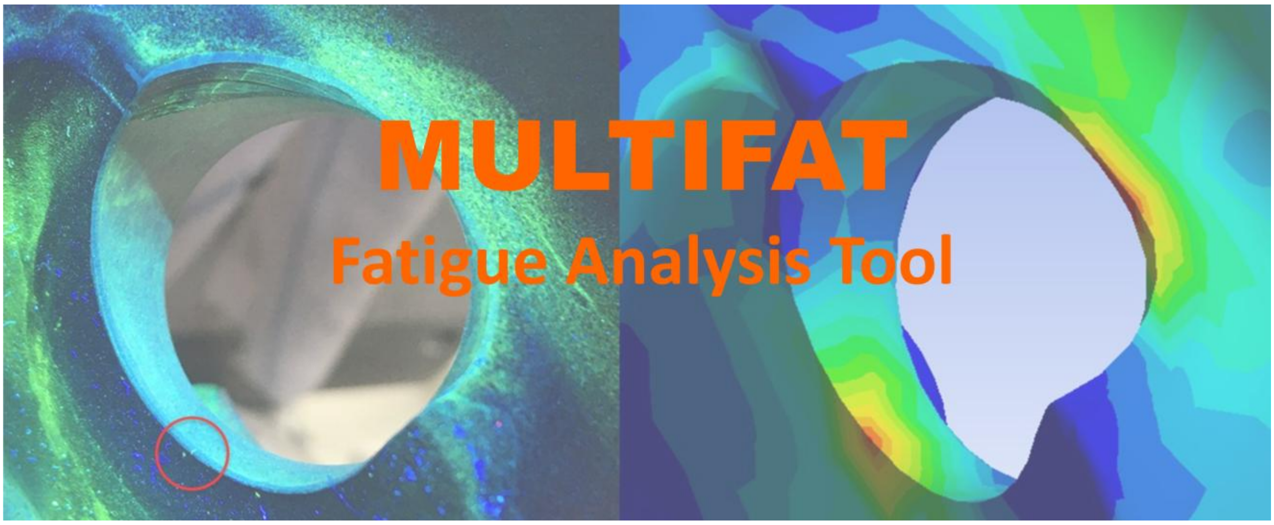
MULTIFAT

User Guide

v25.02



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1 Introduction

This User Guide explains the usage of MULTIFAT, the free software for fatigue analysis. For any questions or clarifications, the MULTIFAT team will be happy to answer you! You can contact us via our contact page:

https://multiaxialfatigue.com/contact/

2 The multiaxial rainflow principle

2.1 Generalities

Let a stress time-history be defined by a closed tensor path in the stress space.

A *Multiaxial Rainflow* extracts cycles in the form:

$\sigma_{a,k}$ the stress-amplitude of the k[th] cycle

$\sigma_{m,k}$ the mean stress of the k[th] cycle

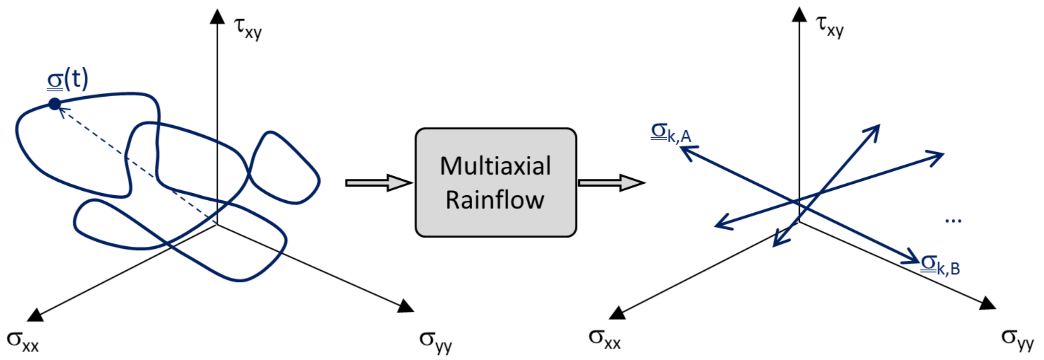


Figure 1: General principle of Multiaxial Rainflow

For each extracted cycle C_k defined by $\sigma_{a,k}$ and $\sigma_{m,k}$ its fatigue life N_k and thus its damage $D_k = 1/N_k$ can be calculated.

