FS2000

Fatigue and Fracture Assessments

Advanced Structural Analysis
for Windows
(c) A.E.S. Ltd 1988,2023

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1.0 Introduction

General Fatigue Analysis

The program performs interactive fatigue analysis in accordance with industry accepted procedures for:

SN Fatigue - As-Welded Structures

SN Fatigue - Stress Life - Smooth and Notched Components (Machined surfaces)

SE Fatigue - Strain Life - Smooth and Notched Components (Machined Surfaces)

The program can:

- Read the results data (stress ranges) of FS-OffFat to provided a very efficient tool for the fatigue assessment of flaws in offshore structures.
- Interface with FS-DyNoFlex time history solutions.
- Be used in an independent mode using user defined stress histories.

BS 7910

FS-Crack performs defect assessments based on the requirements of BS 7910:2005 "Guidance methods for assessing the acceptability of flaws in metallic structures".

It undertakes both fatigue and fracture assessments for surface, embedded and through-thickness flaws. The fatigue assessments only consider the fracture mechanics approach of BS 7910.

To use the program it is essential that the user is familiar with the scope and content of BS 7910. Any references to the code are shown in Italics.

Fatigue Data - Processing

Stress histories may be in the form of stress block occurrence histograms or raw data. Raw data can be processed using peak search and Rainflow cycle counting algorithms to produce stress block occurrence histograms. Mean stresses can be accounted for using the mean stress triangle diagrams

The data structure of FS-Fracture is based on the model files of FS2000.

Data used for defect assessments are saved as user defined model files and the results of an assessment are saved as Results Cases.

It is not essential for the FS2000 model to be a valid structural model but one must be opened before FS-Crack can be used.

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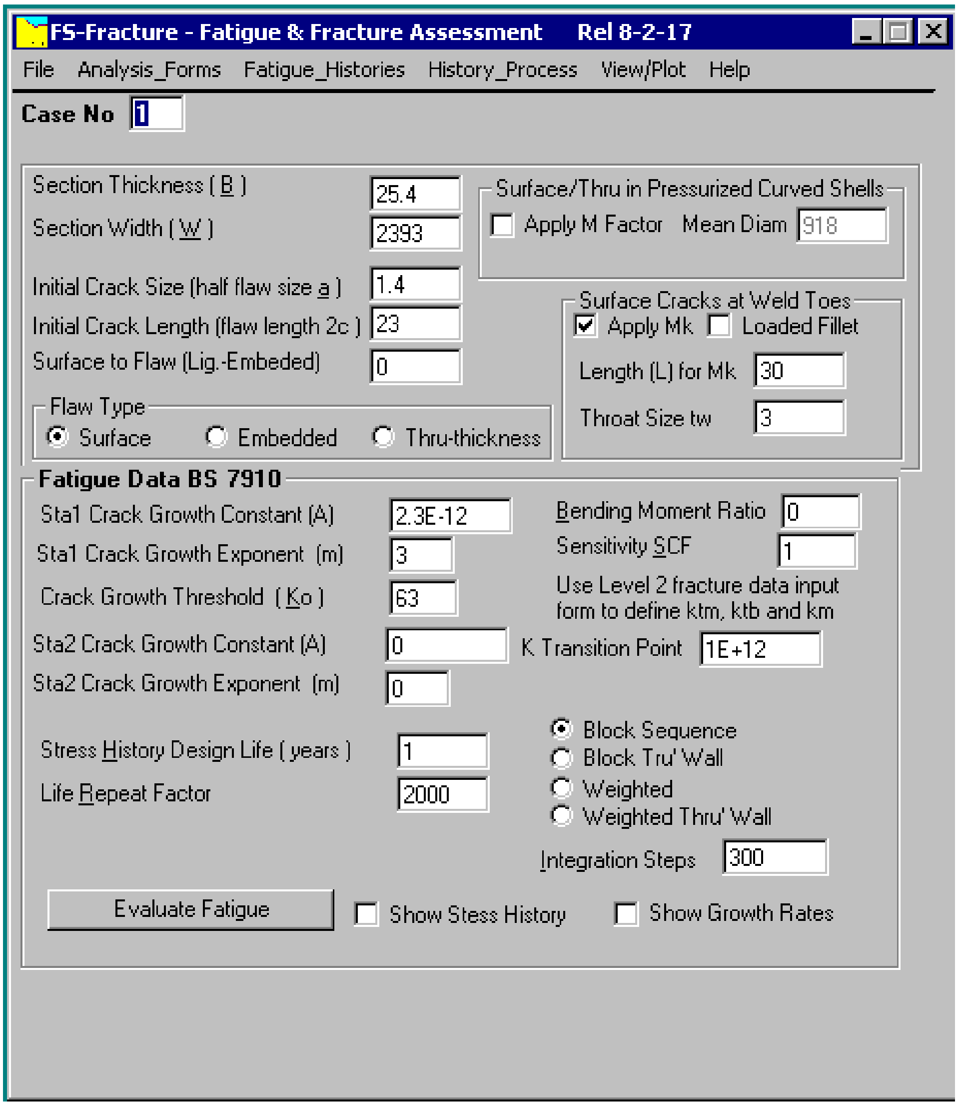
2.0 Operation

The software is started from the FS-Crack command in the Windows Start \Programs\FS2000 menu.

When the software is started the following window will become visible.



The Menu commands are described in Menu Commands.

Case No This the Case number for the current assessment. The case number will be added to the default prompts when is data saved or opened. The Result Case will also use this number. It is always recommended that the default naming conventions be adhered to when saving data. The assesdment case options are save as **<model>.UFDef(caseNo)** files.

It is good practice to enter the case number before using any of the command options.

Analysis Forms

Data input forms that show the data required for the specific type of analysis being undertaken are made visible using the **Analysis_Forms** menu command. This command makes the following forms visible

Fracture BS 7910 See Sect 3

Fatigue Bs 7910 See Sect 4

Fatigue SN Stress Life See Sect 5

Fatigue SE Strain Life See Sect 6

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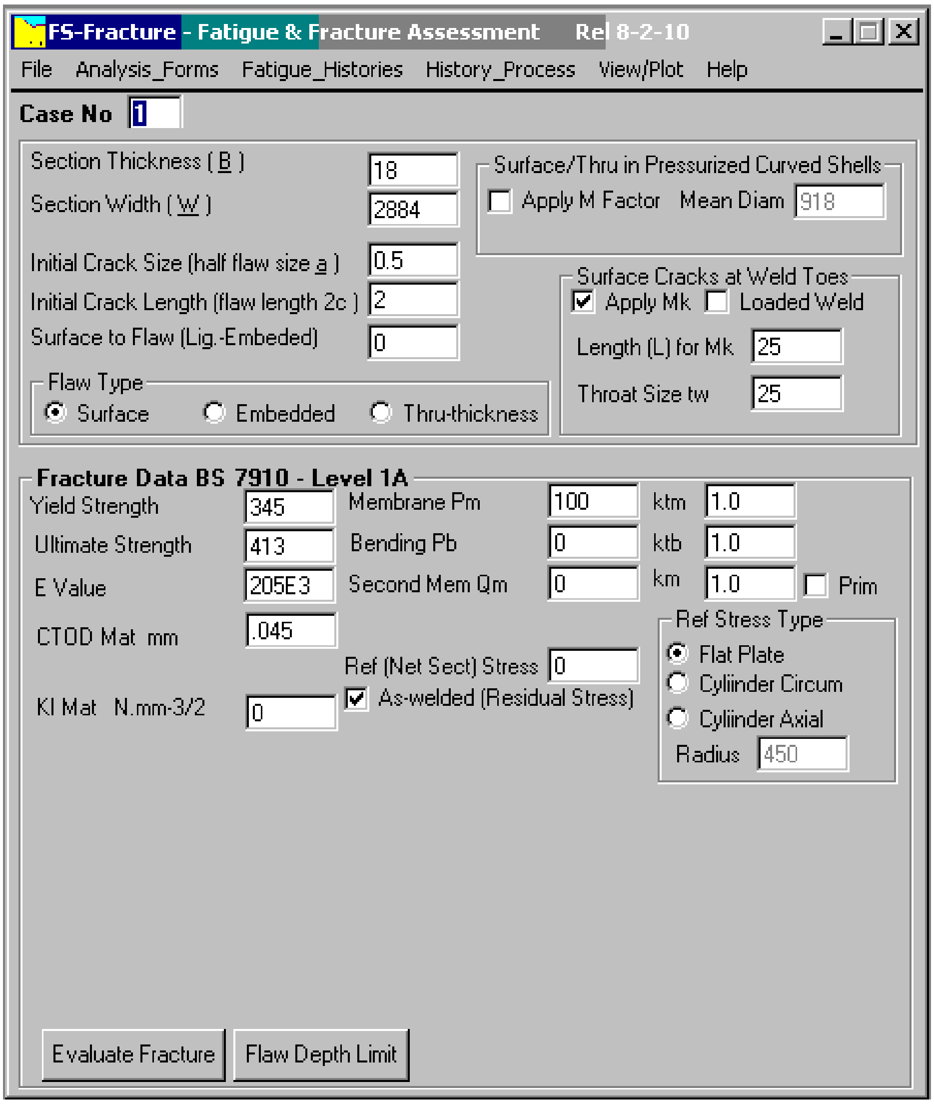
3.0 Fracture Data - BS 7910

The **Fracture Data** frame is used to define data that is specific to undertaking a fracture assessment. The data required to be define is dependent upon the level of assessment.

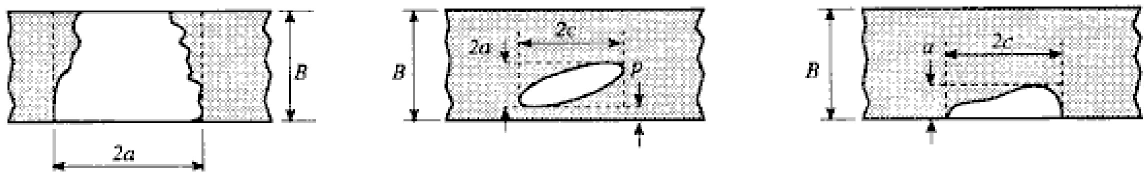


The **Evaluate Fracture** button will perform the fracture assessment. The results will be written to a 'Fract1 Subcase of Result Case '**CaseNo'.** ie ModelName.FractT.O1. It can be viewed using the Fracture Output command of the View menu.

The **Flaw Depth Limit** button will evaluate the maximum depth a for the current data settings. The initial value of a must be in the safe region of the FAD.

Crack Geometry Definition

Flaw Type is the flaw type category. Flaw categories and their dimensions are given *Figure 5*. *Figure 9* gives guidance on flaw interaction.



Section Thickness (B) is the section thickness in the plane of the flaw. (*Figure 8*)

Section Width (W) is the plate width in the plane of the flaw.

