 | 7 | 8 | 39.80 | 25.10 | 29.800 | 44.998 | 44.998 | 29.800 | 0 | 0.25 | 22 | 21.9 |
| ABS-F2A | 3 | 5 | 5 | 7 | 8 | 35.00 | 22.11 | 29.632 | 44.729 | 44.729 | 29.632 | 0 | 0.25 | 22 | 21.9 |
| ABS-G-A | 3 | 5 | 5 | 7 | 8 | 29.20 | 18.45 | 29.396 | 44.320 | 44.320 | 29.396 | 0 | 0.25 | 22 | 21.9 |
| ABS-T-A | 3 | 5 | 5 | 7 | 8 | 52.70 | 33.23 | 30.165 | 45.608 | 45.608 | 30.165 | 0 | 0.25 | 32 | 22.0 |
| ABS-W-A | 3 | 5 | 5 | 7 | 8 | 25.20 | 15.91 | 29.204 | 44.008 | 44.008 | 29.204 | 0 | 0.25 | 22 | 21.9 |

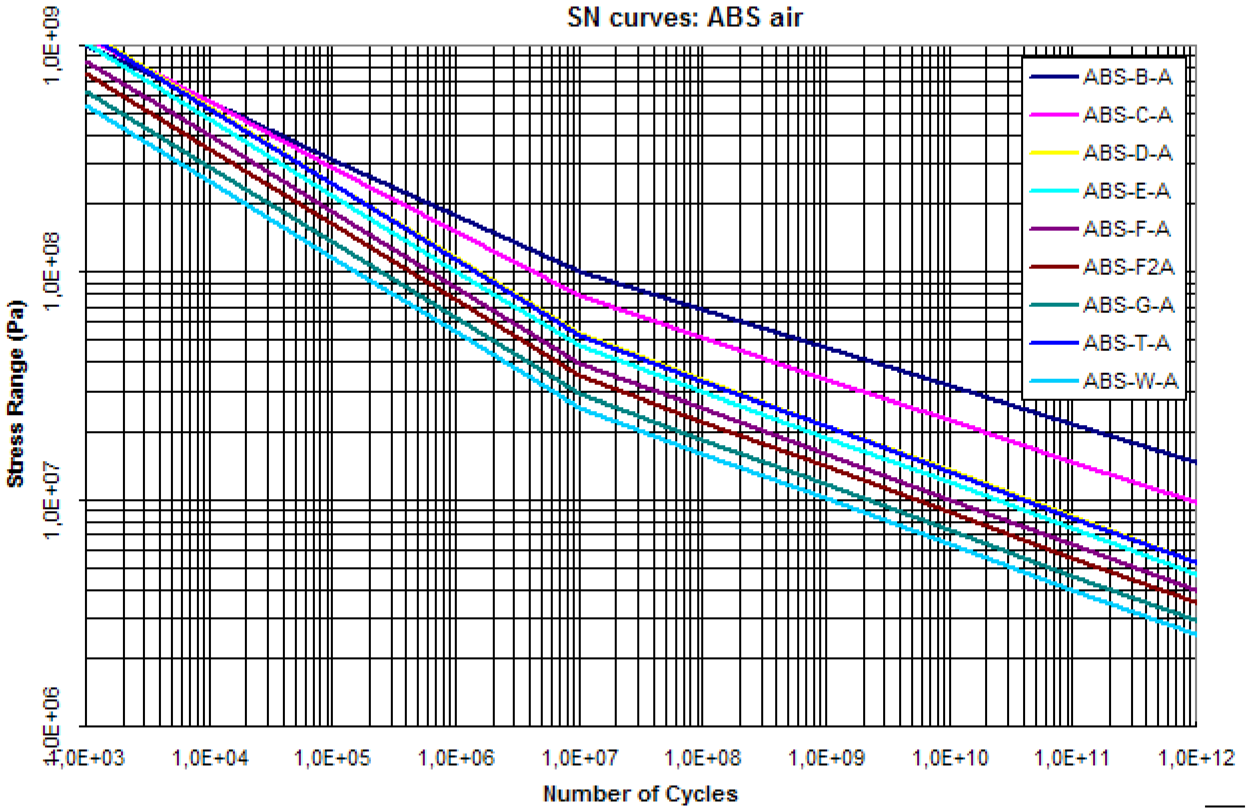



Figure E.4: ABS SN curves in air

Table E.2: ABS SN curves in sea with cathodic protection

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| ABS-B-CP | 4 | 6 | 6 | 5.806 | 8 | 158.50 | 68.35 | 38.606 | 55.080 | 55.080 | 38.606 | 0 | 0.25 | 22 | 21.9 |
| ABS-C-CP | 3.5 | 5.5 | 5.5 | 5.908 | 8 | 123.70 | 51.46 | 34.231 | 50.413 | 50.413 | 34.231 | 0 | 0.25 | 22 | 21.9 |
| ABS-D-CP | 3 | 5 | 5 | 6.004 | 8 | 84.40 | 33.67 | 29.783 | 45.636 | 45.636 | 29.783 | 0 | 0.25 | 22 | 21.9 |
| ABS-E-CP | 3 | 5 | 5 | 6.004 | 8 | 74.40 | 29.67 | 29.619 | 45.362 | 45.362 | 29.619 | 0 | 0.25 | 22 | 21.9 |
| ABS-F-CP | 3 | 5 | 5 | 6.004 | 8 | 62.90 | 25.10 | 29.400 | 44.998 | 44.998 | 29.400 | 0 | 0.25 | 22 | 21.9 |
| ABS-F2CP | 3 | 5 | 5 | 6.004 | 8 | 55.40 | 22.11 | 29.235 | 44.729 | 44.729 | 29.235 | 0 | 0.25 | 22 | 21.9 |
| ABS-G-CP | 3 | 5 | 5 | 6.004 | 8 | 46.20 | 18.45 | 28.998 | 44.320 | 44.320 | 28.998 | 0 | 0.25 | 22 | 21.9 |
| ABS-T-CP | 3 | 5 | 5 | 6.004 | 8 | 74.50 | 33.23 | 29.864 | 45.608 | 45.608 | 29.864 | 0 | 0.25 | 32 | 22.0 |
| ABS-W-CP | 3 | 5 | 5 | 6.004 | 8 | 39.80 | 15.91 | 28.804 | 44.008 | 44.008 | 28.804 | 0 | 0.25 | 22 | 21.9 |

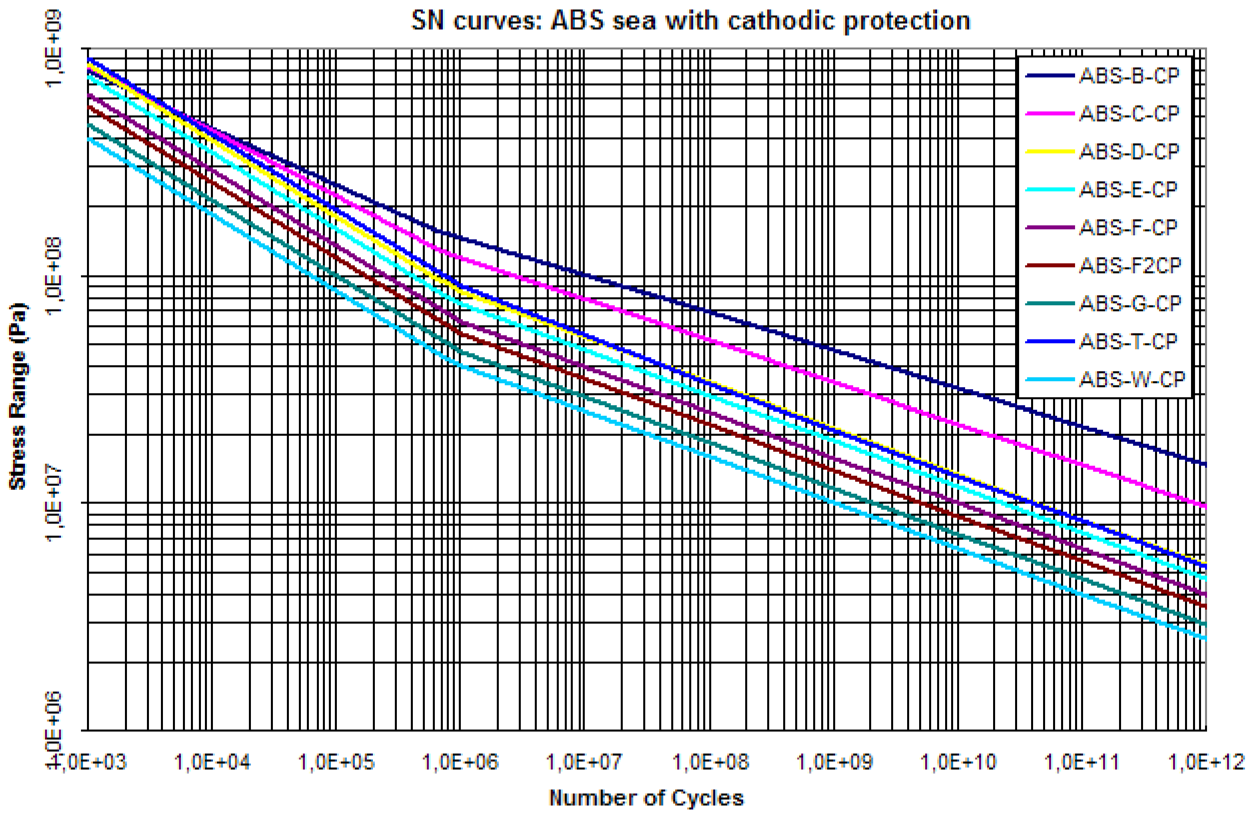



Figure E.5: ABS SN curves in sea with cathodic protection

Table E.3: ABS SN curves in sea and free corrosion

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| ABS-B-FC | 4 | 4 | 4 | 8 | 8 | 42.85 | 42.85 | 38.528 | 38.528 | 38.528 | 38.528 | 0 | 0.25 | 22 | 21.9 |
| ABS-C-FC | 3.5 | 3.5 | 3.5 | 8 | 8 | 29.59 | 29.59 | 34.149 | 34.149 | 34.149 | 34.149 | 0 | 0.25 | 22 | 21.9 |
| ABS-D-FC | 3 | 3 | 3 | 8 | 8 | 17.18 | 17.18 | 29.705 | 29.705 | 29.705 | 29.705 | 0 | 0.25 | 22 | 21.9 |
| ABS-E-FC | 3 | 3 | 3 | 8 | 8 | 15.14 | 15.14 | 29.540 | 29.540 | 29.540 | 29.540 | 0 | 0.25 | 22 | 21.9 |
| ABS-F-FC | 3 | 3 | 3 | 8 | 8 | 12.81 | 12.81 | 29.323 | 29.323 | 29.323 | 29.323 | 0 | 0.25 | 22 | 21.9 |
| ABS-F2FC | 3 | 3 | 3 | 8 | 8 | 11.27 | 11.27 | 29.156 | 29.156 | 29.156 | 29.156 | 0 | 0.25 | 22 | 21.9 |
| ABS-G-FC | 3 | 3 | 3 | 8 | 8 | 9.41 | 9.41 | 29.921 | 29.921 | 29.921 | 29.921 | 0 | 0.25 | 22 | 21.9 |
| ABS-T-FC | 3 | 3 | 3 | 8 | 8 | 16.95 | 16.95 | 29.688 | 29.688 | 29.688 | 29.688 | 0 | 0.25 | 32 | 22.0 |
| ABS-W-FC | 3 | 3 | 3 | 8 | 8 | 8.11 | 8.11 | 28.727 | 28.727 | 28.727 | 28.727 | 0 | 0.25 | 22 | 21.9 |

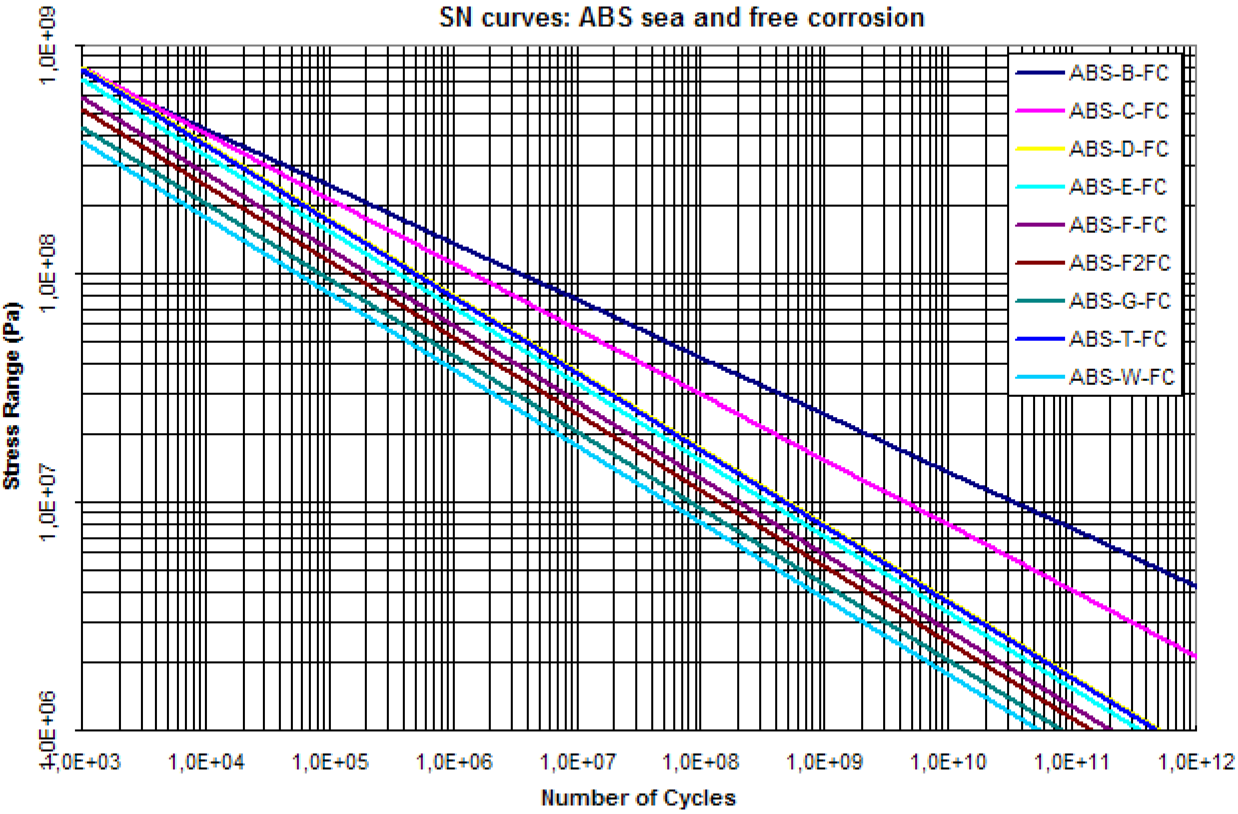



Figure E.6: ABS SN curves in sea and free corrosion

## E.5 API SN curves

Parameters and plots of API SN curves [15]:

Table E.4: API SN curves

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| API-X | 4.38 | - | - | 8.30103 | - | 35.00 | 35.00 | 41.344 | - | - | 41.912 | 0.2838 | 0 | 0 | 0 |
| API-XP | 3.74 | - | - | 8.30103 | - | 23.00 | 23.00 | 35.834 | - | - | 35.834 | 0 | 0 | 0 | 0 |

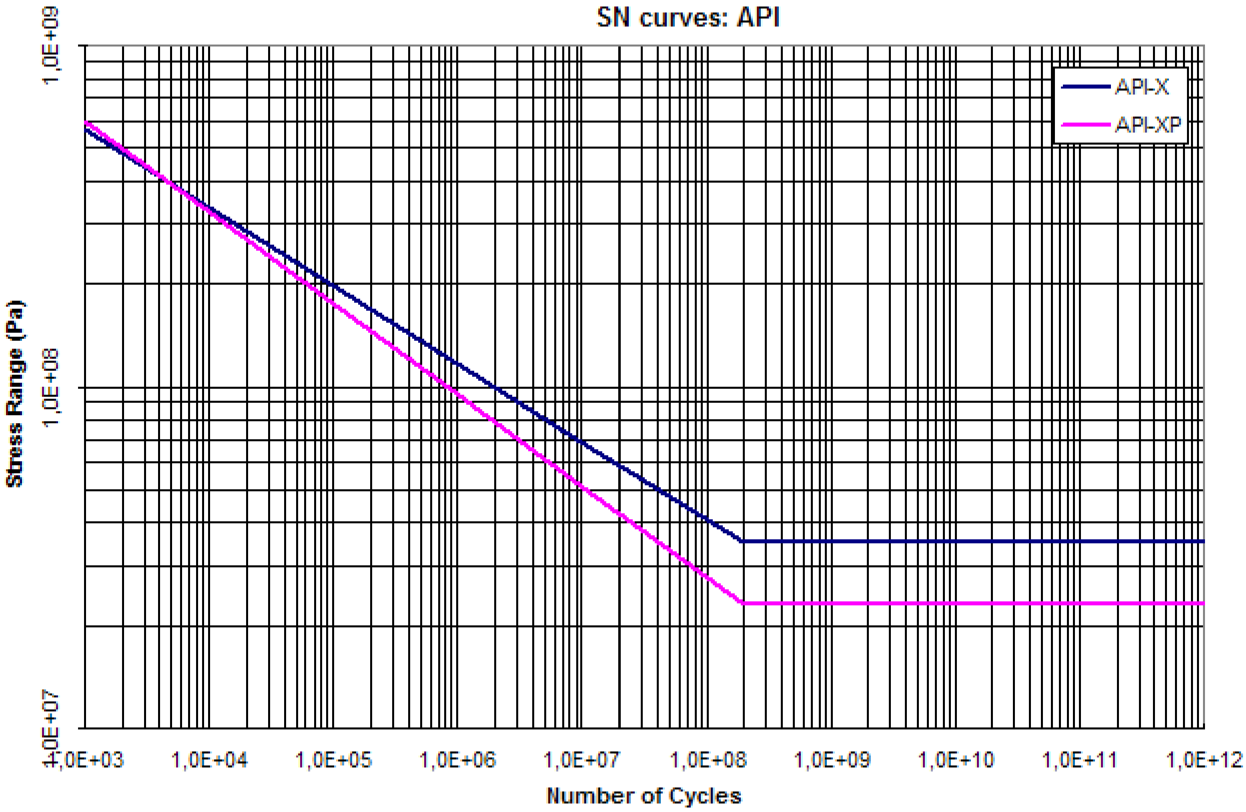



Figure E.7: API SN curves

A latter update to API SN curves, leads to add a list of new SN curves are described below:

| | |
|---|---|
| **API-X-A** | API X-curve in air |
| **API-X-CP** | API X-curve sea cathodic protection |
| **API-X-FC** | API X-curve sea free corrosion |
| **API-XP-A** | API XP-curve in air |
| **API-XP-CP** | API XP-curve sea cathodic protection |
| **API-XP-FC** | API XP-curve sea free corrosion |
| **API-WJ-A** | Weld joint curve in air |
| **API-WJ-CP** | Weld joint curve sea cathodic protection |
| **API-WJ-FC** | Weld joint urve free corrosion |
| **API-WJP-A** | Weld joint curve profile improvement |
| **API-WJP-CP** | Weld joint curve profile improvement cathodic protection |
| **API-WJP-FC** | Weld joint curve profile improvement free corrosion |
| **API-WJTBG-A** | API weld toe burr grind in air |
| **API-WJTBG-CP** | API weld toe burr grind: cathodic protection |
| **API-WJTBG-FC** | API weld toe burr grind: free corrosion |
| **API-WJHP-A** | API weld hammer peening in air |
| **API-WJHP-CP** | API weld hammer peening: cathodic protection |
| **API-WJHP-FC** | API weld hammer peening: free corrosion |
| **API-CJ-A** | API cast joint curve in air |

**API-CJ-CP** API cast joint curve cathodic protection

**API-CJ-FC** API cast joint curve free corrosion

Table E.5: Updated API SN curves in air

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| API-X-A | 4.38 | - | - | 7 | - | 69.23 | 69.23 | 41.34048917 | 0 | 0 | 41.908 | 0.2838 | 0.25 | 16 | 16 |
| API-XP-A | 3.74 | - | - | 7.30103 | - | 42.6766 | - | 35.8379399 | - | 0 | 35.838 | 0 | 0.25 | 16 | 16 |
| API-WJ-A | 3 | 5 | 5 | 7 | 16.13 | 66.834 | 1 | 30.47499236 | 46.13 | 46.13 | 30.475 | 0 | 0.25 | 16 | 16 |
| API-WJP-A | 3 | 5 | 5 | 7 | 16.13 | 66.834 | 1 | 30.47499236 | 46.13 | 46.13 | 30.475 | 0 | 0.2 | 16 | 16 |
| API-WJTBG-A | 3 | 5 | 5 | 7.30103 | 16.43103 | 66.834 | 1 | 30.77602236 | 46.43103 | 46.43103 | 30.776 | 0 | 0.15 | 16 | 16 |
| API-WJHP-A | 3 | 5 | 5 | 7.60206 | 16.73206 | 66.834 | 1 | 31.07705236 | 46.73206 | 46.73206 | 31.077 | 0 | 0.15 | 16 | 16 |
| API-CJ-A | 4 | 5 | 5 | 7 | 17.21 | 109.65 | 1 | 39.16003454 | 47.21 | 47.21 | 39.160 | 0 | 0.15 | 38 | 38 |

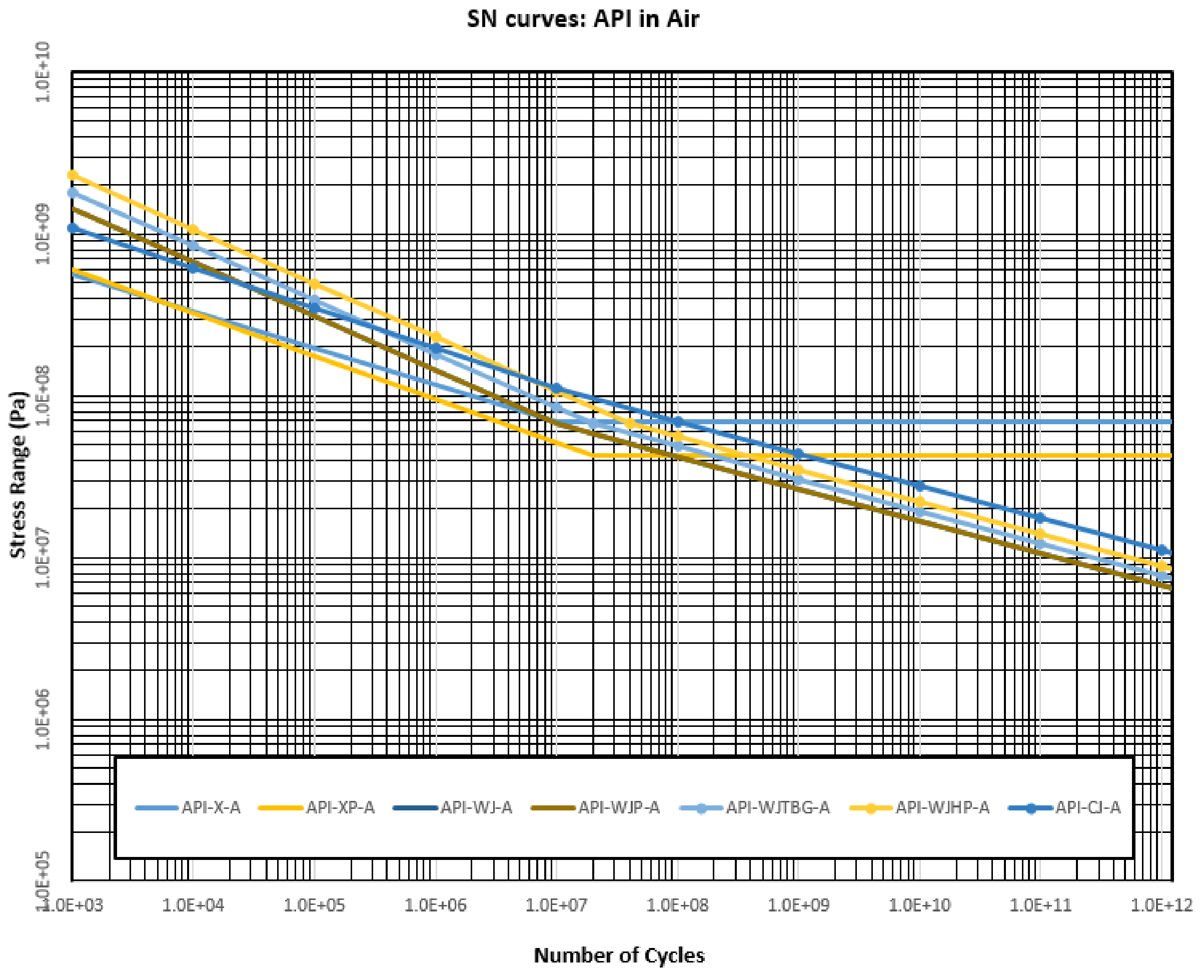



Figure E.8: API SN curves in Air

Table E.6: Updated API SN curves with Cathodic Protection

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| API-X-CP | 4.38 | - | - | 8.30103 | - | 35 | 35 | 41.34404803 | 0 | 0 | 41.912 | 0.2838 | 0.25 | 16 | 16 |
| API-XP-CP | 3.74 | - | - | 8.30103 | - | 23 | - | 35.83389211 | - | 0 | 35.834 | 0 | 0.25 | 16 | 16 |
| API-WJ-CP | 3 | 5 | 5 | 6.2525 | 16.13 | 94.51 | 1 | 30.17893329 | 46.13 | 46.13 | 30.179 | 0 | 0.25 | 16 | 16 |
| API-WJP-CP | 3 | 5 | 5 | 6.2525 | 16.13 | 94.51 | 1 | 30.17893329 | 46.13 | 46.13 | 30.179 | 0 | 0.2 | 16 | 16 |
| API-WJTBG-CP | 3 | 5 | 5 | 6.55353 | 16.43103 | 94.51 | 1 | 30.47996329 | 46.43103 | 46.43103 | 30.480 | 0 | 0.15 | 16 | 16 |
| API-WJHP-CP | 3 | 5 | 5 | 6.85456 | 16.73206 | 94.51 | 1 | 30.78099329 | 46.73206 | 46.73206 | 30.781 | 0 | 0.15 | 16 | 16 |
| API-CJ-CP | 4 | 5 | 5 | 5.50485 | 17.21 | 219.3 | 1 | 38.86900453 | 47.21 | 47.21 | 38.869 | 0 | 0.15 | 38 | 38 |

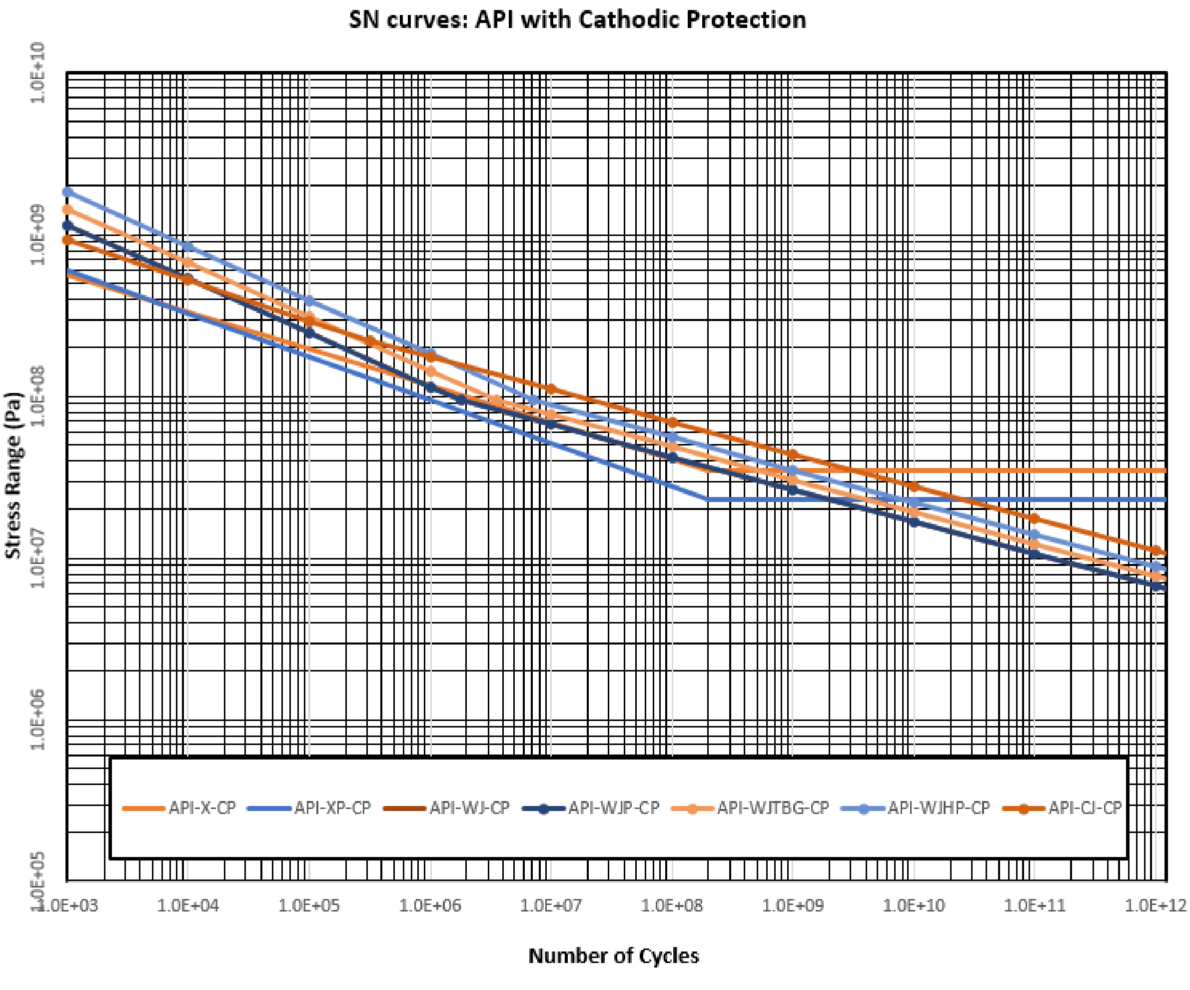



Figure E.9: API SN curves with cathodic protection

Table E.7: Updated API SN curves with Free Corrosion

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| API-X-FC | 4.38 | 4.38 | 4.38 | 8.30103 | 15.06103 | 35 | 1 | 41.34404803 | 41.34103 | 41.34103 | 41.344 | 0 | 0.25 | 16 | 16 |
| API-XP-FC | 3.74 | 3.74 | 3.74 | 8.30103 | 13.3981553 | 23 | 1 | 35.83389211 | 35.8381553 | 35.8381553 | 35.834 | 0 | 0.25 | 16 | 16 |
| API-WJ-FC | 3 | 3 | 3 | 7 | 12.003 | 46.52 | 1 | 30.00291912 | 30.003 | 30.003 | 30.003 | 0 | 0.25 | 16 | 16 |
| API-WJP-FC | 3 | 3 | 3 | 7 | 12.003 | 46.52 | 1 | 30.00291912 | 30.003 | 30.003 | 30.003 | 0 | 0.2 | 16 | 16 |
| API-WJTBG-FC | 3 | 3 | 3 | 7.30103 | 12.30403 | 46.52 | 1 | 30.30394912 | 30.30403 | 30.30403 | 30.304 | 0 | 0.15 | 16 | 16 |
| API-WJHP-FC | 3 | 3 | 3 | 7.60206 | 12.60506 | 46.52 | 1 | 30.60497912 | 30.60506 | 30.60506 | 30.605 | 0 | 0.15 | 16 | 16 |
| API-CJ-FC | 4 | 4 | 4 | 7 | 14.69288 | 83.79531 | 1 | 38.69287885 | 38.69288 | 38.69288 | 38.693 | 0 | 0.15 | 38 | 38 |

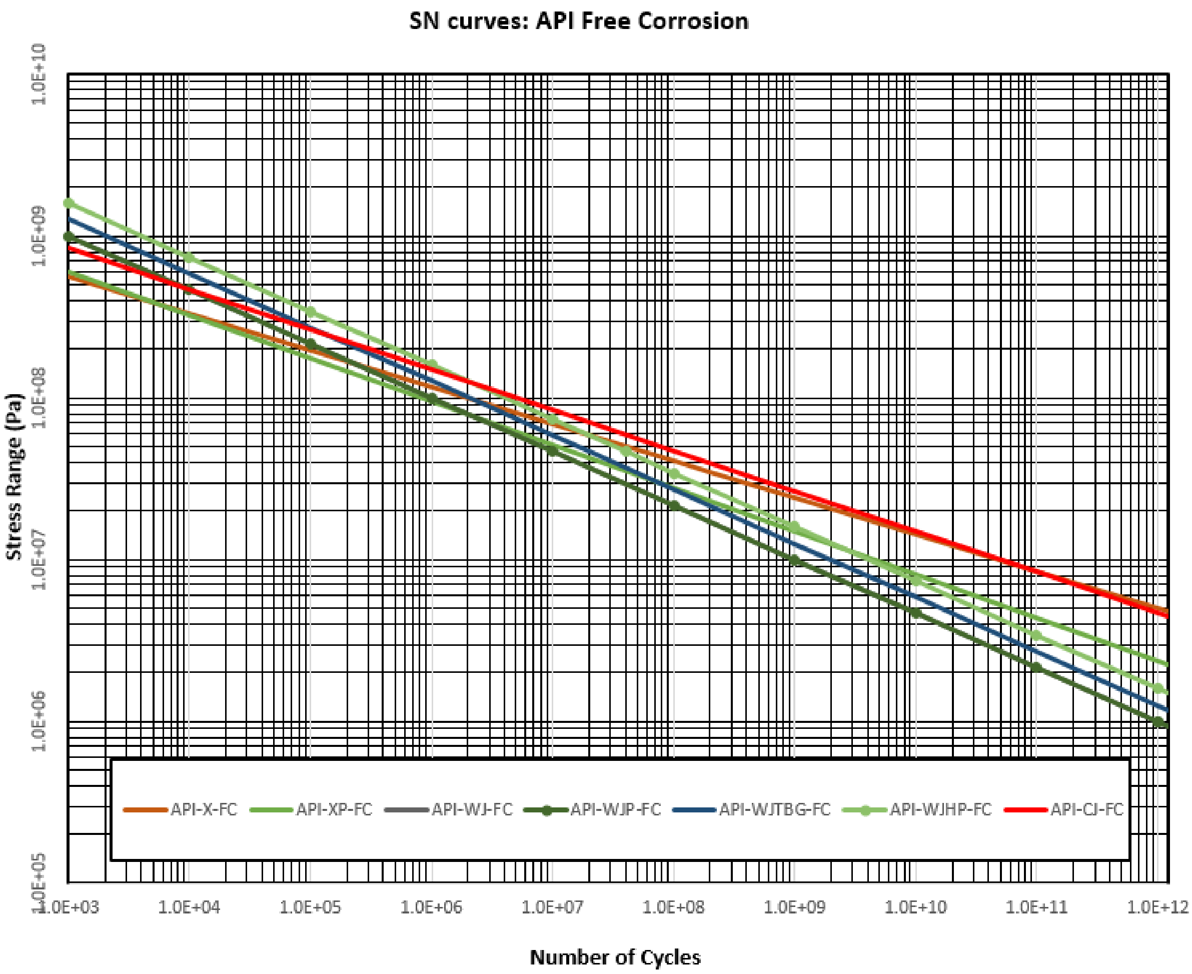



Figure E.10: API SN curves Free Corrosion

## E.6 DNV SN curves

### E.6.1 DNV Older

Parameters and plots of older SN curves given in [30]