Then a damage accumulation law is used in order to get the total damage. Typically, the linear Palmgren-Miner summation applies:

$$D = \Sigma_k D_k \qquad (2.1)$$

Finally the corresponding fatigue life in terms of repetitions of the periodic sequence is:

$$N = 1 / D \qquad (2.2)$$

REMARK

For a given input stress-sequence defined via a stress tensor time-history, MULTIFAT reorders the sequence starting from the point with highest stress-parameter (ex. Von Mises) and then closes the sequence by adding the first stress-point at the end. This is coherent with the principle illustrated in the *Theory Manual* [Ref 1].

2.2 Definitions for a stress-cycle

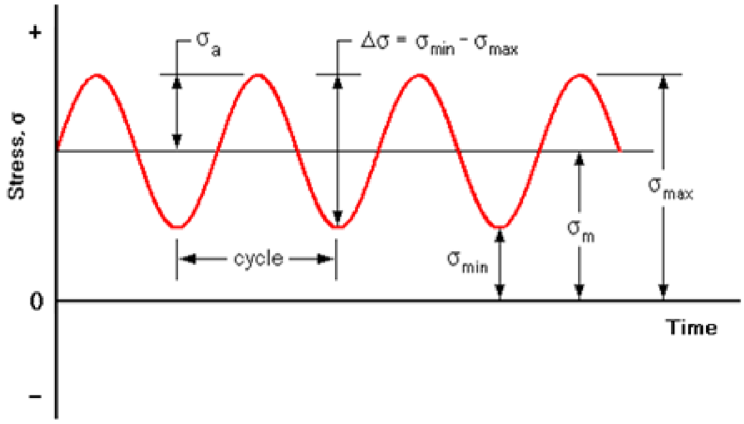


Figure 2: Stress cycle

σ_{max}	Maximal stress	(2.3)
σ_{min}	Minimal stress	(2.4)
$R = \sigma_{min} / \sigma_{max}$	Stress ratio	(2.5)
$\Delta\sigma = \sigma_{max} - \sigma_{min}$	Stress range	(2.6)
$\sigma_a = \Delta\sigma / 2$	Stress amplitude	(2.7)
$\sigma_m = (\sigma_{max} + \sigma_{min}) / 2$	Mean stress	(2.8)

3 Types of analysis available in MULTIFAT

Two types of analysis are available in MULTIFAT:

- **Stress sequence**

A single sequence of stress-tensor values is given as input, as in a time history analysis. MULTIFAT calculates its fatigue damage and thus the life repeats until failure.

- **Stress linear combination**

The following sets of data are given as input (see also 9.2.2):

- The stress tensor $\sigma_{k,ij}(t, N)$ for a certain number of *Unit Fatigue Load Cases* (UFLC) and for a given set of nodes
- A sequence of coefficients $c_k(t)$ representing the linear combination to be applied for all the k^{th} of the N_{LC} Load Cases at each instant on the same UFLC
- A constant offset-stress $\sigma_{ij}{}^{0}(N)$ for each node
- Two scalar scaling-parameters A, B

N.B. Here and in the whole document, the term "node" is used in a wide sense, referring to a calculation-point where the stress is known and the fatigue analysis is performed, and not necessarily related to the nodes of a finite element model.

The stress at a node "N" and at the instant "t" is then calculated as follows:

$$\sigma_{ij}(t, N) = A\left(\sigma_{ij}^{0}(N) + B\sum_{k=1}^{N_{LC}} c_k(t)\sigma_{k,ij}(N)\right)$$

where k represents the k^{th} Load Case and N_{LC} is the total number of Load Cases

MULTIFAT calculates for each node the fatigue damage and thus the life repeats, of the so-defined stress.

- **Blocks of cycles**

The following sets of data are given as input:

- The stress tensor $\sigma_{k,ij}(t, N)$ for a certain number of *Unit Fatigue Load Cases* (UFLC) and for a given set of nodes. This has the same meaning as the Stress Linear Combination analysis, see 9.2.2.
- A constant offset-stress $\sigma_{ij}{}^{0}(N)$ for each node. This has the same meaning as the Stress Linear Combination analysis, see 9.2.2.
- A list of coefficients defining Linear Combinations of the UFLC's and thus forming each one a block of cycles. A number of repeats is then defined for each block.

MULTIFAT calculates for each node the fatigue damage and thus the life repeats, for the whole set of cycle-blocks.

In the following, if a feature applies specifically to only one of the three types of analysis, then it is marked with the following symbols

Stress sequence

Stress linear combination

Blocks of cycles

4 Input files in MULTIFAT

4.1 Multifat files

The following three files ("multifat files") need to be in the same directory. This is not necessarily the same as the *working directory*.

