NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Attachment V
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1. IR 296: FlawCheck Manual. Pages: 3-9

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Input / Output Files

OVERVIEW

The BMT Fleet Technology Limited flaw assessment tool, ***FlawCheck***, was developed to support design analysis and integrity programs for metallic structures. The tool utilizes loading data for fatigue analysis and/or the determination of the potential for failure due to the presence of flaws in steels. The software package is designed to:

- use accepted industry analytic techniques;
- facilitate the assessment process;
- provide easily interpreted intermediate and final results;
- document the analysis assumptions and procedures
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- The software package is comprised of 3 analysis modules (loading data characterization, fatigue analysis and failure assessment) and a reporting module. The load characterization module is able to transform raw time-loading data into a loading spectrum. The spectrum is representative of actual service loading data and can be used to estimate the fatigue life to a specified limiting criterion. The failure assessment module can be used to determine the safety factor for a particular flaw size (or range of flaws) and the governing failure mode, whether it be fracture or plastic collapse. The final reporting module is used to assemble the selected analysis results into a comprehensive summary document easily appended to an existing report or used as a stand-alone reporting tool.

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- The integrity assessment software allows the user to:
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- characterize operating load histories;
- calculate the fatigue rates or history;
- determine the critical flaw sizes and safety margins;
- document the analysis results

The software package also includes a probabilistic analysis module allowing the user to include the inherent uncertainty associated with the various input parameters used in carrying out a fatigue and fracture assessment. The output from a probabilistic analysis ranges from the probability of failure with time to the flaw size distribution after a user defined time

Assumptions

The general assumptions inherent in the integrity calculations performed in this software, related to the flaw type and material characteristics include:

- The BS 7910 [1] and API RP 579 [18] algorithms apply to steel and aluminum alloys;
- The S-N Damage Accumulation analysis is based on BS 7608 : 1993 [19] (successor to BS 5400);
- The PRCI NG-18 Surface Flaw Equation [13] failure option applies to axial surface flaws in curved shells;
- The CSA Z662-03 Annex K [14] failure option applies to circumferential surface and embedded flaws in the weld of a curved shell section;
- Weld geometry related stress concentration factors are user defined, whereas the weld toe related stress concentrations can be calculated by the software.
- The material properties such as yield and tensile strength and fracture toughness defined by the user are representative for the material at the flaw location of interest;
- "Level B" analyses determine the yield and tensile strengths based on user supplied stress-strain data;
- The pipe or plate geometry provided by the user is representative of the section being assessed and considers local wall thinning if appropriate;
- The user supplied initial flaw size is representative of the flaws existing in the section;
- A plane strain condition is assumed for failure calculations in the BS 7910 and API RP 579 algorithms.
- Weld versus parent material mismatch must be less than 25%.
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- In addition, the following general assumptions are inherent in the integrity calculations performed in this software related to the flaw type and material characteristics:
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- The loading data used in the analysis is representative of the future operational conditions of the structure including infrequent large load fluctuation events such as proof tests;
- The primary and secondary stress data is representative of the state of the material.

The user is responsible for ensuring the validity of all assumptions for each specific analysis.

USEFUL DEFINITIONS

B

Bending Restraint: The bending restraint applies to (BS 7910 [1]) and (API RP 579 [18] analyses for surface flaws. Affects the reference stress (for secondary stress) and load ratio (Lr) calculations.

Bending Stress: A compressive or tensile stress resulting from the application of a non-axial load applied to a structural member.

Bin: Term used in the rainflow analysis to describe the method of grouping loading cycles. Each grouping, or bin, of load cycles is represented by a constant loading range (e.g. bin size) to be applied in fatigue. The binning method is used to reduce computation time.

C

Charpy V-Notch Area (CVN-Area): The area of a Charpy specimen remaining after the notch has been removed. E.g. A typical Charpy is 10 x 10 mm square, with a 2 mm deep notch. The remaining CVN-Area is 80 mm^2.

Charpy V-Notch Impact Energy (CVN): The Charpy impact test uses a swinging hammer to assess the resistance of a material to brittle fracture. The energy absorbed by the material from the swinging hammer is measured from a calibrated scale, encoder, and/or an instrumented striker. The low cost and simple configuration of the test have made it a common requirement in codes for metals used in critical structures

Crack Retardation: The application of an overload causing a decrease in the crack growth rate.