Initial Crack Size (a) is dependent upon the type of flaw. (*Figure 8*)

Initial Crack Length (2c) Not applicable to through thickness flaws.

Surface to flaw (Lig.Embedded) is the minimum ligament thickness between the flaw and the surface. It is only applicable to embedded flaws.

Surface-Thru Thickness on Curved Shells - If the **Apply M Factor** is active the bulging correction factor (*M4.2.1*) will be applied using the specified mean **Diameter**.

Surface Cracks at Weld Toes - If the **Apply Mk** is active the Mk factors are evaluated in accordance with *M5.1.2*. The initial crack method using a size of 0.15 mm is used for the evaluation of Mk at the ends of the crack. The default value for L is 1.25B - this will be entered when B is changed. If the **Loaded Weld** is active the weld will be considered to be load carrying and with a throat thickness of tw.

Level 1A Assessments

Material Properties & Loading

If the **CTOD Mat** is specified as zero the **KI Mat** value will be used for the assessments.

The **Primary, Secondary and Peak** stresses to be used are discussed in *Clause 6.4.*

Note that in the assessments the Secondary stress may be relaxed in accordance with *Clauses 7.2.4.* and *Clauses 7.3.4.*

If the **Reference (Net Section) Stress** is specified as a non-zero value then this value will be used in *Clause 7.2.7 and 7.3.7.* If the value is zero the Net Section stress will be evaluated in accordance with the **Ref Stress Type Option**.

The reference stress will be evaluated by depending upon the active **Ref Stress Type Option.** The evaluations used are:

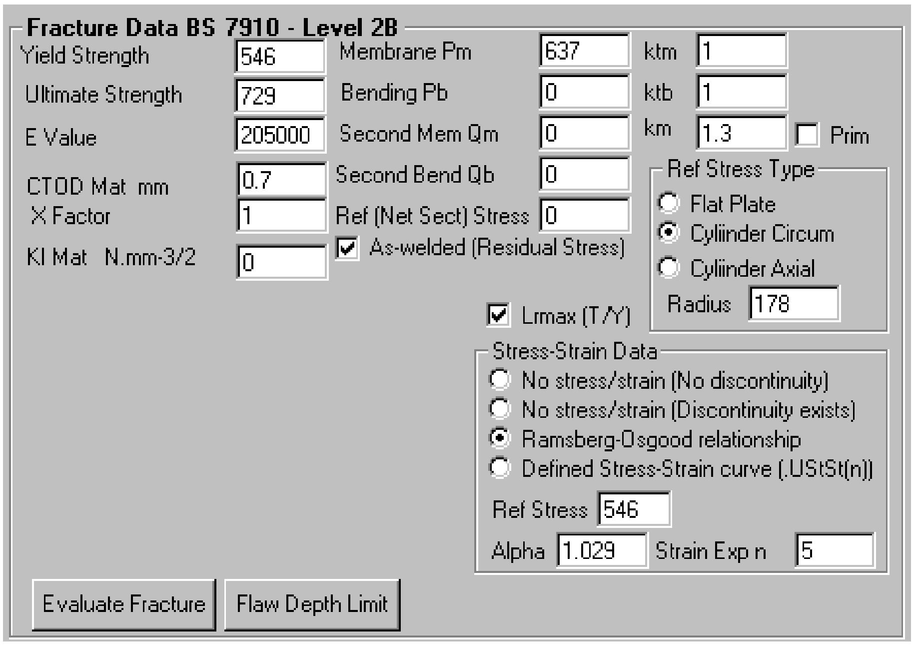
Option	Through, Surface and Embedded
Flat Plate	*Annex P3.1, P.3.2 (Normal Bending Restraint)* and *P3.4*.
Cylinder Circum	*Annex P3.1,* P4.3.2 and *P3.4*.
Cylinder Axial	Annex P4.2.1, P4.3.1 and *P3.4*.

If the **As-welded (Residual)** option is active and no secondary stresses are defined the secondary stress Q will be evaluated in accordance with *Clause 7.3.4.2* for Level 2 assessments.

The SCFs **ktm**, **ktb** and **km** are applied in Accordance with Clauses 7.2.3 and 7.3.5.1. If the **Prim** option is active the **km** stress will be considered primary and the reference stress evaluation will be in accordance with Annex P2.

Level 2 Assessments

The additional data requirements for a level 2 assessment are described below.



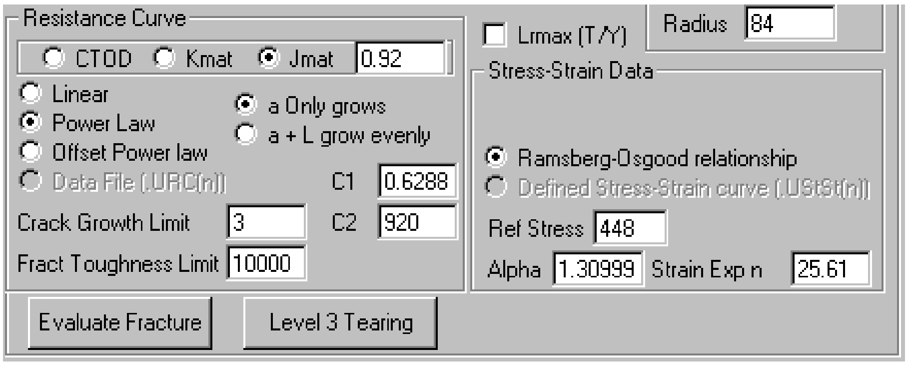
The **X Factor** if the factor defined in *Clause 7.3.6.1*.

Stress-Strain Data These options set the stress/stain options. The first two are for 2A assessments and the latter two for 2B assessments. The No stress/strain (Discontinuity exists) option for the 2A assessments will set the Lr cut-off value to unity (*Clause 7.3.2.1*). The file format for the stress-strain data file if given in Section 9.

The **Lrmax(T/y)** option is used to set the Lr cut-off value to the ratio of UTS/YST. This is not within BS 7910 but may be used for certain assessments in strain controlled applications . Use with CAUTION

Level 3 Assessments

The additional resistance curve data requirements for a level 3 assessment are described below.



CTOD, K or J may be used to define the toughness/crack extension relationship. The following units must be used.

CTOD - mm K - N/mm3/2 J - kN/m (kJ/m2)

If a Jr curve is used an additional factor (f)is required to be defined which is used to convert the J value to a K value using the following expression.

J = f . K . K / E

The default value of 0.91 corresponds to *Clause 7.1.4.2* when u = 0.3

The use of the resistance curve constants is:

Linear C1.a

Power law	C2.a**C1

Offset power law	C3 + C2.a**C1

The **Crack Growth Limit** is used to define the maximum crack extension. The crack increments of 0.02 of this value are used in the evaluation. The initial value is limited to a maximum value of 0.2mm.

The **Fract Toughness Limit** is used to define a limiting value of fracture toughness defined in terms of the definition type eg CTOD value.

The **Level 3 Tearing** button will start the assessment. If the locus lies within the FAD curve the output file will give data relating to the point at which the locus crosses or is within the FAD curve. The Level 3 plot option in the View/Plot menu plots the FAD and assessment locus. Incremental assessment data is also written to a scratch file (Modelname.~Fract).

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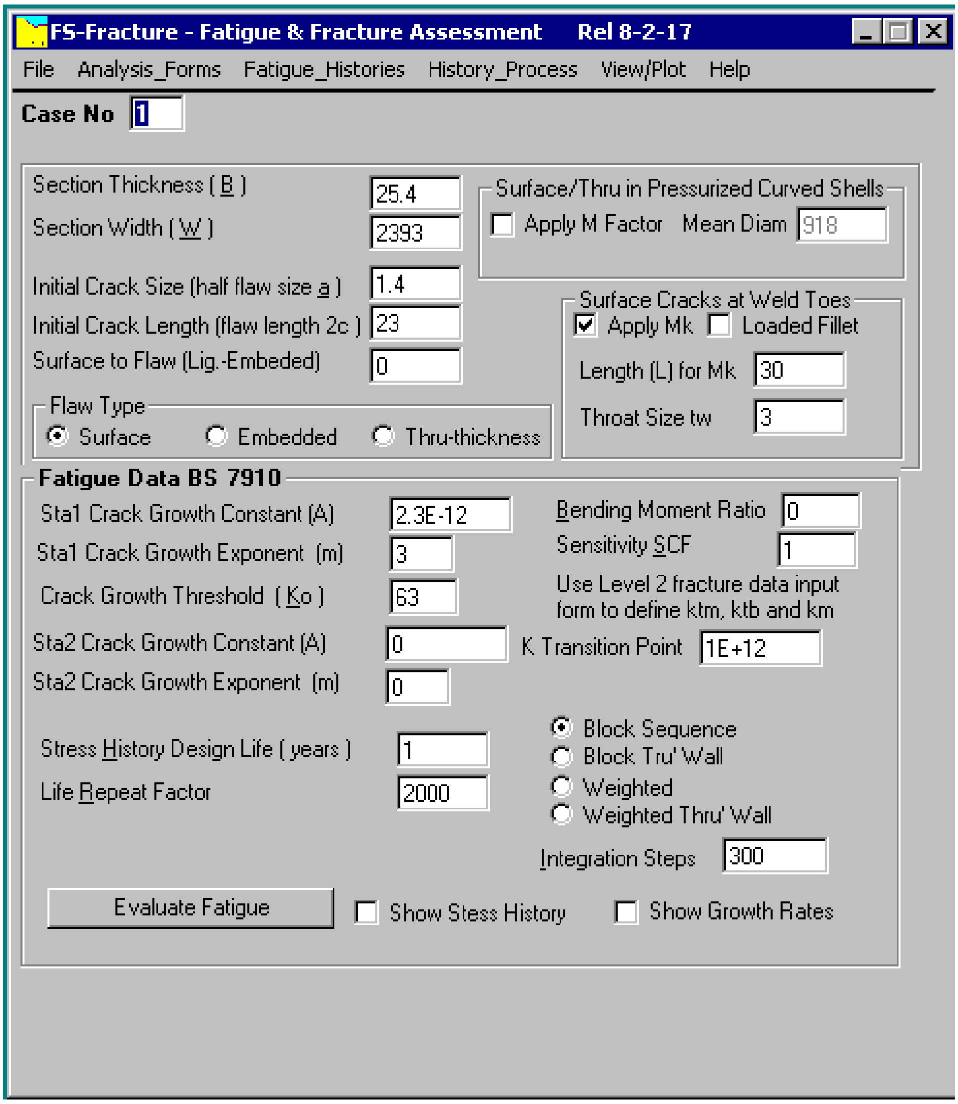
4.0 Fatigue Data - BS 7910

The **Fatigue Data** frame is used to define data that is specific to undertaking a fatigue assessment.

In addition to the data in the frame a stress history must be defined. This data is defined by reading a data file using the commands of the **Fatigue_Data** menu. The Stress Range/Means Stress History is not applicable to this type of analysis since the mean stress would be interpreted as a bending stress.