Table E.8: DNV Older SN curves

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| DNV-X | 4.1 | - | - | 8.301 | 0.0 | 34.000 | 0 | 39.180 | 0 | - | 39.980 | 0.4 | 0 | 0 | 0 |
| DNV-I | 3.0 | 5.0 | - | 7.0 | 46.420 | 76.442 | 0 | 30.650 | 46.420 | - | 30.650 | 0 | 0 | 0 | 0 |
| DNV-II | 3.0 | 3.0 | - | 7.0 | 30.380 | 62.135 | 0 | 30.380 | 30.380 | - | 30.380 | 0 | 0 | 0 | 0 |
| DNV-III | 3.0 | 5.0 | - | 7.0 | 46.810 | 91.904 | 0 | 30.890 | 30.890 | - | 30.890 | 0 | 0 | 0 | 0 |
| DNV-IV | 3.0 | 3.0 | - | 7.0 | 30.620 | 74.702 | 0 | 30.620 | 30.620 | - | 30.620 | 0 | 0 | 0 | 0 |
| DNV-Ib | 3.0 | 3.0 | - | 7.0 | 30.760 | 83.176 | 0 | 30.760 | 30.760 | - | 30.760 | 0 | 0 | 0 | 0 |
| DNV-IIb | 3.0 | 3.0 | - | 7.0 | 31.000 | 100.00 | 0 | 31.000 | 31.000 | - | 31.000 | 0 | 0 | 0 | 0 |

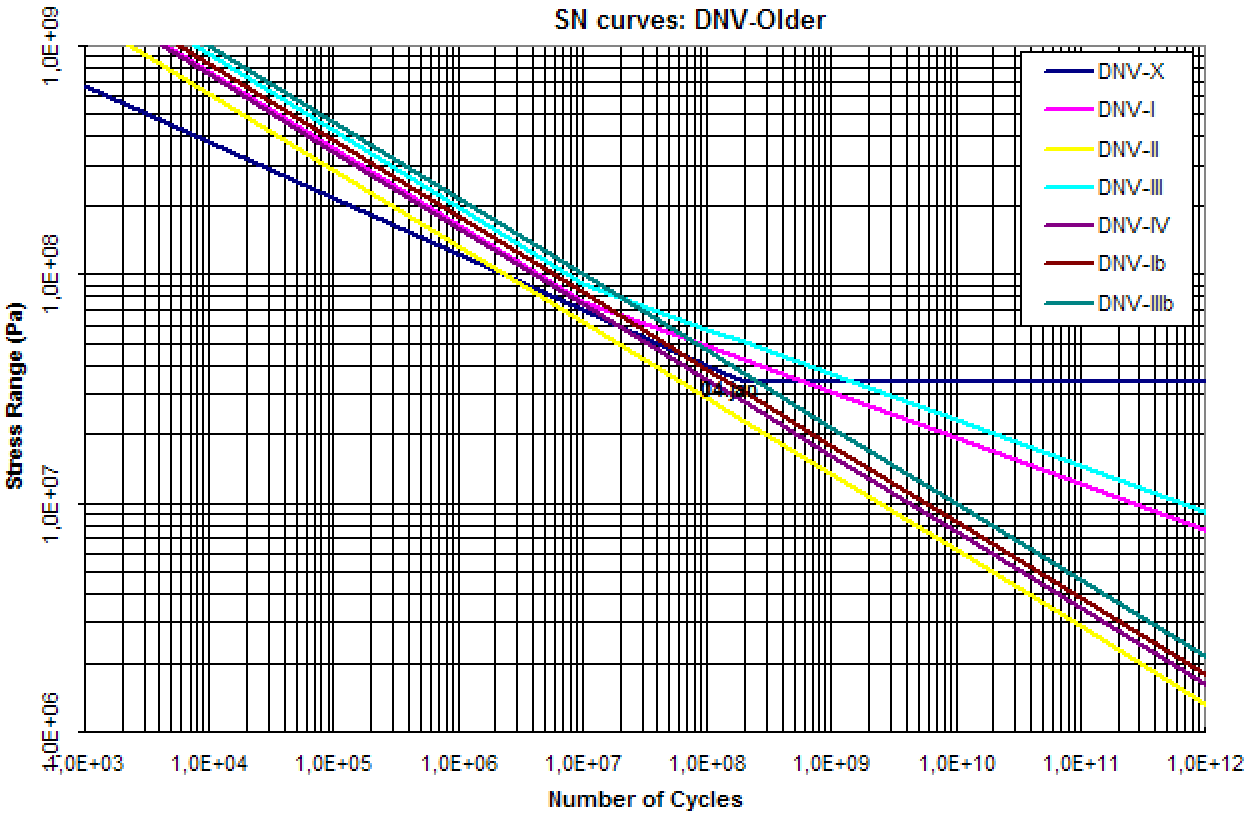



Figure E.11: DNV older SN curves

## E.6.2 DNV-RP-C203 2010

Parameters and plots of SN curves of DNV-RP-C203 April 2010, Ref. [31]

Table E.9: DNV-RP-C203 2010 SN curves in air

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DNV2010_ | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| B1-AIR | 4.0 | 5.0 | - | 7 | 47.146 | 106.967 | 0 | 39.117 | 47.146 | - | 39.117 | 0 | 0 | 0 | 0 |
| B2-AIR | 4.0 | 5.0 | - | 7 | 46.856 | 93.594 | 0 | 38.885 | 46.856 | - | 38.885 | 0 | 0 | 0 | 0 |
| C-AIR | 3.0 | 5.0 | - | 7 | 46.320 | 73.114 | 0 | 30.592 | 46.320 | - | 30.592 | 0 | 0.15 | 25 | 25 |
| C1-AIR | 3.0 | 5.0 | - | 7 | 46.081 | 65.514 | 0 | 30.449 | 46.081 | - | 30.449 | 0 | 0.15 | 25 | 25 |
| C2-AIR | 3.0 | 5.0 | - | 7 | 45.835 | 58.479 | 0 | 30.301 | 45.835 | - | 30.301 | 0 | 0.15 | 25 | 25 |
| D-AIR | 3.0 | 5.0 | - | 7 | 45.606 | 52.642 | 0 | 30.164 | 45.606 | - | 30.164 | 0 | 0.20 | 25 | 25 |
| E-AIR | 3.0 | 5.0 | - | 7 | 45.350 | 46.774 | 0 | 30.010 | 45.350 | - | 30.010 | 0 | 0.20 | 25 | 25 |
| F-AIR | 3.0 | 5.0 | - | 7 | 45.091 | 41.527 | 0 | 29.855 | 45.091 | - | 29.855 | 0 | 0.25 | 25 | 25 |
| F1-AIR | 3.0 | 5.0 | - | 7 | 44.832 | 36.841 | 0 | 29.699 | 44.832 | - | 29.699 | 0 | 0.25 | 25 | 25 |
| F3-AIR | 3.0 | 5.0 | - | 7 | 44.576 | 32.759 | 0 | 29.546 | 44.576 | - | 29.546 | 0 | 0.25 | 25 | 25 |
| G-AIR | 3.0 | 5.0 | - | 7 | 44.330 | 29.242 | 0 | 29.398 | 44.330 | - | 29.398 | 0 | 0.25 | 25 | 25 |
| T-AIR | 3.0 | 5.0 | - | 7 | 45.606 | 52.642 | 0 | 30.164 | 45.606 | - | 30.164 | 0 | 0.25 | 32 | 32 |
| W1-AIR | 3.0 | 5.0 | - | 7 | 44.101 | 26.323 | 0 | 29.261 | 44.101 | - | 29.261 | 0 | 0.25 | 25 | 25 |
| W2-AIR | 3.0 | 5.0 | - | 7 | 43.845 | 23.388 | 0 | 29.107 | 43.845 | - | 29.107 | 0 | 0.25 | 25 | 25 |
| W3-AIR | 3.0 | 5.0 | - | 7 | 43.617 | 21.054 | 0 | 28.970 | 43.617 | - | 28.970 | 0 | 0.25 | 25 | 25 |

Table E.10: DNV-RP-C203 2010 SN curves in seawater with cathodic protection

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DNV2010_ | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| B1-SEACP | 4.0 | 5.0 | - | 6 | 47.146 | 169.531 | 0 | 38.917 | 47.146 | - | 38.917 | 0 | 0 | 0 | 0 |
| B2-SEACP | 4.0 | 5.0 | - | 6 | 46.856 | 148.337 | 0 | 38.685 | 46.856 | - | 38.685 | 0 | 0 | 0 | 0 |
| C-SEACP | 3.0 | 5.0 | - | 6 | 46.320 | 115.878 | 0 | 30.192 | 46.320 | - | 30.192 | 0 | 0.15 | 25 | 25 |
| C1-SEACP | 3.0 | 5.0 | - | 6 | 46.081 | 103.833 | 0 | 30.049 | 46.081 | - | 30.049 | 0 | 0.15 | 25 | 25 |
| C2-SEACP | 3.0 | 5.0 | - | 6 | 45.835 | 92.683 | 0 | 29.901 | 45.835 | - | 29.901 | 0 | 0.15 | 25 | 25 |
| D-SEACP | 3.0 | 5.0 | - | 6 | 45.606 | 83.432 | 0 | 29.764 | 45.606 | - | 29.764 | 0 | 0.20 | 25 | 25 |
| E-SEACP | 3.0 | 5.0 | - | 6 | 45.350 | 74.131 | 0 | 29.610 | 45.350 | - | 29.610 | 0 | 0.20 | 25 | 25 |
| F-SEACP | 3.0 | 5.0 | - | 6 | 45.091 | 65.816 | 0 | 29.455 | 45.091 | - | 29.455 | 0 | 0.25 | 25 | 25 |
| F1-SEACP | 3.0 | 5.0 | - | 6 | 44.832 | 58.389 | 0 | 29.299 | 44.832 | - | 29.299 | 0 | 0.25 | 25 | 25 |
| F3-SEACP | 3.0 | 5.0 | - | 6 | 44.576 | 51.920 | 0 | 29.146 | 44.576 | - | 29.146 | 0 | 0.25 | 25 | 25 |
| G-SEACP | 3.0 | 5.0 | - | 6 | 44.330 | 46.345 | 0 | 28.998 | 44.330 | - | 28.998 | 0 | 0.25 | 25 | 25 |
| T-SEACP | 3.0 | 5.0 | - | 6 | 45.606 | 83.432 | 0 | 29.764 | 45.606 | - | 29.764 | 0 | 0.25 | 32 | 32 |
| W1-SEACP | 3.0 | 5.0 | - | 6 | 44.101 | 41.719 | 0 | 28.861 | 44.101 | - | 28.861 | 0 | 0.25 | 25 | 25 |
| W2-SEACP | 3.0 | 5.0 | - | 6 | 43.845 | 37.068 | 0 | 28.707 | 43.845 | - | 28.707 | 0 | 0.25 | 25 | 25 |
| W3- SEACP | 3.0 | 5.0 | - | 6 | 43.617 | 33.368 | 0 | 28.570 | 43.617 | - | 28.570 | 0 | 0.25 | 25 | 25 |

Table E.11: DNV-RP-C203 2010 SN curves in seawater for free corrosion

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DNV2010_ | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| B1-SEAFC | 3.0 | 3.0 | - | 7 | 30.436 | 64.863 | 0 | 30.436 | 30.436 | - | 30.436 | 0 | 0 | 0 | 0 |
| B2-SEAFC | 3.0 | 3.0 | - | 7 | 30.262 | 56.754 | 0 | 30.262 | 30.262 | - | 30.262 | 0 | 0 | 0 | 0 |
| C-SEAFC | 3.0 | 3.0 | - | 7 | 30.115 | 50.699 | 0 | 30.115 | 30.115 | - | 30.115 | 0 | 0.15 | 25 | 25 |
| C1-SEAFC | 3.0 | 3.0 | - | 7 | 29.972 | 45.429 | 0 | 29.972 | 29.972 | - | 29.972 | 0 | 0.15 | 25 | 25 |
| C2-SEAFC | 3.0 | 3.0 | - | 7 | 29.824 | 40.551 | 0 | 29.824 | 29.824 | - | 29.824 | 0 | 0.15 | 25 | 25 |
| D-SEAFC | 3.0 | 3.0 | - | 7 | 29.687 | 36.503 | 0 | 29.687 | 29.687 | - | 29.687 | 0 | 0.20 | 25 | 25 |
| E-SEAFC | 3.0 | 3.0 | - | 7 | 29.533 | 32.434 | 0 | 29.533 | 29.533 | - | 29.533 | 0 | 0.20 | 25 | 25 |
| F-SEAFC | 3.0 | 3.0 | - | 7 | 29.378 | 28.796 | 0 | 29.378 | 29.378 | - | 29.378 | 0 | 0.25 | 25 | 25 |
| F1-SEAFC | 3.0 | 3.0 | - | 7 | 29.222 | 25.547 | 0 | 29.222 | 29.222 | - | 29.222 | 0 | 0.25 | 25 | 25 |
| F3-SEAFC | 3.0 | 3.0 | - | 7 | 29.068 | 22.699 | 0 | 29.068 | 29.068 | - | 29.068 | 0 | 0.25 | 25 | 25 |
| G-SEAFC | 3.0 | 3.0 | - | 7 | 28.921 | 20.277 | 0 | 28.921 | 28.921 | - | 28.921 | 0 | 0.25 | 25 | 25 |
| T-SEAFC | 3.0 | 3.0 | - | 7 | 29.687 | 36.503 | 0 | 29.687 | 29.687 | - | 29.687 | 0 | 0.25 | 32 | 32 |
| W1-SEAFC | 3.0 | 3.0 | - | 7 | 28.784 | 18.253 | 0 | 28.784 | 28.784 | - | 28.784 | 0 | 0.25 | 25 | 25 |
| W2-SEAFC | 3.0 | 3.0 | - | 7 | 28.630 | 16.218 | 0 | 28.630 | 28.630 | - | 28.630 | 0 | 0.25 | 25 | 25 |
| W3- SEAFC | 3.0 | 3.0 | - | 7 | 28.493 | 14.599 | 0 | 28.493 | 28.493 | - | 28.493 | 0 | 0.25 | 25 | 25 |

Table E.12: DNV-RP-C203 2010 SN curves for cast node (CN), high strength steel (HS) and small diameter pipe umbilicals (UM)

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DNV2010_ | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| CN-AIR | 3.0 | 5.0 | - | 7 | 46.320 | 73.114 | 0 | 30.592 | 46.320 | - | 30.592 | 0 | 0.15 | 38 | 38 |
| CN-SEACP | 3.0 | 5.0 | - | 6 | 46.320 | 115.878 | 0 | 30.192 | 46.320 | - | 30.192 | 0 | 0.15 | 38 | 38 |
| CN-SEAFC | 3.0 | 3.0 | - | 7 | 30.115 | 50.699 | 0 | 30.115 | 30.115 | - | 30.115 | 0 | 0.15 | 38 | 38 |
| HS-BMAIR | 4.7 | 0 | - | 6.301 | 0 | 235.110 | 235.110 | 45.646 | 0 | - | 45.646 | 0 | 0 | 0 | 0 |
| HS-BMVAM | 4.7 | 4.7 | - | 7 | 45.970 | 195.654 | 0 | 45.970 | 45.970 | - | 45.970 | 0 | 0 | 0 | 0 |
| HS-SEACP | 4.7 | 4.7 | - | 7 | 45.646 | 166.937 | 0 | 45.646 | 45.646 | - | 45.646 | 0 | 0 | 0 | 0 |
| UM-BM | 4.0 | 5.0 | - | 7 | 47.376 | 32.434 | 0 | 39.301 | 47.376 | - | 39.301 | 0 | 0 | 0 | 0 |
| UM-TC | 4.0 | 5.0 | - | 7 | 47.376 | 28.796 | 0 | 39.301 | 47.376 | - | 39.301 | 0 | 0.25 | 1 | 1 |

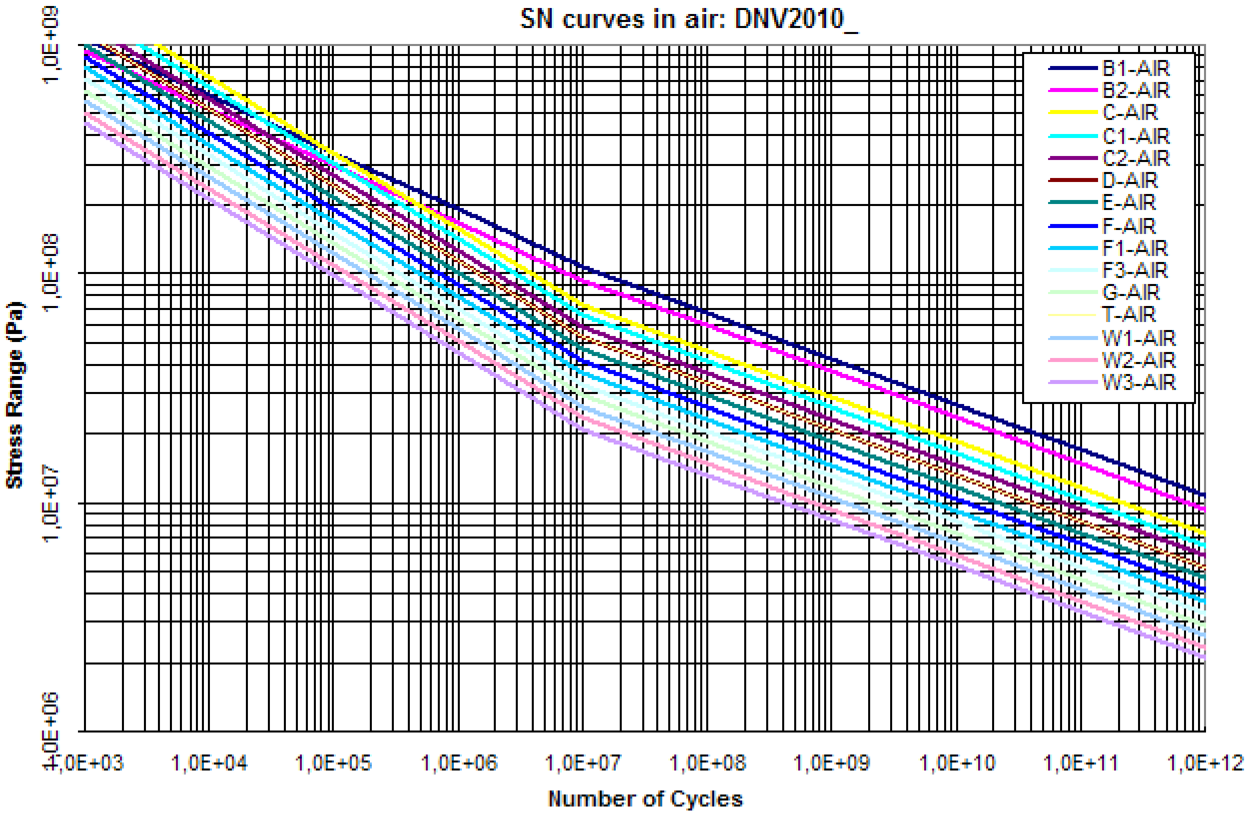



Figure E.12: DNV-RP-C203 2010 SN curves in air

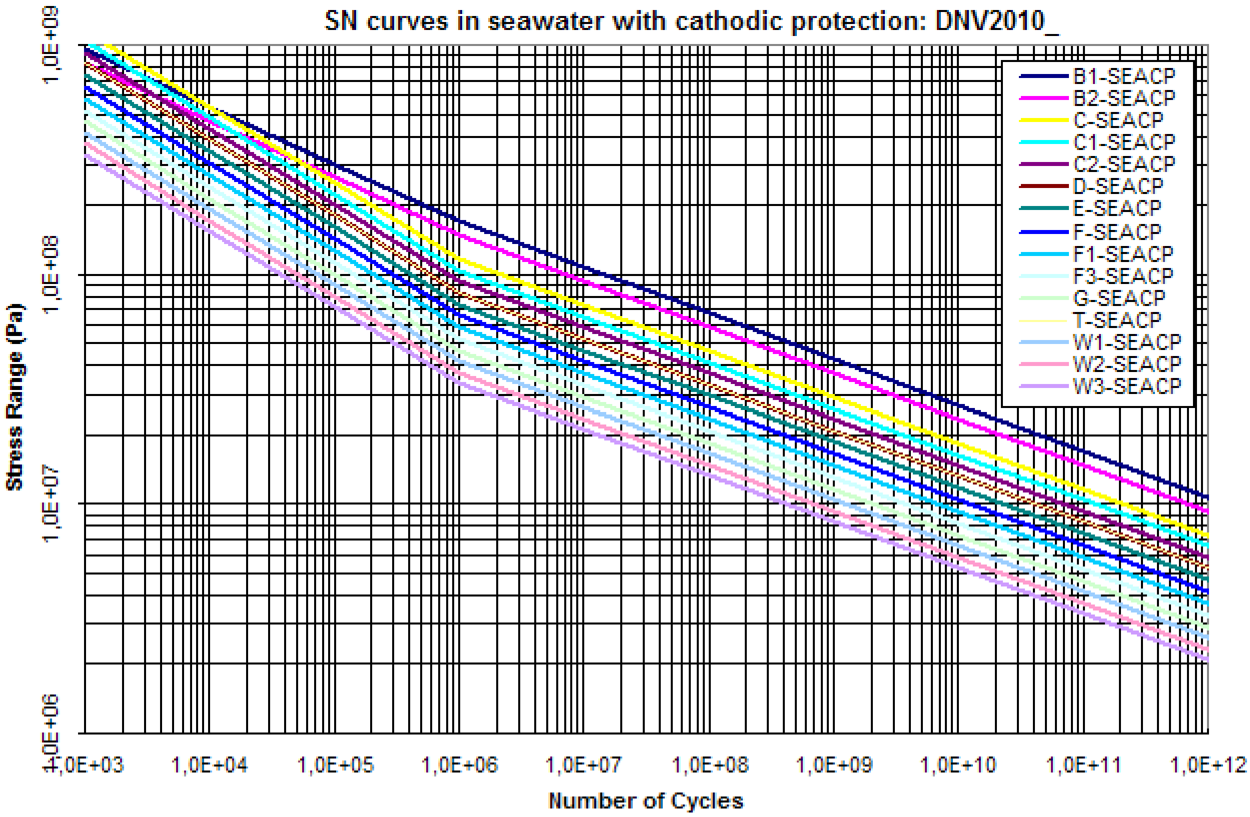



Figure E.13: DNV-RP-C203 2010 SN curves in seawater with cathodic protection

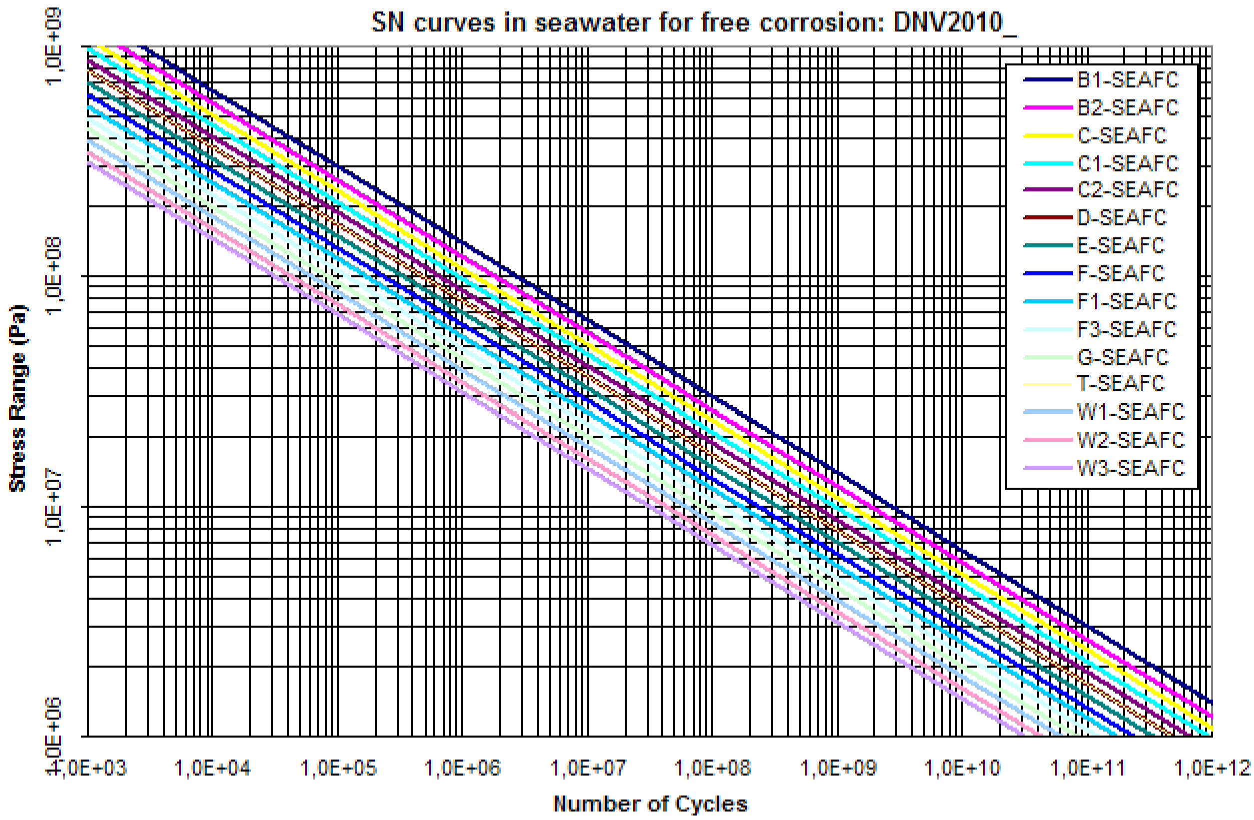



Figure E.14: DNV-RP-C203 2010 SN curves in seawater for free corrosion

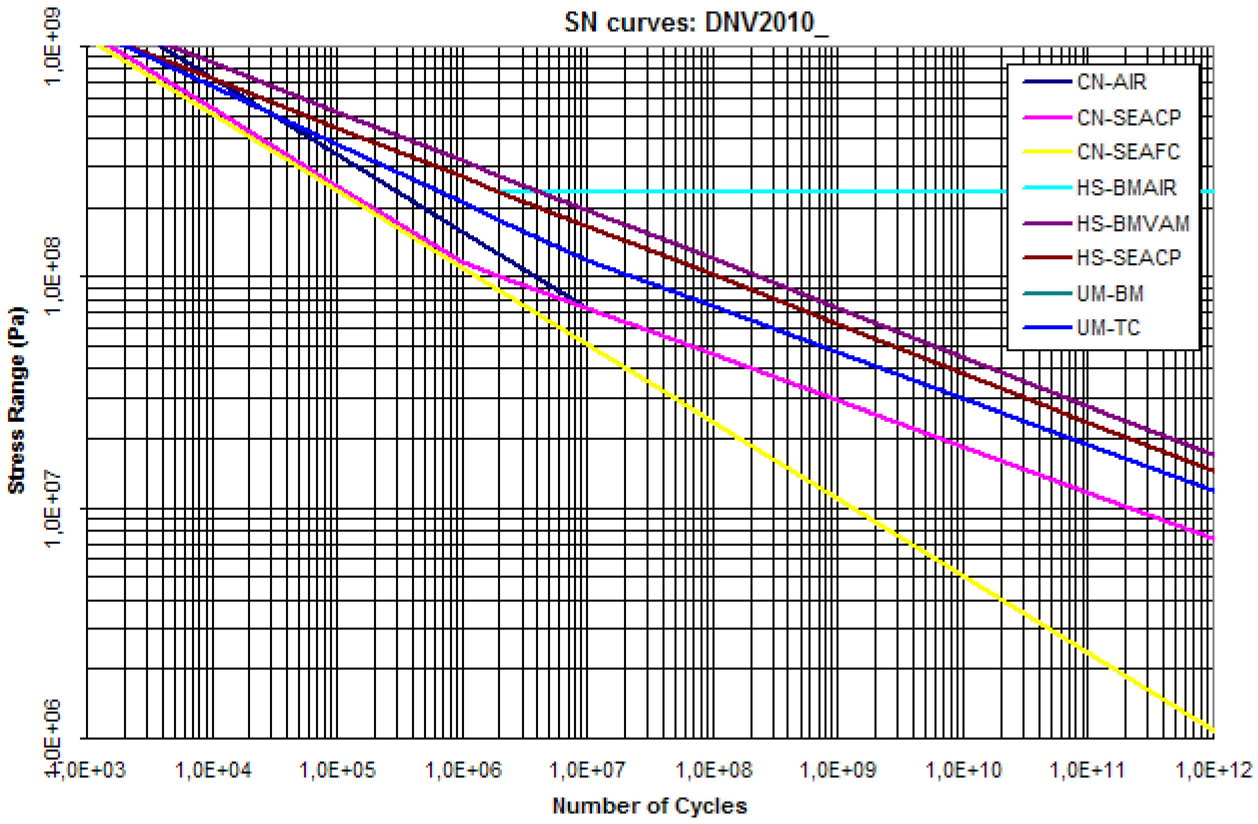



Figure E.15: DNV-RP-C203 2010 SN curves for cast node (CN), high strength steel (HS) and small diameter pipe umbilicals (UM)

## E.6.3 DNV-CN-30.7 2010

Parameters and plots of SN curves of DNV CN 30.7 June 2010, Ref. [8]:

Table E.13: DNV-CN-30.7 2010 SN curves

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DNV2010_ | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| DNVC-I | 3.0 | 5.0 | 0 | 7.0 | 45.606 | 52.642 | 0 | 30.164 | 45.606 | 0 | 30.164 | 0 | 0 | 0 | 0 |
| DNVC-III | 4.0 | 5.0 | 0 | 7.0 | 47.146 | 106.967 | 0 | 39.117 | 47.146 | 0 | 39.117 | 0 | 0 | 0 | 0 |
| DNV-IV | 3.0 | 3.0 | 0 | 7.0 | 30.436 | 64.863 | 0 | 30.436 | 30.436 | 0 | 30.436 | 0 | 0 | 0 | 0 |

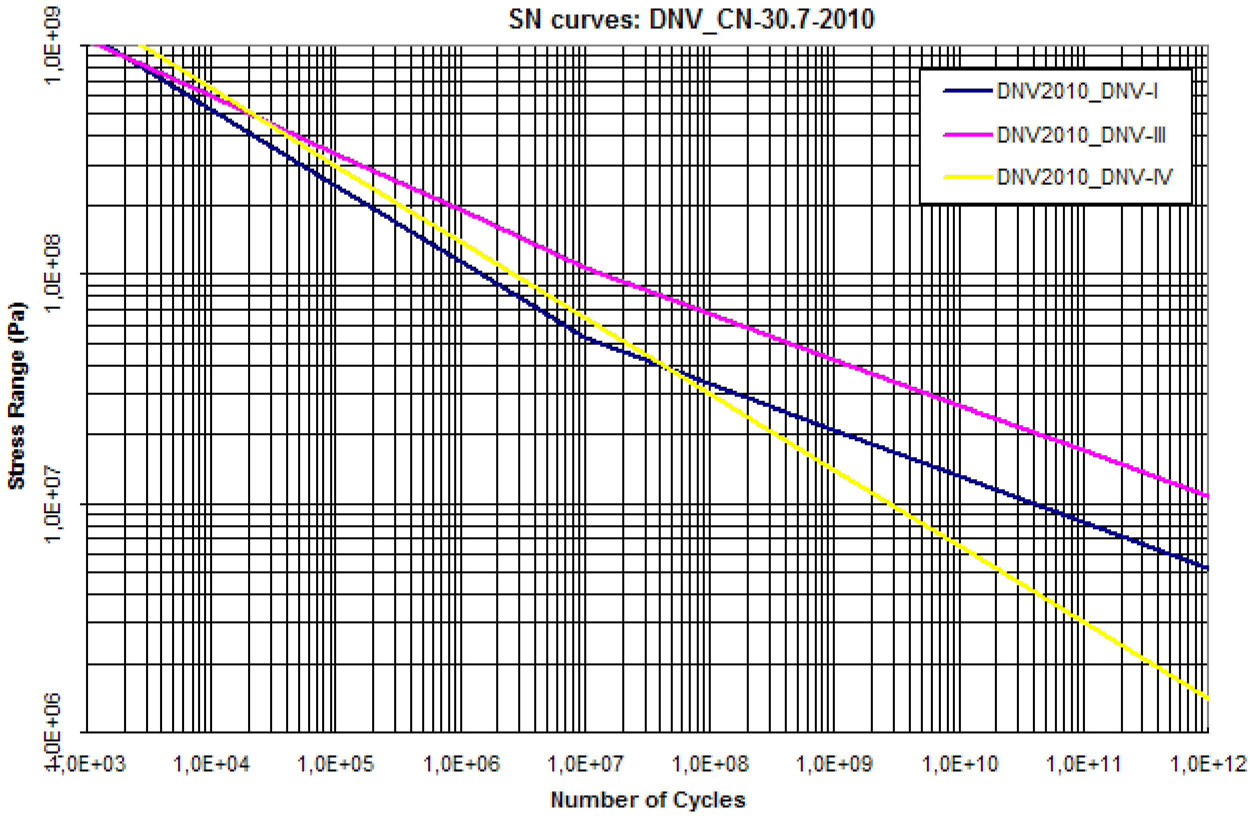



Figure E.16: DNV-CN-30.7 2010 SN curves

## E.7 DOE SN curves

Parameters and plots of DOE SN curves Ref. [7]:

Table E.14: DOE SN curves

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| DOE-E | 3.0 | 5.0 | 5.0 | 7.0 | 8.0 | 46.96 | 29.63 | 30.015 | 45.359 | 45.359 | 30.015 | 0 | 0.25 | 22 | 22 |
| DOE-F | 3.0 | 5.0 | 5.0 | 7.0 | 8.0 | 46.82 | 25.00 | 30.011 | 44.990 | 44.990 | 30.011 | 0 | 0.25 | 22 | 22 |
| DOE-F2 | 3.0 | 5.0 | 5.0 | 7.0 | 8.0 | 35.05 | 22.12 | 29.634 | 44.724 | 44.724 | 29.634 | 0 | 0.25 | 22 | 22 |
| DOE-T | 3.0 | 5.0 | 5.0 | 7.0 | 8.0 | 52.63 | 33.21 | 30.164 | 45.606 | 45.606 | 30.164 | 0 | 0.25 | 32 | 32 |

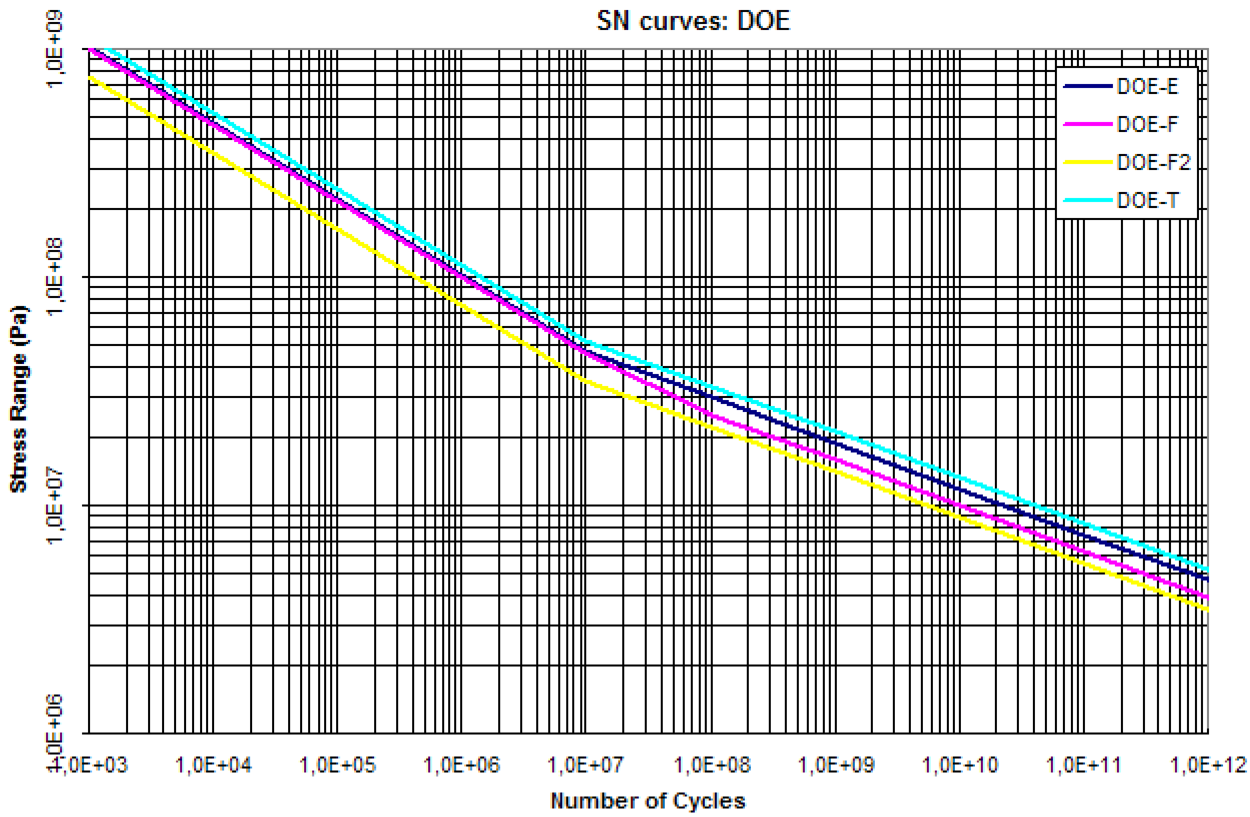



Figure E.17: DOE SN curves

## E.8 HSE SN curves

Parameters and plots of HSE SN curves Ref. [13]:

Table E.15: HSE SN curves in air

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| HSE-C-IA | 3 | 5 | 5 | 7 | 8 | 69.74 | 44.32 | 30.530 | 46.233 | 46.233 | 30.530 | 0 | 0.3 | 16 | 16 |
| HSE-E-IA | 3 | 5 | 5 | 7 | 8 | 46.49 | 29.55 | 30.002 | 45.353 | 45.353 | 30.002 | 0 | 0.3 | 16 | 16 |
| HSE-F-IA | 3 | 5 | 5 | 7 | 8 | 39.55 | 25.14 | 29.791 | 45.002 | 45.002 | 29.791 | 0 | 0.3 | 16 | 16 |
| HSE-F2IA | 3 | 5 | 5 | 7 | 8 | 34.87 | 22.16 | 29.627 | 44.728 | 44.728 | 29.627 | 0 | 0.3 | 16 | 16 |
| HSE-G-IA | 3 | 5 | 5 | 7 | 8 | 28.96 | 18.41 | 29.385 | 44.325 | 44.325 | 29.385 | 0 | 0.3 | 16 | 16 |
| HSE-P-IA | 3 | 5 | 5 | 7 | 8 | 53.00 | 33.68 | 30.173 | 45.637 | 45.637 | 30.173 | 0 | 0.3 | 16 | 16 |
| HSE-T-IA | 3 | 5 | 5 | 7 | 8 | 67.00 | 42.21 | 30.478 | 46.127 | 46.127 | 30.478 | 0 | 0.3 | 16 | 16 |
| HSE-W-IA | 3 | 5 | 5 | 7 | 8 | 20.87 | 13.26 | 28.959 | 43.613 | 43.613 | 28.959 | 0 | 0.3 | 16 | 16 |

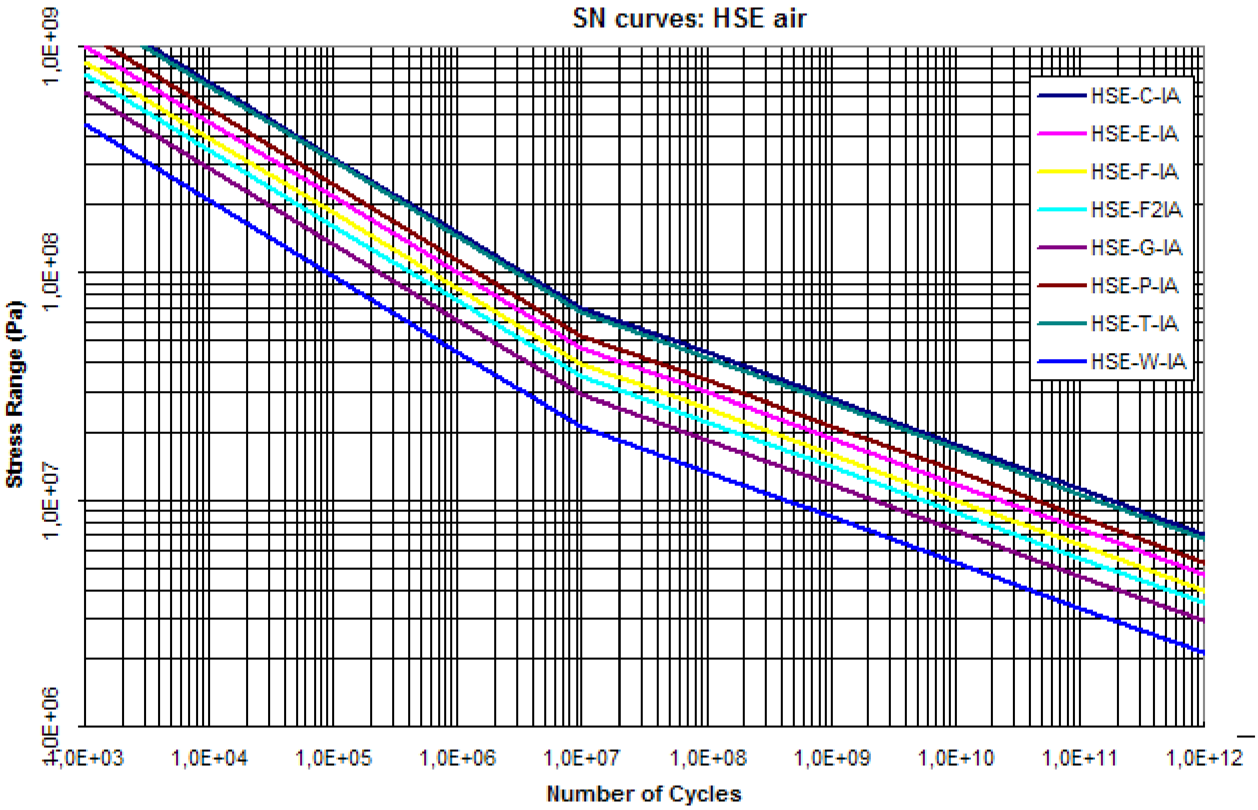



Figure E.18: HSE SN curves in air

Table E.16: HSE SN curves in sea with cathodic protection

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| HSE-C-CP | 3 | 5 | 5 | 6.011 | 8 | 110.53 | 44.32 | 30.141 | 46.233 | 46.233 | 30.141 | 0 | 0.3 | 16 | 16 |
| HSE-E-CP | 3 | 5 | 5 | 6.011 | 8 | 73.68 | 29.55 | 29.613 | 45.353 | 45.353 | 29.613 | 0 | 0.3 | 16 | 16 |
| HSE-F-CP | 3 | 5 | 5 | 6.011 | 8 | 62.69 | 25.14 | 29.403 | 45.002 | 45.002 | 29.403 | 0 | 0.3 | 16 | 16 |
| HSE-F2CP | 3 | 5 | 5 | 6.011 | 8 | 55.26 | 22.16 | 29.238 | 44.728 | 44.728 | 29.238 | 0 | 0.3 | 16 | 16 |
| HSE-G-CP | 3 | 5 | 5 | 6.011 | 8 | 45.90 | 18.41 | 28.996 | 44.325 | 44.325 | 28.996 | 0 | 0.3 | 16 | 16 |
| HSE-P-CP | 3 | 5 | 5 | 6.011 | 8 | 84.00 | 33.68 | 29.784 | 45.637 | 45.637 | 29.784 | 0 | 0.3 | 16 | 16 |
| HSE-T-CP | 3 | 5 | 5 | 6.242 | 8 | 95.00 | 42.21 | 30.175 | 46.127 | 46.127 | 30.175 | 0 | 0.3 | 16 | 16 |
| HSE-W-CP | 3 | 5 | 5 | 6.011 | 8 | 33.07 | 13.26 | 28.569 | 43.613 | 43.613 | 28.569 | 0 | 0.3 | 16 | 16 |

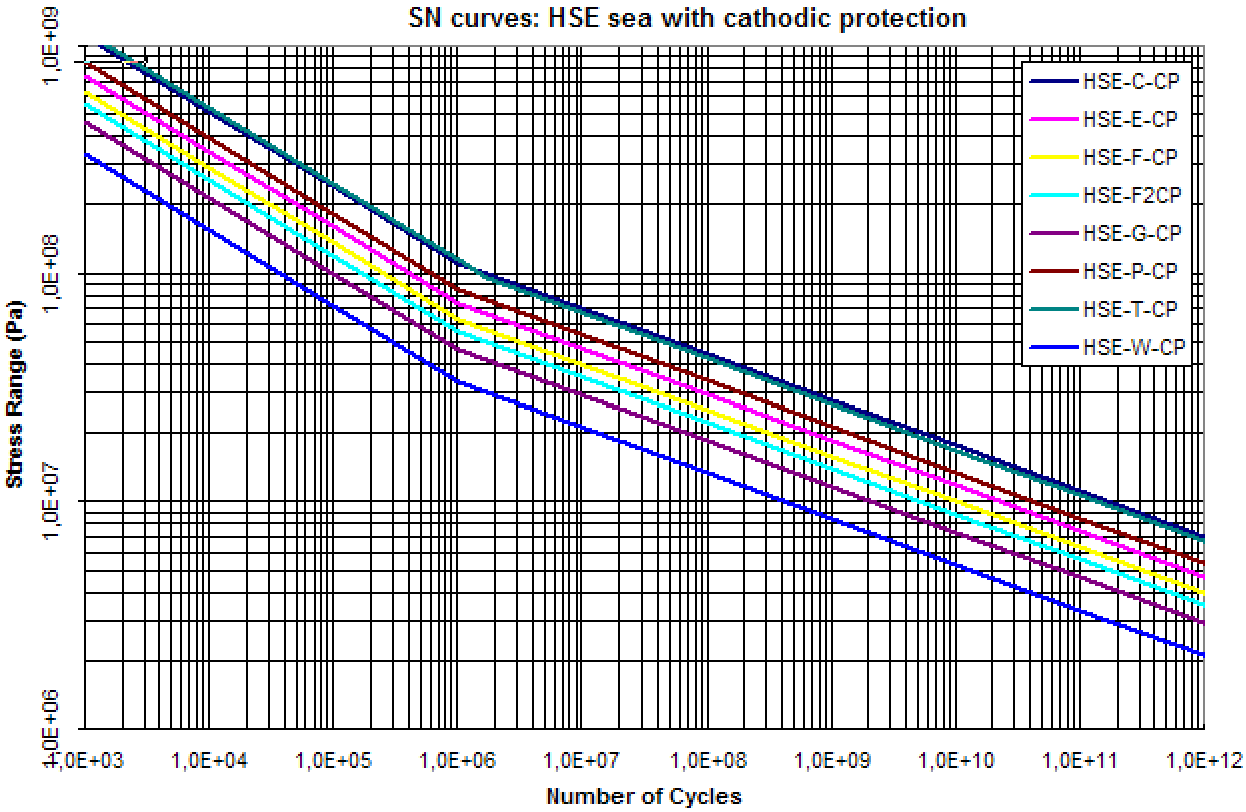



Figure E.19: HSE SN curves in sea with cathodic protection

Table E.17: HSE SN curves in sea and free corrosion

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| HSE-C-FC | 3 | 3 | 3 | 8 | 8 | 22.60 | 22.60 | 30.062 | 30.062 | 30.062 | 30.062 | 0 | 0.3 | 16 | 16 |
| HSE-E-FC | 3 | 3 | 3 | 8 | 8 | 15.07 | 15.07 | 29.534 | 29.534 | 29.534 | 29.534 | 0 | 0.3 | 16 | 16 |
| HSE-F-FC | 3 | 3 | 3 | 8 | 8 | 12.82 | 12.82 | 29.324 | 29.324 | 29.324 | 29.324 | 0 | 0.3 | 16 | 16 |
| HSE-F2FC | 3 | 3 | 3 | 8 | 8 | 11.30 | 11.30 | 29.159 | 29.159 | 29.159 | 29.159 | 0 | 0.3 | 16 | 16 |
| HSE-G-FC | 3 | 3 | 3 | 8 | 8 | 9.39 | 9.39 | 28.918 | 28.918 | 28.918 | 28.918 | 0 | 0.3 | 16 | 16 |
| HSE-P-FC | 3 | 3 | 3 | 8 | 8 | 17.18 | 17.18 | 29.705 | 29.705 | 29.705 | 29.705 | 0 | 0.3 | 16 | 16 |
| HSE-T-FC | 3 | 3 | 3 | 8 | 8 | 21.54 | 21.54 | 30.000 | 30.000 | 30.000 | 30.000 | 0 | 0.3 | 16 | 16 |
| HSE-W-FC | 3 | 3 | 3 | 8 | 8 | 6.76 | 6.76 | 28.490 | 28.490 | 28.490 | 28.490 | 0 | 0.3 | 16 | 16 |

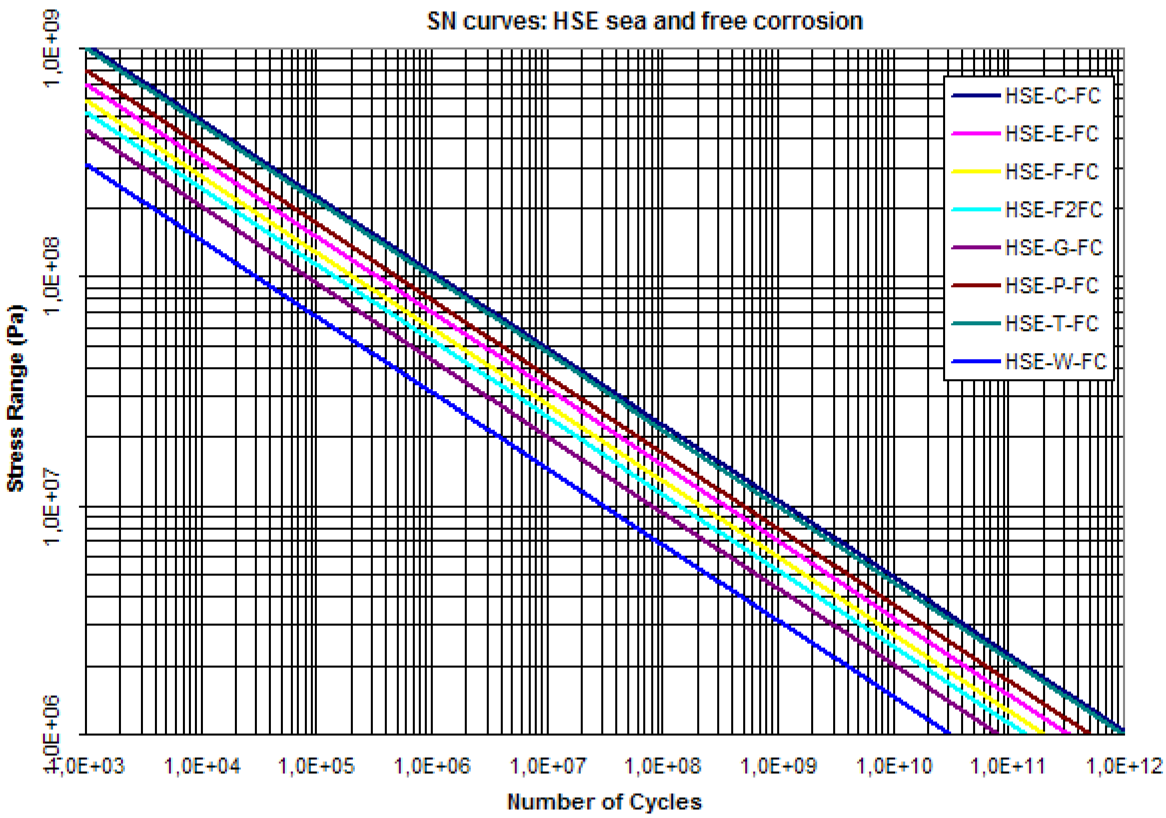



Figure E.20: HSE SN curves in sea an free corrosion

## E.9 ISO SN curves

Parameters and plots of ISO SN curves.

| | |
|---|---|
| **ISO-TJ-A** | ISO Tubular Joint Curve in air |
| **ISO-TJ-CP** | ISO TJ curve sea corrosion protection corrosion protection |
| **ISO-TJ-FC** | ISO TJ curve free corrosion free corrosion |
| **ISO-TJHP-A** | ISO TJ curve Hammer Peening improvement in air |
| **ISO-TJHP-CP** | ISO TJ curve Hammer Peening corrosion protection |
| **ISO-TJHP-FC** | ISO TJ curve Hammer Peening free corrosion |
| **ISO-TJWTG-A** | ISO TJ curve Weld Toe Grinding in air |
| **ISO-TJWTG-CP** | ISO TJ curve Weld Toe Grinding corrosion protection |
| **ISO-TJWTG-FC** | ISO TJ curve Weld Toe Grinding free corrosion |
| **ISO-CJ-A** | API Cast Joint curve in air |
| **ISO-CJ-CP** | API Cast Joint curve corrosion protection |
| **ISO-CJ-FC** | API Cast Joint curve free corrosion |
| **ISO-OJB-A** | ISO Other Joint B curve in air |
| **ISO-OJB-CP** | ISO OJ B curve corrosion protection |
| **ISO-OJB-FC** | ISO Other Joint B curve free corrosion |
| **ISO-OJC-A** | ISO Other Joint C curve in air |
| **ISO-OJC-CP** | ISO Other Joint C curve corrosion protection |
| **ISO-OJC-FC** | ISO Other Joint C curve free corrosion |

**ISO-OJD-A** ISO Other Joint D curve in air

**ISO-OJD-CP** ISO Other Joint D curve corrosion protection

**ISO-OJD-FC** ISO Other Joint D curve free corrosion

**ISO-OJE-A** ISO Other Joint E curve in air

**ISO-OJE-CP** ISO Other Joint E curve corrosion protection

**ISO-OJE-FC** ISO Other Joint E curve free corrosion

**ISO-OJF-A ISO** Other Joint F curve in air

**ISO-OJF-CP** ISO Other Joint F curve corrosion protection

**ISO-OJF-FC** ISO Other Joint F curve free corrosion

**ISO-OJF2-A** ISO Other Joint F2 curve in air

**ISO-OJF2-CP** ISO Other Joint F2 curve corrosion protection

**ISO-OJF2-FC** ISO Other Joint F2 curve free corrosion

**ISO-OJG-A** ISO Other Joint G curve in air

**ISO-OJG-CP** ISO Other Joint G curve corrosion protection

**ISO-OJG-FC** ISO Other Joint G curve free corrosion

**ISO-OJW1-A** ISO Other Joint W1 curve in air

**ISO-OJW1-CP** ISO Other Joint W1 curve corrosion protection

**ISO-OJW1-FC** ISO Other Joint W1 curve free corrosion

Table E.18: ISO SN curves in air

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| ISO-TJ-A | 3 | 5 | 5 | 7.005 | 16.13 | 66.83439176 | 1 | 30.48 | 46.13 | 46.13 | 30.480 | 0 | 0.25 | 16 | 16 |
| ISO-TJHP-A | 3 | 5 | 5 | 7.607059991 | 16.73205999 | 66.83439176 | 1 | 31.08205999 | 46.73205999 | 46.73205999 | 31.082 | 0 | 0.25 | 16 | 16 |
| ISO-TJWTG-A | 3 | 5 | 5 | 7.306029996 | 16.43103 | 66.83439176 | 1 | 30.78103 | 46.43103 | 46.43103 | 30.781 | 0 | 0.25 | 16 | 16 |
| ISO-CJ-A | 4 | 4 | 4 | 7 | 15.17 | 110.2808234 | 1 | 39.17 | 39.17 | 39.17 | 39.170 | 0 | 0.15 | 38 | 38 |
| ISO-OJB-A | 4 | 5 | 5 | 7.01 | 17.01 | 100 | 1 | 39.01 | 47.01 | 47.01 | 39.010 | 0 | 0.25 | 16 | 16 |
| ISO-OJC-A | 3.5 | 5 | 5 | 7.003333333 | 16.47 | 78.22279564 | 1 | 34.63 | 46.47 | 46.47 | 34.630 | 0 | 0.25 | 16 | 16 |
| ISO-OJD-A | 3 | 5 | 5 | 7.005 | 15.63 | 53.08844442 | 1 | 30.18 | 45.63 | 45.63 | 30.180 | 0 | 0.25 | 16 | 16 |
| ISO-OJE-A | 3 | 5 | 5 | 6.995 | 15.37 | 47.3151259 | 1 | 30.02 | 45.37 | 45.37 | 30.020 | 0 | 0.25 | 16 | 16 |
| ISO-OJF-A | 3 | 5 | 5 | 7 | 15 | 39.81071706 | 1 | 29.8 | 45 | 45 | 29.800 | 0 | 0.25 | 16 | 16 |
| ISO-OJF2-A | 3 | 5 | 5 | 7.01 | 14.71 | 34.67368505 | 1 | 29.63 | 44.71 | 44.71 | 29.630 | 0 | 0.25 | 16 | 16 |
| ISO-OJG-A | 3 | 5 | 5 | 7.005 | 14.33 | 29.17427014 | 1 | 29.4 | 44.33 | 44.33 | 29.400 | 0 | 0.25 | 16 | 16 |
| ISO-OJW1-A | 3 | 5 | 5 | 6.995 | 13.62 | 21.1348904 | 1 | 28.97 | 43.62 | 43.62 | 28.970 | 0 | 0.25 | 16 | 16 |

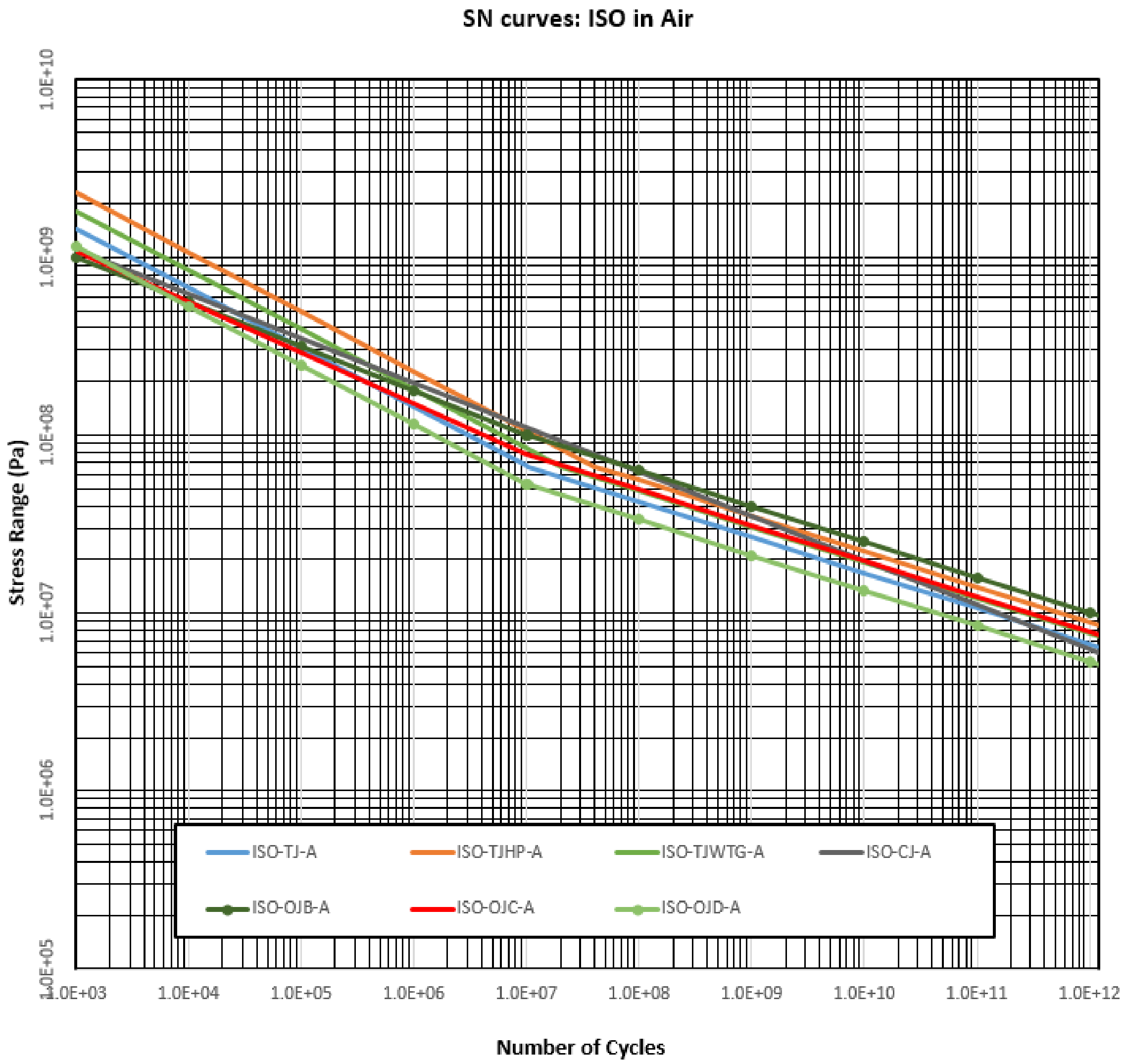



Figure E.21: ISO SN curves in air

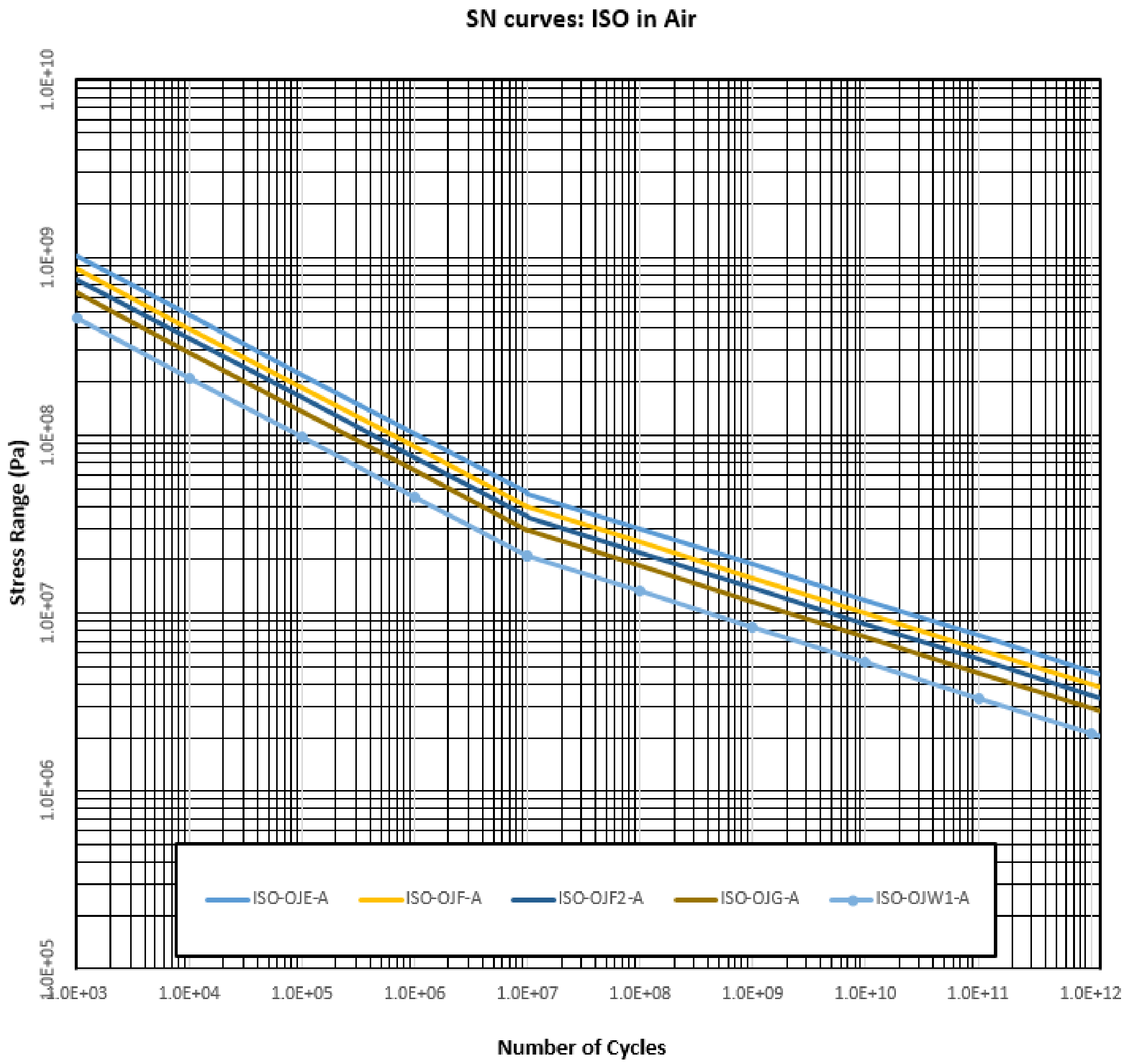



Figure E.22: ISO SN curves in air (cont.)

Table E.19: ISO SN curves with Cathodic Protection

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| ISO-TJ-CP | 3 | 5 | 5 | 6.255 | 16.13 | 94.40608763 | 1 | 30.18 | 46.13 | 46.13 | 30.180 | 0 | 0.25 | 16 | 16 |
| ISO-TJHP-CP | 3 | 5 | 5 | 6.857059991 | 16.73205999 | 94.40608763 | 1 | 30.78205999 | 46.73205999 | 46.73205999 | 30.782 | 0 | 0.25 | 16 | 16 |
| ISO-TJWTG-CP | 3 | 5 | 5 | 6.556029996 | 16.43103 | 94.40608763 | 1 | 30.48103 | 46.43103 | 46.43103 | 30.481 | 0 | 0.25 | 16 | 16 |
| ISO-CJ-CP | 4 | 4 | 4 | 7 | 14.86897 | 92.73474906 | 1 | 38.86897 | 38.86897 | 38.86897 | 38.869 | 0 | 0.15 | 38 | 38 |
| ISO-OJB-CP | 4 | 5 | 5 | 5.01 | 17.01 | 251.1886432 | 1 | 38.61 | 47.01 | 47.01 | 38.610 | 0 | 0.25 | 16 | 16 |
| ISO-OJC-CP | 3.5 | 5 | 5 | 5.67 | 16.47 | 144.5439771 | 1 | 34.23 | 46.47 | 46.47 | 34.230 | 0 | 0.25 | 16 | 16 |
| ISO-OJD-CP | 3 | 5 | 5 | 6.005 | 15.63 | 84.13951416 | 1 | 29.78 | 45.63 | 45.63 | 29.780 | 0 | 0.25 | 16 | 16 |
| ISO-OJE-CP | 3 | 5 | 5 | 5.995 | 15.37 | 74.98942093 | 1 | 29.62 | 45.37 | 45.37 | 29.620 | 0 | 0.25 | 16 | 16 |
| ISO-OJF-CP | 3 | 5 | 5 | 6 | 15 | 63.09573445 | 1 | 29.4 | 45 | 45 | 29.400 | 0 | 0.25 | 16 | 16 |
| ISO-OJF2-CP | 3 | 5 | 5 | 6.01 | 14.71 | 54.95408739 | 1 | 29.23 | 44.71 | 44.71 | 29.230 | 0 | 0.25 | 16 | 16 |
| ISO-OJG-CP | 3 | 5 | 5 | 6.005 | 14.33 | 46.23810214 | 1 | 29 | 44.33 | 44.33 | 29.000 | 0 | 0.25 | 16 | 16 |
| ISO-OJW1-CP | 3 | 5 | 5 | 5.995 | 13.62 | 33.49654392 | 1 | 28.57 | 43.62 | 43.62 | 28.570 | 0 | 0.25 | 16 | 16 |

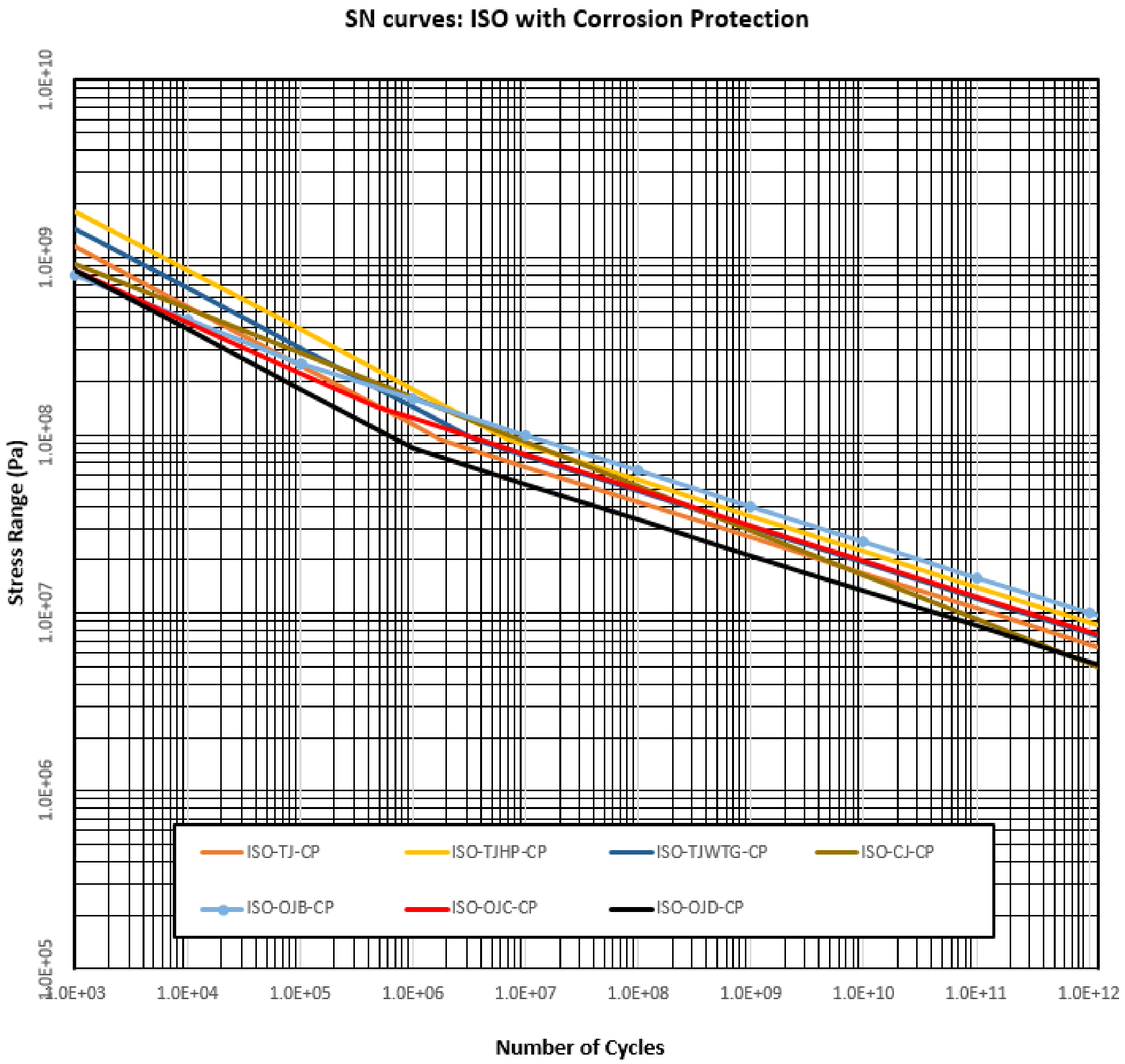



Figure E.23: ISO SN curves with cathodic protection

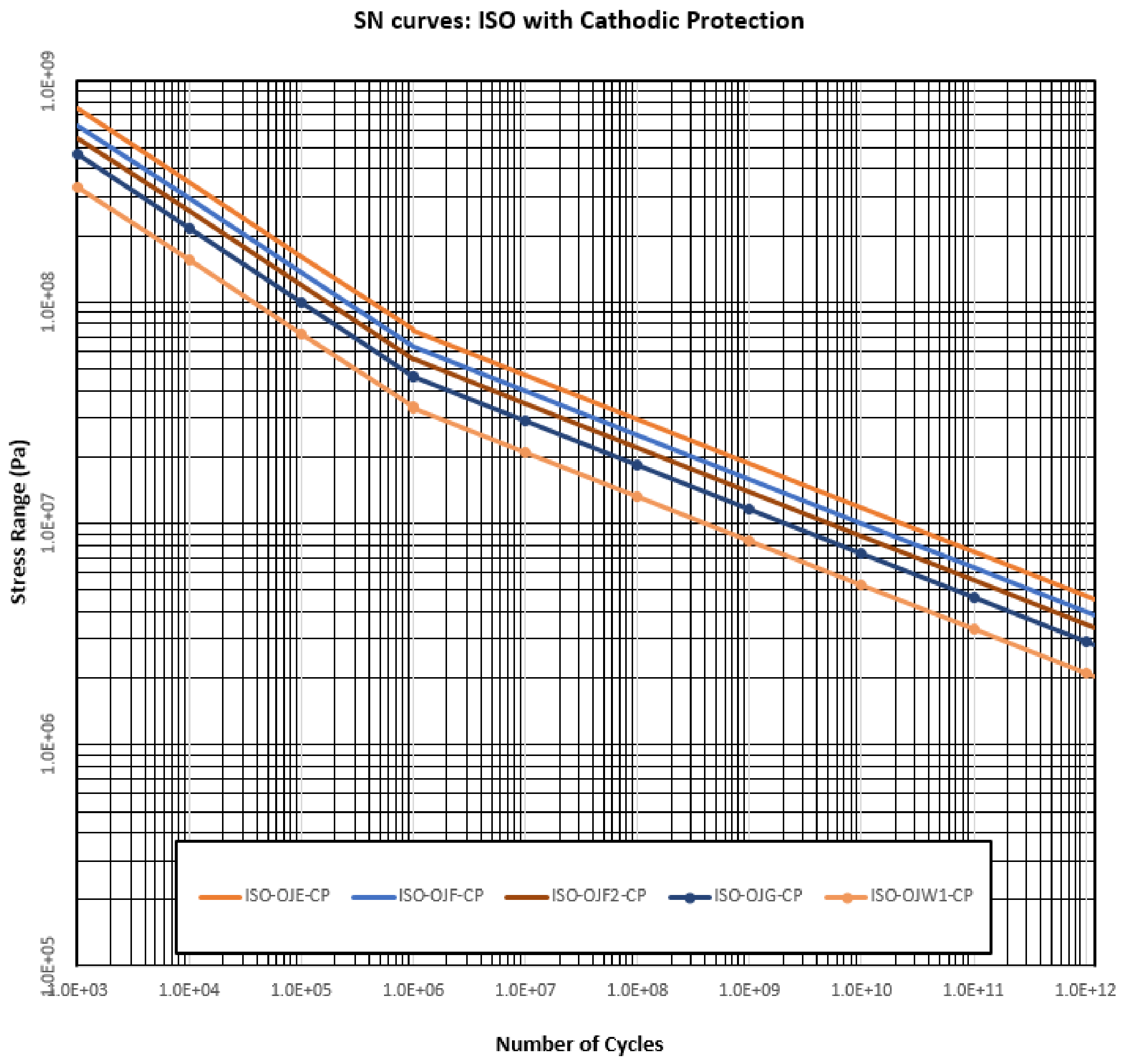



Figure E.24: ISO SN curves with cathodic protection (cont.)

