



Structural Durability Pseudo-Fatigue Damage Analysis

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. The purpose of this standard is to provide a guideline for performing pseudo-fatigue damage analysis for structural durability analysis as used in laboratory testing.

1.2 Applicability. This standard is based on the strain-life approach and is intended to be used on load or strain data for metallic components. It is not to be used with displacement or acceleration data. Plastic, composite, or elastomeric components may require use of the stress-life, fracture mechanics, strain energy or other approaches which are not covered in this document.

1.3 Remarks. This standard applies to the pseudo-fatigue damage analysis typically used to compare road data to laboratory data. Pseudo-Fatigue Damage is a damage value calculated using a time history (load, displacement, etc.) with non-strain engineering units to approximate the strain at a hypothetical notch on the test specimen. This standard is written such that it could be used for several software packages, but with an emphasis on MTS' RPC Pro (see Appendix B). Issues considered by this document include rainflow cycle counting, material, linearity of the material model, which back-calculation factor (K_f or S_f) to back-calculate to, mean stress correction, polarity, assumed life, damage distribution and optimization. The type of input data (strain or load) affects some of the choices.

For special cases, deviation from this standard may be acceptable. The Computer Aided Test (CAT) Technology Manager should be consulted regarding the deviation.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

None

2.2 GM Standards/Specifications.

GMW2	GMW10	GMW15242	GMW15245
GMW5	GMW3032	GMW15243	

Note: This list of standards is for reference only. Not all will be required for all analyses. Review entire procedure to determine needed references.

2.3 Additional References.

- Advanced Vehicle Development (AVD)/Computer Aided Engineering (CAE) Fatigue Technical Team web site: <https://share.gm.com/sites/FTT/SitePages/home>.
- A Random Loading Sequence of Gaussian Type Recommended for General Application in Fatigue Testing: Its Mathematical Background and Digital Generation by E. Haibach, W. Fischer, M. Huch, and Fatigue Testing and Design, Volume 2, 1976.
- Global Structural Durability Laboratory Expert Team (GSDLET) web site:
 - a. <https://gmweb.gm.com/sites/GSDLET/Pages/Main.aspx>
 - b. <http://gmna1.gm.com/pgtl/gddl/index.htm>
- GM Global Material Properties Database: <https://share.gm.com/sites/FTT/SitePages/home.aspx>
- Mechanical Behavior of Materials, by N.E. Dowling, Prentice Hall, pages 633 thru 640.

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- Signal Processing for Reliability-Based Laboratory Test, by Thomas Schallhorn, SAE Technical Paper 871939.

3 Resources

3.1 Facilities.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment. Not applicable.

3.3 Test Vehicle/Test Piece. Not applicable.

3.4 Test Time. Variable depending on data volume. Typically, 1 h to 4 h for baseline and approximately 1 h for each of the “Edited” and “Simulated” datasets. Results interpretation and review not included in this time.

3.5 Test Required Information. Useful information can be found in the additional references listed in 2.3.

3.6 Personnel/Skills. Experience and training in RPC software and GM durability schedules.

4 Procedure

A graphical view of the following procedure is shown in Figure A1 in Appendix A. An example following this process using MTS’ RPC Pro tools is shown in Appendix B.

4.1 Preparation. Not applicable.

4.2 Conditions.

4.2.1 Environmental Conditions. Not applicable.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions.

4.3.1 Process Outline. This outline provides the typical answers that will work for most pseudo-fatigue comparisons. Details are provided in the following sections. For each channel, the user needs to select the following.

- **Static offsets:** Add or subtract offsets to reach a common reference.
- **Noise band:** Select a noise band of 1% of maximum peak to remove noise.
- **Bin size:** Calculate by dividing the maximum range for each channel by 50 and 64. Select a bin size that ends in 5 or 0 and falls between these two values.
- **Material:** Use GMW2M grade 3 for material.
- Linear material modeling.
- **Scale factor:** For baseline, Back-calculate for scale factor Use the back-calculated value from baseline run for edited or lab results.
- **Notch factor:** 1.
- **Mean stress correction:** Morrow.
- **Assumed life:** Assume a life of 3 for back-calculation.