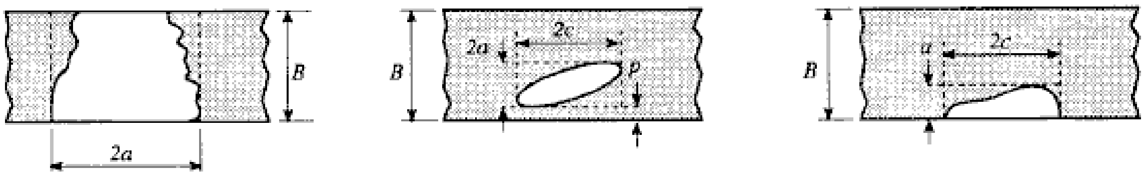
Important - Read the stress history data only after the data options in the form have been set.



The **Evaluate Fatigue** button will perform the fatigue assessment. The results will be written to a 'Fatig' Subcase of Result Case '**CaseNo'.** ie ModelName.FatigT.O1. It can be viewed using the Fracture Output command of the View menu.

Crack Geometry

Flaw Type is the flaw type category. Flaw categories and their dimensions are given *Figure 5*. *Figure 6* gives guidance on flaw interaction.



Section Thickness (B) is the section thickness in the plane of the flaw. (*Figure 8*)

Section Width (W) is the plate width in the plane of the flaw.

Initial Crack Size (a) is dependent upon the type of flaw. (*Figure 8*)

Initial Crack Length (2c) Not applicable to through thickness flaws.

Surface to flaw (Lig.Embedded) is the minimum ligament thickness between the flaw and the surface. It is only applicable to embedded flaws.

Surface-Thru Thickness on Curved Shells - If the **Apply M Factor** is active the bulging factor (*M4.2.1*) will be applied using the specified **Diameter**.

Surface Cracks at Weld Toes - If the **Apply Mk** is active the Mk factors are evaluated in accordance with *M5.1.2*. The initial crack method using a size of 0.15 mm is used for the evaluation of Mk at the ends of the crack. The default value for L is 1.25B - this will be entered when B is changed. If the **Loaded Weld** is active the weld will be considered to be load carrying and with a throat thickness of tw.

Material Properties & Crack Category

Recommendations for the crack growth data A, Ko and M are given on *Clause 8.2.3*. If using a single growth curve ensure that the K transition point is set to a high value.

The **Bending Moment Ratio** is used to evaluate bending stress for stress histories in which only the total stress is defined. This is used when stresses are read from the Total Stress history command of the **Fatigue_Data** menu. The Bending Moment Ratio is defined as:

BMR = Bending Stress / Membrane Stress

It is used when stress histories are being read. It should not be changed once a history has been read.

The **Block Sequence** option will apply the stress history blocks in the same sequence as the stress history data.

The **Block Thru'Wall** option will apply the stress history blocks in the same sequence as the stress history data and if necessary repeat it until the crack depth is greater than the wall thickness.

The **Weighted** options are the same as the above but the stress history is converted to weighted average (see Section 10). If weighted averages are used the life is likely to be shorter since these options require that the crack growth threshold be disabled.

The **Stress History Design Life** is used define the time period applicable to the time history. If this is set to zero the growth rates will be quoted in terms of applied cycles.

The **Life Repeat Factor** is used to apply the stress history a defined number of times.

The **Integration Steps** is used to increase the accuracy of the integration by effectively decreasing the time step. Warning will be given if the time step is too large. To assess the accuracy, increase the Integration Step and observe the effect on the crack size. If the size do not change significantly the solution is can be considered as sufficiently accurate. If this is changed click on any input box then re-read the stress history.

The **Sensitivity SCF** is used to assess the effect of changing stress levels on the predicted growth rates. If factors both the membrane and bending stresses.

The **Show Stress History** will echo the stress history in the output case.

The **Show Growth Rates** will plot selected points of the crack growth history

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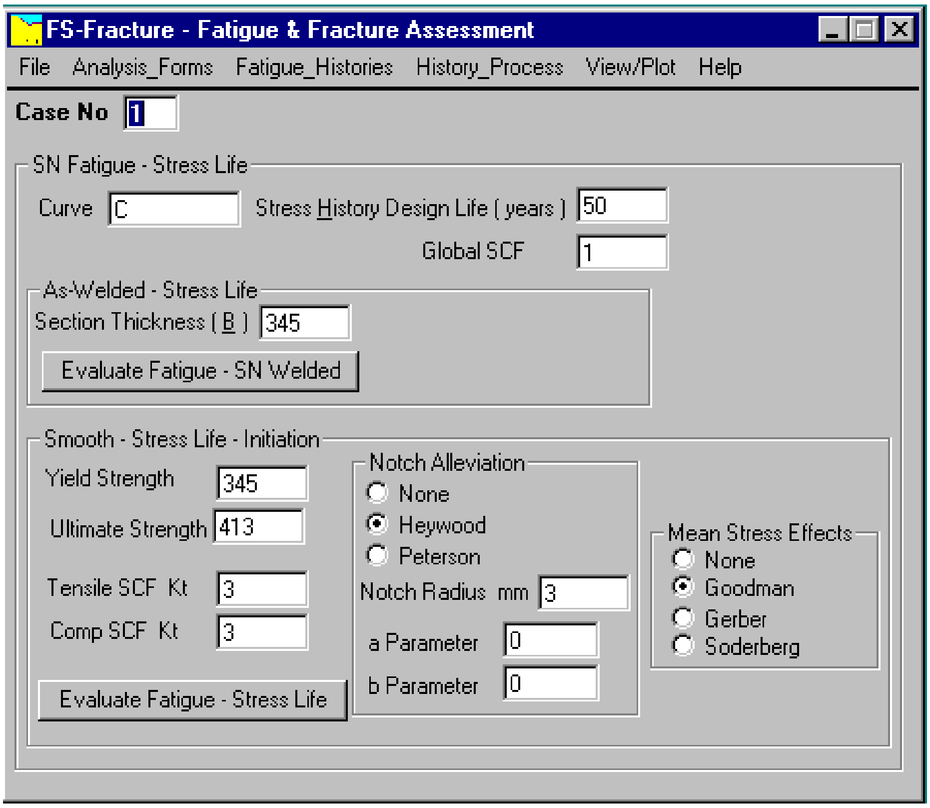
5.0 Fatigue Data - SN Stress Life

The **SN Stress Life** frame is used to define data that is specific to undertaking a fatigue assessment using the stress life approach.

In addition to the data in the frame a stress history must be defined. This data is defined by reading a data file using the commands of the **Fatigue_Data** menu. The Membrane/Bending History is not applicable to this type of analysis since the bending stress would be interpreted as a mean stress.

Important - Read the stress history data only after the data options in the form have been set.



The **Curve** box is used to identify the SN curve to be used. See Section for format details.

The **Stress History Design Life** is used define the time period applicable to the time history.

The **Global SCF** is used to factor the stress date. It may also be regarded as fatigue life reduction factor where values.

As Welded SN Fatigue

The **Section Thickness** is used when the SN curve includes thickness correction.

Smooth - Stress Life - Initiation

The **Tensile** and **Compressive SCF Kt's** are used to define the geometric SCF at the notch. Different tensile and compressive Kt's are only used when load paths are load direction dependent.

The **Yield** and **Ultimate** tensile strengths must be define in N/mm2 (MPa).

The **Notch Alleviation** options is used to enable notch sensitivity factors based on the notch radius defined in the **Notch Radius** box and the notch Kt. Non zero value of the **a** and **b** parameters will be used in defined. Note that b is only used in the Heywood method.

Mean stress effects can be included by selecting the appropriate option from the **Mean Stress Effects** frame.

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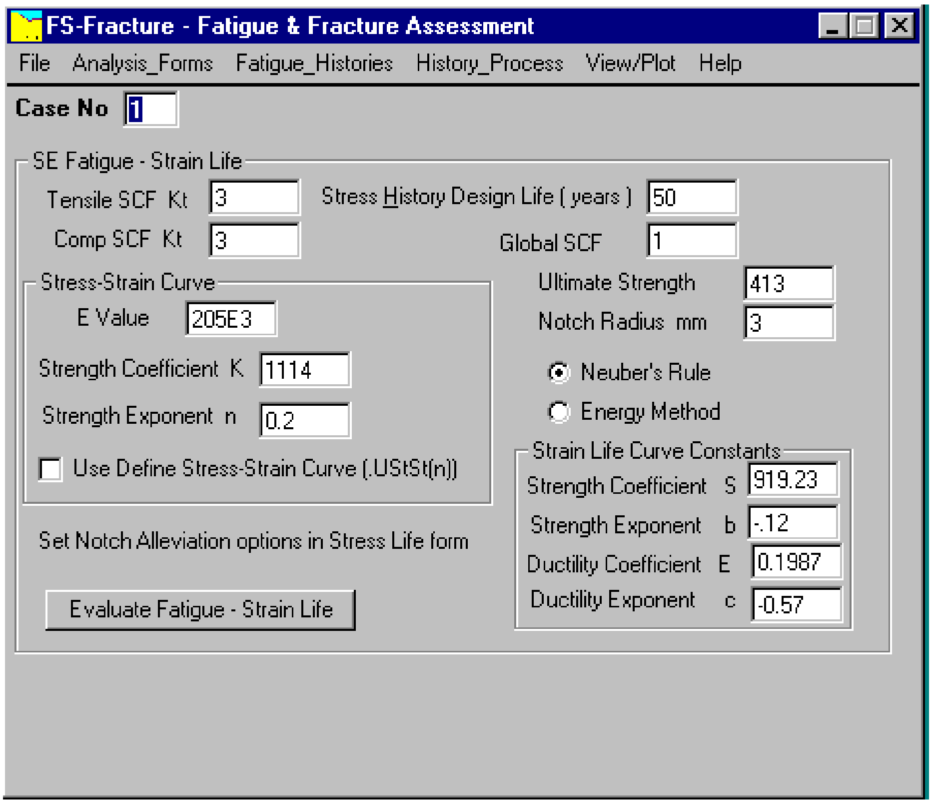
6.0 Fatigue Data - SE Strain Life

The **SE Strain Life** frame is used to define data that is specific to undertaking a fatigue assessment using the strain life approach.

In addition to the data in the frame a stress history must be defined. This data is defined by reading a data file using the commands of the **Fatigue_Data** menu. The Membrane/Bending History is not applicable to this type of analysis since the bending stress would be interpreted as a mean stress.

Important - Read the stress history data only after the data options in the form have been set.



The **Stress History Design Life** is used define the time period applicable to the time history.

The **Global SCF** is used to factor the stress history. It may also be regarded as fatigue life reduction factor where values.

The **Tensile** and **Compressive SCF Kt's** are used to define the geometric SCF at the notch. Different tensile and compressive Kt's are only used when load paths are load direction dependent.