Table E.20: ISO SN curves: Free Corrosion

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| ISO-TJ-FC | 3 | 3 | 3 | 7 | 12.00287875 | 46.51855849 | 1 | 30.00287875 | 30.00287875 | 30.00287875 | 30.003 | 0 | 0.25 | 16 | 16 |
| ISO-TJHP-FC | 3 | 3 | 3 | 6 | 12.60493874 | 159.0912322 | 1 | 30.60493874 | 30.60493874 | 30.60493874 | 30.605 | 0 | 0.25 | 16 | 16 |
| ISO-TJWTG-FC | 3 | 3 | 3 | 6 | 12.00287875 | 100.2211961 | 1 | 30.00287875 | 30.00287875 | 30.00287875 | 30.003 | 0 | 0.25 | 16 | 16 |
| ISO-CJ-FC | 4 | 4 | 4 | 7 | 14.69287875 | 83.79530505 | 1 | 38.69287875 | 38.69287875 | 38.69287875 | 38.693 | 0 | 0.15 | 38 | 38 |
| ISO-OJB-FC | 4 | 4 | 4 | 5 | 14.53287875 | 241.6682996 | 1 | 38.53287875 | 38.53287875 | 38.53287875 | 38.533 | 0 | 0.25 | 16 | 16 |
| ISO-OJC-FC | 3.5 | 3.5 | 3.5 | 6 | 13.15287875 | 110.5807781 | 1 | 34.15287875 | 34.15287875 | 34.15287875 | 34.153 | 0 | 0.25 | 16 | 16 |
| ISO-OJD-FC | 3 | 3 | 3 | 6 | 11.70287875 | 79.60852582 | 1 | 29.70287875 | 29.70287875 | 29.70287875 | 29.703 | 0 | 0.25 | 16 | 16 |
| ISO-OJE-FC | 3 | 3 | 3 | 6 | 11.54287875 | 70.40868747 | 1 | 29.54287875 | 29.54287875 | 29.54287875 | 29.543 | 0 | 0.25 | 16 | 16 |
| ISO-OJF-FC | 3 | 3 | 3 | 6 | 11.32287875 | 59.46931213 | 1 | 29.32287875 | 29.32287875 | 29.32287875 | 29.323 | 0 | 0.25 | 16 | 16 |
| ISO-OJF2-FC | 3 | 3 | 3 | 6 | 11.15287875 | 52.19468109 | 1 | 29.15287875 | 29.15287875 | 29.15287875 | 29.153 | 0 | 0.25 | 16 | 16 |
| ISO-OJG-FC | 3 | 3 | 3 | 6 | 10.92287875 | 43.74813884 | 1 | 28.92287875 | 28.92287875 | 28.92287875 | 28.923 | 0 | 0.25 | 16 | 16 |
| ISO-OJW1-FC | 3 | 3 | 3 | 6 | 10.49287875 | 31.45040544 | 1 | 28.49287875 | 28.49287875 | 28.49287875 | 28.493 | 0 | 0.25 | 16 | 16 |

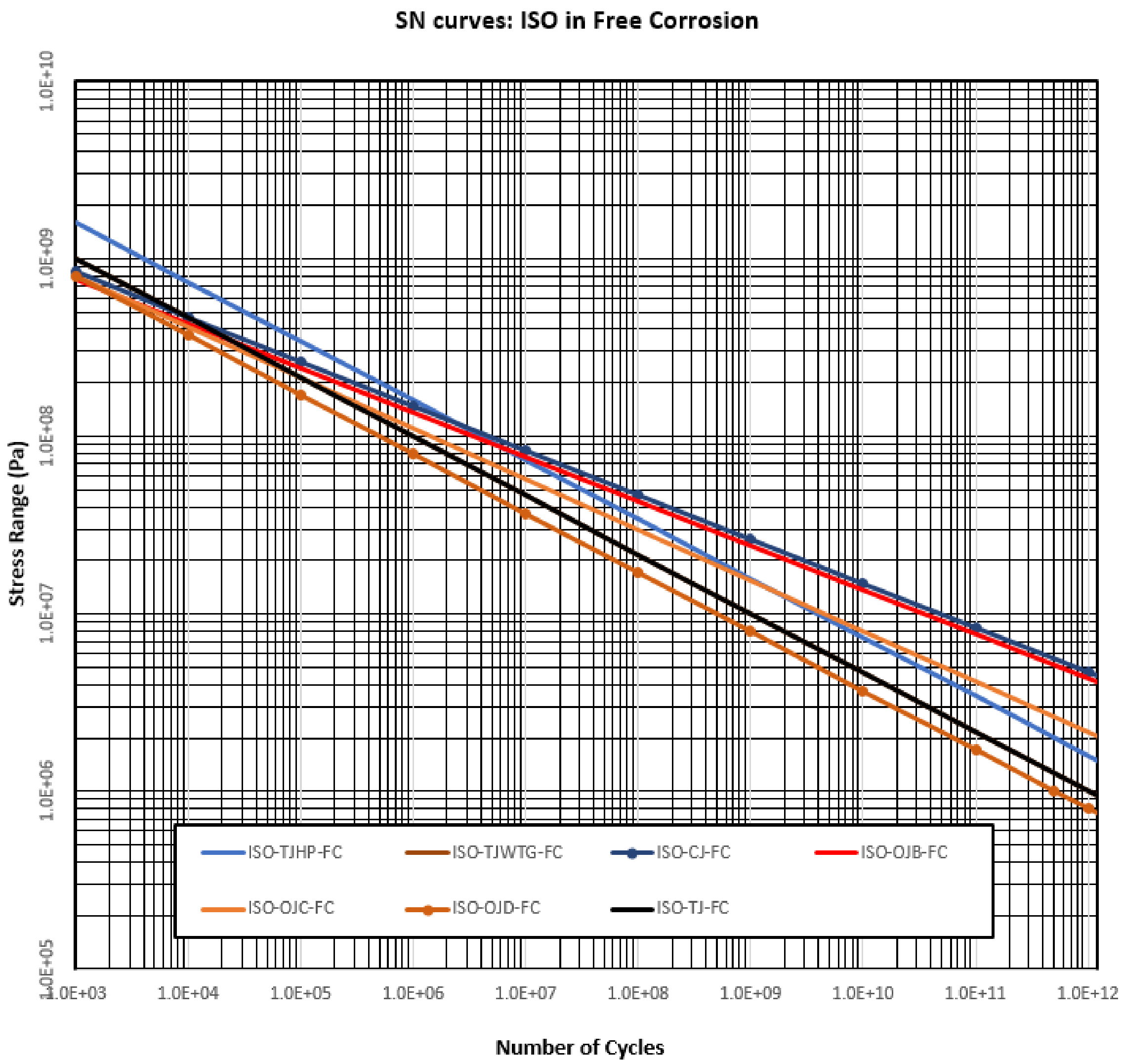



Figure E.25: ISO SN curves free corrosion

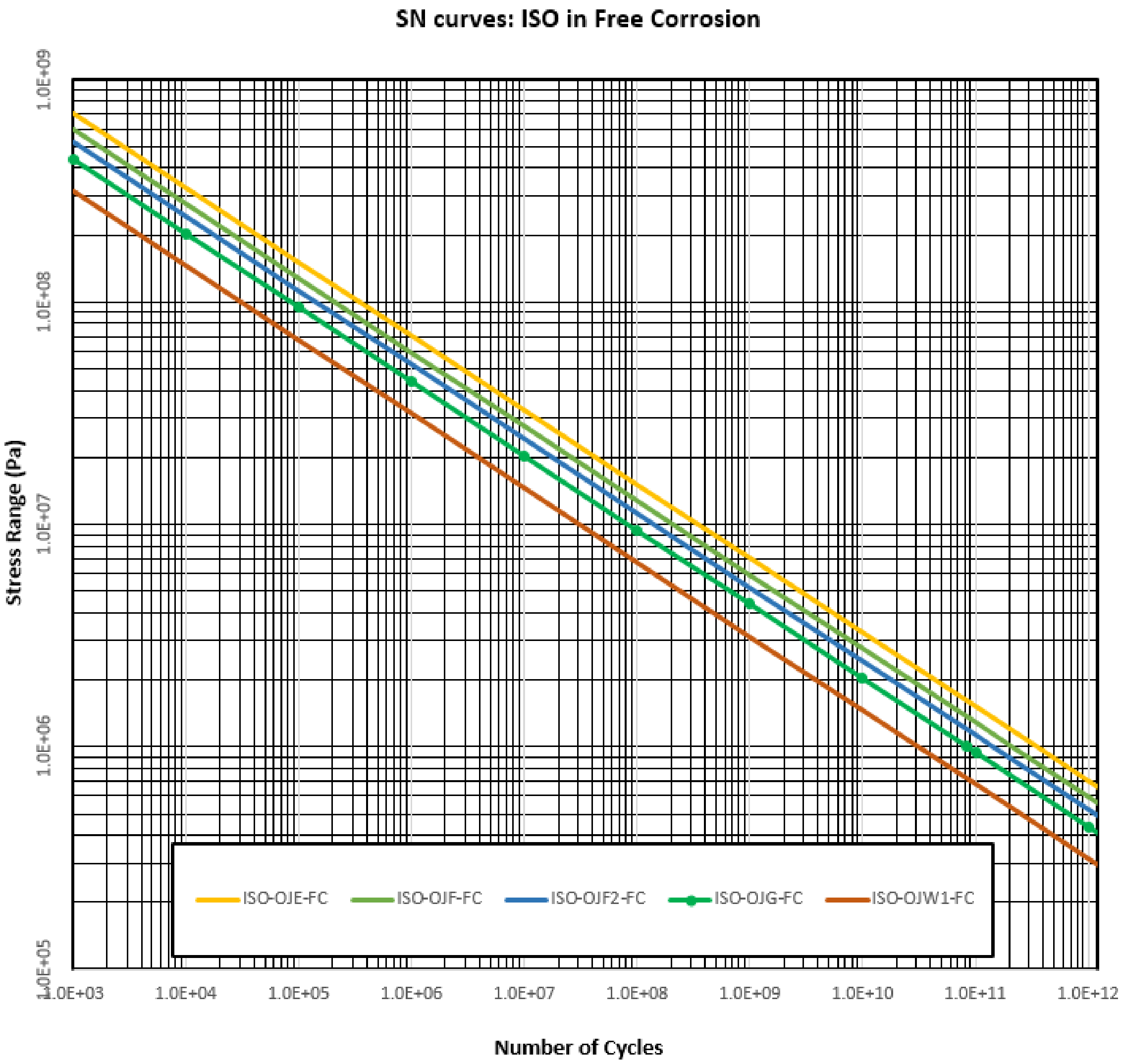



Figure E.26: ISO SN curves free corrosion (cont.)

## E.10 NORSOK SN curves

Parameters and plots of NORSOK SN curves Ref. [29]:

Table E.21: NORSOK SN curves in sea with cathodic protection

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| NO-B1-S | 3 | 5 | 5 | 6 | 8 | 148.30 | 59.04 | 30.513 | 46.856 | 46.856 | 30.513 | 0 | 0 | 0 | 0 |
| NO-B2-S | 3 | 5 | 5 | 6 | 8 | 129.76 | 51.66 | 30.339 | 46.566 | 46.566 | 30.339 | 0 | 0 | 0 | 0 |
| NO-C-S | 3 | 5 | 5 | 6 | 8 | 115.86 | 46.12 | 30.192 | 46.319 | 46.319 | 30.192 | 0 | 0.15 | 25 | 25 |
| NO-C1-S | 3 | 5 | 5 | 6 | 8 | 103.81 | 41.33 | 30.049 | 46.081 | 46.081 | 30.049 | 0 | 0.15 | 25 | 25 |
| NO-C2-S | 3 | 5 | 5 | 6 | 8 | 92.68 | 36.90 | 29.901 | 45.835 | 45.835 | 29.901 | 0 | 0.15 | 25 | 25 |
| NO-D-S | 3 | 5 | 5 | 6 | 8 | 83.41 | 33.21 | 29.764 | 45.606 | 45.606 | 29.764 | 0 | 0.2 | 25 | 25 |
| NO-E-S | 3 | 5 | 5 | 6 | 8 | 74.14 | 29.52 | 29.610 | 45.351 | 45.351 | 29.610 | 0 | 0.2 | 25 | 25 |

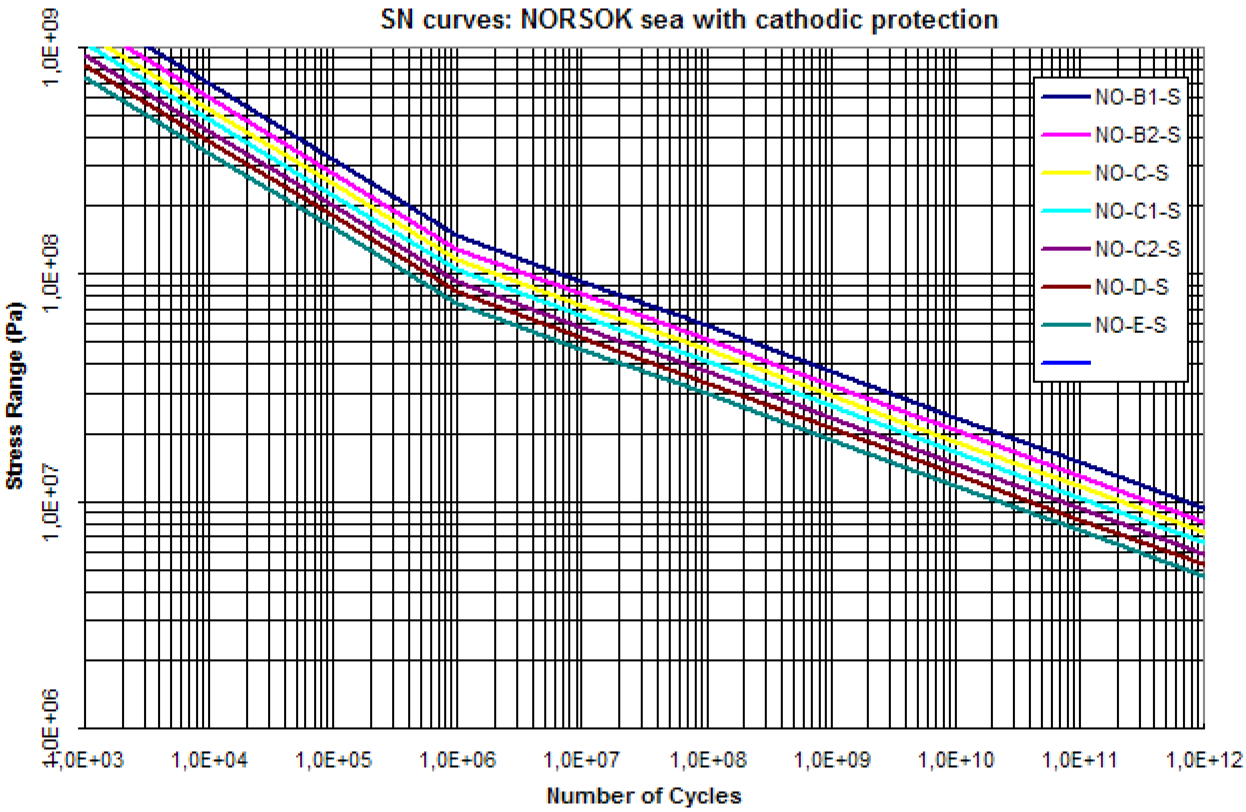



Figure E.27: NORSOK SN curves in sea with cathodic protection

Table E.22: NORSOK SN curves in sea with cathodic protection

| Name | SN curve parameters | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| NO-F-S | 3 | 5 | 5 | 6 | 8 | 65.80 | 26.20 | 29.455 | 45.092 | 45.092 | 29.455 | 0 | 0.25 | 25 | 24.9 |
| NO-F1-S | 3 | 5 | 5 | 6 | 8 | 58.39 | 23.24 | 29.299 | 44.831 | 44.831 | 29.299 | 0 | 0.25 | 25 | 24.9 |
| NO-F3-S | 3 | 5 | 5 | 6 | 8 | 51.91 | 20.66 | 29.146 | 44.576 | 44.576 | 29.146 | 0 | 0.25 | 25 | 24.9 |
| NO-G-S | 3 | 5 | 5 | 6 | 8 | 46.34 | 18.45 | 28.998 | 44.330 | 44.330 | 28.998 | 0 | 0.25 | 25 | 24.9 |
| NO-T-S | 3 | 5 | 5 | 6 | 9 | 83.41 | 20.95 | 29.764 | 45.606 | 45.606 | 29.764 | 0 | 0.25 | 32 | 32 |
| NO-W1-S | 3 | 5 | 5 | 6 | 8 | 41.71 | 16.61 | 28.861 | 44.102 | 44.102 | 28.861 | 0 | 0.25 | 25 | 24.9 |
| NO-W2-S | 3 | 5 | 5 | 6 | 8 | 37.07 | 14.76 | 28.707 | 43.845 | 43.845 | 28.707 | 0 | 0.25 | 25 | 24.9 |
| NO-W3-S | 3 | 5 | 5 | 6 | 8 | 33.36 | 13.28 | 28.570 | 43.616 | 43.616 | 28.570 | 0 | 0.25 | 25 | 24.9 |

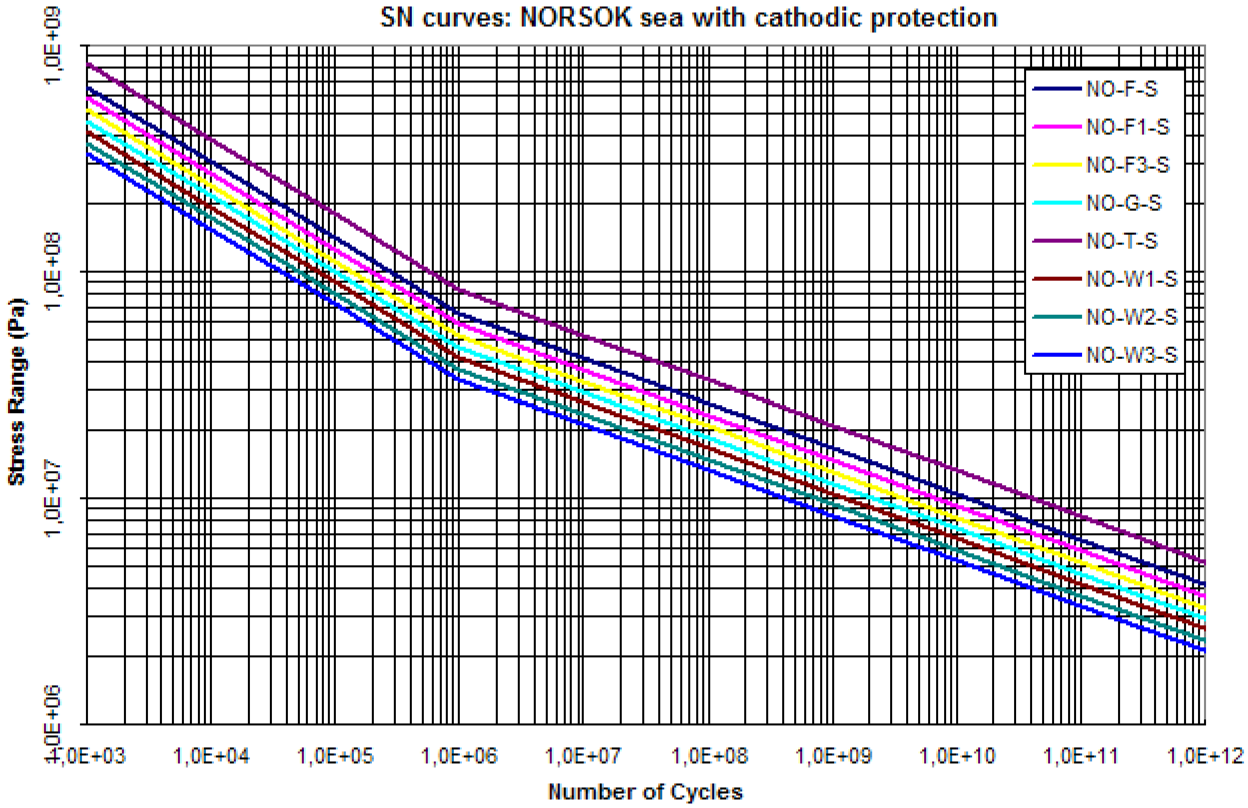



Figure E.28: NORSOK SN curves in sea with cathodic protection

## E.11 NS SN curves

Parameters and plots of NS SN curves Ref. [9]:

Table E.23: NS SN curves in sea with cathodic protection

| Name | SN curve parameters | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m0 | m1 | m2 | N0 | N1 | S0 $(*10^6)$ | S1 $(*10^6)$ | $\log A0$ | $\log A1$ | $\log A2$ | $\log K0$ | $\sigma$ | $t_{exp}$ | $t_{ref}$ (mm) | $t_{cut}$ (mm) |
| NS-B-SEA | 4 | - | - | 8.30103 | 0 | 47.437 | 47.437 | 39.606 | - | - | 39.970 | 0.1821 | 0 | 0 | 0 |
| NS-C-SEA | 3.5 | - | - | 8.30103 | 0 | 33.221 | 33.221 | 34.626 | - | - | 35.034 | 0.2041 | 0 | 0 | 0 |
| NS-D-SEA | 3 | - | - | 8.30103 | 0 | 19.659 | 19.659 | 30.182 | - | - | 30.601 | 0.2095 | 0 | 0 | 0 |
| NS-E-SEA | 3 | - | - | 8.30103 | 0 | 17.299 | 17.299 | 30.015 | - | - | 30.517 | 0.2509 | 0 | 0 | 0 |
| NS-F-SEA | 3 | - | - | 8.30103 | 0 | 14.671 | 14.671 | 29.800 | - | - | 30.237 | 0.2183 | 0 | 0 | 0 |
| NS-F2-SE | 3 | - | - | 8.30103 | 0 | 12.914 | 12.914 | 29.634 | - | - | 30.090 | 0.2279 | 0 | 0 | 0 |
| NS-G-SEA | 3 | - | - | 8.30103 | 0 | 10.738 | 10.738 | 29.394 | - | - | 29.752 | 0.1793 | 0 | 0 | 0 |
| NS-T-SEA | 3 | - | - | 8.30103 | 0 | 19.390 | 19.390 | 30.164 | - | - | 30.661 | 0.2484 | 0 | 0 | 0 |
| NS-W-SEA | 3 | - | - | 8.30103 | 0 | 9.233 | 9.233 | 29.197 | - | - | 29.566 | 0.1846 | 0 | 0 | 0 |

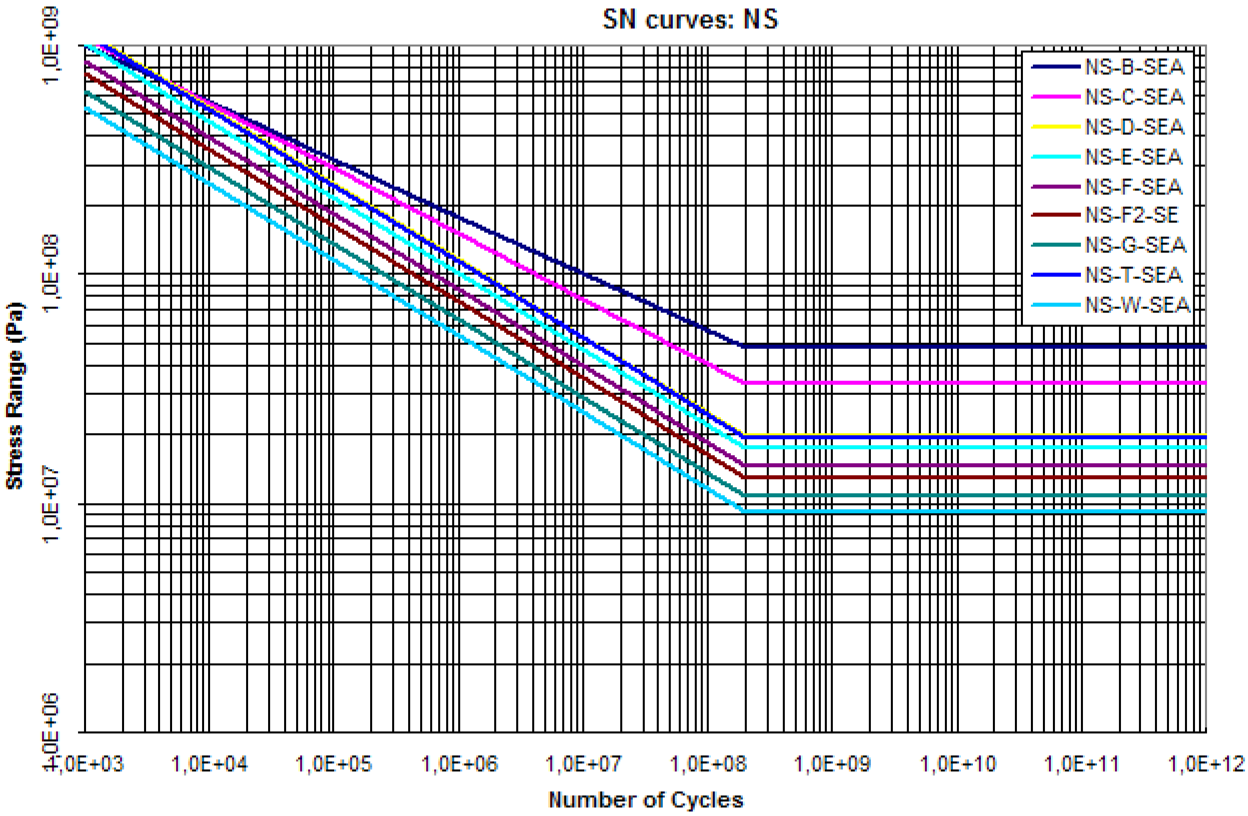



Figure E.29: NS SN curves in sea with cathodic protection

# F PULLDOWN MENUS AND DIALOG WINDOWS OF STOFAT

This appendix shows the pulldown menus of the Stofat commands and dialog windows connected to the items in the pulldown menus.

When clicking an item in the pull down menus, three different actions may take place;

1. the command initiates a program execution immediately
2. the command opens a dialog window through which user interaction may take place
3. a subcommand list pops up to the right of the command

The action rules are illustrated below.

Action rules for items in the pulldown menu:

1. The command button 

initiates a program execution
2. The command button 

opens a dialog window
3. The command button 

shows a list of commands to the right of the button

## F.1 FILE Menu

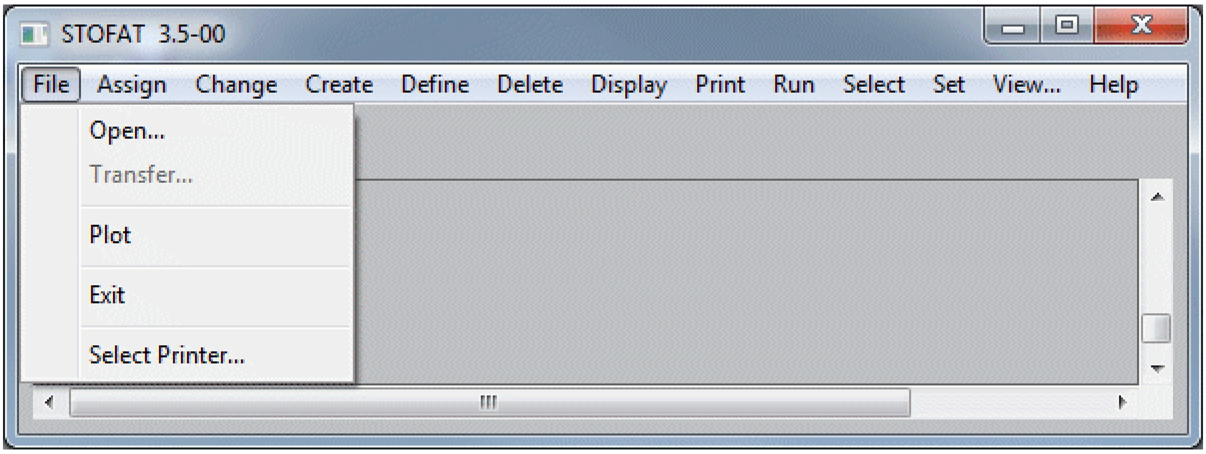



Figure F.1: FILE puldown menu

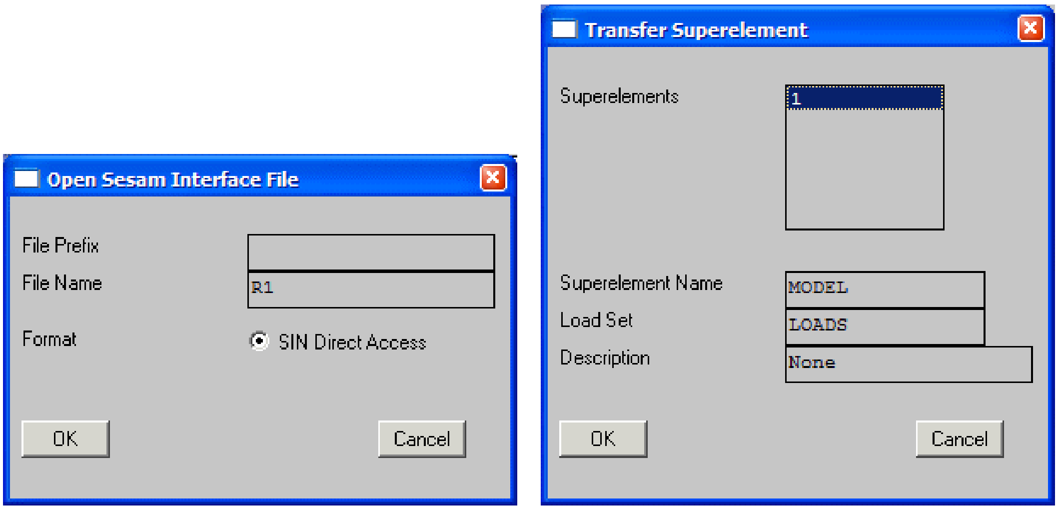



Figure F.2: FILE OPEN, FILE TRANSFER

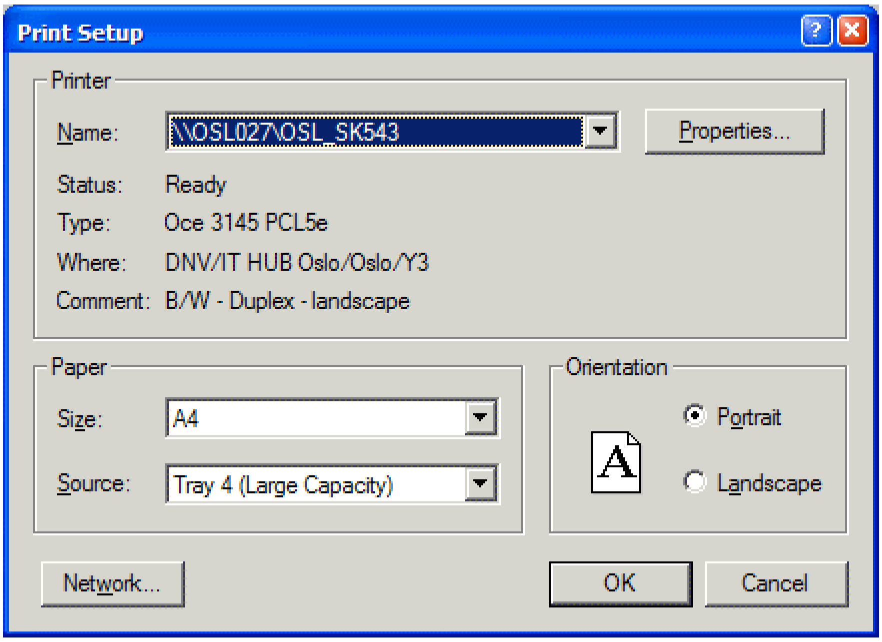



Figure F.3: FILE SELECT-PRINTER

## F.2 ASSIGN Menu

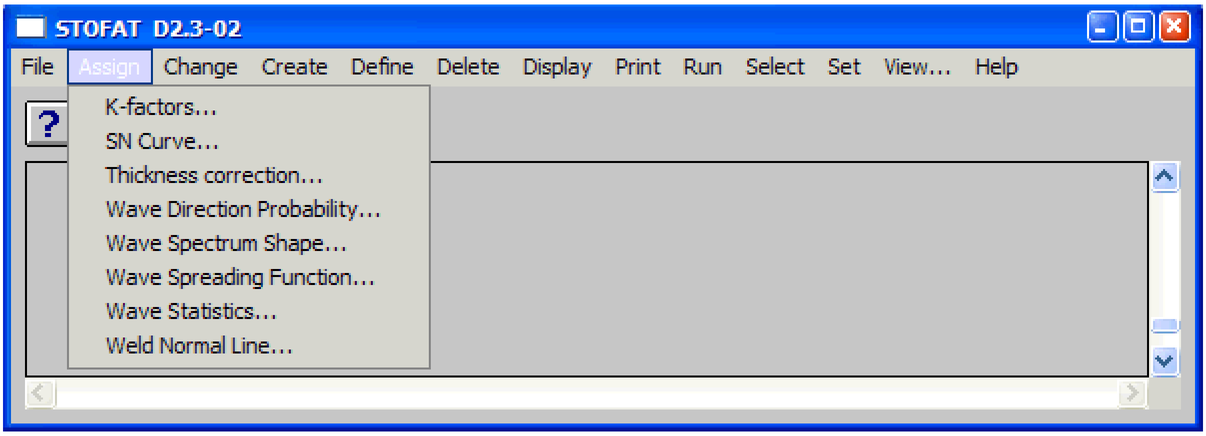



Figure F.4: ASSIGN pulldown menu

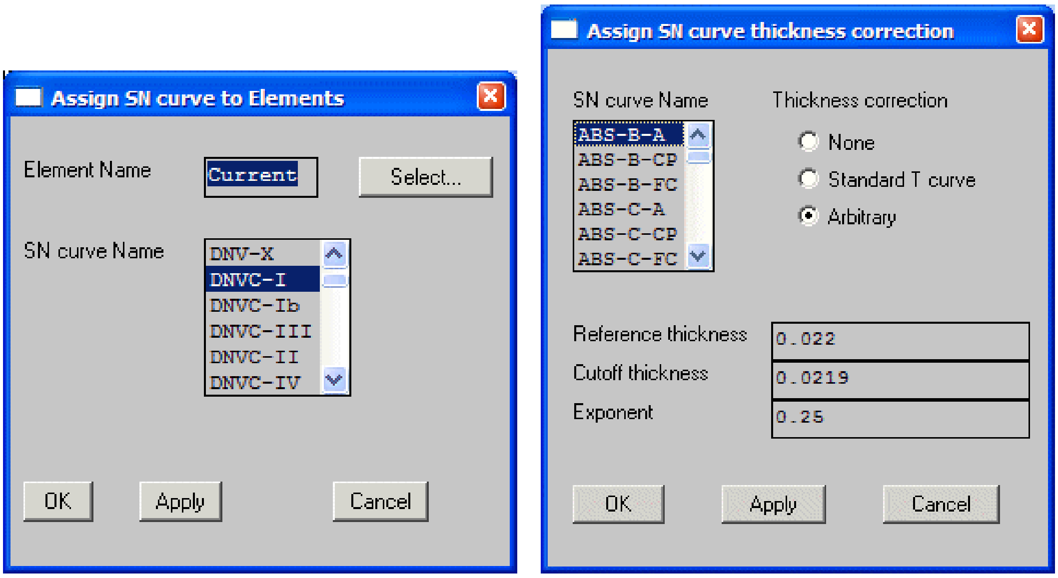



Figure F.5: ASSIGN SN-CURVE, ASSIGN THICKNESS-CORRECTION

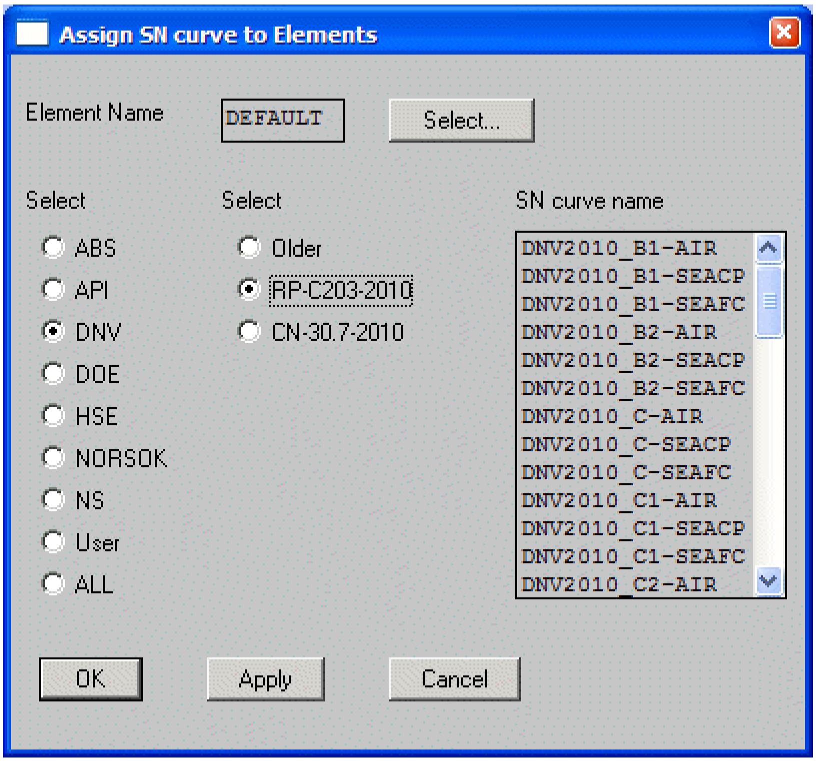



Figure F.6: ASSIGN SN-CURVE-SORTED

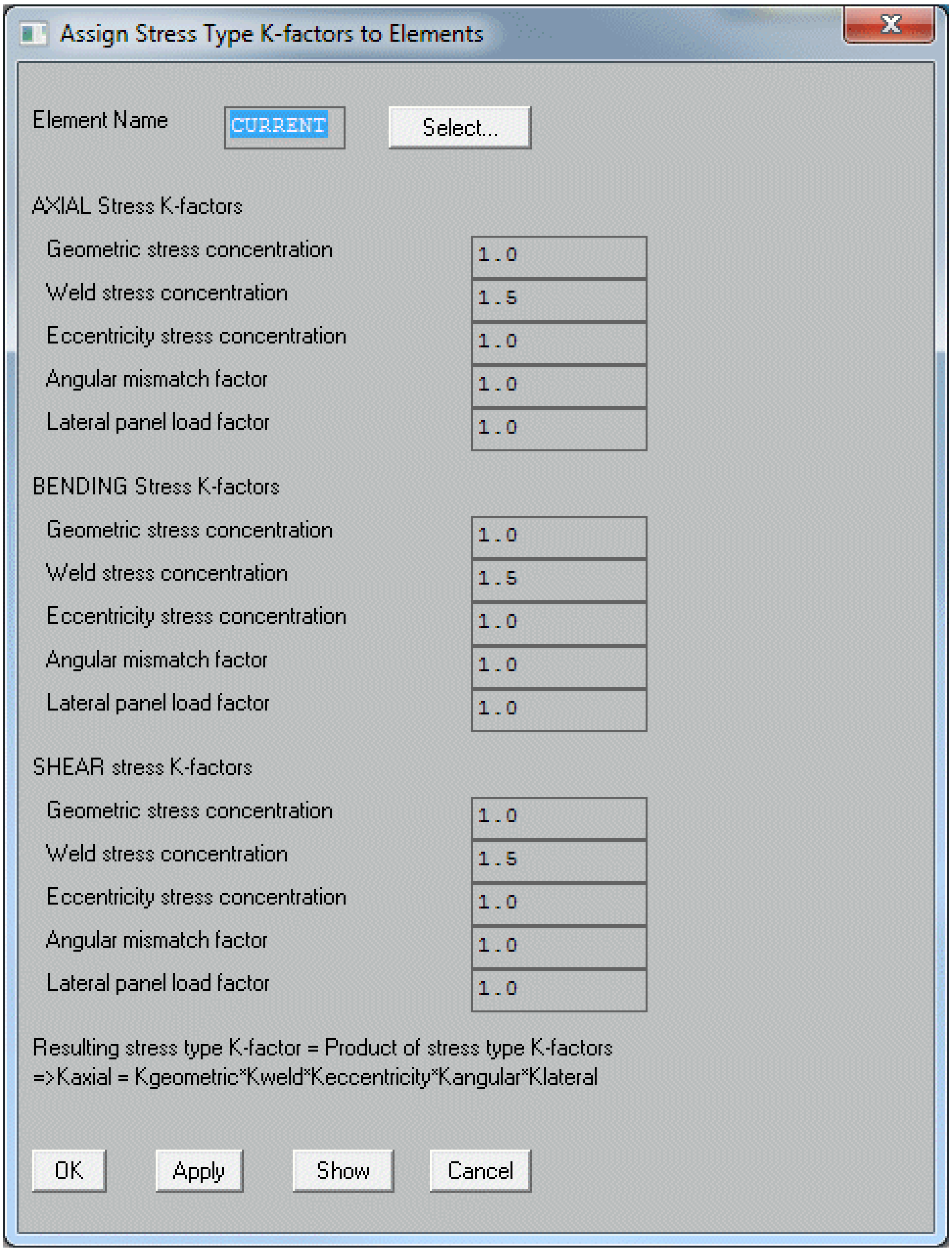



Figure F.7: ASSIGN STRESS-TYPE-K-FACTORS

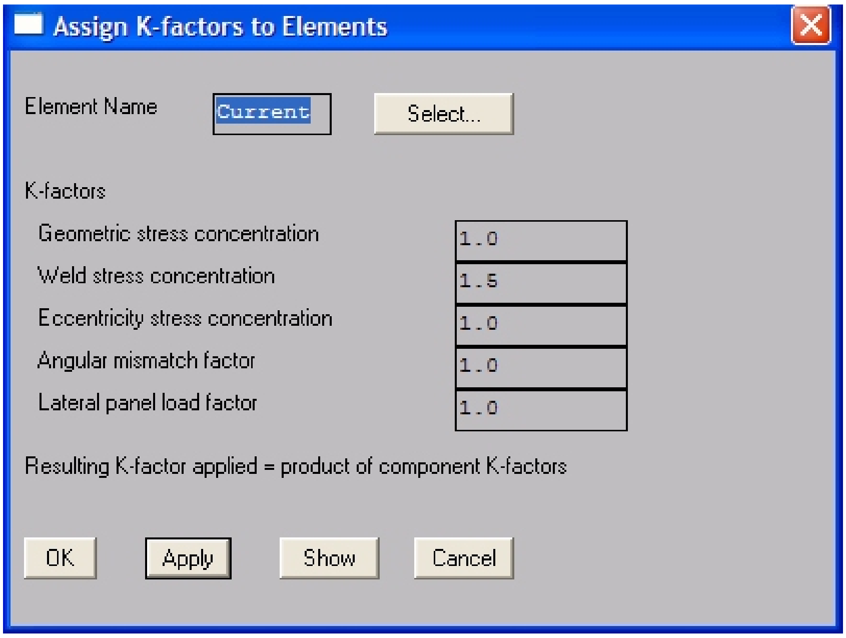
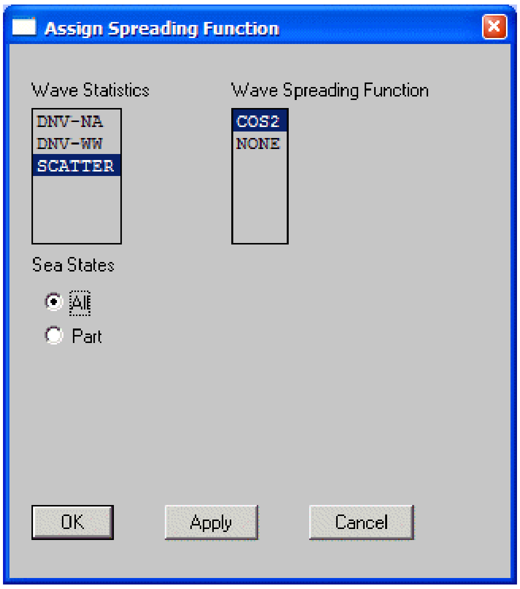