4.3.2 Time History Evaluation and Rainflow Cycle Counting. After recording the time histories and verifying the data integrity checking for any glitches in the data, (see GMW15243 for more information on this), any static offsets must be compensated for. A common baseline or reference is required.

4.3.2.1 Offsets. For exact fatigue life, all offsets, including residual stresses and strains, must be accounted for. A common reference, for example, between road and lab, is usually sufficient for pseudo-fatigue (A-B comparisons). Shifts or yielding in the data must be accounted for based on whether the shift or yield is a one-time occurrence on a large event (likely a one-time **set**) or if the shift or yield is a continuous occurrence.

4.3.2.2 Polarity. For pseudo fatigue, the polarity of the transducer may or may not match the resultant strain. That is, a positive force may or may not result in a tensile strain.

4.3.2.2.1 If the polarity of the data will need to be adjusted, this will need to be completed now. Ideally, for non-strain data, analysis should be performed using tension positive and tension negative for each channel and the worst case (smallest K_f and S_f - see 4.3.5) should be used for further study.

4.3.2.2.2 Certain standard transducers (such as wheel force transducers) have standard polarities that should be used for analysis unless otherwise known.

4.3.2.2.3 For strain data, tensile strain must be positive.

4.3.2.3 Noise Band. Next, it is advisable to eliminate the noise in the data by defining a noise band filter and applying it to the time history.

4.3.2.3.1 This noise band is often based on a known characteristic of the measuring system, e.g., noise level of instrumentation with transducers un-powered, 1% of the maximum peak, or a noise band equivalent to 1 bin (1.5% to 2%). Applying the noise band filter will not change the fatigue life of the raw data and the result should still be referred to as the baseline data. The noise band in the rainflow counting software can be used for this function.

4.3.2.4 Rainflow Counting. The next step is to choose a reasonable number of bins (levels). A software-driven standard of 64 has become common, but most software can also provide data in user-friendly bin sizes ending in 5 or 0 so that the results from two data sets can more easily be compared. The algorithm in Appendix C can be used to generate 50 to 64 rainflow bins per channel.

4.3.2.4.1 For pseudo-fatigue comparisons, a pseudo-composite rainflow histogram may be needed in order to back-calculate the notch factor/scale factor. This combines the individual surface rainflow files with residuals closed.

4.3.2.4.2 Other analyses, such as block cycle testing, may need composite rainflow matrices. These matrices should set the bin size in the same manner, BUT rainflow residuals will need to be left open so that composite rainflow histograms can be calculated. The residuals must NOT be left open for pseudo-fatigue calculation! Open residuals will result in erroneous calculated fatigue lives.

4.3.2.4.3 For adequate peak resolution in the digital domain, the sample rate must be at least 13 times the maximum frequency content of the data (as determined by the frequency of the low-pass filter) to allow for a quantization error < 1 bin. (See the following note.)

Note: Maximum percent error is defined by the equation:

$$Error = 2 * \sin^2 \left(\frac{\pi/2}{f_s/f_d} \right)$$

Where:

f_s = sample rate

f_d = data bandwidth

If 32 bins is assumed, the error must be < $1/32 = 0.03125$ (3.125%), which requires a value for f_s/f_d of 13.

4.3.2.4.4 Bin sizes for like channels (left to right) should be the same.

4.3.2.4.5 If the rainflow counts in the low-range bins exceed 10^8 (100 000 000) counts, the user may need to apply an additional gate level to the rainflow histogram. The gate level will eliminate the low amplitude/high number of cycles that are non-damaging events (see the section on the mean stress correction). The recommended gate level is 1 bin size.

4.3.3 Material. The material properties should be obtained from the GM Global Material Properties Database: <https://share.gm.com/sites/FTT/SitePages/home.aspx>

Note: The supplier shall work with the GM Design Responsible Engineer to comprehend this requirement.

4.3.3.1 For A-B (pseudo-fatigue) comparisons, it is generally acceptable to assume a material from which most of the components are made. For example, GMW2M grade 3 is often used when suspension loads are analyzed, including wheel force transducer loads.