The evaluation of the notch strains can be based on **Neubers Rule** or the **Energy Method**.

The **Notch Radius** is the effective radius used to account for the notch size effect sensitivity. The Notch Alleviation options are defined using the stress Life form.

The stress strain curve for the material can be define by a Ramsberg-Osgood relationship using **E** the **Strength Coefficient K** and the **Strength Exponent N**. It can also be defined using a piecewise stress-strain curve if the **Use Defined Stress-Strain** curve is active. The format for the stress-strain curve is described in Section 8.

The material strain life curve is described by the constants in the **Strain Life Curve Constant's** frame.

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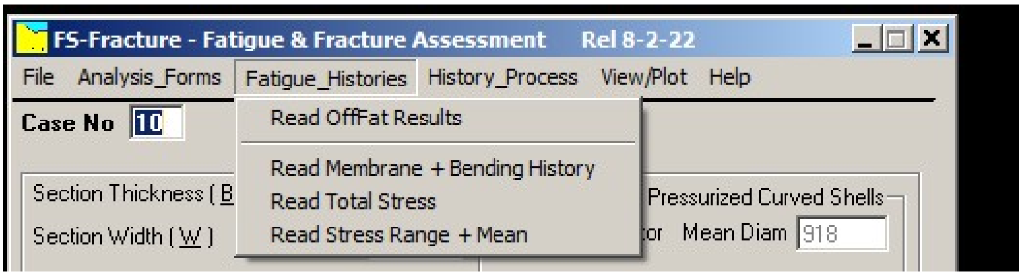
7.0 Fatigue Data

Fatigue data in FS-Fracture is read from the text(ASCII) files described in this section. The file formats are described in Section 9.

Contact AES if other types of file or formats are a requirement.

The **Fatigue_Histories** menu is used to identify fatigue data files.



They listed below by the menu command description.

- **Read OffFat Results**
- **Stress Block Histograms**

Important - Read the stress history data only after the data options in the form have been set.

Irregular Stress

Irregular stress data from user defined data or FS2000 time history solutions can be processed to produce stress data in the Stress Block Histogram format.

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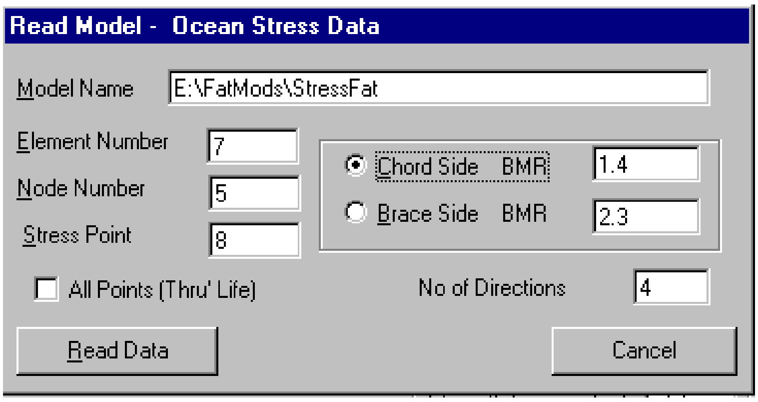
7.1 Offat Results

Read Offat Results:Fatigue Data menu

This command is used to read stress history data from the results of a previously performed offshore fatigue analysis by FS-Offat. When this is command is selected the following form will appear.



The bending moment ratios (BMR) are only used in the BS 7910 flaw based (fracture mechanics) assessments. If the stress is wholly membrane a value of o

The All Points (Thru Life) is used in BS7910 to check all stress points at that joint.

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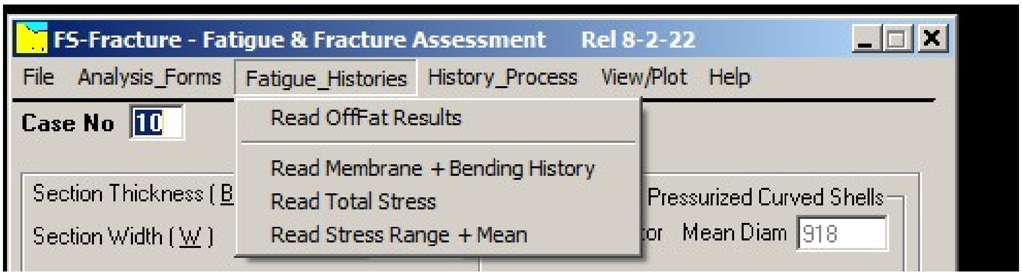
7.2 Stress Block Histograms

There are thre basic type of stress data.formats. These are read using the relevent Fatigue_Histories



Read Membrane + Bending History

Important - Read the stress history data only after the data options in the form have been set because weighted averages (equiv. stress) are evaluated using the growth exponent.

This command is used to read stress history data from an existing file. This type of data is only applicable to the fracture mechanics (BS 7910) fatigue analysis.

Membrane Range ***Bending*** ***Range No of Occurrences***

The default name will be ModelName.UHistB'n' where n is the Case No. This file is a text file that uses the file format described in File Format & Files Used. Any file can be read provided the format is valid.

Read Total Stress History

Important - Read the stress history data only after the data options in the form have been set because weighted averages (equiv. stress) are evaluated using the growth exponent.

This command is used to read stress history data from an existing file. This type of file can be used with all fatigue assessments (mean stress is always zero).

Total Stress Range ***No of Occurences***

The default name will be ModelName.UHistT'n' where n is the Case No. This file is a text file that uses the files format described in File Format & Files Used. Any file can be read provided the format is valid.

A prompt for BMR will be appear when the the total stress format to be read. The BMR only applicable to the fracture mechanics (BS 7910) fatigue analysis and should be set to 0 for SN & SE fatigue assessments.

The membrane and bending proportions of a total stress history can be specified using the bending moment ratio BMR

Membrane Stress = Total Stress / (1 + BMR)

Bending Stress = Membrane x BMR

Read StressRange+Mean

This command is used to read stress history data from an existing file.

Range ***Mean*** ***No of Occurrences***

The default name will be ModelName.UHistM'n' where n is the Case No. This file is a text file that uses the files format described in File Format & Files Used. Any file can be read provided the format is valid.

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7.3 Raw Stress History Processing

The **History_Process** menu is used to access the commands used to process raw stress data to a form suitable for fatigue analysis. Its main purpose is to cycle count a random load history i.e. convert an irregular loading history into a series of single amplitude events.

A raw stress history is a single list of stress values such as those obtained from a time history analysis or from strain gauge signals. The stress data units has to be in N/mm2 (MPa).

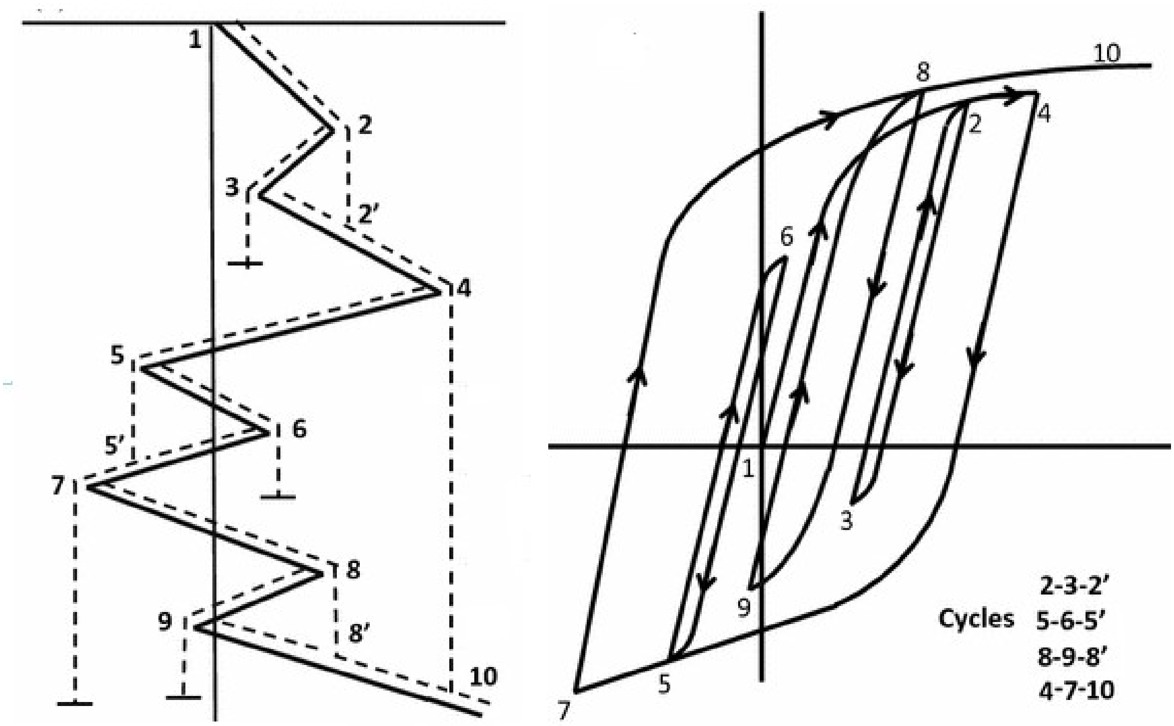
When processed the output file can be read using the **Read Total Stress** or **Read Stress Range+Mean** commands from the Fatigue_ Histories menu command.

Rainflow Cycle Counting

The rainflow algorithm used is a 3 point counting method. that also pairs residual cycles (half cycles). This pairing enables a decreasing (converging) sequence to be processes. It only partially preserve the sequential property of the data. If for example the data was a continually decaying the data would be completely reversed. On a long random history the sequential nature will be broadly followed.

The raw data is first scanned so that the peak/valley points are identified and any intermediate data points eliminated as shown in the two examples below. The peak/valley data can be inspected in the the scratch file: <modelname>.~scr1

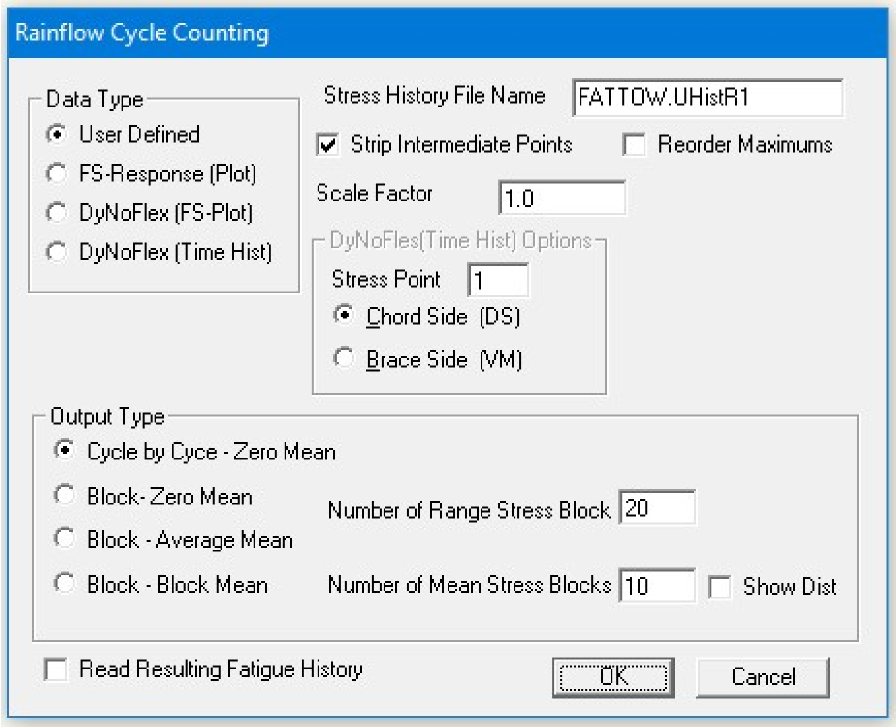
.