Crack Tip Opening Displacement (CTOD), δ: The crack displacement due to elastic and plastic deformation at variously defined locations near the original (prior to the application of load) crack tip. Refer to ASTM standard E1290 [22] for CTOD testing methods.

Critical Flaw Size: The flaw size which, for a given applied stress, causes unstable crack propagation.

Cycle: A single complete execution of a periodically repeated phenomenon (e.g. loading).

Cyclic Plastic Zone Size: As the nominal tensile load is reduced, the plastic region near the crack tip is put into compression by the surrounding elastic body. Cyclic

F

FAD: **F**ailure **A**ssessment **D**iagram

Fatigue limit (endurance limit): The limiting stress level below which fatigue failure will not occur. This property only applies to some ferrous and titanium alloys where the stress versus cycles to failure curve (or S-N curve) becomes horizontal at high N values.

Folias Factor: Curvature correction factor or "bulging factor" that accounts for increased stresses due to curvature for longitudinal and circumferential cracks in un-stiffened pressurized cylindrical shells (pipe).

Fracture Ratio: The fracture ratio is the vertical axis on the failure assessment diagram (FAD) used to determine the acceptability of a flaw under stress.

G

Growth Threshold: Click on the link to view the appropriate section.

H

Heat Treatment: High temperature procedures to which materials are subjected, to alter and improve their mechanical properties. The heating processes cause transformations that involve atomic diffusion to occur over reasonable time periods (hours).

High Cycle Fatigue: The fatigue life of a structure is considered to be caused be high cycle fatigue when the failure occurs after the structure has been subjected to more than load cycles. The phenomenon generally occurs when the cycle magnitudes are low with respect to the structure's material properties.

Hoop Stress: Defined as the stress in a pipe wall acting circumferentially. The plane is perpendicular to the longitudinal axis of the pipe and produced by the pressure of the fluid in the pipe.

I

Infrequent Load: One infrequent event such as a shut down or other irregular loading event which is not included in the loading spectrum. The event will only be applied at a user defined time interval

L

Load History: The loading data used in the analysis is representative of the future operational conditions of the structure including infrequent large load fluctuation events such as proof tests.

Load Ratio: The load ratio is the horizontal axis of the failure assessment diagram (FAD) used to determine the acceptability of a flaw under stress

Load Spectrum: A grouping of load range bins deemed to be representative of the loading history applied to a structure over a specified time. The spectrum is used in fatigue as an approximation of the actual loading history to compute the fatigue life of the structure.

Local Stress: The stress state of a specific location in the structure of interest, (e.g. At a bend or joint) versus the global stress applied to the complete structure.

Low Cycle Fatigue: The fatigue life of a structure is considered to be caused be high cycle fatigue when the failure occurs after the structure has been subjected to less than load cycles. The phenomenon generally occurs when the cycle magnitudes are high with respect to the structure's material properties.

M

Mechanical Loading: In **FlawCheck**, mechanical loading refers to all loading not cause by an internal pressure load in a curved shell section.

Mean Stress (load): In fatigue, the mean stress is the amplitude about which a cyclic load is centered. For example, an R-ratio of -1 has a mean stress value of 0. The mean value reported in the Load Characterization module is the average mean stress for all cyclic reversals found during the rainflow analysis.

Membrane Stress: A compressive or tensile stress resulting from the application of an axial load applied to a structural member

P

Paris-Erdogan law [17]: The relationship between stress intensity factor and crack growth rate assumed for this analysis: da/dN = C(ΔK)m where C,m are material specific constants.

Pipe Formulation: The stresses for the internal pressure in a pipe are calculated using the Barlow equation.

Plastic Collapse: Plastic collapse occurs when the complete load bearing cross section of a structure becomes fully plastic, and as a result, collapse of the structure occurs.

Plastic Zone Size: Materials develop plastic strains as the yield stress is exceeded in the region near the crack tip. The amount of plastic deformation is restricted by the surrounding material, which remains elastic. The size of this plastic zone is dependent on the stress conditions of the body.

Poisson's Ratio: Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force.

Pressure History: A time stamped record of the internal pressure seen in a pipeline.

Pressure Spectrum: A grouping of pressure range bins, deemed to be representative of the loading history an internally pressurized pipeline over a specified time. The spectrum is used in fatigue as an approximation of the pressure history in order to estimate a fatigue life.

Primary Stress: Click on the link to view the appropriate section.

Proof Load: The greatest load than can be applied to a piece without straining the piece beyond the elastic limit.