- **multifat.exe** Solver file provided by MULTIFAT Team (binary)
- **multifat.lic** License file provided by MULTIFAT Team (binary)
- **multifat.inp** Text file written by the User, defining the working directory and the name of the project (see Figure 4)

Name	Date modified	Type	Size
multifat.exe	15.01.2021 10:56	Application	134 KB
multifat.inp	23.01.2021 12:10	INP File	1 KB
multifat.lic	23.01.2021 12:10	LIC File	2 KB

Figure 3: multifat files

The text file **multifat.inp** contains only the name of the working directory as well as the project name chosen by the user. It must be in the following format:

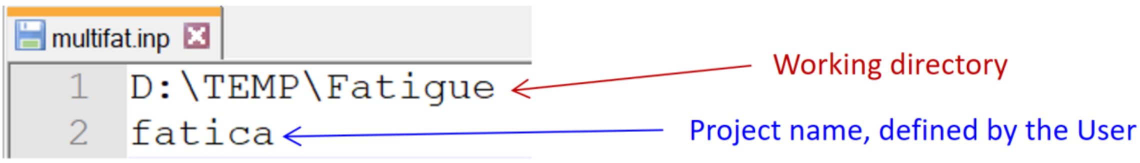


Figure 4: multifat.inp file

If the working directory is the same as the directory where MULTIFAT is run, the file multifat.inp can be simply in the following form

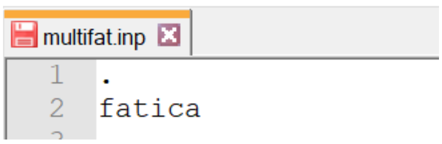


Figure 5: multifat.inp file for work in a unique directory

4.2 Input files in the working directory

In the working directory, in this example named *D:|TEMP|Fatigue*, the following files must be present:

- **NAME_OF_THE_PROJECT.inp**

where *NAME_OF_THE_PROJECT* is the name defined by the User: "*fatica*" in the example of Figure 6.

For the different types of analysis the following specific input files are needed.

Stress sequence

- **NAME_OF_THE_PROJECT.sig**

This is the general stress input data file for a Stress sequence analysis: see § 9.1

Stress linear combination

- ***NAME_OF_THE_PROJECT*.cmb**
- ***NAME_OF_THE_PROJECT*.nds**

These are the general stress input data files for a Stress linear combination analysis: see § 9.2

Blocks of cycles

- ***NAME_OF_THE_PROJECT*.blc**
- ***NAME_OF_THE_PROJECT*.nds**

An example of working directory is given in the Figure 6:

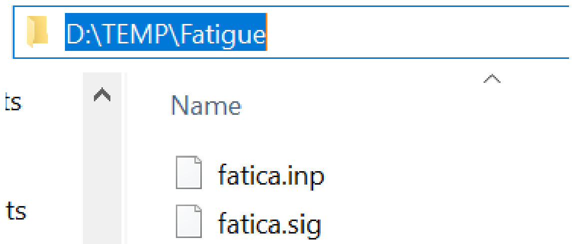


Figure 6: Working directory input files example

4.3 General input data

The text file **NAME_OF_THE_PROJECT.inp** contains the basic data useful to perform the fatigue analysis. This file must be in the working directory.

The Figure 7 illustrates the file **NAME_OF_THE_PROJECT.inp**.

fatigue.inp

```
Stress-strain relationship: fty, E, ftu, Atot%
420 71000   490 9
Elastoplastic correction is performed (1) or not (0)
0
Elastoplastic correction with Linearized (1) or classical Neuber (2)
1
Stress-path based correction performed (1) or not (0)
1
S-N curve in the format of Palmgren (1), Weibull (2) or Multilinear (3)
1
Palmgren parameters
L1,p,C,EndLim
9.177539713 -2.072581815    10026   156.3
Weibull parameters
sainf,sasup,alfaw,betaw
13.97   319 3   4.3
Multilinear parameters
sE, NE, kE, N1, k1, N2, k2, k3
32.8    10000000    3.7 560 1000000 1000000000  6   0
Goodman correction exponent, type of behavior for Sm<0, SmMAX
1   2   490
Stress Sequence (1), Linear Combination (2) or Blocks (3)
3
Coeffs A, B when Linear Combination or Blocks are used
1   1
Write complete output to the following node ID
1644
Analysis made with one material (1) or multiple materials (2)
1
Number of Nodes and Number of Load Cases (Preload excluded)
913877  6
LVF for Sa in Blocks Fatigue
1
For linear combination only: GAG analysis (1) or All Cycles analysis (0)
0
For Stress Sequence only: extract cycles (1) or not (0)
1
For Blocks analysis only: sum of damages (1), highest (0), highest flight (2)
1
Number of Flight Hours
1884
```

Figure 7: File *NAME_OF_THE_PROJECT.inp*

In the file **NAME_OF_THE_PROJECT.inp**, text lines are alternated with numeric inputs. The text lines do not have in principle to be modified by the User, and they serve only for remind about the input data that is just below. The meaning of all the inputs is described below.