In the example above (0, 10, 5, 15, -4,-3, -9, 6, -1, 20), the resulting **Cycle by Cycle Count** output is:

Range	Mean	
5	7.5	1
7	-0.5	1
7	2.5	1
24	3	1

The following input form is used to set Rainfllow Counting Options



Stress History File - This specifies the data to be read. Use the Data Type option to select the file type.

Data Type Options

- **User Defined**
  This will read a user created file <ModelName>.UHistR'r' where r is the Case Number. The format is a simple a list containing the stress data (single column).
- **FS- Response (Plot**
  The results of a transient time history from FS-Response can be used by reading the stress plot file created by FS-Response. <ModelName>.HFT'r' where r is the Case Number used in FS-Response. This is the last plot file used in FS-Response for transient time history solution.
- **DyNoFlex (FS-Plot)**
  The results of a transient time history from DyNoFlex can be read by first plotting the stress data using FS-Graph. FS-Graph produces a file that can be read, <ModelName>.~PLOTF'r' where r is the Case Number used in DyNoFlex plot. Note that this only uses one stress component and is only applicable applicably to axial stress or single component bending stress.
- **DyNoFlex (Time Hist)**
  The results of a transient time history from DyNoFlex using stress points can be undertaken by reading the stress file <ModelName>.ZD where r is the Case Number. This stress file is created using the OffFat modules FATIG1 or FATIG1S. This file and its use is described in more detail in Section 7.4. When this data type option is used a stress point and a stress type have to be specified using the DyNoFlex(TimeHist) Options frame.

Strip Intermediate Points

A raw stress history may contain intermediate points, not just peak and valley points. These intermediate points have to be removed from the data prior to undertaking a rainflow count. If this option is active any intermediate points will be removed from the file. A file named <modelname>.~scr1 is created and this file will only contain peaks and valleys.

Reorder Maximums

The rainflow algorithm is based on an approach that required the first point and the last point in an a history to be the maximum point. This is achieved by reordering the history so that this condition is realised. When this is done the sequential property of the data is lost.

It is not always necessary to reorder the data because the algorthm used will, in most cases, pair residual values and add them on to the end the data and this will more likely retain the sequential property of the data. The odd cycles may be lost but this would not be significant long histories.

It should be note that only the fracture mechanics fatigue approach would be affected by sequence effects i.e. the rate of crack growth would vary. For SN curve fatigue assessments using Miners Rule sequential effect are not included.

Scale Factor

This will scale the raw stress data. This must to be 1E-6 for the plot related data if the model uses S.I unit (converts N/m2 to N/mm2).

Output Type

- **Cycle by Cycle - Zero Mean**
  This will produce a cycle by cycle list. The output file will be a Total Stress history <modelname>.UHistT'r'.
- **Block - Zero Mean**
  This will produce a stress history divided into stress blocks. The output file will be a StressRange+Mean history <modelname>.UHistM'r'. The mean will be zero. The **Number of Range Stress** blocks set the block width based on the max and mins in the data.
- **Block - Average Mean**
  This will produce a stress history divided into stress blocks. The output file will be a StressRange+Mean history <modelname>.UHistM'r'. The mean will be average mean for the whole of the data.The **Number of Range Stress** blocks set the block width based on the max and mins in the data. Only blocks that contain occurrences will be listed.
- **Block - Block Mean**
  This will produce a stress history divided into stress blocks grouped within mean stress blocks. The output file will be a StressRange+Mean history <modelname>.UHistM'r'. The **Number of Range Stress** blocks set the block width based on the max and mins in the data. The **Number of Mean Stress** blocks set the block width based on the max and mins in the data. Only blocks that contain occurrences will be listed.

  The **Show Dist** option can be use to create a distribution table. Note: This for info only and must cannot be used for a fatigue assessment (invalid format).

Read Fatigue Data

If this option is active the resulting fatigue data will be read. This avoids have to us the the **Fatigue_Histories** menu prior to undertaking the fatigue assessment.

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7.4 DyNoFlex Time History

The OffFat fatigue modules FATIG1 and FATIG1S can be used to generate stress data resulting from a DyNoFlex time history solution. These modules evaluate stresses at a specific location (stress point) at a member end. This data can then be processed using the Raw Stress History Processing.

FATIG1 is used for tubular joints. This produces chord side and brace side stresses
FATIG1S is for normal beam stresses (similar to StdOut). The produces direct stresses (axial & bending) and signed VM stresses.

These modules read the **Time History Plot** data created during a DyNoFlex solution and then create a file containing stress point data at a specific element and node. Stresses at all time step plot intervals in the solution are listed. Note Linear beam elements (Type 0) do not produce Time History Plot data.

The modules FATIG1 and FATIG1s are described in the OffFat Help file. These modules have to be run in batch mode.

The command line switches to create the ZD files are given below.

FATIG1 C1/C2/C3/C4/C4/C5/C6/C7/

C1 Number of Locations (stress points) at Brace Joint (Up to 12)

C2 DyNoFlex Results Case Number

C3 DyNoFlex Options Case Number

C4 SCF equations (1-Design Rec: 2-UEG Recommended: 3-HSE : 4-Efthymiou DNV/API/EC3/ISO 1434)

C5 Result Type - Must be set to 1 to create the ZD file.

C6 Element Label

C7 Node Label

C8 Case ID No - This would typically be the used to ID the Elem, Node and Results Case

FATIG1S C1/C2/C3/C4/C5/C6/C7/

C1 Number of Locations (stress points) at member End (Up to 12)

C2 DyNoFlex Results Case Number

C3 DyNoFlex Options Case Number

C4 Not used - Must be set to 0

C5 Result Type - Must be set to 1 to create the ZD file.

C6 Element Label

C7 Node Label

C8 Case ID No - This would typically be the used to ID the Elem, Node and Results Case

Note the C1 in FATIG1S is only applied to tubular elements. Beam elements only have 4 stress points.

The file produces is a text file <model>.ZD(n) file, where n is the Case ID No. This is similar the an OffFat Z where both chord (direct stresses) and brace stresses(VM stresses) are listed. The file format is shown below.

Line of Stress Data (Time Steps), No of Stress Points(Number of columns), Element Label, Node Label Case No Option No

Time Date (when created)
Brace Stress(DS) -----
Chord Stress(VM)

e.g.

```
 100          8            4            4
 120          120
11:21:37      06/10/2020
8.761E+05 7.892E+05 7.905E+05 5.602E+05 5.522E+05 1.090E+06 1.540E+06 1.319E+06
1.171E+06 6.822E+05 5.269E+05 3.157E+05 6.529E+05 1.822E+06 2.657E+06 2.188E+06
7.591E+05 -4.373E+05 -1.334E+06 -1.432E+06 -6.474E+05 5.843E+05 1.517E+06 1.579E+06
1.162E+06 -6.714E+06 -1.184E+07 -1.044E+07 -4.104E+06 2.675E+06 6.704E+06 6.399E+06
4.787E+05 -2.550E+06 -4.933E+06 -4.783E+06 -2.679E+06 -3.448E+05 1.343E+06 1.888E+06
...
...
etc
```

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8.0 Menu Commands

The following Menu commands are used

File

- Open Case Data
- Save Case Data
- Run FSEdit
- Exit

Analysis_Forms

- Fracture BS 7910
- Fatigue BS 7910
- Fatigue SN Stress Life
- Fatigue SE Strain Life

Fatigue_Data

See Section 7 for more information on these options

- Read Offat Results
- Ream Membrane/Bending Stress History
- Read Total Stress History
- Read Stress Range/Mean History

History_Process

- RainFlow Cycle Count
  - Cycle By Cycle Count
  - Zero Mean Block
  - Average mean Block

View/Plots

- Fracture Output
- Fatigue Output

- Crack Depth Plot
- Crack Length Plot
- Crack Depth Ratio
- Weld SCF (Mk)

- FAD Level 1
- FAD Level 2

- Stress Histogram
- Damage Ratios (SN)

Damage Ratios (SE)

Component SN Curve

Components SN(SE) Curve

The following provides a more detailed description of the use of some of the above commands.

File Menu

Open Case Data:File menu

When this is command is selected the user is required to enter the name of an existing definition file. The default name will be ModelName.UFDef'n' where n is the Case No. It is always recommended that the default name be used.

Open Case Data:File menu

When this is command is selected the user is require to enter the name of the definition file to which the current assesssment setttings are to be saved. The default name will be ModelName.UFDef'n' where n is the Case No. It is always recommended that the default name be used.

Stress histories are not save in the UFDef file.

Run FS-Edit:File menu

This command will run FS-Edit a text editor. This text editor can be used to create stress history files. The format and naming convention of stress history files are given in File Format & Files Used.

Data Menu

Read Offat Results:Fatigue Data menu

This command is used to read stress history data from the results of an offshore fatigue analysis using FS-Offat. When this is command is selected the following form will appear.

Read Membrane + Bending History:Fatigue Data menu

This command is used to read stress history data from an existing file. The default name will be ModelName.UHistB'n' where n is the Case No. This file is a text file that uses the file format described in File Format & Files Used. Any file can be read provided the format is valid.

Read Total Stress History:Fatigue Data menu

This command is used to read stress history data from an existing file. The default name will be ModelName.UHistT'n' where n is the Case No. This file is a text file that uses the files format described in File Format & Files Used. Any file can be read provided the format is valid.

Read StressRange+Mean History:Fatigue Data menu

This command is used to read stress history data from an existing file. The default name will be ModelName.UHistM'n' where n is the Case No. This file is a text file that uses the files format described in File Format & Files Used. Any file can be read provided the format is valid.

View/Plot menu

Always run the assessment before using the plot routines

Fracture Output

Displays the text results data for Fracture assessment for the current case number

Fatigue Output

Displays the text results data for Fatigue assessment for the current case number.

Crack Depth Plot

Plots the crack depth as a function of cycles or time.