Figure F.8: ASSIGN K-FACTORS



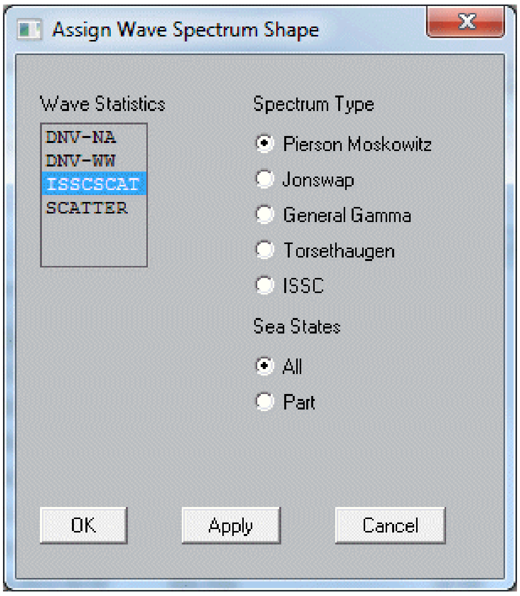




Figure F.9: ASSIGN WAVE-SPREADING-FUNCTION, ASSIGN WAVE-SPECTRUM-SHAPE

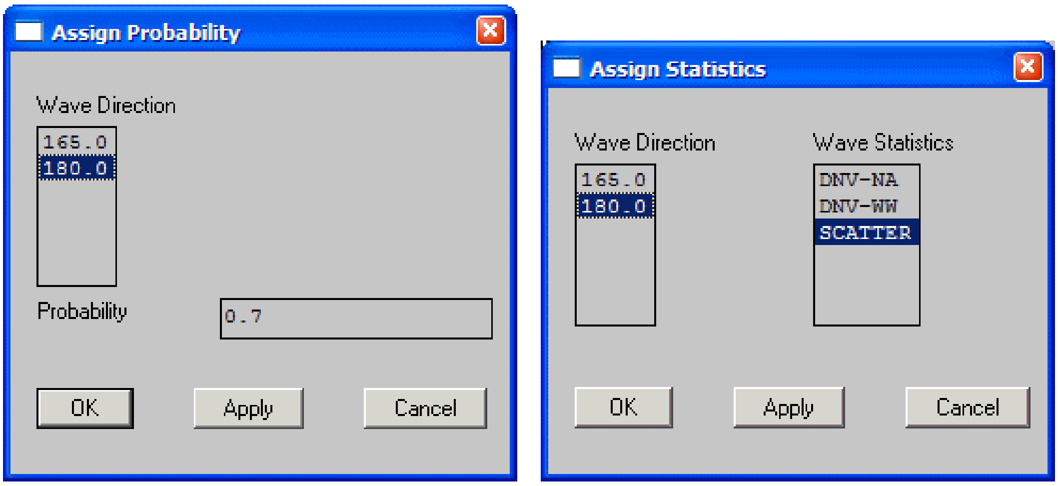



Figure F.10: ASSIGN WAVE-DIRECTION-PROBABILITY, ASSIGN WAVE-STATISTICS

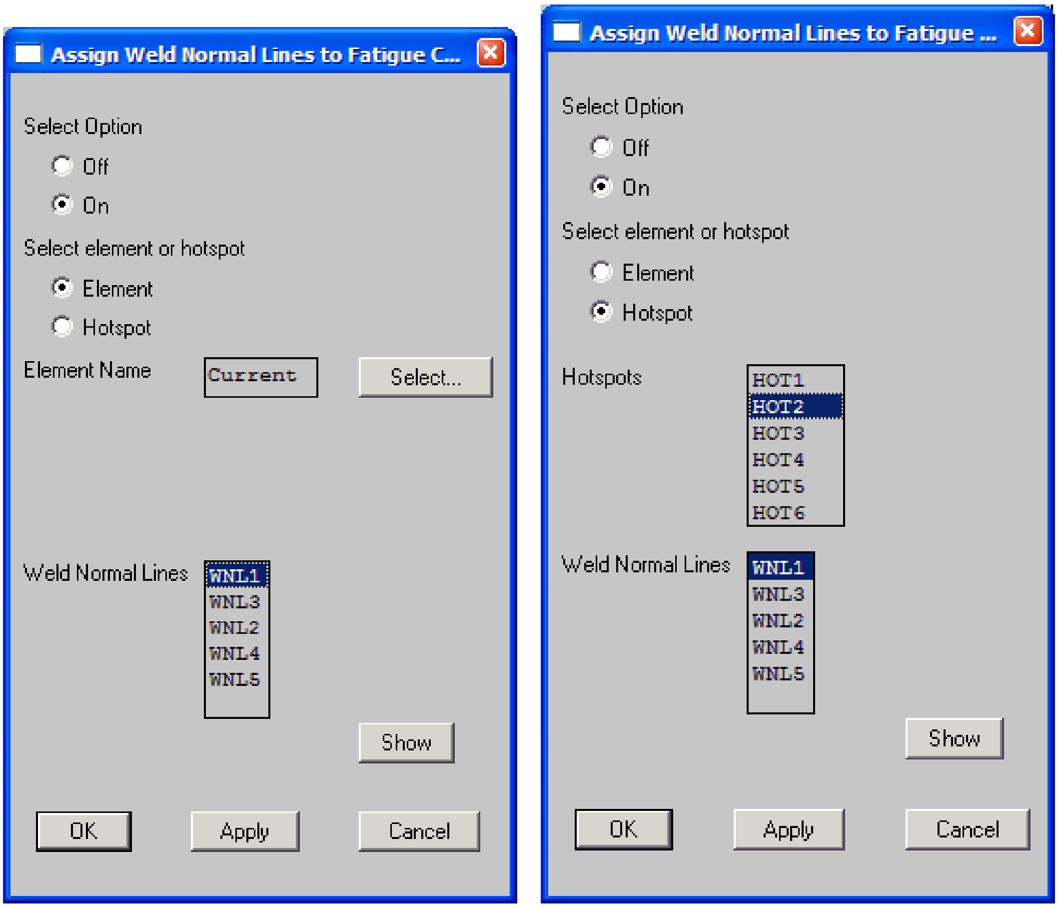



Figure F.11: ASSIGN WELD-NORMAL-LINE

## F.3 CHANGE Menu

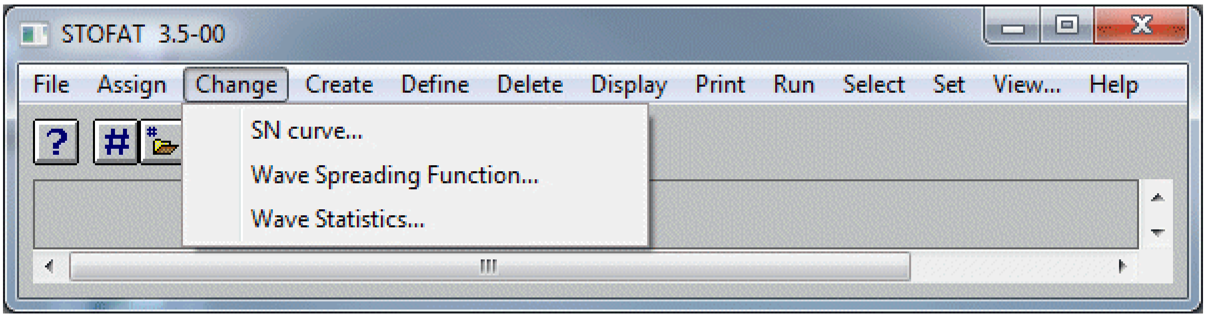



Figure F.12: CHANGE pulldown menu

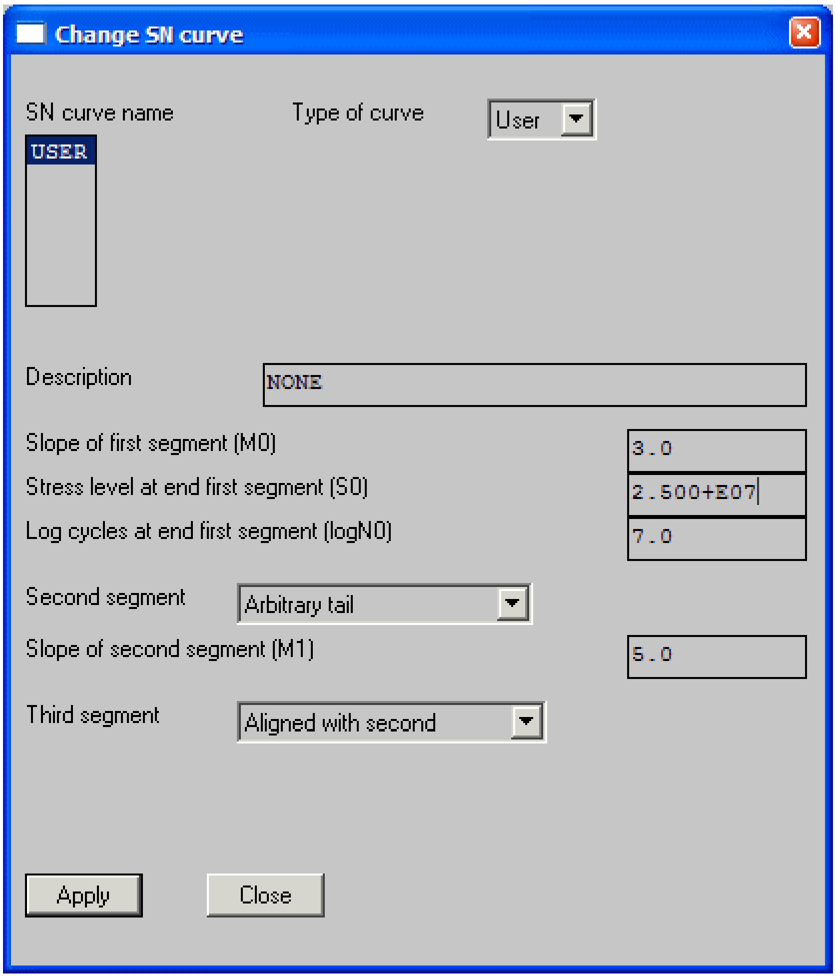



Figure F.13: CHANGE SN-CURVE

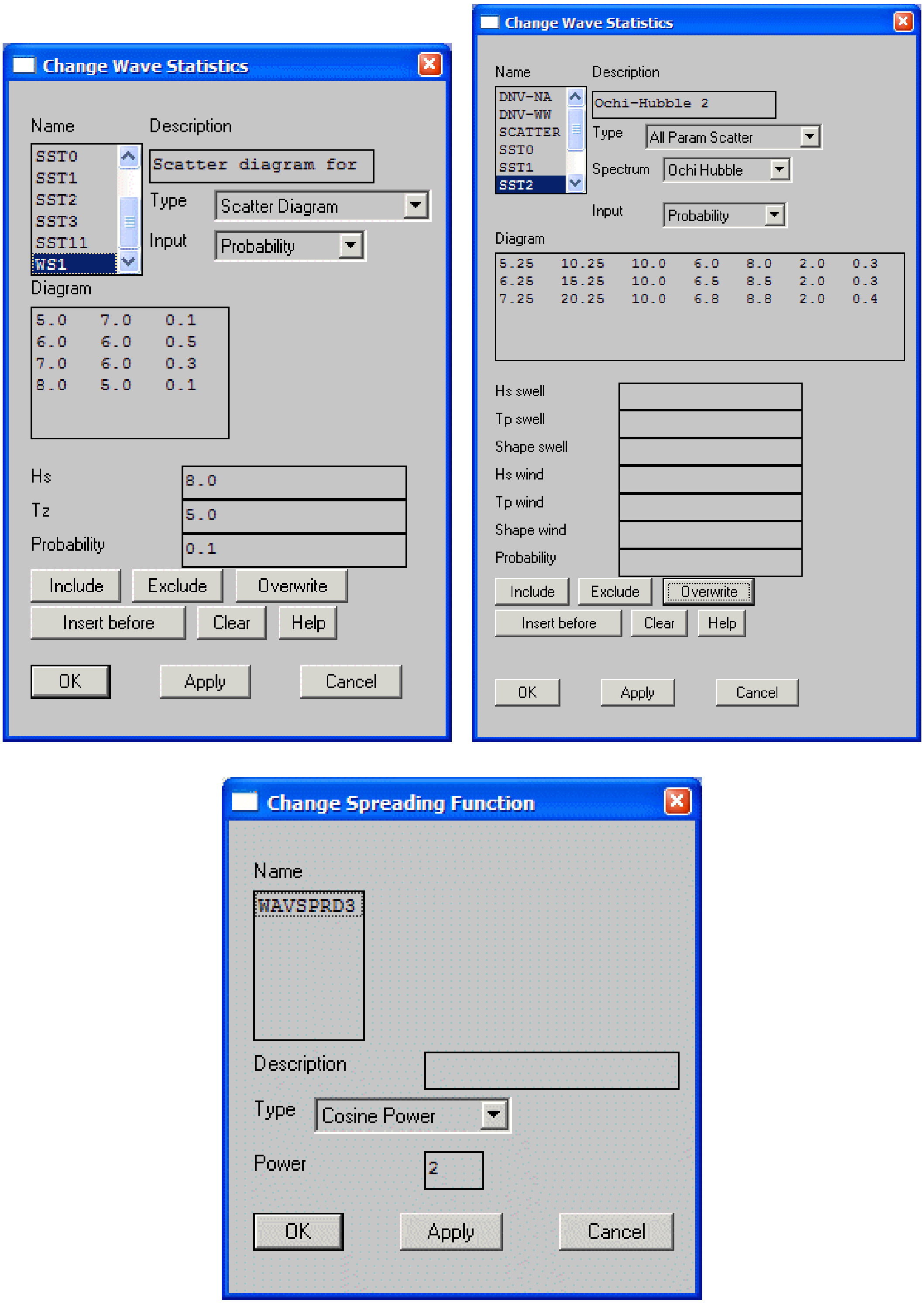



Figure F.14: CHANGE WAVE-STATISTICS, CHANGE WAVE-SPREADING FUNCTION

## F.4 CREATE Menu

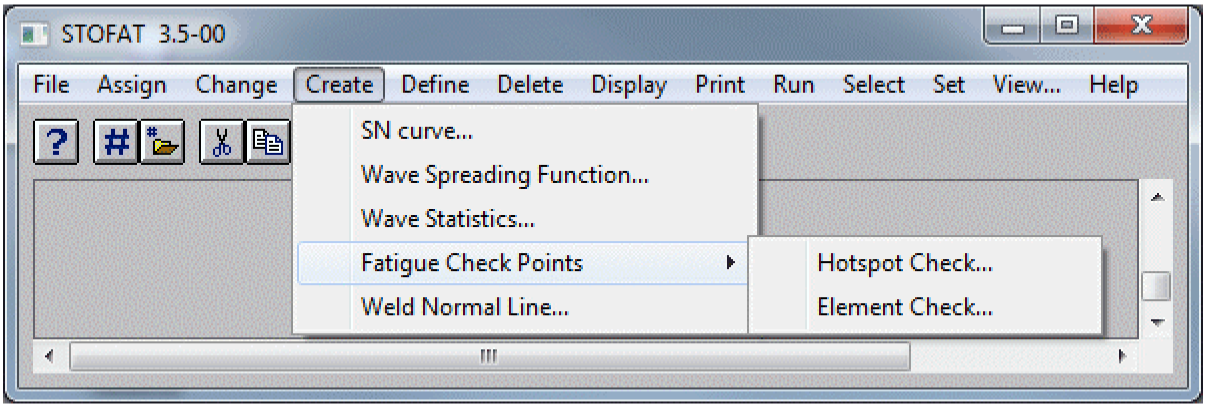



Figure F.15: CREATE pulldown menu

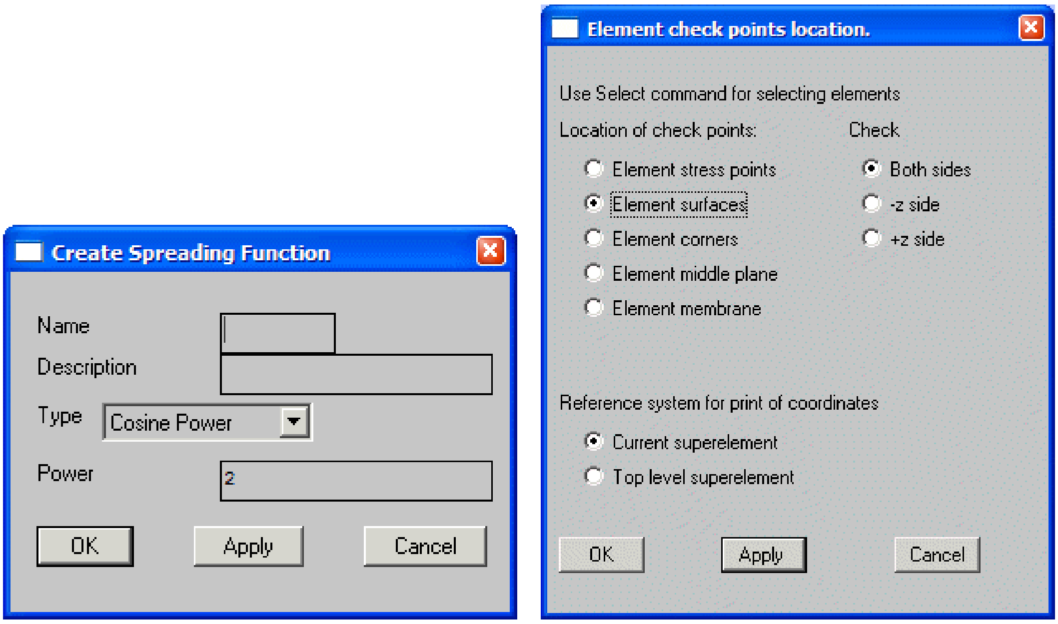



Figure F.16: CREATE WAVE-SPREADING-FUNCTION, CREATE FATIGUE-CHECK-POINTS ELEMENT-CHECK

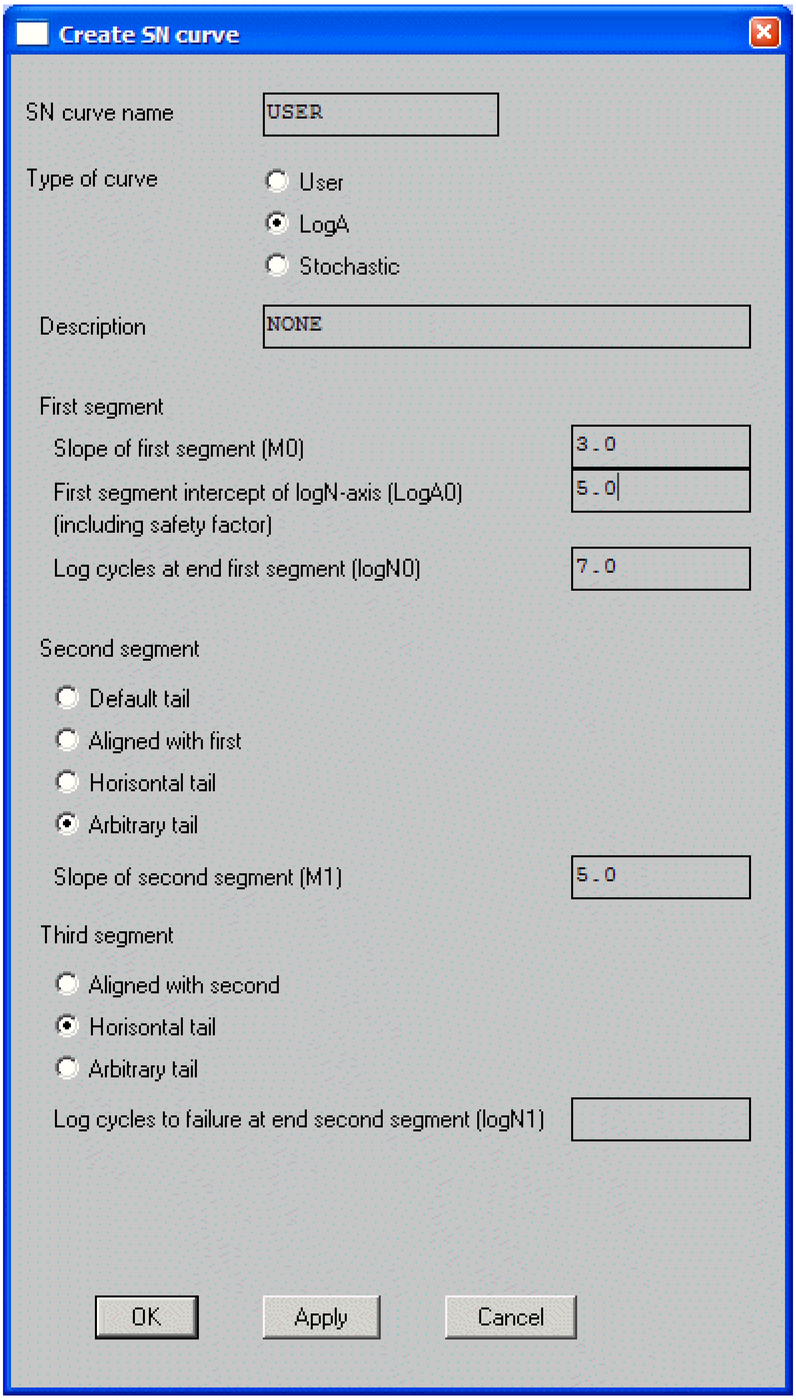



Figure F.17: CREATE SN-CURVE

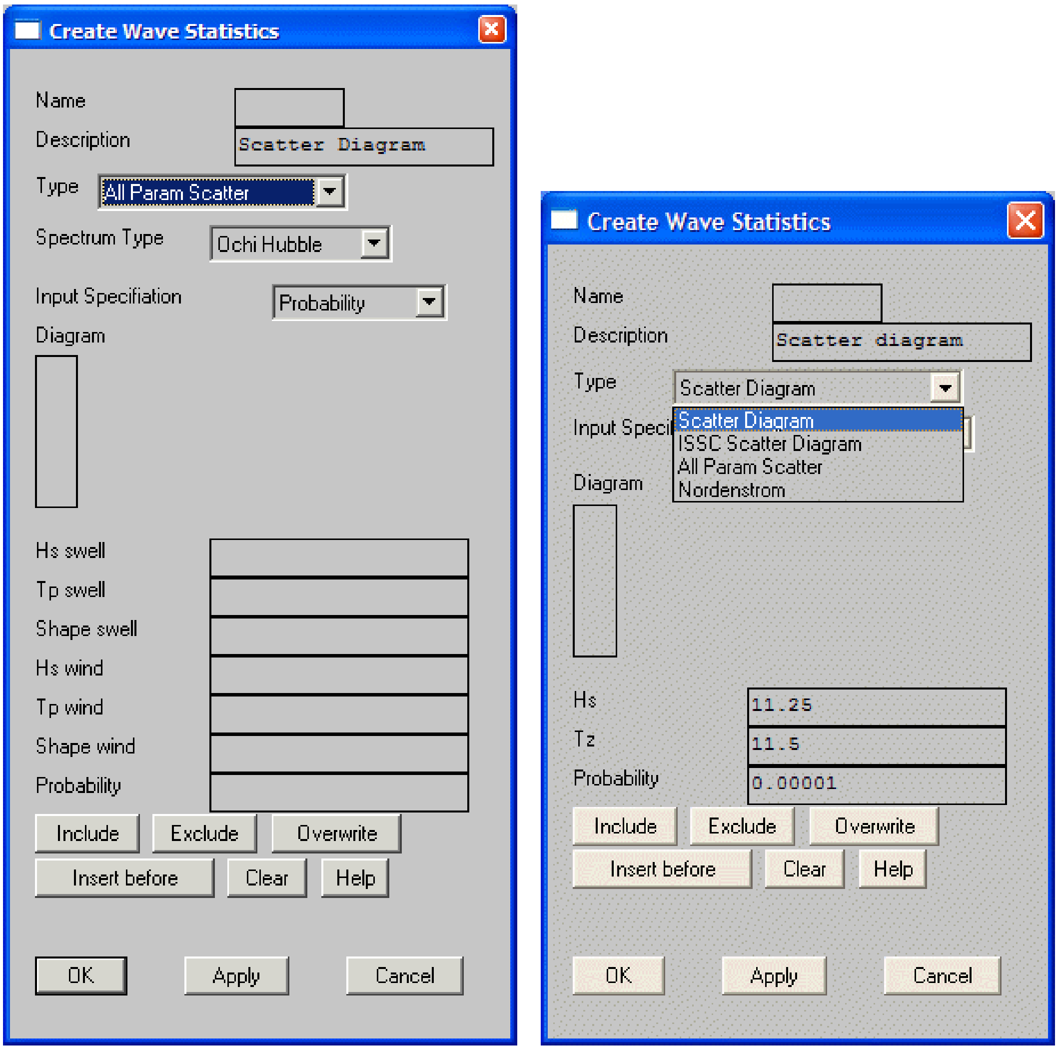



Figure F.18: CREATE WAVE-STATISTICS

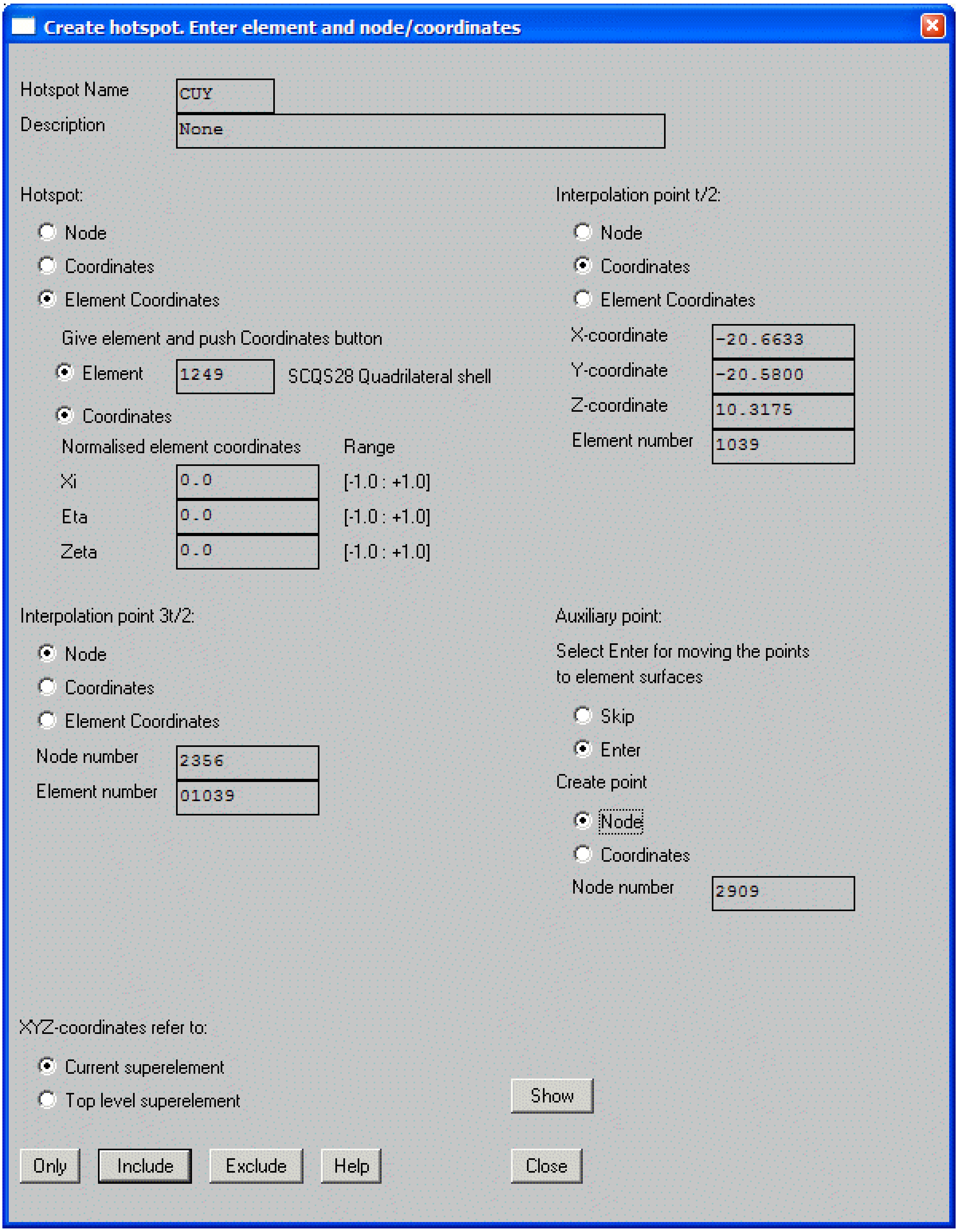



Figure F.19: CREATE FATIGUE-CHECK-POINTS HOTSPOT-CHECK

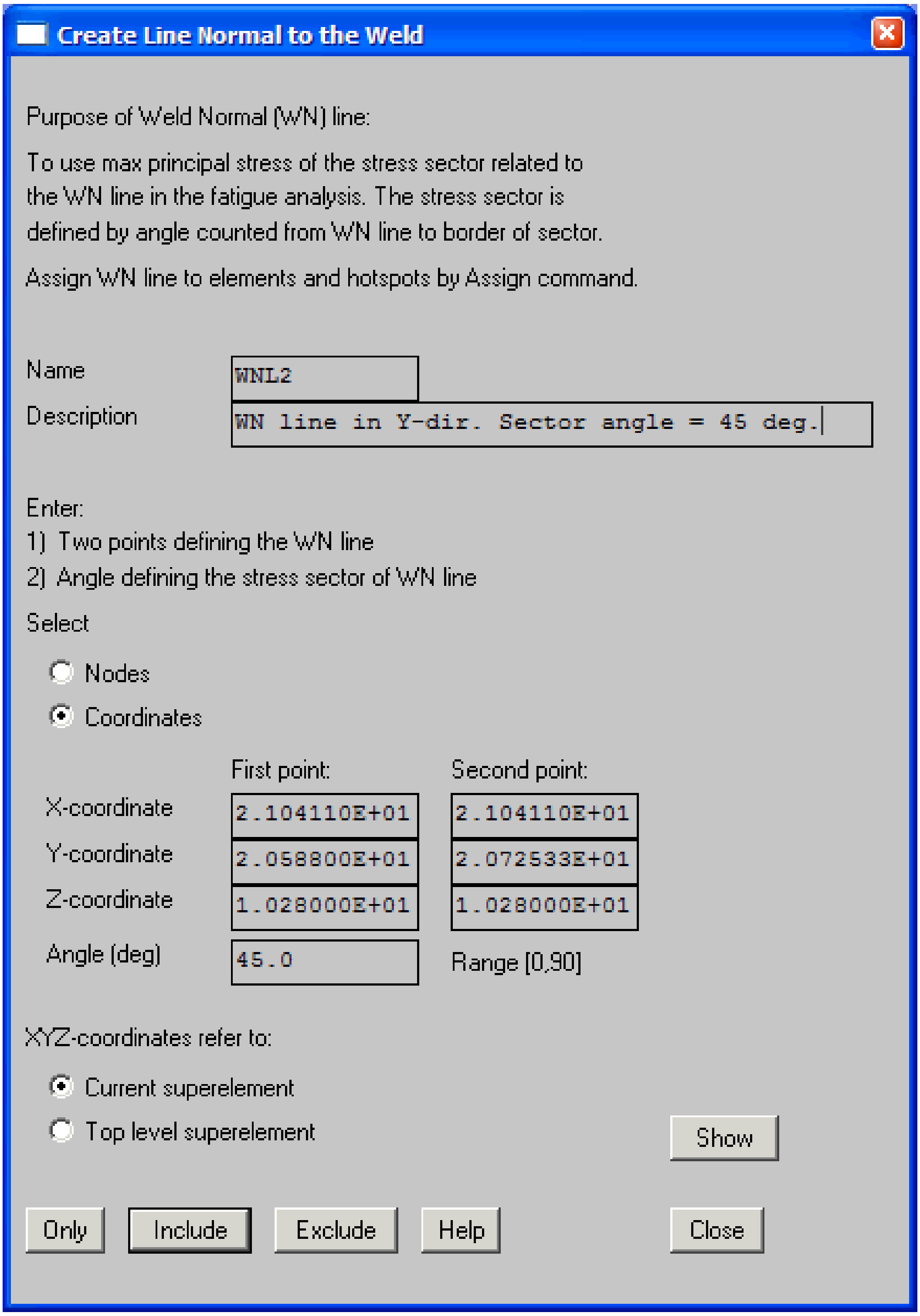



Figure F.20: CREATE WELD-NORMAL-LINE COORDINATES

## F.5 DEFINE Menu

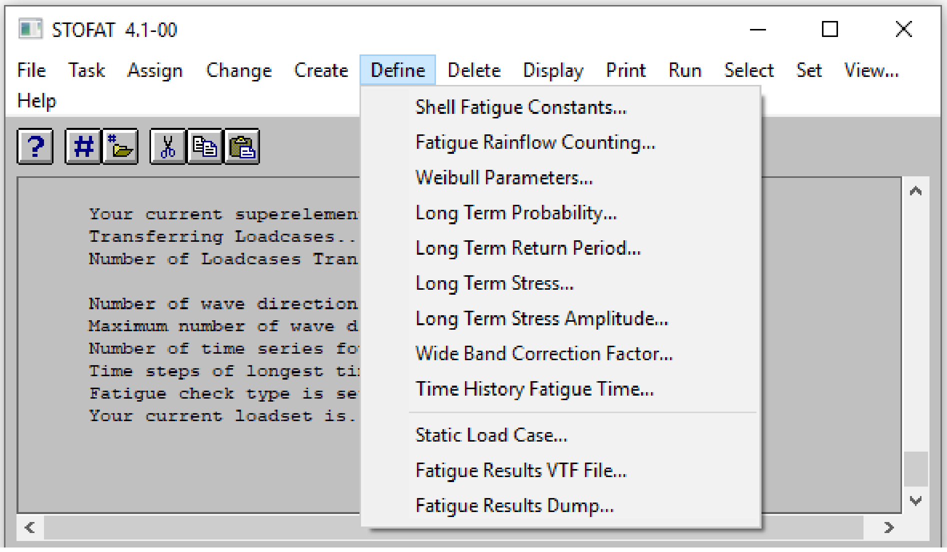



Figure F.21: DEFINE PULLDOWN MENU

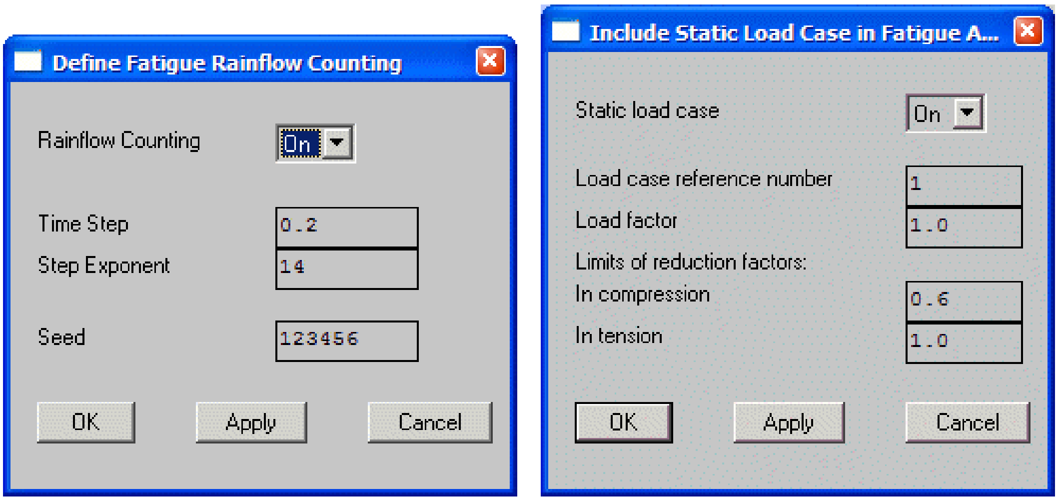



Figure F.22: DEFINE FATIGUE RAINFLOW-COUNTING, DEFINE STATIC-LOAD-CASE

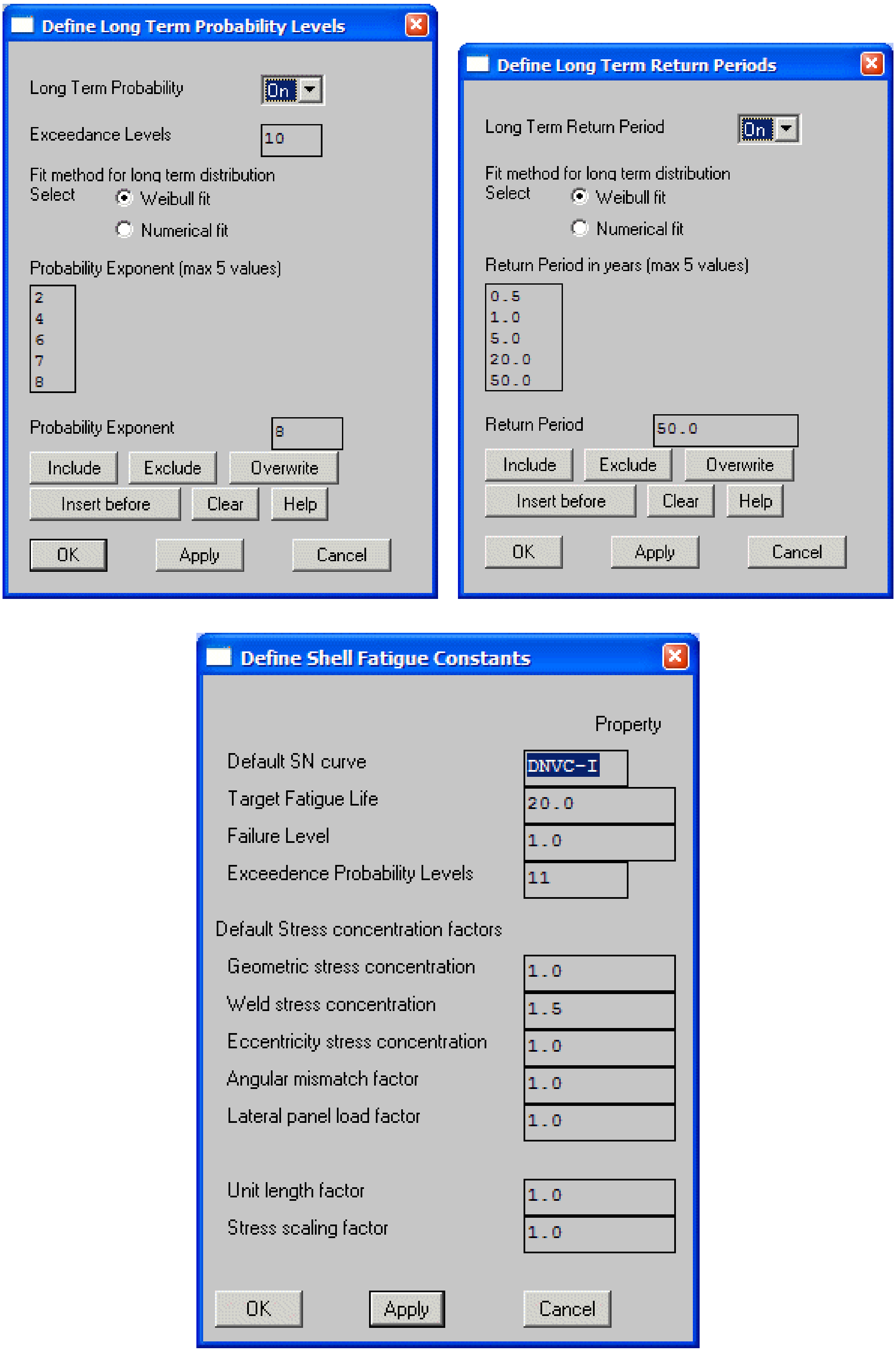



Figure F.23: DEFINE LONG-TERM-PROBABILITY, DEFINE LONG-TERM-RETURN-PERIOD DEFINE FATIGUE-CONSTANTS

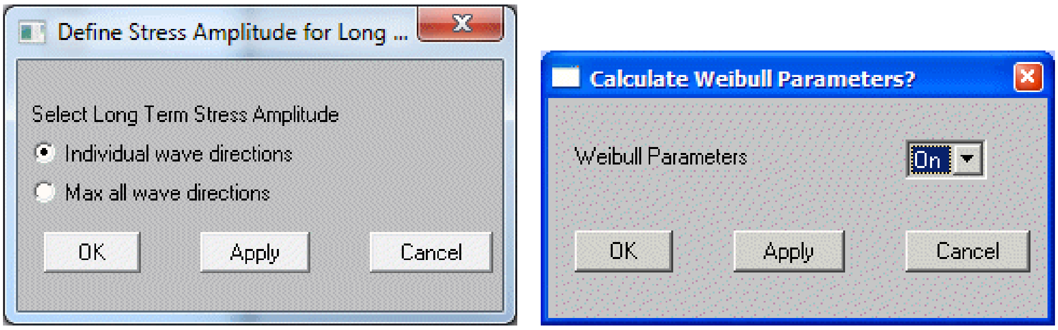



Figure F.24: DEFINE LONG-TERM-AMPLITUDE, WEIBULL-PARAMETERS

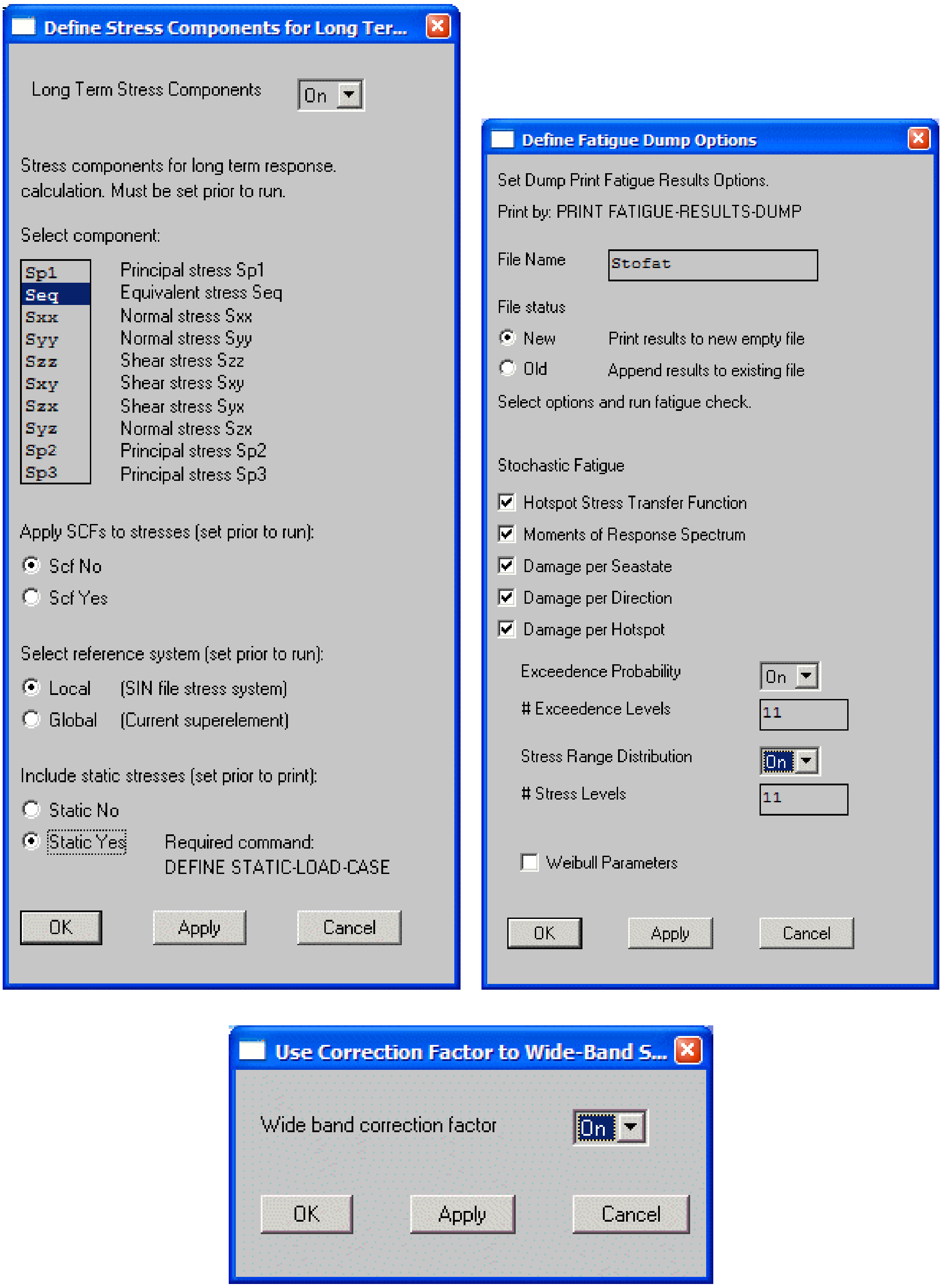



Figure F.25: DEFINE FATIGUE-RESULTS-DUMP, DEFINE LONG-TERM-STRESS, WIDE-BAND-CORRECTION-FACTOR

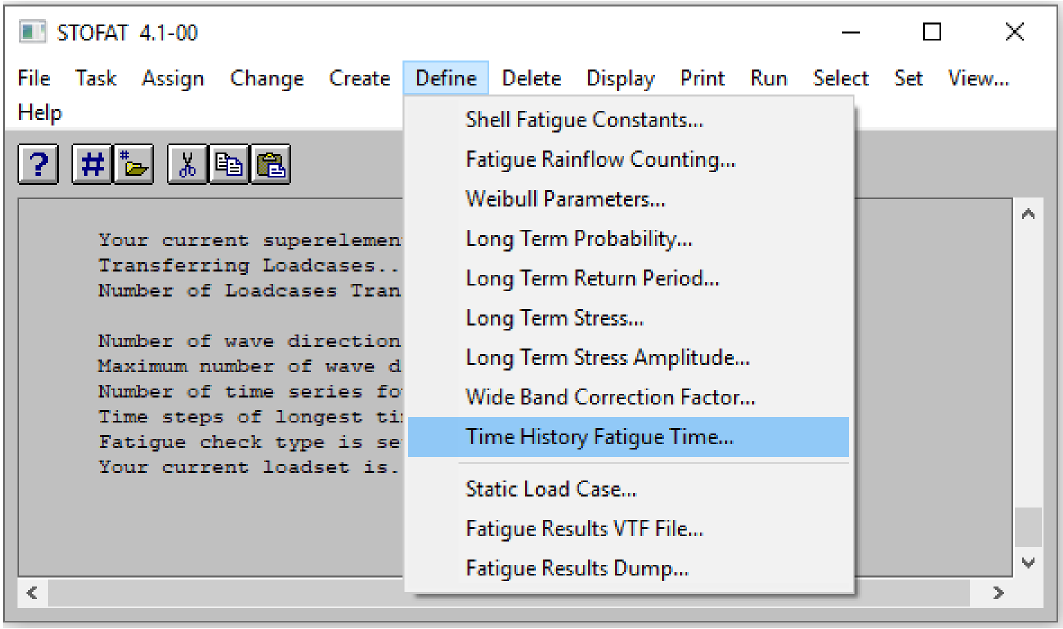



Figure F.26: DEFINE TIME-HISTORY-FATIGUE-TIME

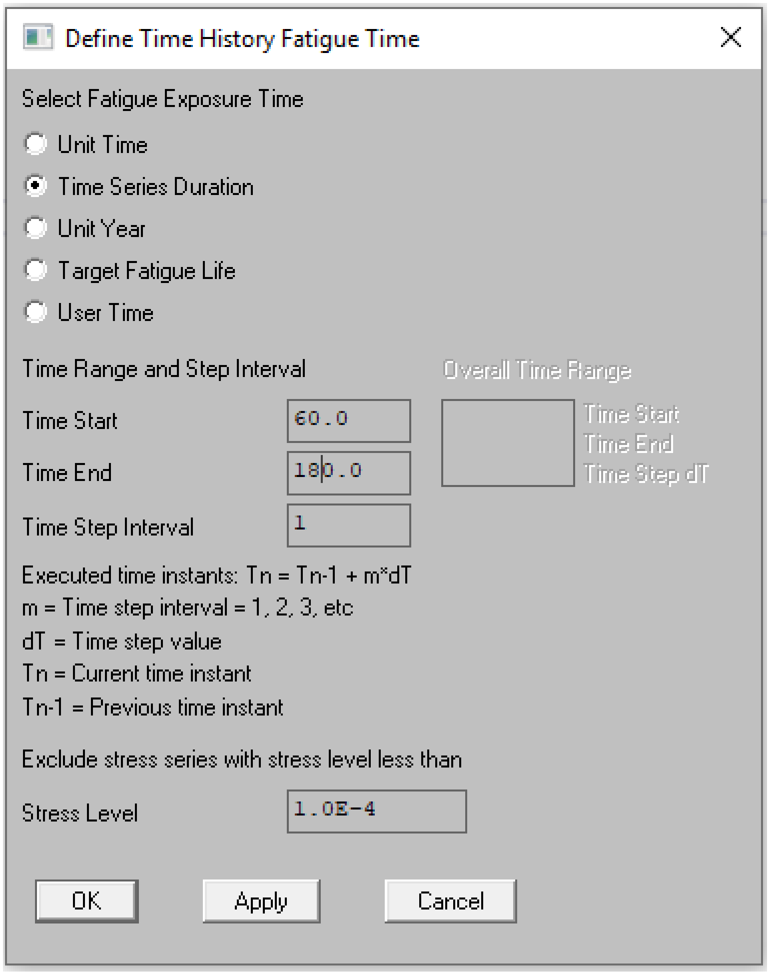



Figure F.27: DEFINE TIME-HISTORY-FATIGUE-TIME TIME-SERIES-DURATION

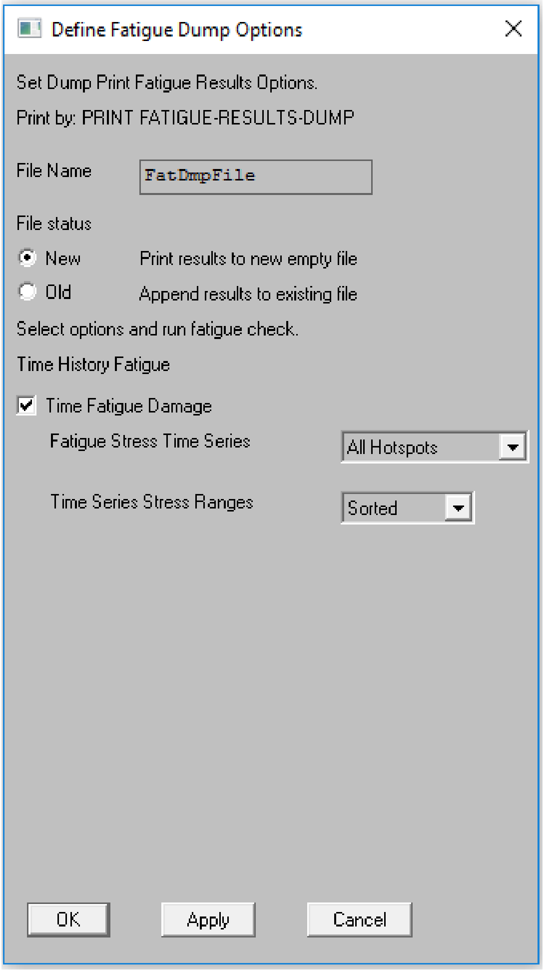



Figure F.28: DEFINE FATIGUE-RESULTS-DUMP

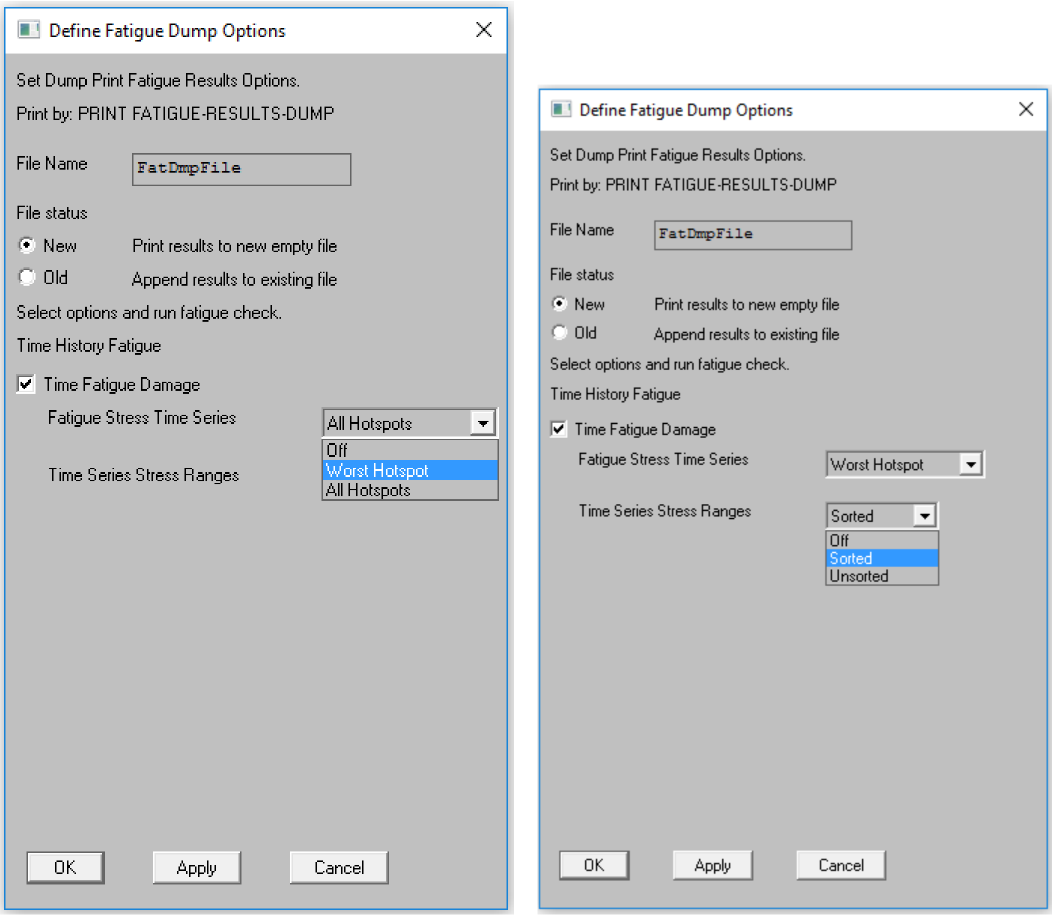



Figure F.29: DEFINE FATIGUE-RESULTS-DUMP FATIGUE-STRESS-TIME-SERIES WORST-HOTSPOT, DEFINE FATIGUE-RESULTS-DUMP TIME-SERIES-STRESS-RANGES SORTED

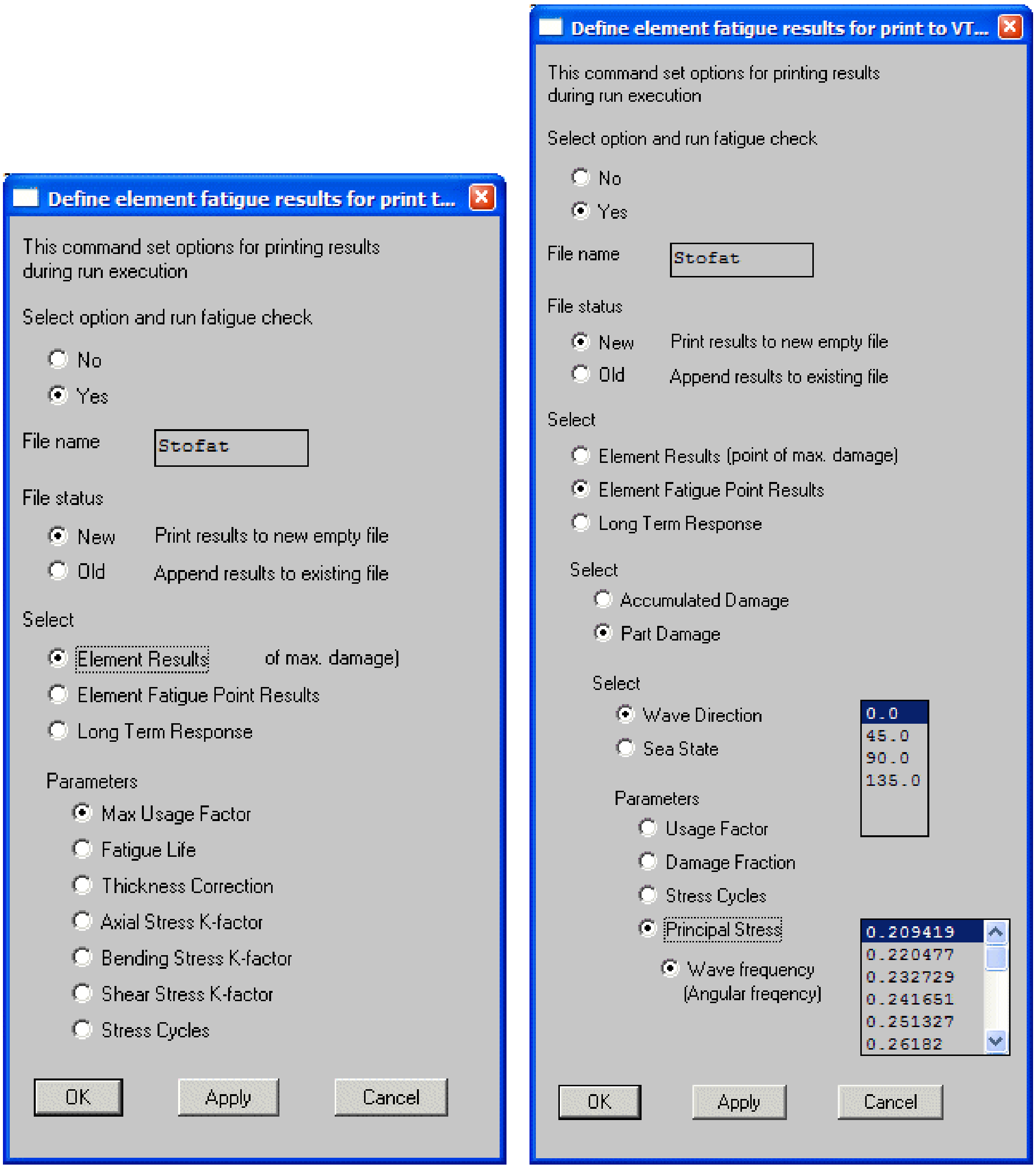



Figure F.30: DEFINE FATIGUE-RESULTS-VTF-FILE ELEMENT-RESULTS,
DEFINE FATIGUE-RESULTS-VTF-FILE ELEMENT-FATIGUE-POINT-RESULTS