N.B. Some details in the text format can slightly change from version to version and with respect to the pictures illustrated here. This does not change the format and the meaning of the numerical User input data, which have impact on the subsequent fatigue analysis.

- **fty, E, ftu , Atot%**

Coefficients defining the mechanical material properties useful to perform the elasto-plastic correction and the mean-stress correction. See more explanation in Section 5: *The elasto-plastic correction*.

fty = yield stress

E = Young's modulus

ftu = ultimate tensile stress

Atotperc = total elongation at ftu, in %

- **Elasto-plastic correction**

An elasto-plastic correction is performed if this parameter is = 1 (see Section 5), not performed if it is = 0

- **Linearized Neuber (1) or Classical Neuber (2)**

If this parameter is = 1 a linearized version of Neuber's method is applied, if = 2 the classical Neuber's method is applied, see Section 5

- **Stress-path based correction performed (1) or not (0)**

Stress-path based improvement (see *MULTIFAT Theory Manual* [Ref 1]) of the rainflow counting is performed if this parameter is = 1, not performed if it is = 0

- **S-N curve Palmgren (1) or Weibull (2)**

If this parameter is = 1, the S-N curve is described in the form of Palmgren, if = 2 of Weibull, see Section 5.

- **Palmgren parameters**
  L1, p, C, EndLim

The four Palmgren coefficients for describing the S-N curve, see § 7.1

- **Weibull parameters**
  sainf,sasup,alfaw,betaw

The four Weibull coefficients for describing the S-N curve, see Section 5.

- **Goodman Exponent, Goodman Method, Static Max**

Goodman Exponent is the exponent used in the Mean Stress correction: see Section 8.

Goodman Method is the parameter that drives the Mean Stress correction for negative values of Sm: see Section 8

Static Max is the static value used as Sm_{MAX} in the Mean Stress correction: see Section 8

- **Stress sequence (1) or Stress linear combination (2)**

If this parameter is = 1, MULTIFAT will perform an analysis of the type "Stress sequence", if it is = 2 a "Stress linear combination", see Section 3.

- **Coefficients A, B for Stress linear combination**

These two parameters are used in case of Stress linear combination as illustrated in the § 9.2.2.

- **Write complete output for a specified node**

For an analysis of the type "Stress linear combination", the output of the fatigue calculation is a summary on all the calculated nodes. Nevertheless, through this line, a specific node ID can be indicated, and for this node MULTIFAT will write a complete output data about all the extracted fatigue-cycles: see § 12.5

- **Analysis made with one material (1) or multiple materials (2)**

If this parameter is set = 1, all the fatigue calculations will be performed with the material properties written in the file **NAME_OF_THE_PROJECT.inp** itself (see here above), whereas if it set = 2, the calculation will be performed by using for each node the corresponding material, indicated by its ID in the file **NAME_OF_THE_PROJECT.nds** (see § 9.2.1).

- **Number of Nodes and Number of Load Cases (Preload excluded)**

These parameters give the number of Nodes on which the analysis is performed, and the number of Load Cases used for the analysis in addition to the preload one.

- **LVF for Sa in Blocks Fatigue**

This "Load Variability Factor" LVF is a multiplication factor applied to the alternate stress part only of each cycle, in the case of analysis made with Blocks of Cycle. This has been introduced as a customization for specific Users of helicopters domain.

- **GAG analysis or All Cycles analysis**

In the Aircrafts domain, it can be necessary to extract from a generic set of cycles the only one giving maximum damage, defined as the "Ground-Air-Ground" (GAG) cycle: this is possible by putting equal to 1 this parameter. The GAG analysis applies only to the "Stress Linear Combination". Among all the extracted cycles, the GAG cycle is simply defined for each node as the most damaging one. If the corresponding parameter in the file **NAME_OF_THE_PROJECT.inp** is = 1, then the damage in output will be the only one given by the GAG cycle, whereas the damages of all other cycles are neglected. If the parameter is = 0, the damages are calculated as common, using all the extracted cycles.