Crack Length Plot

Plots the crack length as a function of cycles or time.

Crack Depth Ratio

Plots the ratio crack depth to crack length as a function of cycles or time.

Weld SCF (Mk)

Plots the Mk (local weld SCF) at the deepest point and ends of a surface crack as a function of cycles or time.

FAD Level 1A

Failure assessment diagram to BS 9710 Level 1A

FAD Level 2

Failure assessment diagram to BS 9710 Level 2A or 2B

FAD Level 3 Tearing

Failure assessment diagram to BS 9710 Level 3A or 3B

Stress Histogram

Plots the Stress Range/Number of Occurrences histogram for the most recently read stress history.

Damage Ratios (SN)

Plots the Damage Ratios as a function of Stress Range for the most recently run Stress Life fatigue assessment.

Damage Ratios (SE)

Plots the Damage Ratios as a function of Stress Range for the most recently run Strain Life fatigue assessment.

Component SN Curve

Plots the Stress History stress range as a function of Number of Cycles to failure for the most recently run Stress Life fatigue assessment.

Components SN(SE) Curve

Plots the Stress History stress range as a function of Number of Cycles to failure for the most recently run Strain Life fatigue assessment.

Stress-Strain Data

Plots the stress- strain data for the Ramsberg-Osgood curves.

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9.0 File Format & Files Used

The following files are files that would be created by the user for use by FS-Fracture.Use FS-Edit (File menu) or any other plain text editor to create them.

Assessment Property Definition

ModelName.UFDef'n' where 'n' is the Case Number

Stress History Data - Membrane + Bending History

ModelName.UHistB'n' where 'n' is the case number

Format - Text File - Simple list

The list should hold no more that 5000 entries

Membrane Stress Range Bending Stress Range Number of Occurrences

Eg

0.1	**0.3**	**7447**
0.8	**2**	**3239**
2.4	**5.4**	**1409**
4.6	**10.5**	**613**

Stress History Data - Total Stress History

ModelName.UHistT'n' where 'n' is the case number

Format - Text File - Simple list

The list should hold no more that 5000 entries

Total Stress Number of Occurrences

Eg

0.1	**7447**
0.8	**3239**
2.4	**1409**
4.6	**613**

Stress History Data - Stress Range + Mean History

ModelName.UHistM'n' where 'n' is the case number

Format - Text File - Simple list

The list should hold no more that 5000 entries

Stress Range Mean Stress Number of Occurrences

Eg

0.1	**130**	**7447**
0.8	**50**	**3239**
2.4	**78**	**1409**
4.6	**43**	**613**

SN Data

Fatigue life damage based on the following expression

$$LOG(N) = LOG(K2) - mLOG(Sr) - mLOG(Sr/(tref/t)^{q})$$

The curve definition permits two slopes to be defined Slope a and Slope b . Sl is the stress range at which the slope changes.

K2a ma SL K2b mb EndurLim tref q

If tref is defined as zero it will be ignored.

The SN curve constants are read from a text data files named SNCURVE.DAT or ModelName.USNC. This file SNCURVE.DAT **MUST EXIST** in the FS2000 directory. This file may be extended to include user defined curves. The file format (and the file supplied) is given below.

```
 B
15.0055   4  100.3172  17.00688  5    0    .022       .25
C
13.626   3.5 78.18847  16.46571  5    0    .022       .25
D
12.1817   3  53.36218  15.63617  5    0    .022       .25
E
12.0151   3  46.95698  15.3585   5    0    .022       .25
F
11.8004   3  39.82296  15.00067  5    0    .022       .25
F2
11.6342   3  35.05366  14.72367  5    0    .022       .25
G
11.3939   3  29.14965  14.32317  5    0    .022       .25
W
11.197    3  25.0611   13.995    5    0    .022       .25
T
12.1638   3  52.63401  15.60633  5    0    .032       .25
GR
25.43    7.3 0         25.43    7.3   0     0 0
```

Material Stress Strain Definition

The material stress strain relationship for strain life fatigue analysis can be defined using a piecewise curve i.e. a curve defined by discrete data points. The file must be named as ModelNmae.UstSt. The format for the curve is

No of Points

Stresss Strain

Eg

```
9
50     244E-6
10     493E-6
150    776E-6
200    1162E-6
250    1789E-6
```

300	2880E-6
350	4769E-6
400	7920E-6
413	9199E-6

Assessment Results

The assessment results become registered result cases of FS2000. The text files created are.

Fracture Assessments ModelName.Fract.O'n' where 'n' is the case number

Fatigue Assessments ModelName.Fatig.O'n' where 'n' is the case number

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10.0 Background Theory

This section presents the basic background theory to the Stress Life and Strain life approaches to fatigue assessments. The references listed at the end of this section provide more thorough description

In both methods the damage summation employs the Palmgren-Miners hypothesis (Linear Damage Rule).

Total Damage = ni/Ni I = 1 to Number of stress blocks

Stress Life - Welded Components

Stress life methods when applied to welded structures are generally concerned with total life, where the predominant life is during the crack propagation phase. SN curves such as the C curve and F are typically used in such cases.

Non-Welded Components

Stress Life and Strain Life methods when applied to machine (smooth) surfaces are concerned with the prediction of life to crack initiation. In such cases the life to crack initiation is far greater than that due to the propagation phase. The background to how the program performs this type of analysis is given in following sections.

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10.1 Stress Life

Stress Life methods are generally applied to high cycle fatigue/low stress range applications. Material data (SN curves) are often readily available. Various method and correlations are available to use stress life methods in low cycle applications. This program offers the Heywood method to achieve this.

Notch Alleviation at Infinite Life (10E7 cycles)

Heywood

Kf = Kt / (1 + 2*((Kt-1) / Kt)*(a/ r)**.5)

Kt = elastic notch SCF

R = notch radius

a = material constant Default = (104/UTS)**0.5 for steel

For Steel	Transverse hole	(174/UTS)**0.5
	Shoulder	(139/UTS)**0.5
	Groove	(104/UTS)**0.5
Aluminium alloys		(834/UTS)**0.53
Cast Iron		3.05
Cats Iron -Spheroidal Graph		173/UTS
Cast Steels		0.863
Magnesium Alloys		0.381
Titanium Alloys (notch sensitive)		1E-6

Peterson

Kf = 1 + (Kt - 1)/((1 + a/r)

Kt = elastic notch SCF

R = notch radius

a = material constant Default = (270.2/UTS)**1.8 for steel

Notch Alleviation at Finite Life

Heywood

Kf ' = Ks + (Kt - Ks)*q

q = (logN)**4/(b + (logN)**4) + (1 - 7**4/(b +7**4)*N/1E7

q = 1 for N > 1E7

b = material constant Default = (12066/ULT)**2

Steel	(12066/ULT)**2
Aluminium (Al-Zn-Mg)	25
Aluminium (Al-Cu)	60
Magnesium Alloys	80

Ks = 1 for N > 10E4 Ks = 1.1 for N < 10E4

Peterson

If the Peterson option is active Kf ' = Kf

Alternative methods to account for this effect are

- Take q = 0 or q = .2 at 10E3 cycles and assume a log linear relationship to 10E7 cycles.
- The fatigue strength at 1E6 cycles is divided by Kf. Th notched stress life curve is approximated by a line drawn between this point and the unnotched fatigue strength at 1 cycles.
- The fatigue strength at 1E6 cycles is divided by Kf. Th notched stress life curve is approximated by a line drawn between this point and the unnotched fatigue strength at 10E3 cycles.

Mean Stress Notch Alleviation

Heywood

Kfm ' = Ks + (Kf - Ks)*qm

qm = (1 - (Stmn + Stan)/UTS)**2

Stmn = Nominal mean stress

Stan = Nominal alternating stress

Ks = 1 for N > 10E4 Ks = 1.1 for N < 10E4

This correlation lies somewhere between the methods of applying Kf to nominal mean stresses or using nominal mean stresses.

Peterson

If the Peterson option is active Kf is applied to the nominal mean stress.

Mean Stress Effects - SN Curve

Goodman	Sa = San(1 - Sm/ULT)
Gerber	Sa = San(1- (Sm/ULT)**2)
Soderberg	Sa = San(1 - Sm/YST)

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10.2 Strain Life

Strain Life methods can applied to both high cycle fatigue/low stress range applications and low cycle fatigue/high stress range applications. Material data (Strain life curves) are not often available.

To undertake a low cycle fatigue analysis requires that the plastic strains be known. The program offers Neubers Rule or the Equivalent Energy Method for the evaluation of Notch plastic strains using elastic Kt's.

Neuber's Rule

(Kf'S)**2/E = StressN**2/E

Energy Method

(Kf'S)**2/E = (StressN)**2/2E + StressN/(n + 1)(StressN/K)**1/n

Kf = Notch fatigue coefficient

S = Nominal Stress

StressN = Elasto/plastic notch stress

E = Modulus of Elasticity

n = Cyclic Strain hardening coefficient

K = Cyclic strength coefficient

Stress/Strain Relationship

The above equations are solved in conjunction with the material cyclic stress-strain curve. In the program this can be represented by a Ramsberg-Osgood relationship

ie DStrain = Dstress/E + (DStress/K)**1/n

$\varepsilon = \sigma / E + (\sigma / K)^{**}1/n$

Or a numerical procedure where the stress/strain curve is represented by a piecewise curve comprising of a finite number of linear elements.

Mean Stress Effects

Mean stress effects are taken into account by including them into the elastic component of the Manson-Coffin relationship.

Strain/2 = (Sf - Sm)/E(2Nf)**b + ef("Nf)**c

Sm = Mean Stress

Nf = Number of cycles to failure

Sf = Strength Coefficient

b = Strength Exponent

ef = Ductility Coefficient

c = Ductiliy Exponent

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11.0 Validation Examples

Example 1 BS 7910 - Leve 1A and Level 2A Fracture Assessments

A cylindrical as-welded pressure vessel contains an internal axial surface penetrating flaw, 10 mm deep and 54mm long in a longitudinal seem weld. The stresses in the section where the stress is located is subject to a linearly varying stress distribution from 320 MPa at the inner surface to 200 MPa at the outer surface.

Vessel configuration
- Length = 5m
- OD = 1.86m
- Wall thickness = 50mm

Crack Size
- Depth (a) = 10mm
- Lenght (2c) = 54mm

Material Properties
- Yield = 480 MPa
- UTS = 610 MPa
- E = 208 GPa
- Minimum CTDO = 0.17mm

Since the welds are in their as welded condition the residual stresses are assumed to be tensile and equal to the yield stress for the Level 1 assessment. For the Level 2 assessment the residual stress are evaluated in accordance with Clause 7.3.4.2.

The input and output from the assessment is given below. The results are as those obtained from TWS's Crackwise program.