R

R-ratio: The ratio of minimum to maximum stress in a fatigue load cycle.

Rainflow: Method of counting cycles in a random load history. (see ASTM E 1049 [16])

Residual Strength: The maximum load carrying capacity of a damaged structure.

Residual Stress: Stresses developed in a material in response to the following: plastic deformation, non-uniform cooling (welding), and phase transformation induced upon cooling, causing the material to be under constant strain in the absence of external loading. Residual stresses may be in tension or compression within the material.

Retardation Effect: When an overload is introduced during crack propagation, a large plastic zone is produced altering the crack propagation curve. The elastic material surrounding the plastic zone will exert a compressive stress on the plastic zone until the crack has grown through the area of residual stress, thus retarding the crack growth rate.

S

Secondary Stress: See residual stress.

Spectrum: The spectrum is the final result of a load characterization (Rainflow) analysis.

Spectrum Severity Indicator: A fatigue load range (pressure or stress) with a magnitude of user specified fraction of the material yield strength value. The number of cycles reported on the Load Characterization tab is an indicator of spectrum severity. The module reports the number of these cycles which would cause the same crack growth as the raw data spectrum histogram. The flaw depth, a and flaw length, 2c are also user specified.

Stress Concentration Factor (SCF): When a flaw or crack is situated in a region of local stress concentration, such as the weld toe, gross structural discontinuity, or misalignment, it is necessary to consider the effect of the local stress concentration when calculating the stress intensity factor (SIF).

Stress Intensity Factor (SIF): A measure of the stress-field intensity near the tip of an ideal crack in a linear elastic material.

T

Toughness: In general terms, a measure of the ability of a material to absorb energy up to fracture. Fracture toughness is a property indicative of a material's resistance to fracture when a crack is present.

Tensile Strength: The engineering stress value at which necking initiates in a uniaxial tensile test.

Threshold SIF: The maximum value of the stress intensity factor for a given material for which environmentally induced flaw growth, under static tensile stress, does not occur for the specific environment in question.

Transfer Function: Stress transfer functions are needed to **convert** the **loading** ranges or spectrum, **to equivalent stress** ranges.

Y

Yield Strength: The stress corresponding to the transition between elastic and plastic behaviour of a material. The convention used in ***FlawCheck*** for Level B calculations (BS 7910 and API RP 579) is the offset method. In the offset method a straight line is constructed parallel to the elastic portion of the stress-strain curve and intersects the x-axis at 2% strain. The intersection of the offset straight line and the stress-strain curve is taken as the Yield Strength.
Alternatively the a manually input Yield Strength may be taken as the stress at a strain value of 5%.

Yield Strength "appropriate" value: The appropriate value refers to residual strength calculations where the value used for calculations depends on the orientation and the location of the flaw.

Young's Modulus (Modulus of Elasticity) *E*: The proportional relationship relating the degree to which a structure deforms or strains, to the magnitude of stress applied, during elastic loading. The relationship is known as Hooke's Law: $\sigma = E\varepsilon$.

BMT FLEET TECHNOLOGY LIMITED

BMT Fleet Technology Ltd. is a multi- disciplinary engineering company with specialization in fatigue and failure assessment and FE modeling for a range of industries. BMT Fleet Technology Ltd. provides damage tolerance, metallurgical, welding engineering services and mechanical testing services to pipeline, marine, military and civil structure operations and maintenance organizations. The ***FlawCheck*** software is an engineering tool developed to support the needs of many of the company's clients.

BMT Fleet Technology Ltd. is part of the BMT group of companies; world leaders in general engineering and marine consulting with offices in 15 countries.

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AMERICAN BUREAU OF SHIPPING

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At ABS, setting standards of excellence in marine and offshore classification is more than a motto - it is the way we conduct business.

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The responsibility of the classification society is to verify that merchant ships and marine structures comply with Rules that the society has established for design, construction and periodic survey.
The classification process includes:

- the development of standards, known as Rules
- technical plan review and design analysis
- surveys during construction
- source inspection of materials, equipment and machinery
- acceptance by the Classification Committee
- subsequent periodic surveys for maintenance of class
- survey of damage, repairs and modifications

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ABS recognizes that the classification world is changing with more emphasis on complex structures, life cycle management, unified standards and safety equivalencies.
At ABS, we are dedicated to providing leadership in the development of new technologies intended to improve the safety standards for the marine and offshore industries.

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