Note: Standard copies of an RPC Pro material file with all of the materials in 4.3.3.1 can be found on the Global Structural Durability Laboratory Expert Team (GSDLET) web site: <https://gmweb.gm.com/sites/GSDLET/Pages/Main.aspx>. An nCode MXD format material file with most

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materials from the General Motors material database included is available from the AVD/CAE Fatigue Technical Team web site: <https://share.gm.com/sites/FTT/SitePages/home>.

Note: The supplier shall work with the GM Design Responsible Engineer to comprehend these requirements.

- Frames and cradles - GMW2M e.g., GMW2M-ST-S-CR3 (0_NewGMW2M, GMW2MG3).
- Stabilizer Bar - 10B21, 1090M or 4130Al.
 - Tubular - 10B21 e.g., GM_SAE10B21 (10B21QT).
 - Solid - 1090M e.g., GM_SAE1090-quenched-tempered (1090M).
- Springs - 51B60, 9254, 9254Al.
 - Coil - 9254 e.g., GM_SAE9254 (9254MQT).
 - Leaf - 51B60 e.g., GM_SAE51B60 (51B60).
- Control Arms.
 - Ductile Iron - GMW10M, 4010 e.g., GMW10M-IR-C-N400-15 and GM_4010 (GMW10M and 4010).
 - Carbon Steel - GMW2M e.g., GMW2M-ST-S-CR3 (0_NewGMW2M, GMW2MG3).
 - Forged Steel - 15v24 e.g., GM_SAE15V24 (15v24HF).
 - Aluminum Cast - GMW5M, A356-T6 e.g., GMW5M-Al-C-P-Si7Mg-uts237 or GM_A356_AL (GMW5M or A356AL).
- Exhaust Components – 409 Stainless e.g., GM_SS409 (SS409).
- Crank Shafts - SAE5150 e.g., GM_SAE5150 (5150).
- Prop Shafts - 1045, 4140 e.g., GM_SAE1045 (1045QT).
- Connecting Rods - 1070M e.g., GM_SAE1070M-controlled-cool (1070M).
- Wheels - GMW3032 (420 MPa and higher strengths) and A356-T6 e.g., GMW3032M-ST-S-HR420LA or GM_A356_AL (GMW3032_420 or A356AL).

Note: Parenthetical names are the “shorthand” names in the material file posted on the GSDLET website.

4.3.3.2 For predicting actual fatigue life, if the exact material is not known, use a material from the same class (steel, aluminum, etc.) similar hardness, and similar composition to the material in question.

4.3.3.3 To increase the confidence when an exact material is not available, analyze several different materials, with similar hardness values and composition and compare the results. This approach is especially important for aluminum because the relationship between the hardness and fatigue properties for aluminum is not the same as steel.

4.3.3.4 In the case of multiple materials, the proper method is to back-calculate for S_f or K_f (see 4.3.8) for one material using the unedited history. Then use the obtained K_f and S_f and calculate the damage for all materials and compare the damages. If the results are close (within a factor of 2), the user may select any of the materials. If the results are significantly different, then back-calculate for S_f or K_f for all the materials and choose the worst case (lowest S_f and K_f) for further analysis. If neither case can be selected, the CAT Technology Manager should be consulted.

4.3.4 Linear vs. Non-Linear Relationship.

4.3.4.1 For load data (force, moment and torque) always use a linear (fully elastic) material relationship. See Appendix D for a discussion on the reason for linearity.

4.3.4.1.1 For strain data, always use a non-linear (measured) material relationship.

4.3.4.2 Do not use acceleration data for fatigue calculations because high-frequency data content is weighted too heavily. Do not use displacement data because of possible nonlinear relationships between displacement, stress and strain. Wheel to body displacement should not be used for fatigue analysis because jounce bumper contact results in these nonlinearities.

4.3.5 Fatigue Notch Factor (K_f) and Scale Factor (S_f).

4.3.5.1 Linear Calculation. For the linear option, notch factor (K_f) and scale factor (S_f) act the same way. That is, if the user back-calculates on K_f or S_f , they will get the same answer. It is strongly recommended that K_f be set to a value of 1 and then back-calculate for S_f . Note that for many fatigue codes, the data for strain-life calculations are always microstrain; therefore, S_f is in units of microstrain/unit load. (See the following note.)