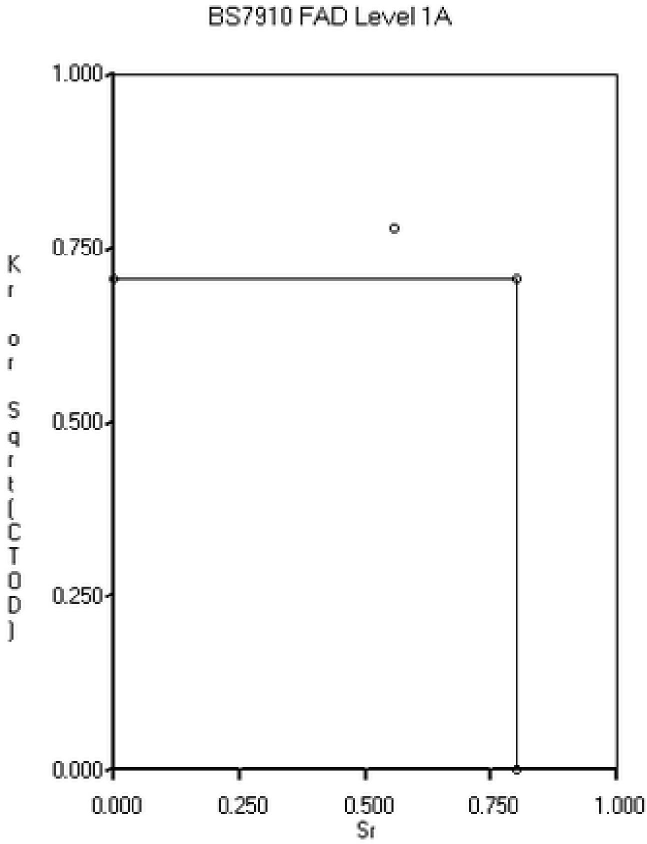
Level 1A Assessment

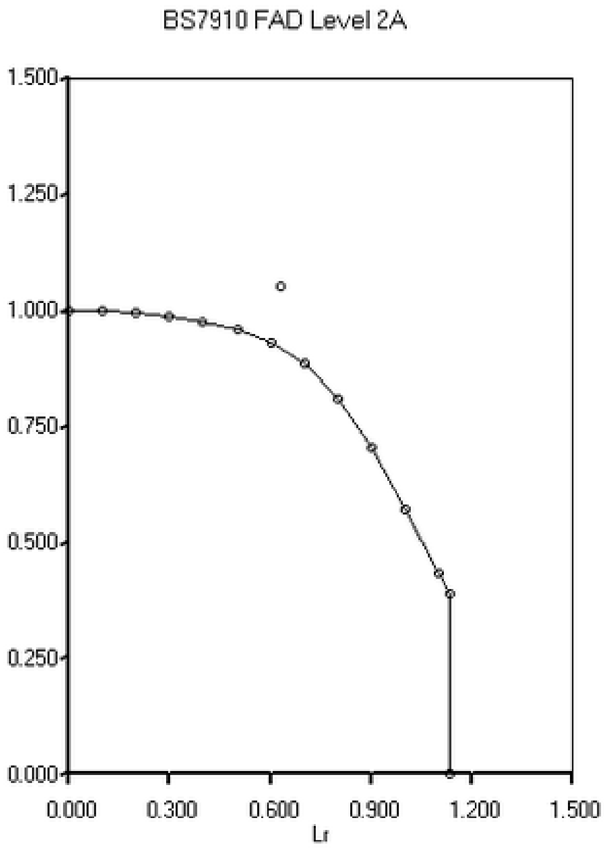
```
Material Properties (N/mm2)
    Yield Strength            480
    Ultimate Strength         610
    Modulus of Elasticity     208000
Material Toughness
    CTOD(mm)                 0.17
Dimensions (mm)
    Thickness  50
    Width      5000
Stresses (N/mm2)
    Pm             260
    Pb             60
    Qm             480
    Qb             0
    Def.Net (Ref)  0
Stress Concentrations
    Ktm      1
    Ktb      1
    Km       1
Flaw Type         Surface
    Flaw Size a       10
    Flaw Length 2c    54
    a/B=0.200     a/2c=0.185

CALCULATED RESULTS
    Calculated Reference (Net Section) Stress (N/mm2)   303.6945
    Flat plate Annex P
Level 1A

    Finite Width Factor fw           1
```

```
    Mm  =1.003    Phi = 1.133    Y = 1.003
    Applied CTOD                (mm)       0.103
    Applied Stress Intensity KI (Nmm-3/2)  4497.608
    Kr(Sqrt(CTOD) Level 1                  0.780
    Flow Stress                            545
    Sr                                     0.557

Flaw is NOT ACCEPTABLE at Level 1A
```

Level 2A Assessment

```
Material Properties (N/mm2)
    Yield Strength           480
    Ultimate Strength        610
    Modulus of Elasticity    208000
Material Toughness
    CTOD(mm)                0.17
Dimensions (mm)
    Thickness  50
    Width      5000
Stresses (N/mm2)
    Pm             260
    Pb             60
    Qm             0
    Qb             0
    Def.Net (Ref)  0
Stress Concentrations
    Ktm      1
    Ktb      1
    Km       1
    As-welded residual stresses = 404.5259
Flaw Type         Surface
Flaw Dimensions (mm)
    Flaw Size a       10
    Flaw Length 2c    54
    a/B=0.200     a/2c=0.185

CALCULATED RESULTS
    Calculated Reference (Net Section) Stress (N/mm2)   303.6945
    Flat plate Annex P
Level 2A
    Finite Width Factor fw = 1
    Mm   = 1.003   Mb  = 0.756    Mkm  = 1.000   Mkb  = 1.000
    Mme  = 0.680   Mbe = 0.628    Mkme = 1.000   Mkbe = 1.000
    KId (Nmm-3/2)    1715.86    KIe (Nmm-3/2)    1202.26
    Phi = 1.133
    Applied CTOD                (mm)           0.159
    Primary Stress Intensity KI (Nmm-3/2)      1715.86
    Secondary Stress Intensity KI (Nmm-3/2)    2274.25
    Applied Stress Intensity KI (Nmm-3/2)      3990.11
    Plasticity Factor                          0.083
    Kr(Sqrt(CTOD)                              1.052
    Lr                                         0.633
Flaw is NOT ACCEPTABLE at Level 2A
```





Example 2 BS 7910 - Level 2A Fracture Assessment

A line pipe contains an external surface crack located in the HAZ of a longitudinal seem weld. Residual stresses are not significant.

Pipeline configuration
- Length = 5.029m
- OD = 918mm
- Wall thickness = 15mm

Crack Size
- Depth (a) = 5.7mm
- Lenght (2c) = 47.5mm

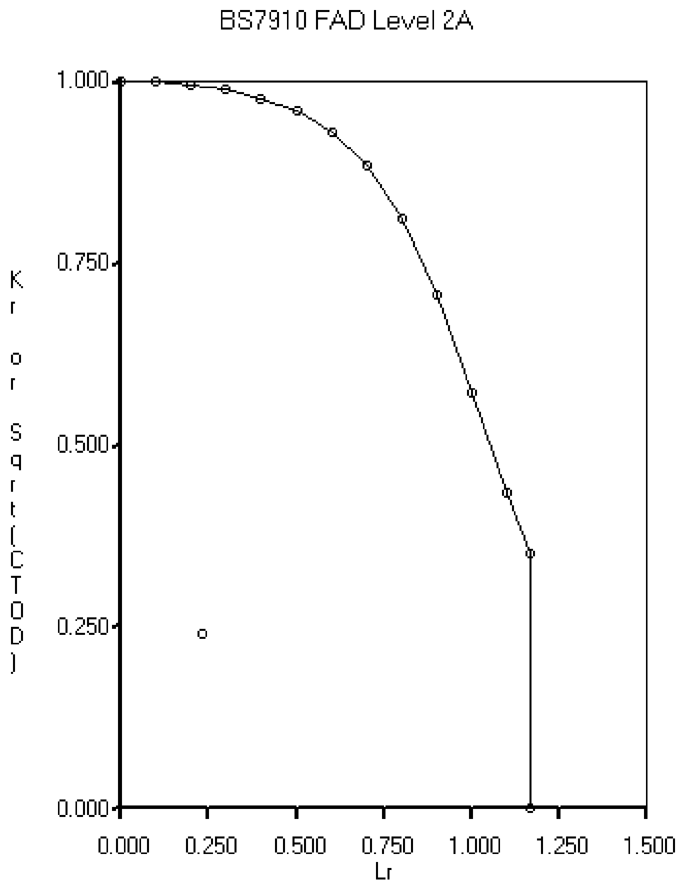
Material Properties
- Yield = 533 MPa
- UTS = 713 MPa
- E = 210 GPa
- Minimum CTDO = 0.045mm

The input and output from the assessment is given below. The results are as those obtained from TWS's Crackwise program

Level 2A Assessment

```
Material Properties (N/mm2)
    Yield Strength           533
    Ultimate Strength        713
    Modulus of Elasticity    210000
Material Toughness
    CTOD(mm)                0.045
Dimensions (mm)
```

```
    Thickness  15
    Width      5029
    Diameter   918
Stresses (N/mm2)
    Pm             100
    Pb             0
    Qm             0
    Qb             0
    Def.Net (Ref)  0
Stress Concentrations
    Ktm      1
    Ktb      1
    Km       1
Flaw Type         Surface
Flaw Dimensions (mm)
    Flaw Size a       5.7
    Flaw Length 2c    47.6
    a/B=0.380     a/2c=0.120

CALCULATED RESULTS
    Bulging Correction Factor        1.036749
    Calculated Reference (Net Section) Stress (N/mm2)   124.5453
    Axially oriented in cylinder Annex P
    Radius  444
Level 2A
    Finite Width Factor fw = 1
    Mm   = 1.228   Mb  = 0.689    Mkm  = 1.000   Mkb  = 1.000
    Mme  = 0.691   Mbe = 0.595    Mkme = 1.000   Mkbe = 1.000
    KId (Nmm-3/2)    538.75    KIe (Nmm-3/2)    303.35
    Phi = 1.067
    Applied CTOD                 (mm)            0.003
    Primary Stress Intensity KI (Nmm-3/2)        538.75
    Secondary Stress Intensity KI (Nmm-3/2)      0.00
    Applied Stress Intensity KI (Nmm-3/2)        538.75
    Plasticity Factor                            0.000
    Kr(Sqrt(CTOD)                                0.240
    Lr                                           0.234
Flaw is ACCEPTABLE at Level 2A
```



Example 3 BS 7910 - Level 3B Fracture Assessment (Ductile Tearing)

An aluminium tubular brace has an 80mm long through thickness crack. Establish the limiting flaw size. The axial stress in the strut is 140 MPa.