If a fatigue calculation is made with the Block fatigue, and the User is interested to know what is the GAG, he can use the blocks definition (file .blc, see § 9.3.2) as an input (file .cmb, see § 9.2.2) for a Linear Combination analysis after removing the last column (number of cycles of each block): the GAG cycle will be extracted by the multiaxial rainflow as the most damaging among all the possible combinations of the points that define all the blocks.

- **Parameter for extracting cycles**

This applies only to the Stress Sequence analysis: if this parameter is set = 1, the file **NAME_OF_THE_PROJECT.cif** is created, that contains all the single half-cycles extracted by the multiaxial rainflow: see § 12.6.

- **Using the sum of all the damages or the most damaging block / flight**

In the Block fatigue only, this parameter allows to select if the damages of all the blocks have to be summed-up in output (parameter = 1) or if the only most damaging block has to be considered (parameter = 0).

An additional possibility (parameter = 2) is to extract the "most damaging flight", a flight being defined as a set of blocks. The single flights are defined in the file **NAME_OF_THE_PROJECT.btf** ("blocks to flights") by giving its first and last element in the list of blocks, as illustrated in the Figure 8.

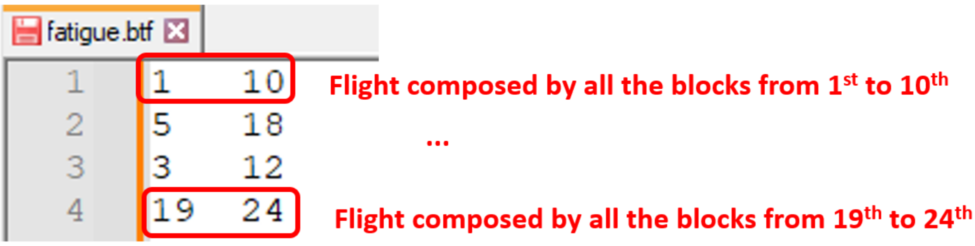


Figure 8: Definition of flight in Blocks fatigue

- **Number of "Flight Hours"**

This parameter indicates how many "Flight Hours" are included in a single repetition of the time sequence (in case of stress sequence or stress linear combination) or of the blocks of cycles (in case of blocks fatigue). The name "Flight Hours" applies to aircraft spectra language but of course it must be intended as fully general for any application, where the calculated fatigue life for sequence or blocks is associated to a given number in "fatigue life units".
This parameter impacts the files ".ndd", ".nds" and ".sum" (see in the following).

<u>NOTE</u>: all the parameters described above have to be assigned in the file **NAME_OF_THE_PROJECT.inp** even if they are not used: for example the Weibull parameters, even when the used form of the S-N curve is the Palmgren one.
But if not used, they can be of course written as dummy values, for example all zeroes as in Figure 9 below.

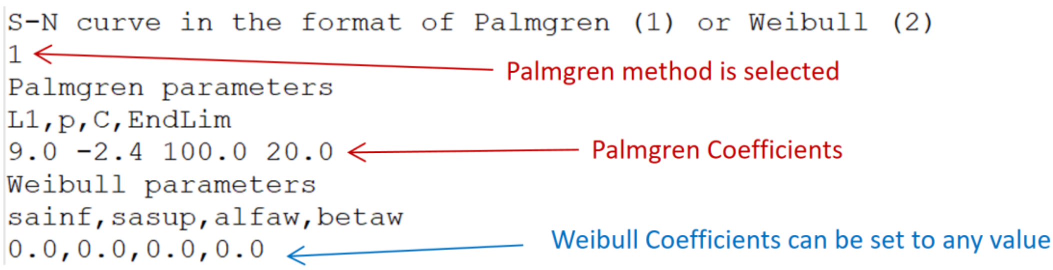


Figure 9: Example of dummy parameters

5 The elasto-plastic correction

When the input stress (see Section 9: The stress input-data) comes from a linear elastic stress-analysis in notches, MULTIFAT offers the possibility to estimate an elastic-plastic corrected stress.

In the current MULTIFAT version, this is provided via a bilinear elasto-plasticity law and based on a Linear Kinematic Hardening model describing the cyclical stress-strain curve.