Note: Stress-life methods may use other units than microstrain, often units of stress, requiring careful documentation by the engineer.

4.3.5.1.1 When communicating with CAE engineers, it is sometimes desired to have S_f in units of stress (MPa/unit load) in order to work with the stresses generated in a finite element model. To convert the S_f in units of microstrain per unit load (typical for RPC Pro, nCode's Glyphworks and many other fatigue engines) to a stress per unit load, a linear assumption is made and the conversion is thus:

$$S_{f,Stress} = S_{f,\mu\epsilon} * \frac{E}{10^6}$$

4.3.5.1.2 It is strongly suggested to include the units of the S_f in the documentation, e.g., microstrain/load or MPa/load.

4.3.5.2 Non-Linear Calculation. For the non-linear option, K_f and S_f act differently. Back-calculations on non-linear data must always be done on K_f since it assumes that the measured strain is **nominal** strain and K_f scales this to **local** strain using Neuber's equation. S_f is left at a value of 1 (microstrain/microstrain).

4.3.6 Mean Stress Correction. Morrow and Smith-Watson-Topper (SWT) are the most common methods of mean-stress correction for strain-life fatigue calculations. Morrow is the recommended method when pseudo-fatigue damage is calculated.

4.3.6.1 For actual fatigue calculations, SWT may be used if tensile mean stresses exist. To check for tensile mean, first calculate with Morrow and **No Mean**. If the Morrow result is longer life (compressive mean), use Morrow. If Morrow is the same as No Mean, there are no significant mean stresses. If the Morrow life is shorter (tensile mean), recalculate with SWT as the mean stress.

4.3.7 Assumed Life for Back Calculation. In general, the actual life is NOT known and an assumed life of 3 (GMW3425 road test as an example) should be used. Note that a life of 3 is equal to a damage of 0.333 (1/3). Repetitions in the duty cycle (substitution matrix) should be for one life.

4.3.7.1 If there is a known fatigue life (crack initiation), the life at which the fatigue crack initiates should be used for the assumed life.

4.3.7.2 The component should be examined by material engineers to confirm/determine that the failure mode(s) is (are) fatigue.

4.3.7.3 For measured strain data, the back-calculated K_f (based on the known fatigue life) must be > 1 and usually < 3 . As the strain gage is closer to the crack and normal to the crack, a smaller K_f will be obtained. If the obtained K_f is > 3 , extra care should be given to the measured data as it is likely that the gage is located too far away from the crack initiation site or in the wrong orientation. In this case, the strain gage reading may not capture the damage.

4.3.8 Damage Result. Depending on the fatigue code, once the back-calculated S_f or K_f is obtained, a forward fatigue calculation may need to be done to obtain the desired results.

4.3.9 Overload Check. For the linear calculation, the back-calculated S_f should be used to check for overload condition.

4.3.9.1 If the product of the S_f (MPa/load) and the overall absolute maximum peak/valley is greater than the ultimate strength (usually by a factor of 3 or more) or a result occurs indicating static overload, then the failure mode is overload and not fatigue. In this situation, typically the assumed life should be increased (damage decreased) such that the new product of S_f multiplied by the absolute maximum peak/valley becomes < 3 times the ultimate strength. This increase will cause a change in assumed failure mode from overload to fatigue. Note that the assumed life should be between 1 to 10 repeats of a proving ground test. If the problem is still not resolved, contact the CAT Technology Manager.

4.3.9.2 If the ultimate strength of the material cannot be found in the database, use the average ultimate strength of materials that have the same chemical composition. For example, if the material is low carbon steel (e.g., GMW2M); use the average ultimate strength of all the low carbon steels in our database as the ultimate strength of the material. For multiple materials, use the worst case (lowest ultimate strength).

4.3.10 Damage Distribution Review. If one schedule with small repetitions (< 50 repeats) is causing most of the damage ($> 50\%$) for a complete durability test, e.g., GMW3425, and the maximum peak of that schedule is 1.5 times or more greater than the peaks of other schedules, then this schedule should be analyzed by separate