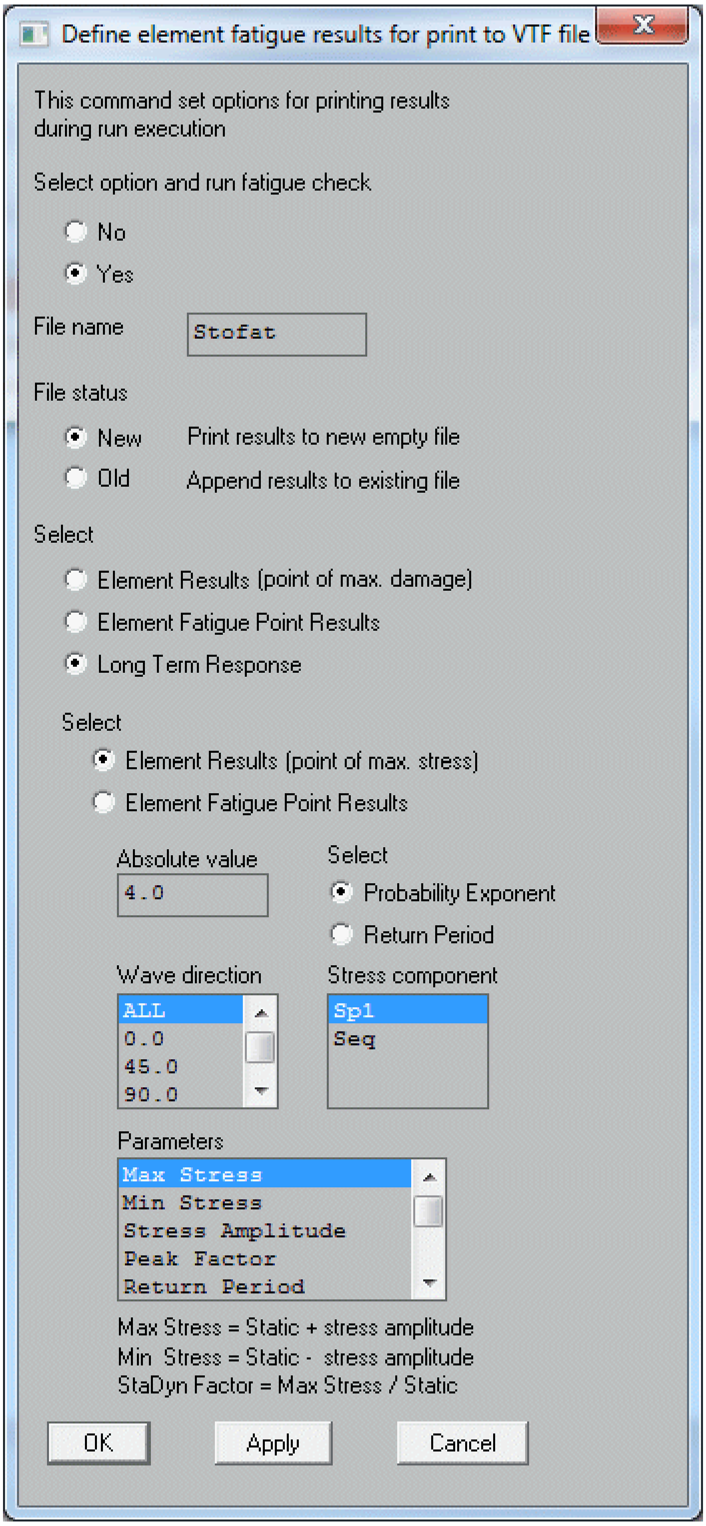



Figure F.31: DEFINE FATIGUE-RESULTS-VTF-FILE LONG-TERM-RESPONSE

# F.6 DELETE Menu

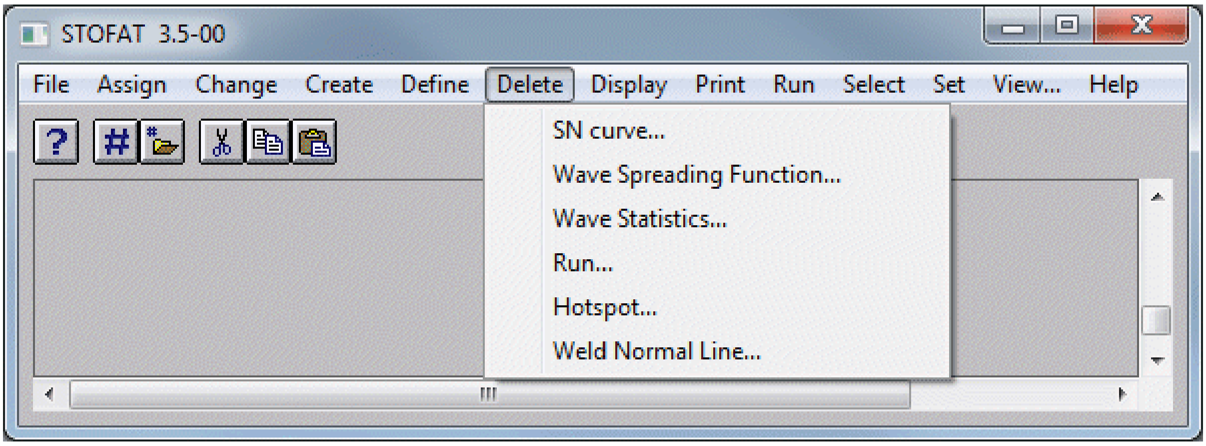



Figure F.32: DELETE pulldown menu

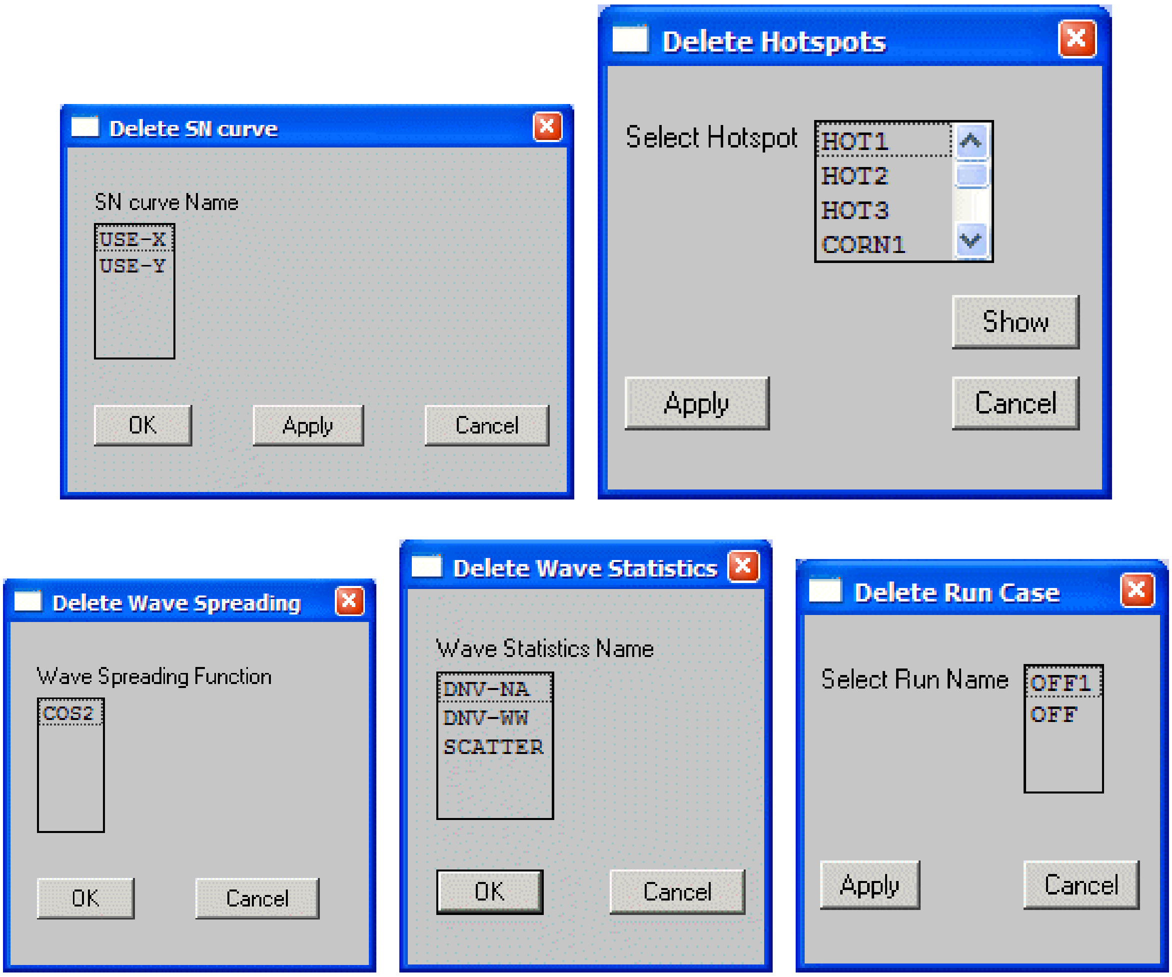



Figure F.33: DELETE SN-CURVE, DELETE HOTSPOT, DELETE WAVE-STATISTICS, DELETE WAVE-SPREADING-FUNCTION, DELETE RUN

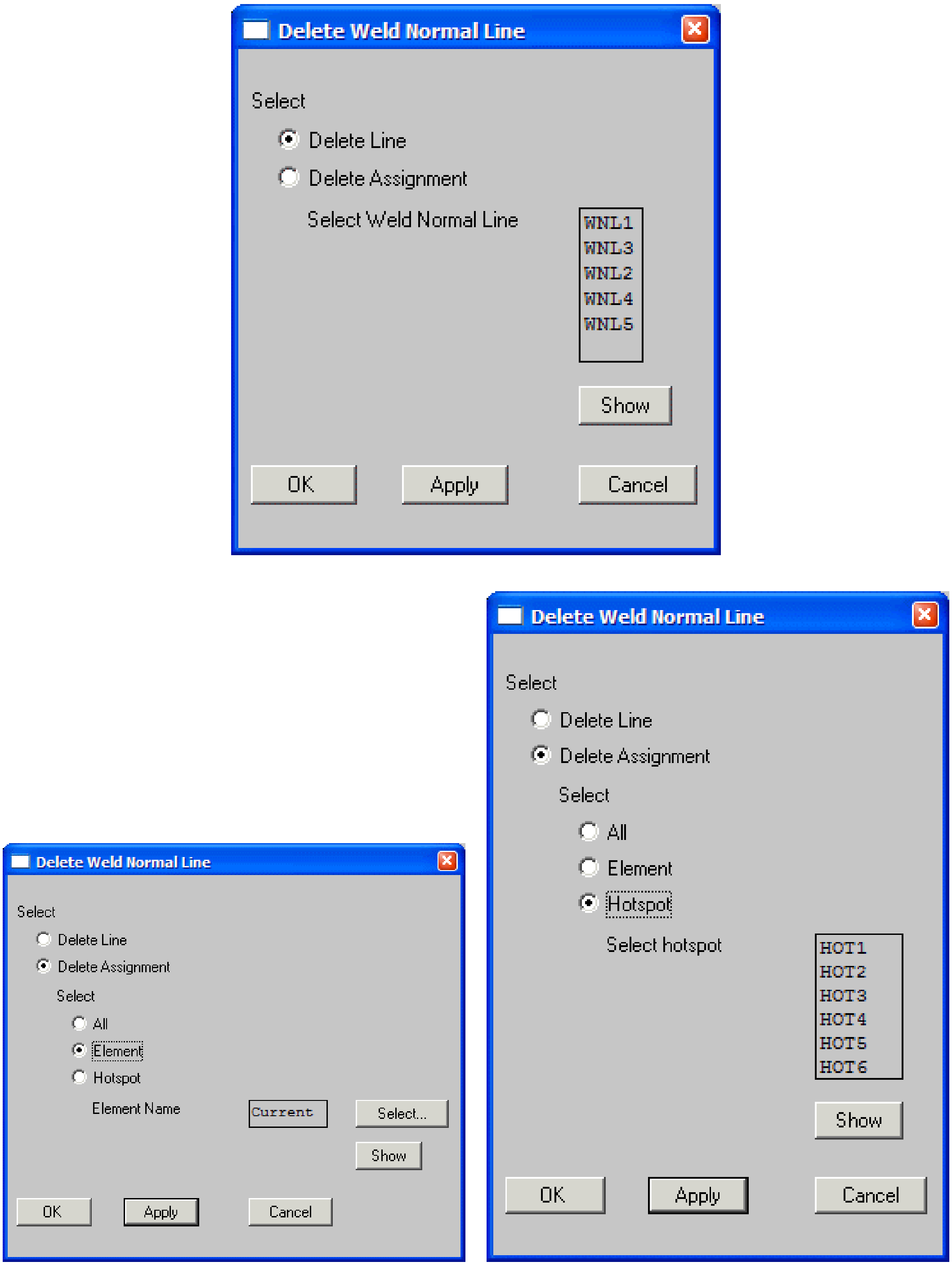



Figure F.34: DELETE WELD-NORMAL-LINE DELETE-LINE,
DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT,
DELETE WELD-NORMAL-LINE DELETE-ASSIGNMENT HOTSPOT

## F.7 DISPLAY Menu

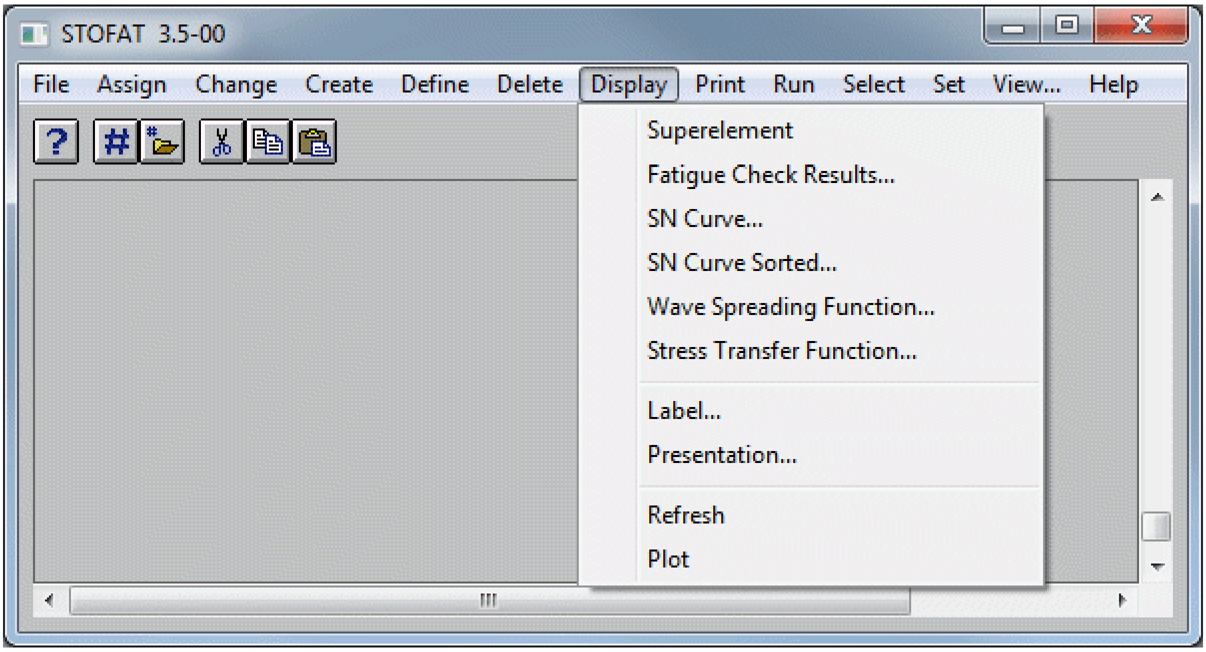



Figure F.35: DISPLAY pulldown menu

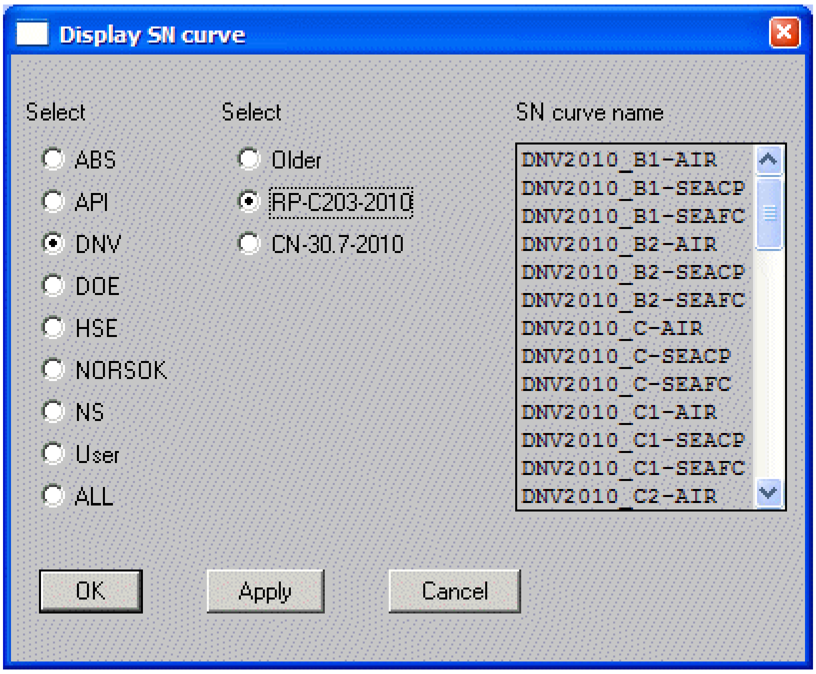



Figure F.36: DISPLAY SN-CURVE-SORTED

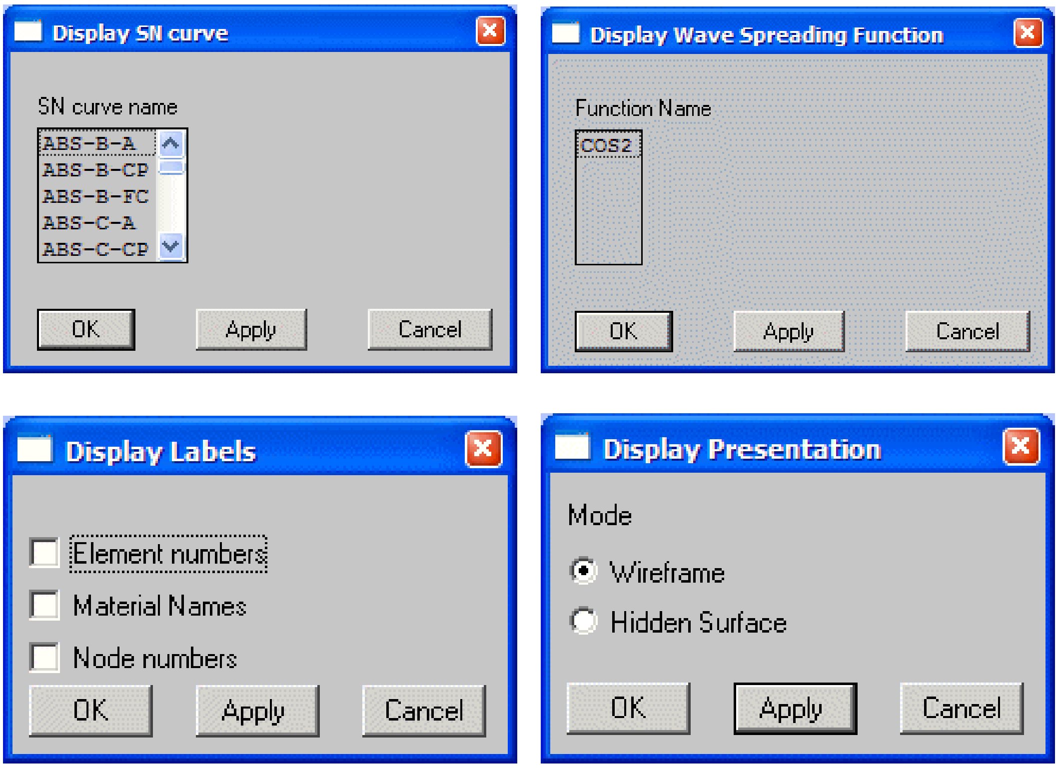



Figure F.37: DISPLAY SN-CURVE, DISPLAY WAVE-SPREADING-FUNCTION, DISPLAY LABEL, DISPLAY PRESENTATION

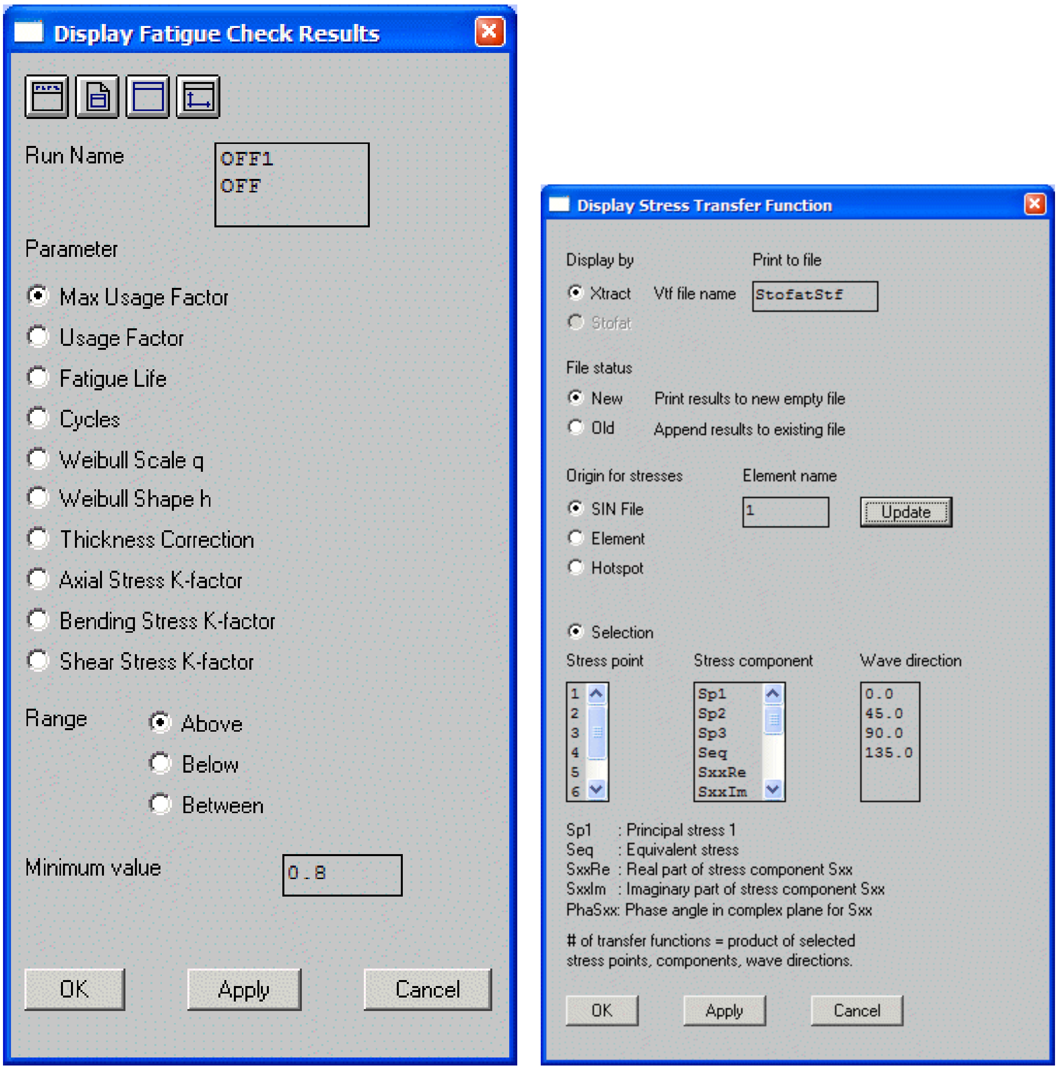



Figure F.38: DISPLAY FATIGUE-CHECK-RESULTS,
DISPLAY STRESS-TRANSFER-FUNCTION SIN-FILE

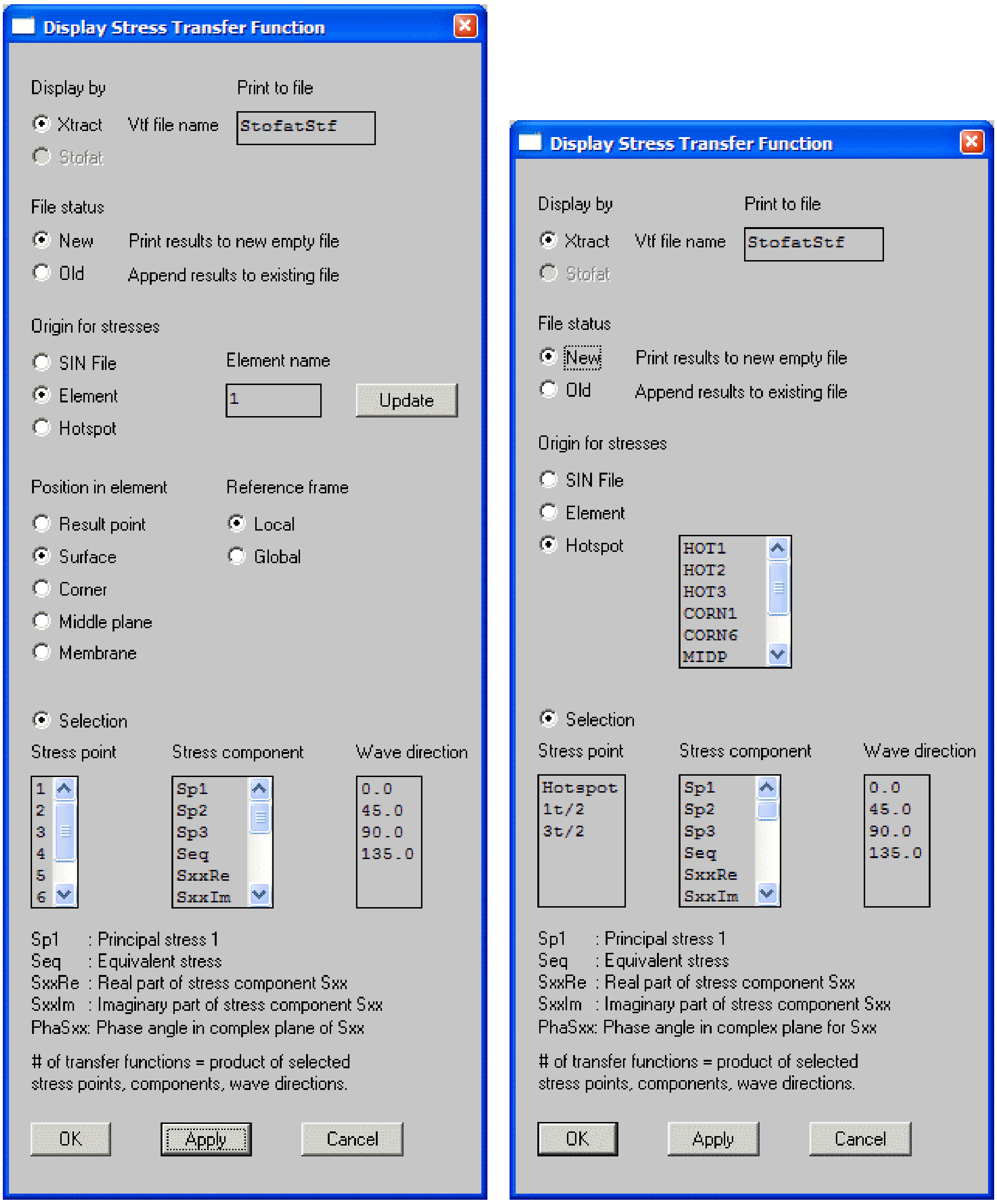



Figure F.39: DISPLAY STRESS-TRANSFER-FUNCTION

## F.8 PRINT Menu

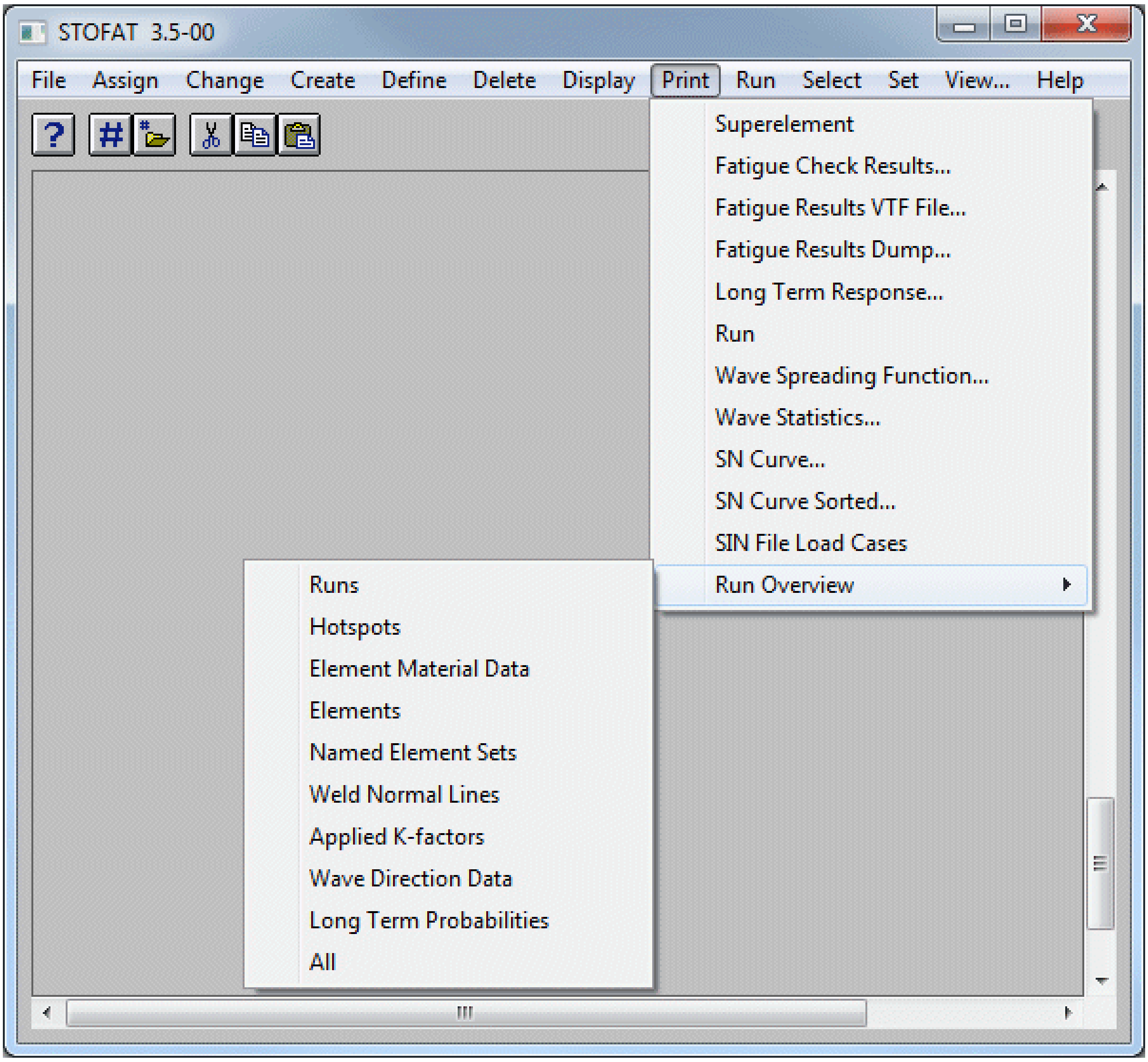



Figure F.40: PRINT pulldown menu and PRINT RUN-OVERVIEW

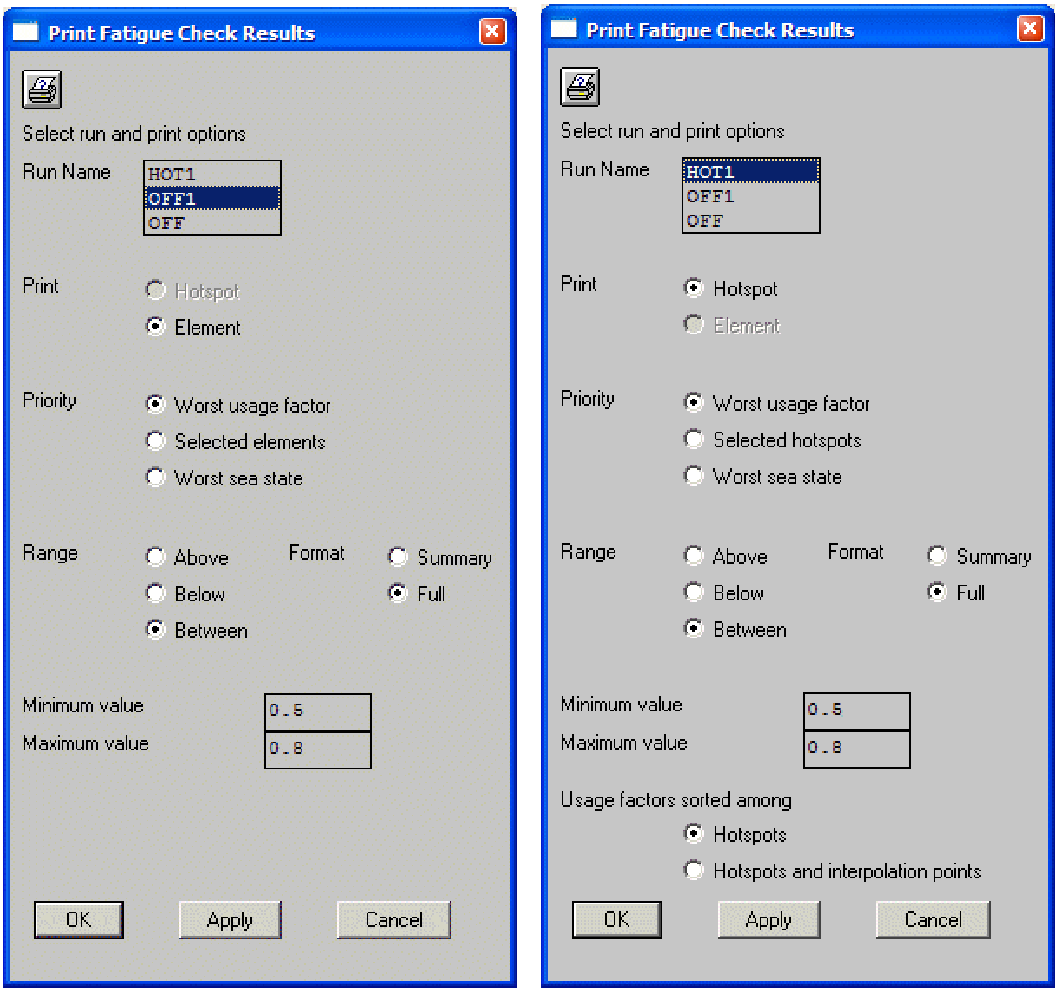



Figure F.41: PRINT FATIGUE-CHECK-RESULTS ELEMENT,
PRINT FATIGUE-CHECK-RESULTS HOTSPOT

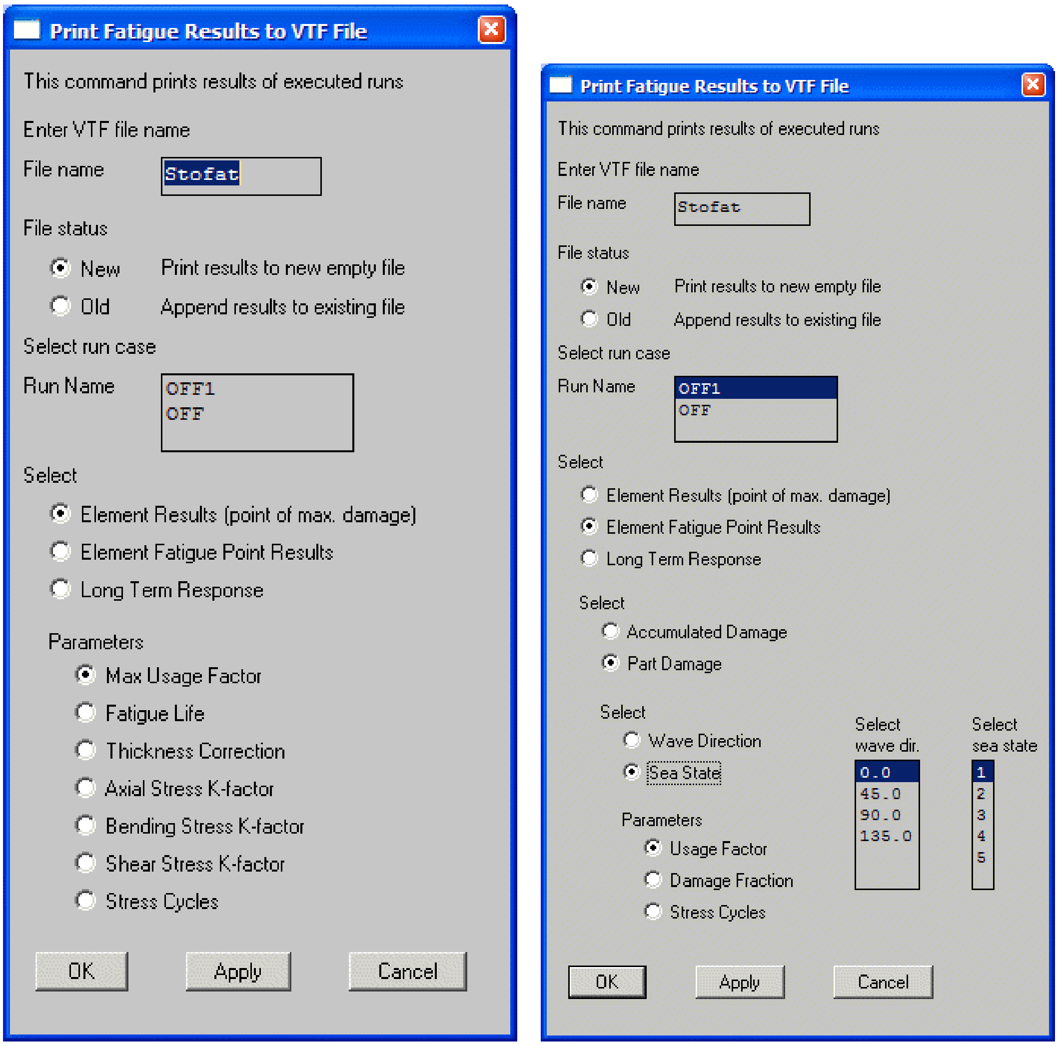



Figure F.42: PRINT FATIGUE-RESULTS-VTF-FILE ELEMENT-RESULTS,
PRINT FATIGUE-RESULTS-VTF-FILE ELEMENT FATIGUE-POINT-RESULTS