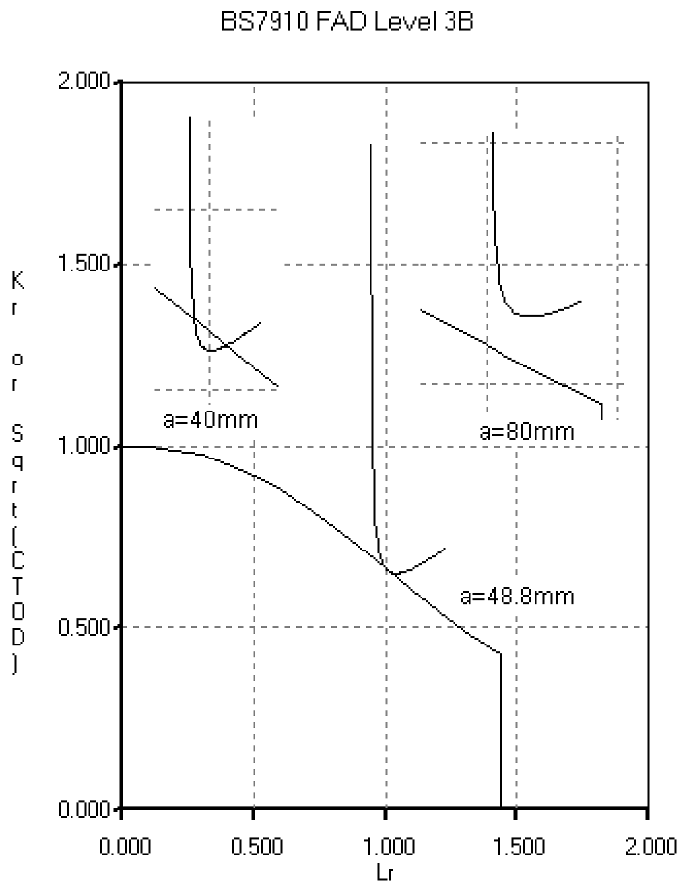
Tube configuration
- Length = 10m
- OD = 300mm
- Wall thickness = 10mm

Crack Size
- Depth (a) = 5.7mm
- Lenght (2c) = 80mm

Material Properties
- Yield = 165 MPa
- UTS = 310 MPa
- E = 70 GPa
- Stress Strain Curve - Ramsberg-Osgood $\varepsilon / \varepsilon o = \sigma / \sigma o + \alpha(\sigma / \sigma o)^{**}n$
- εo = .00236
- σo = 165
- n = 4.96
- α = 1.029
- Fractire toughness
- CTOD R-Curve Power Law $\delta = 0.184(\Delta a)^{**}0.512$

Level 3B Assessment

The plots below show the assessment locus cuts the FAD for crack sizes less than 48.8mm. A solution from Crackwise produced a value of 50.2 mm. The slight differences between the two solutions can be expected since the two programs are unlikely to use the same increments to generate the FAD curve intersection point.



Example 4 BS 7910 - Fracture Mechanics Fatigue Assessment

A tubular contains an external surface crack 1.4mm deep and 23mm long located adjacent to fillet weld. The mean diameter is 761.7mm and the wall thickness is 25.4mm

The stress history is given as

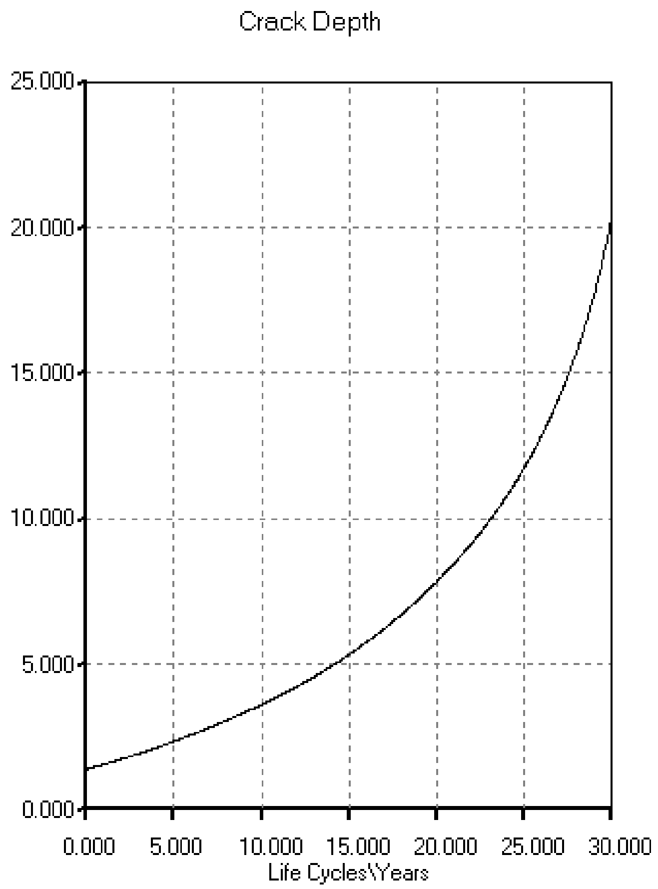
Membrane 20.8 MPa
Bending 48 MPa
Number of Cycles 3E5

Estimate the crack growth.

The input and output for the assessment is given below. TWS's Crackwise program predicted a final size of a=20.23 and c=129.03.

```
INITIAL FLAW SIZE a  1.4         LENGTH 2c 23
Flaw Type  Surface
FINAL FLAW SIZE    a 20.30       LENGTH 2c 260
Duration for Crack Propogation              30  Years

Integration Parameters
Number of Integration Increments      1000
 Crack Increment Ratio (%)  (<0.5) 0.4773242
```

```
 Cycle Increment                    3.000E+02
 Cycle Increment Ratio (%)   (<0.1) 3

Stress History Repetition Factor      30
Total Number of Cycles in History     1.000E+04
Applied Number of Cycles in           3.000E+05
Processed Number of Fatigue Cycles    3.000E+05
Stress History Design Life            1

Material Properties
 Threshold Ko = 63
 Crack Growth Constants m = 3    A = 2.300E-12

Dimensions
 Thickness     25.4
 Width         2393
 Lenght for Mk 43

Sensitivity SCF  1
Stress Concentrations
    Ktm      1
    Ktb      1
    Km       1
Global Bending Moment Ratio B/M  0

Stress History FExp4.UHistB1

*** Stress Range History
Total      Membrane     Bending   No Cycles
 68.80        20.80     48.00     10000.0
```



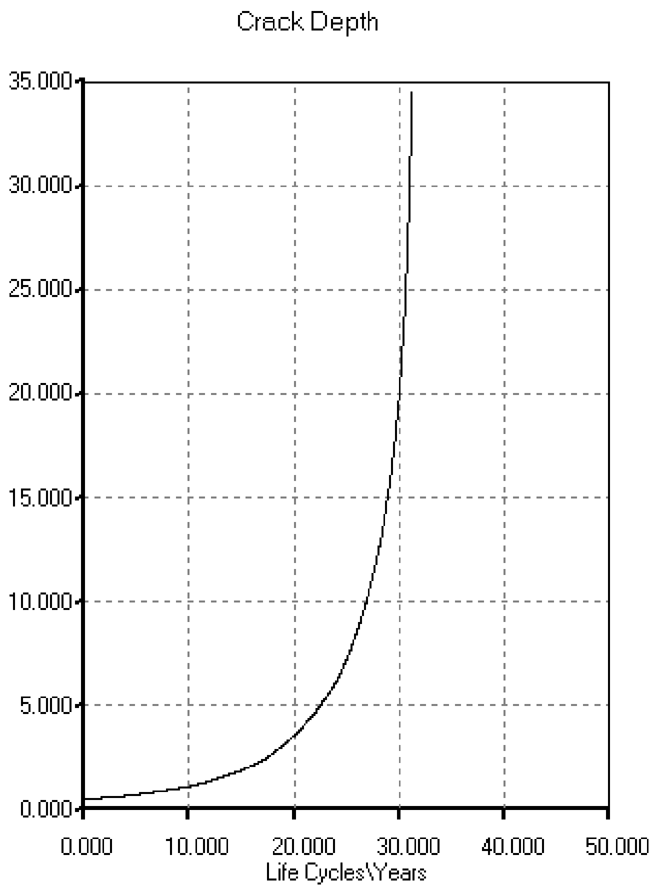
Example 5 BS 7910 - Fracture Mechanics Fatigue Assessment

A tubular joint contains an external surface crack on th chord side 0.5mm deep and 20mm long located in the HAZ. The mean diameter is 1600mm and the wall thickness is 35mm. The stress history data is obtained from a fatigue analsysis which gives the total stress stress at the location of the crack. For the purpose of the assessment the bending moment to membrane stress ratio is taken as 1.4.

The input and output for the assessment is given below. TWS's Crackwise program predicted a through thickness crack at 62.2%

```
**** CRACK THROUGH/AT WALL AT  62.4 % OF LIFE ie 31.2  Years

INITIAL FLAW SIZE a  0.5         LENGTH 2c 2
Flaw Type  Surface

FINAL FLAW SIZE    a 37.03       LENGTH 2c 574.46

Duration for Crack Propogation              31.2  Years

Integration Parameters

Number of Integration Increments      2000
 Crack Increment Ratio (%)  (<0.5) 5.74156
 Cycle Increment                   1.301E+04
 Cycle Increment Ratio (%)  (<0.1) 2.477987E-02

Stress History Repetition Factor      1
Total Number of Cycles in History     5.250E+07
Applied Number of Cycles in           5.250E+07
Processed Number of Fatigue Cycles    3.276E+07
Stress History Design Life            50

Element No  7    Node No  5   Point  8
Chord Side
Material Properties
 Threshold Ko = 63
 Crack Growth Constants m = 3    A = 2.300E-12

Dimensions
 Thickness     35
 Width         5029
 Lenght for Mk 43

Sensitivity SCF  1
Stress Concentrations
    Ktm      1
    Ktb      1
    Km       1
Global Bending Moment Ratio B/M  1.4

Stress History OffFat

*** Stress Range History
```

Total	Membrane	Bending	No Cycles
7.03	2.93	4.10	26018810.0
14.43	6.01	8.42	13123970.0
20.16	8.40	11.76	6619773.0
25.13	10.47	14.66	3339035.0
29.63	12.34	17.28	1684220.0
33.79	14.08	19.71	849526.0
37.08	15.45	21.63	428503.7
39.55	16.48	23.07	216138.4
41.84	17.43	24.41	109021.1
43.99	18.33	25.66	54990.6
46.53	19.39	27.14	27737.5
49.49	20.62	28.87	13990.9
52.37	21.82	30.55	7057.0
55.17	22.99	32.18	3559.6
57.91	24.13	33.78	1795.5
60.58	25.24	35.34	905.6
63.20	26.33	36.87	456.8
65.77	27.41	38.37	230.4
68.30	28.46	39.84	116.2
70.78	29.49	41.29	58.6


Crack Depth
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
0.000
10.000
20.000
30.000
40.000
50.000
Life Cycles\Years

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