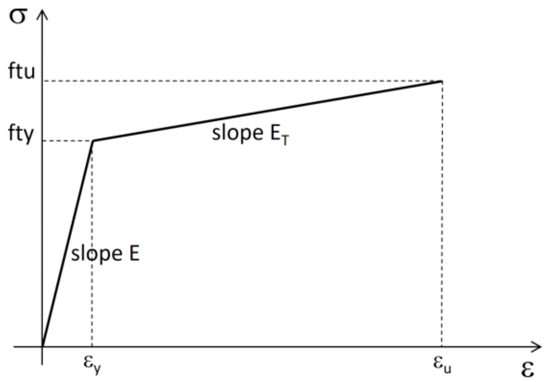


Figure 10: Bilinear elasto-plastic law

The elastic tangent modulus E_T is calculated by MULTIFAT as:

$E_T = (ftu - fty) / (\varepsilon_u - \varepsilon_Y)$ (5.1)

where

$\varepsilon_Y = fty / E$ (5.2)

$\varepsilon_u = Atot\% / 100$ (5.3)

The material properties *fty*, *E*, *ftu*, *Atot%* are given as input by the User (see § 4.3) and have the following meaning:

fty = yield stress

E = Young's modulus

ftu = ultimate tensile stress

Atot% = total elongation at ftu, in %

The material law is then coupled with the elasto-plastic correction as illustrated in the [Ref 1], in order to calculate the corrected elasto-plastic stress. Two possibilities are given to the User (see [Ref 1]):

- Linearized Neuber Law
  This is selected by putting = 1 the corresponding parameter "Linearized or Classical Neuber", see § 4.3

- Classical Neuber Law
  This is selected by putting = 2 the corresponding parameter "Linearized or Classical Neuber", see § 4.3

6 The stress-path based correction

As illustrated in [Ref 1], MULTIFAT provides the option to correct the stress-amplitude of each half-cycle that is not exactly lying on a straight line in the stress space.

In the current MULTIFAT version, this is obtained for a given half-cycle by considering the maximum sum of the two Von Mises stresses among all the segments defined by the two extrema and by any intermediate points used for the cycle construction.

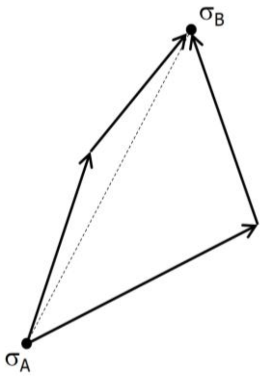


Figure 11: Stress-path correction

As already shown at the paragraph 4.3, this correction is performed if the corresponding parameter in the **NAME_OF_THE_PROJECT.inp** file is set = 1, not performed if it is set = 0, see Figure 12 here below.

fatica.inp

```
stress-strain relationship: fty, E, ftu, Atot%
400.0,71000.0,500.0,20.00
elastoplastic correction is performed (1) or not (0)
0
elastoplastic correction with Linearized Neuber (1) or Classical Neuber (2)
1
stress-path based correction performed (1) or not (0)
1
S-N curve in the format of Palmgren (1) or Weibull (2)
1
Palmgren parameters
L1,p,C,EndLim
9.0 -2.4 100.0 20.0
Weibull parameters
sainf,sasup,alfaw,betaw
0.0,0.0,0.0,0.0
Goodman correction exponent, type of behavior for Sm<0, SmMAX
1.0,2,450.
stress sequence (1) or stress linear combination (2)
1
```

Stress-path correction

Figure 12: Parameter for stress-path correction

The stress-path based correction implemented in the first versions of MULTIFAT appears relatively conservative.

7 The S-N curve forms

MULTIFAT offers different possibilities to describe the S-N curve data, which gives the number of cycles N in function of the stress-amplitude Sa of a cycle.