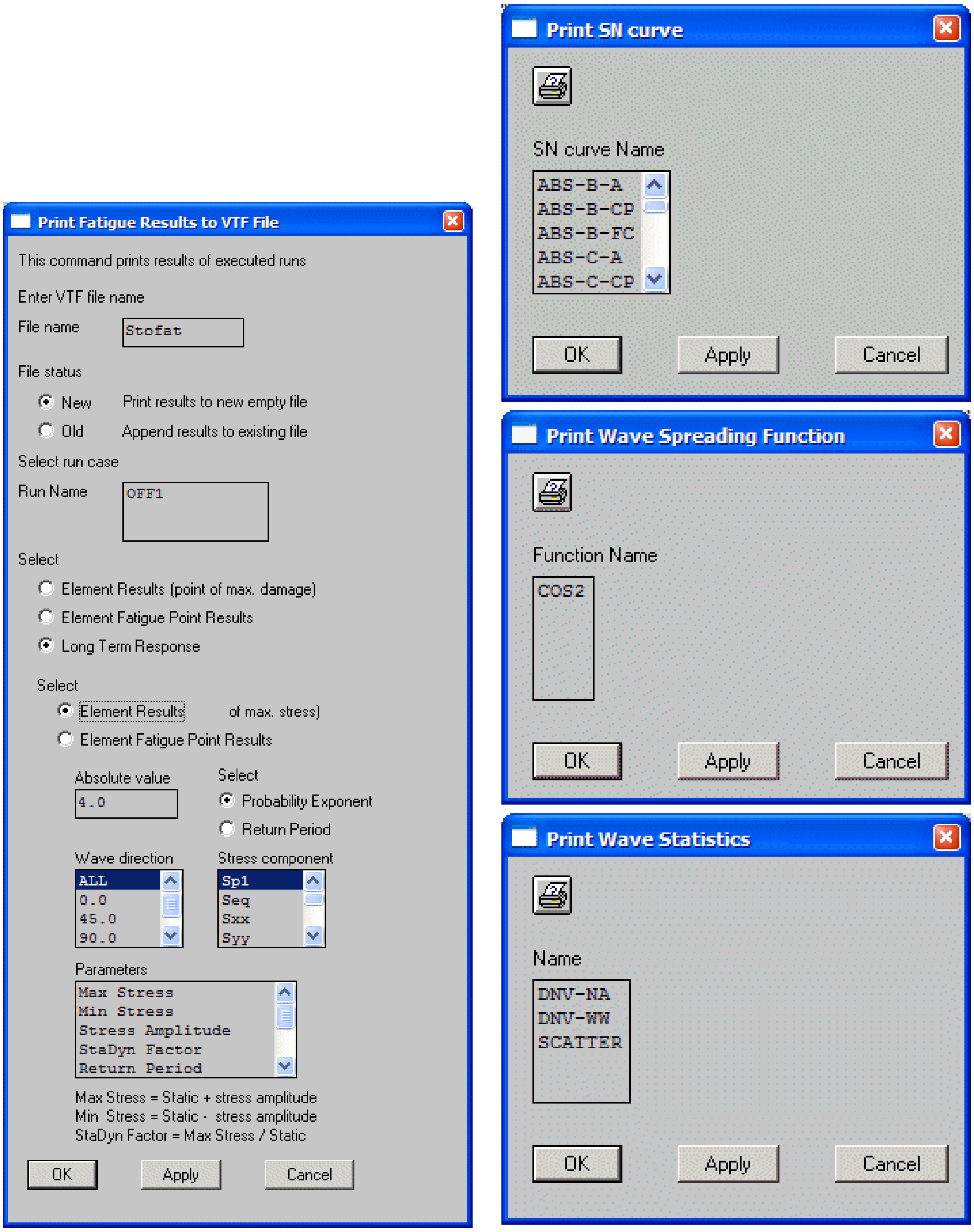
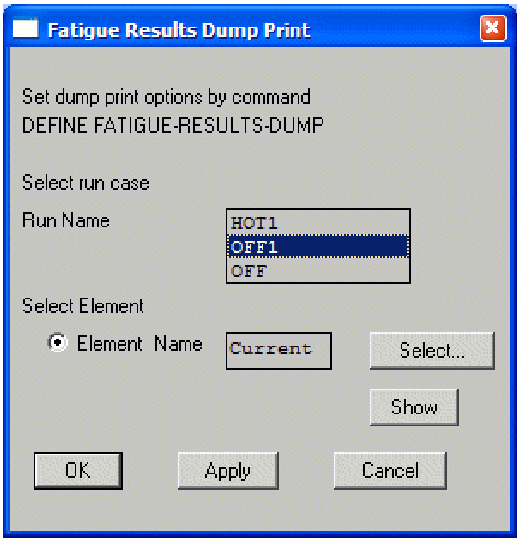



Figure F.43: PRINT LONG-TERM-RESPONSE LONG-TERM-RESPONSE, PRINT SN-CURVE, PRINT WAVE-SPREADING-FUNCTION, PRINT WAVE-STATISTICS



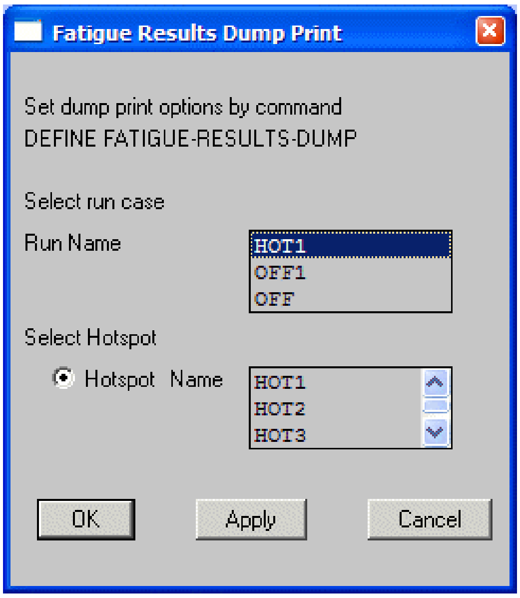




Figure F.44: PRINT FATIGUE-RESULTS-DUMP

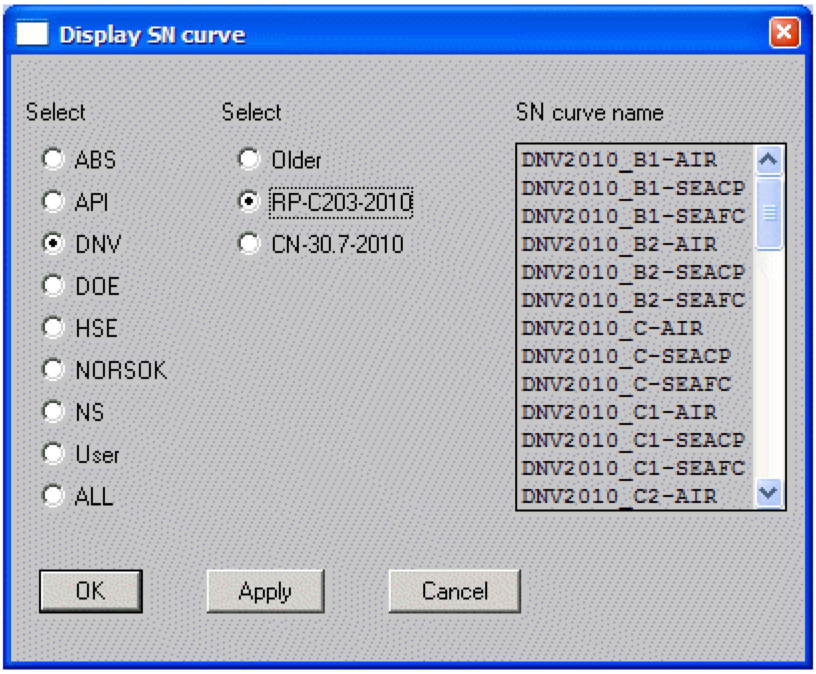



Figure F.45: PRINT SN-CURVE-SORTED

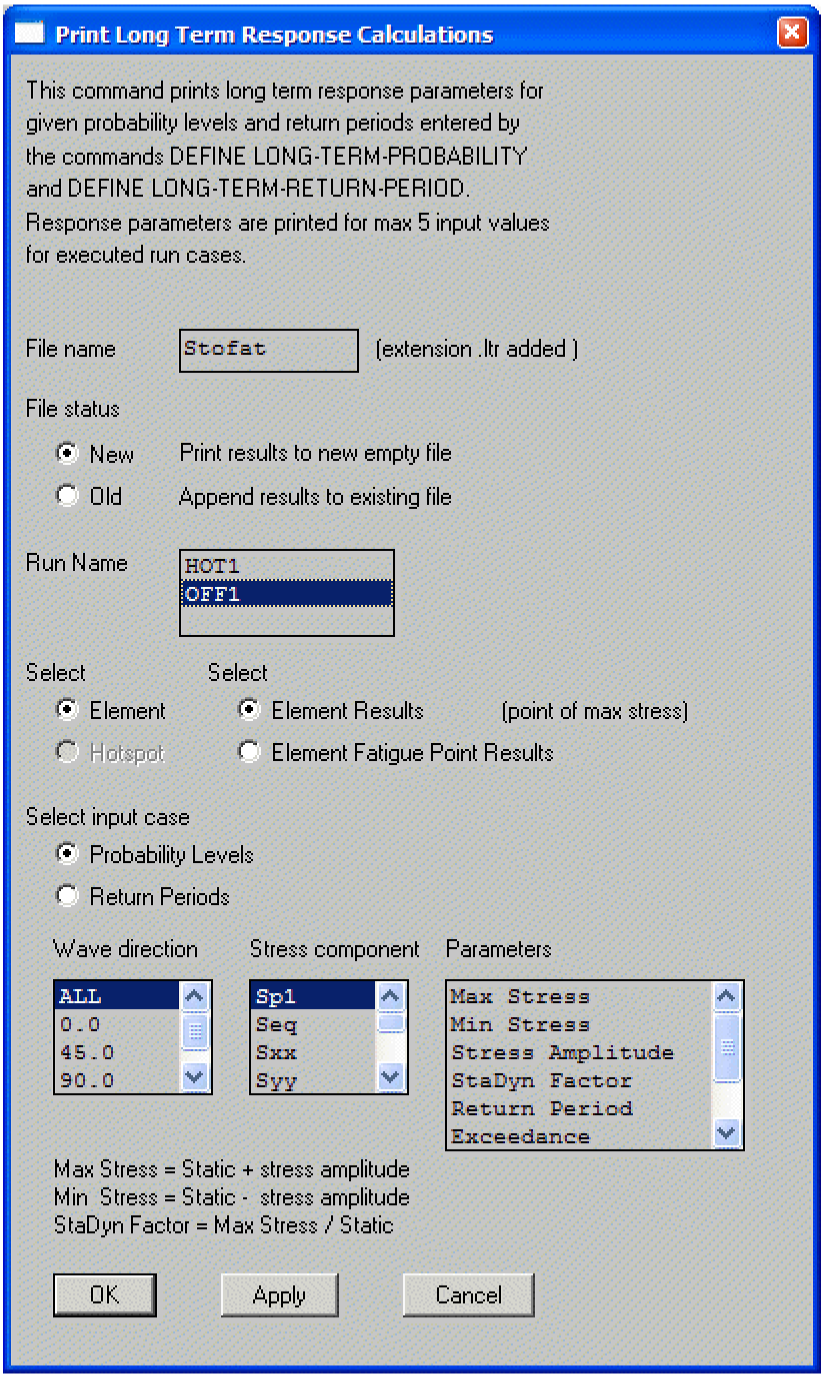



Figure F.46: PRINT LONG-TERM-RESPONSE

## F.9 RUN Menu

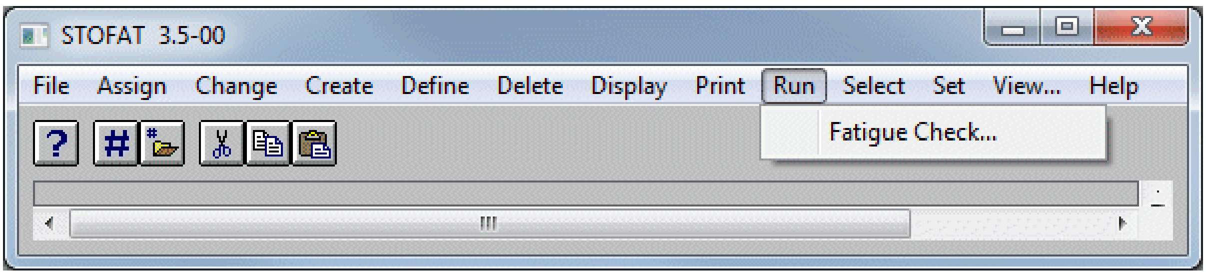



Figure F.47: RUN pulldown menu

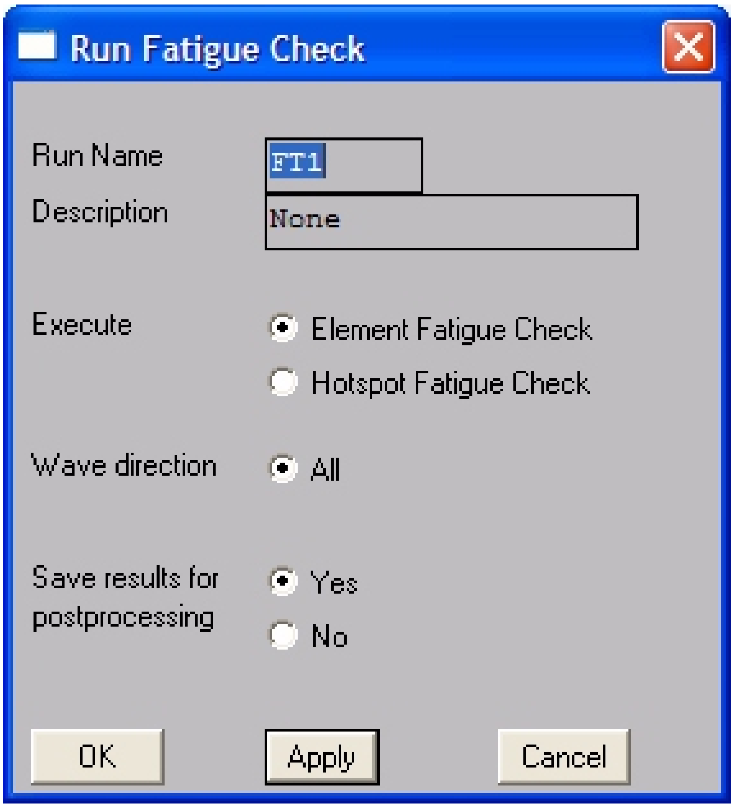



Figure F.48: RUN FATIGUE CHECK

## F.10 SELECT Menu

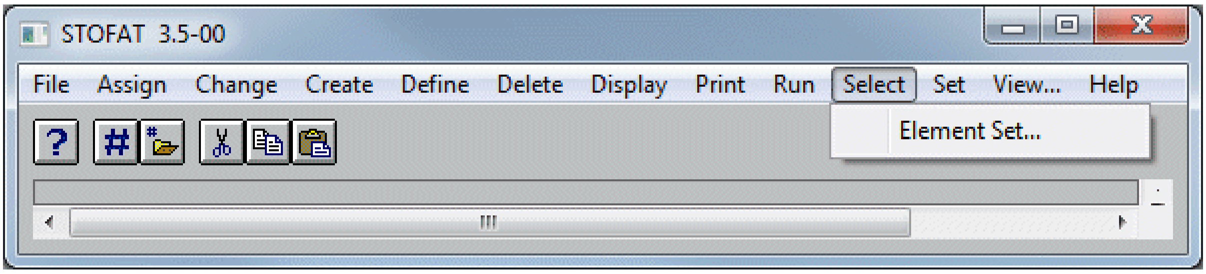



Figure F.49: SELECT pulldown menu

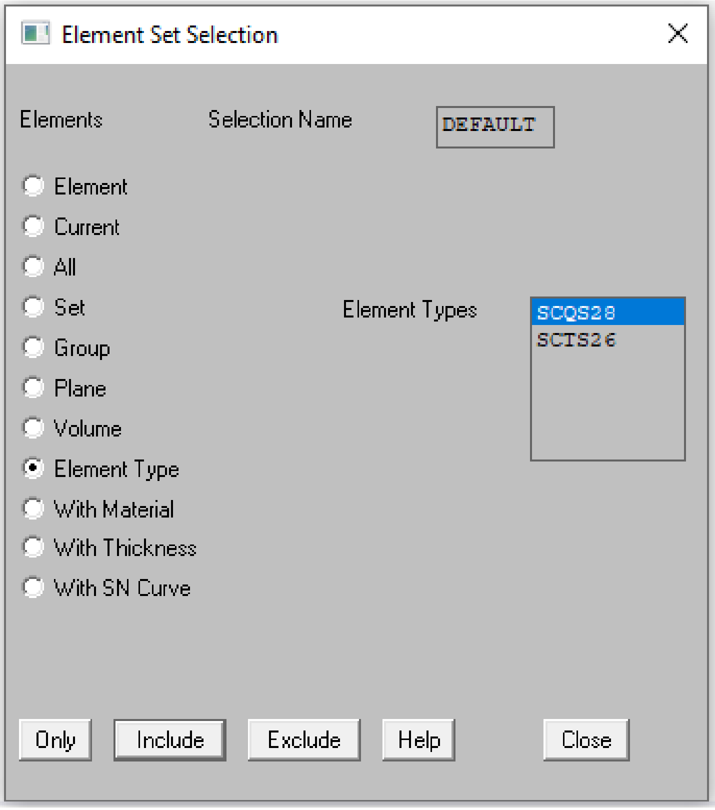



Figure F.50: SELECT SET ELEMENT

## F.11 SET Menu

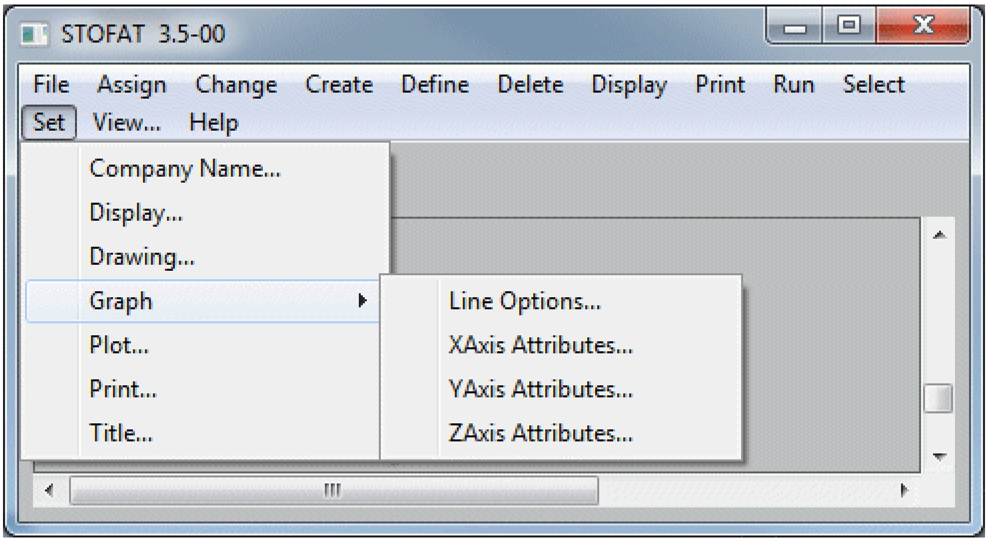



Figure F.51: The SET pulldown menu

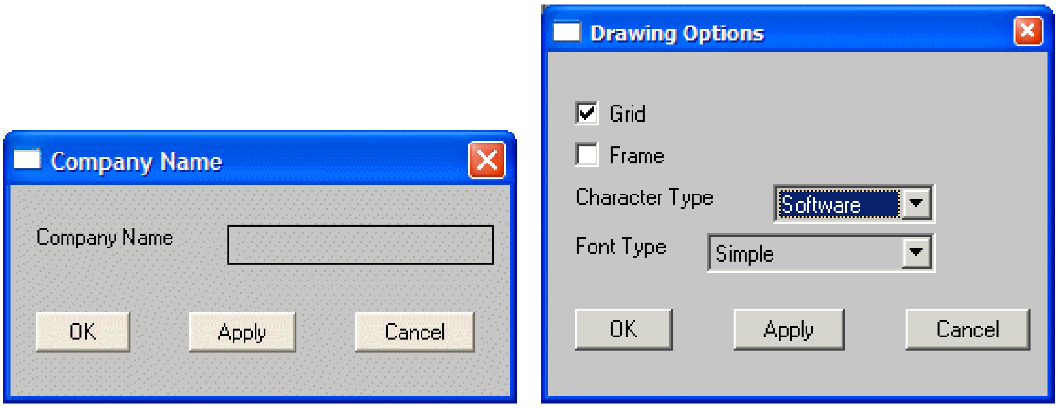



Figure F.52: SET COMPANY NAME, SET DRAWING

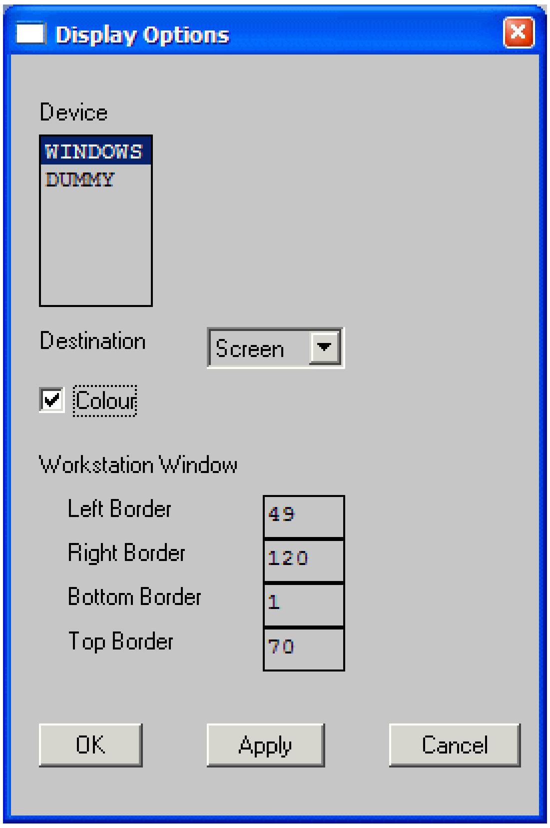



Figure F.53: SET DISPLAY

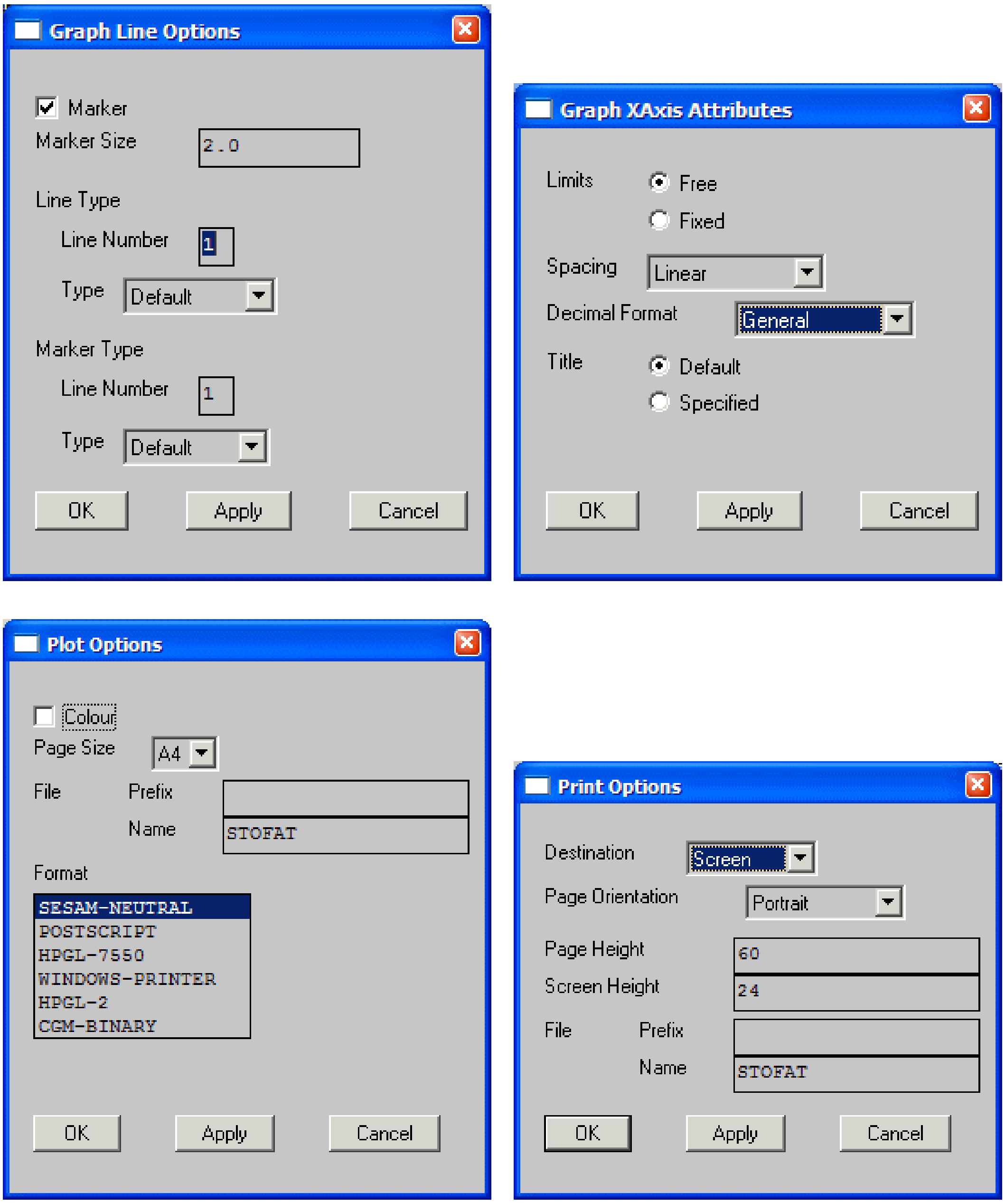



Figure F.54: SET GRAPH LINE-OPTIONS, SET GRAPH XAXIS-ATTRIBUTES, SET PLOT, SET PRINT

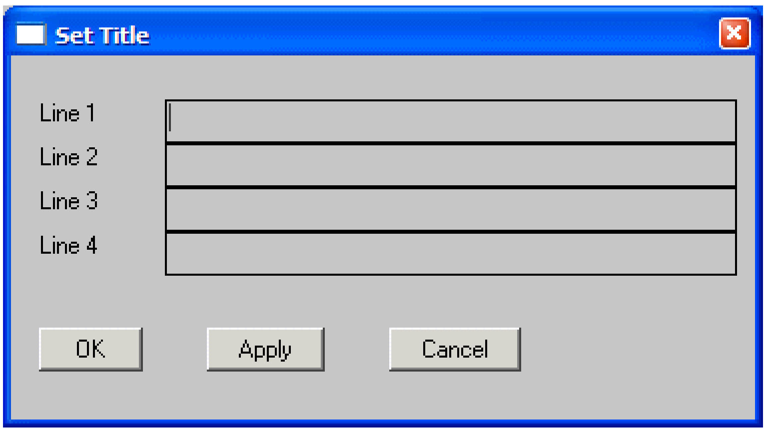



Figure F.55: SET TITLE

## F.12 HELP Menu

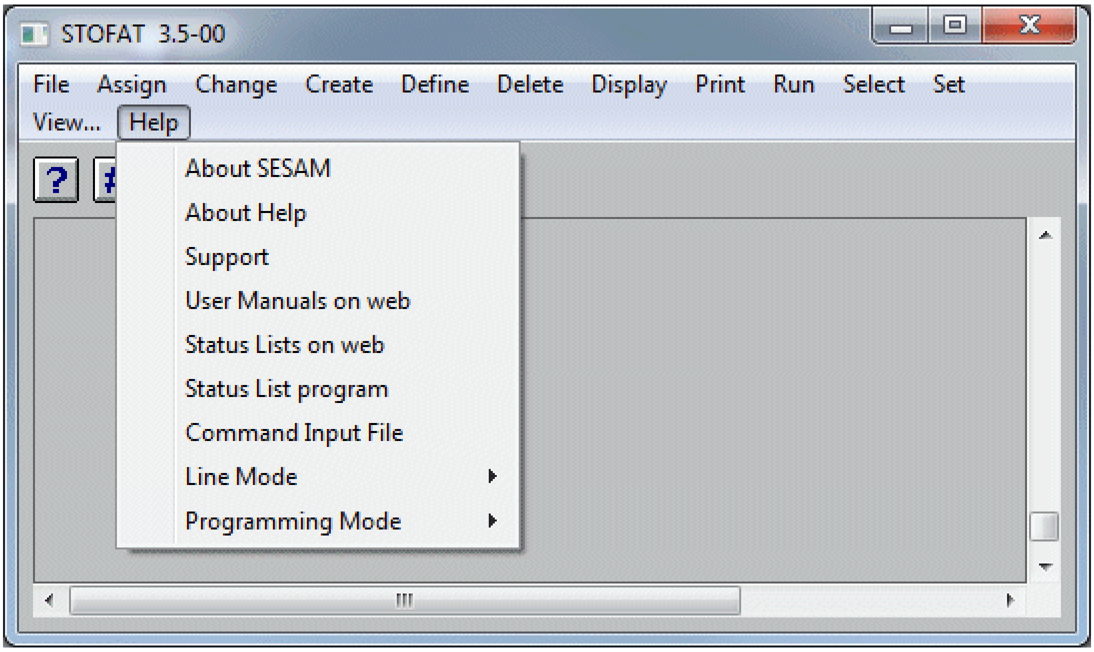



Figure F.56: HELP pulldown menu

## F.13 VIEW Menu

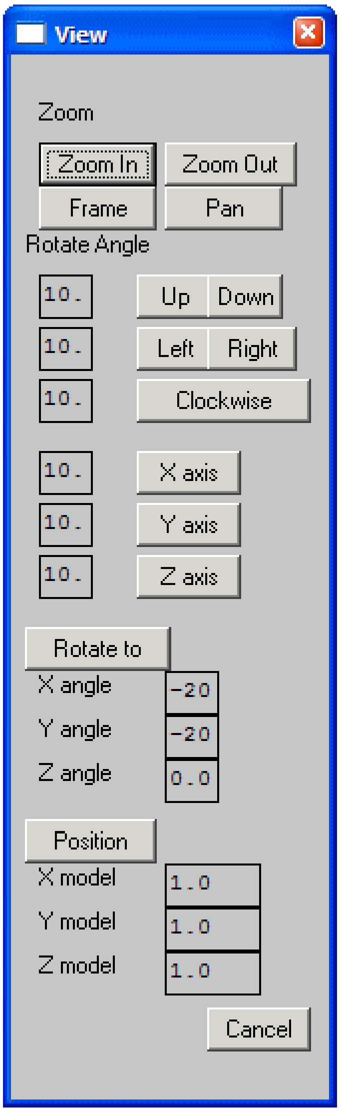



Figure F.57: VIEW

# References


[1] ABS. *American Bureau of Shipping Guide for Fatigue Assessment of Offshore Structures*. ABS-America Bureau of Shipping, 2003. E.2, E.4

[2] L. E. Borgman. Hydrodynamic force coefficients in random wave conditions. *OMAE Proc., Tokyo*, 1967. B.2.2, B.2.3

[3] J. J. H. Brouwers and P. H. J. Verbeek. 1983. B.2.4, C.3

[4] B. Burrows. Expected value analysis for the quasi-static response of offshore structures. *Appl. Math. Modelling*, 7, Oct. 1977. B.2.4

[5] S. K. Chakrabarti. Discussion on dynamics of single point mooring in deep water. *Journ. of Waterways, Harbours and Coastal Eng. Div., ASCE*, 97(WW3), 1971. B.2.3

[6] S. K. Chakrabarti. Total forces on submerged randomly oriented tube due to waves. *Proc. OTC, Paper 2495, Houston, Texas*, 1976. B.2.3

[7] Department of Energy. *Offshore Installations: Guidance on Design and Construction*, 4th edition edition, 1990. E.2, E.7

[8] Det. Fatigue assessment of ship structures, classification note no. 30.7. Technical report, Det Norske Veritas, June 2010. C.2.1, C.2.1, E.2, E.6.3

[9] Norwegian Petroleum Directorate. Norwegian standard ns3472e. 1984. C.2.1, E.2, E.11

[10] D. F. Downing, S. D. Socie. Simple rainflow counting algorithms. *International Journal Fatigue*, 1982. 2.4

[11] M. B. Gibstein. Fatigue strength of welded tubular joints tested at det norske veritas laboratories. *Fatigue strength of welded tubular joints tested at Det norske Veritas laboratories, Proc. Int. Conf. on Steel in Marine Structure*, 1981. B.3

[12] S. Haver. Measured fatigue stress response of north sea jacket platforms. *Proc. ICOSSAR'85*, pages 331–337, 1985. C.3

[13] Health and Safety Executive. *Offshore Installations: Guidance on design, construction and certification*, fourth edition, February 1995. E.2, E.8

[14] N. et al. Hogben. Estimation of fluid loading on offshore structures. *Proc. Institution of Civil Engineers*, 63, September 1977. B.2.3

[15] American Petroleum Institute. Recommended practice for planning, design and construction of fixed offshore structures. *API*, 1993. B.2.2, E.2, E.5

[16] H. B. Kanegaonkar and A. Haldar. Non-gaussian response of offshore platforms: dynamic. *Journal of Structural Engineering, ASCE*, 113(9):1899–1908, Sept. 1987. C.3

[17] N. R. Maddox and A. W. Wildenstein. A spectral fatigue analysis of offshore structures. *Proc. OTC, Paper 2261, Houston, Texas*, 1975. C.3

[18] Krenk S. Lind N. C. Madsen, H. O. Methods of structural safety. 1986a. B.4, C.3

[19] Løseth R. Madsen, H. Extreme-value distribution and fatigue for combined wave and current loading. 1986. B.1.4, B.2.4, B.2.4, B.4, B.4, C.3

[20] O'Brian M. P. Johnson J. W. Morison, J. R. and S. A. Schaaf. The force exerted by surface waves on piles. *Petroleum Transactions, AIME*, 189:149 –154, 1950. B.2.2

[21] N. Nordenstrøm. A method to predict long-term distributions of waves and wave-induced motions and loads on ships and other floating structures. *Det Norske Veritas Publication.*, (81), 1973. B.8

[22] A. Palmgren. Die lebensdauer von kugellagern. *Zeitschrift der Vereines Deutches Ingenieure*, 68(4):339–341, 1924. C.3

[23] J. Penzien and S. Tseng. Three dimensional dynamic analysis of fixed offshore platforms. *Numerical Methods in Offshore Engineering*, 1978. C.3

[24] Holmes Pierson. 1965. B.2.4

[25] W. J. Pierson and L. Moskowitz. A proposed spectral form for fully developed wind seas based on similarity theory of s. a. kitaigorodskii. *Journ. of Geophysical Research*, 69(24, December), 1964. B.1.4

[26] T. Sarpkaya and M. Isaacson. Mechanics of wave forces on offshore structures. 1981. B.2.2

[27] I. Scherf and T. Thuestad. Fatigue design of the oseberg jacket structure. *Proc. OMAE, Houston, Texas.*, 1987. B.2.3

[28] R. Skjong and H. O. Madsen. Practical stochastic fatigue analysis of offshore platforms. *Ocean Engineering*, 14(4):313–324, 1987. C.3

[29] NORSOK Standard. Design of steel structures, n-004. Technical report, NORSOK, October 2004. E.2, E.10

[30] Det Norske Veritas. Fatigue assessment of ship structures, classification note no. 30.7. 2005. 3.4.8, 3.4.9, 5.3, 5.6, 5.35, B.3.2, B.3.2, B.3.2, B.6, B.7, E.2, E.6.1

[31] Det Norske Veritas. Recommended practice dnv-rp-c203, fatigue design of offshore steel structures. Technical report, Det Norske Veritas, April 2012. C.2.2, E.2, E.6.2

[32] J. D. Wheeler. Methods for calculation forces produced by irregular waves. *Journ. of Petroleum Technology*, 1970. B.2.3

[33] P. Wirsching and M. Light. Fatigue under wide band random process. *Journal of the Structural Division*, 106(ST7):1593–1607, July 1980. C.3

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