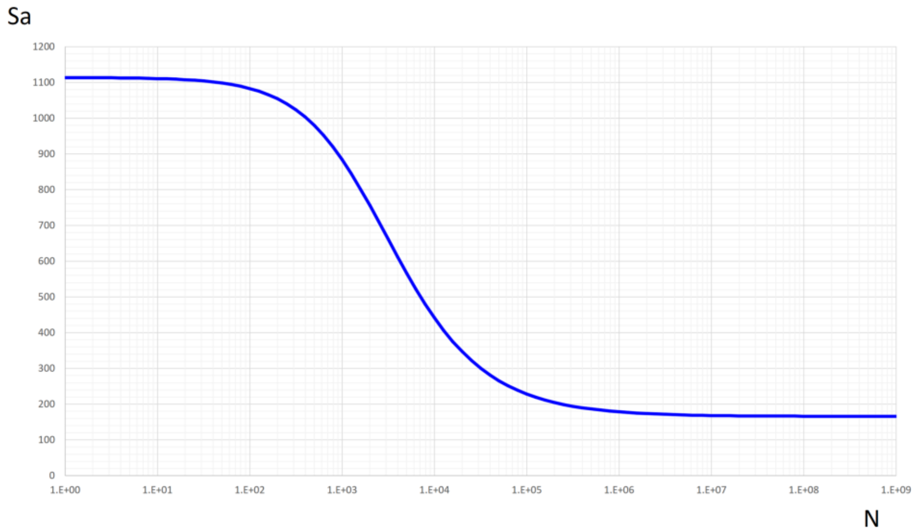


Figure 13: S-N curve

7.1 Palmgren equation

The Palmgren equation uses four parameters to describe the S-N curve, in the following form

$Log_{10}(N+C) = L_1 + p\ Log_{10}(S-E)$ (7.1)

or equivalently

$S = E + 10^{m[Log_{10}(N+C)-L1]}$ (7.2)

where

m=1/p (7.3)

N is the number of cycles

S is the stress

E is the endurance limit

L1, p and C are the Palmgren parameters

All these parameters are assigned by the User in the **NAME_OF_THE_PROJECT.inp** file or in the material properties file **NAME_OF_THE_PROJECT.mtr**, see Section 9.3

REMARK

- For C=0 the equation corresponds to the Stromeyer form, used for example in MMPDS (Mil-Handbook) database
- For C=0 and E=0 the equation corresponds to the Basquin form.

7.2 Weibull equation

The Weibull equation uses four parameters to describe the S-N curve, in the following form

$$L = \alpha\left(-\ln\frac{S-E}{S_U-E}\right)^{1/\beta} \tag{7.4}$$

or equivalently

$$S = E + (S_U - E)\, e^{-\left(\frac{L}{\alpha}\right)^{\beta}} \tag{7.5}$$

where

L = Log_{10}(N), where N is the number of cycles

S is the stress

E is the endurance limit

S_U is the ultimate stress

α and β are the Weibull parameters

All these parameters are assigned by the User in the **NAME_OF_THE_PROJECT.inp** file or in the material properties file **NAME_OF_THE_PROJECT.mtr**, see Section 9.3

The Weibull form is the one used for example in the HSB database, [Ref 2].

8 The mean-stress correction

MULTIFAT uses the following generic form to perform the Mean Stress correction

$$Sa_{Sm=0} = \frac{Sa}{1-\left(\frac{Sm}{Sm_{MAX}}\right)^{n}} \qquad (8.1)$$

where Sm_{MAX} is the stress that determines the intersection with Sa=0, thus it is the value of mean stress at which the allowable Sa drops to 0, see Figure 14.

Note that this value is intentionally left as specific input for the User, independently on the values of fty and ftu defined in the **NAME_OF_THE_PROJECT.inp** file and used in the elasto-plastic correction

In this way, the User has the freedom to apply the most suitable value for his analysis (ex. to apply a conservativism)

Observe that :

For n=1 and Sm_{MAX} = ftu, this corresponds to the Goodman correction

For n=2 and Sm_{MAX} = ftu, this corresponds to the Gerber correction

For n=1 and Sm_{MAX} = fty, this corresponds to the Soderberg correction

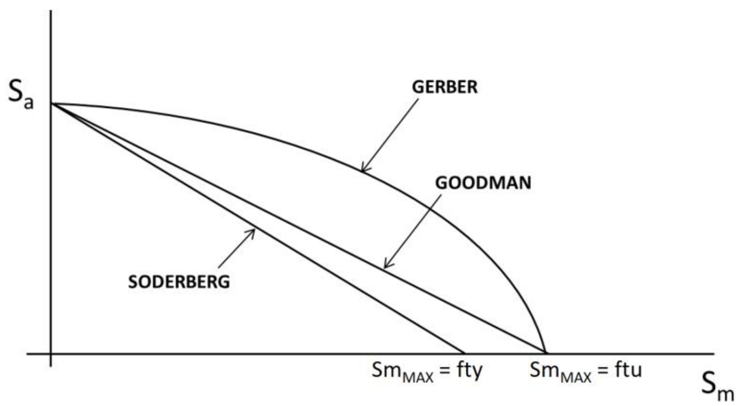


Figure 14: Graphical representation of the mean-stress correction

For negative values of Sm, MULTIFAT offers to the user a triple choice, driven by the parameter *GoodmanMethod*, see § 4.3, namely:

- *GoodmanMethod* = 1 for Sm<0 the behavior is simply the prolongation of the one for Sm≥0, using the same equation (8.1) above.
- *GoodmanMethod* = 2 for Sm<0 the behavior is constant, equal to the value for Sm=0
- *GoodmanMethod* = 3 for Sm<0 the behavior is symmetric to the one for Sm≥0

<u>REMARKS</u>

The option *GoodmanMethod* = 2 (horizontal line for Sm<0) is the recommended one.

The option *GoodmanMethod* = 1 is not recommended for n≠1 since it generates a behavior that appears physically not consistent, as shown in Figure 15.

The Figure 16 below summarizes the different options, for the case of n=1.

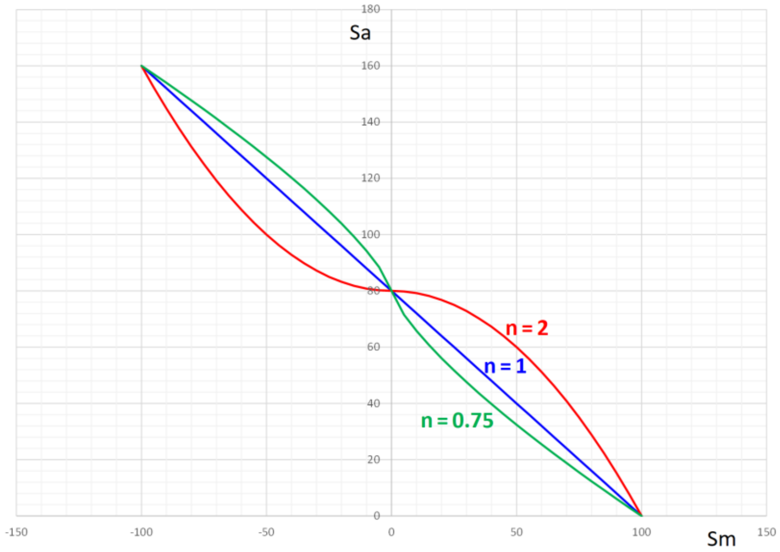


Figure 15: Example of unreliable behavior for Sm<0 and n≠1

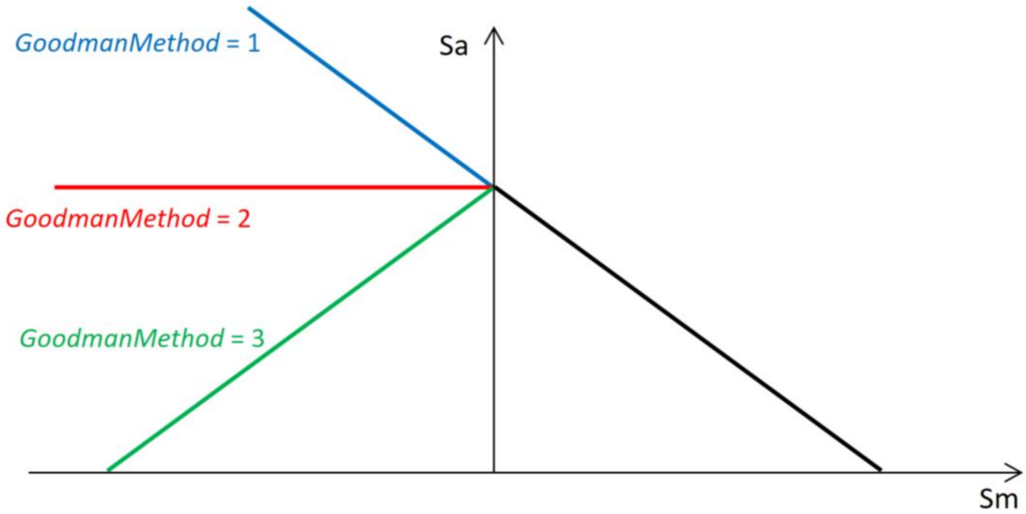


Figure 16: Different types of mean-stress correction for Sm<0

9 The stress input-data

9.1 Input for Stress sequence analysis

Stress sequence

A text file named **NAME_OF_THE_PROJECT.sig** must be present in the working directory, see § 4.2.

This file contains the stress-sequence in the format illustrated in the Figure 17, where the six stress-components are defined. The data represents the stress time-history.

The separator between stress values can be indifferently TAB, COMMA or SPACE, this does not change the subsequent MULTIFAT calculation

σ_{xx}	σ_{yy}	σ_{zz}	τ_{xy}	τ_{yz}	τ_{xz}
-35.17	41.58	97.21	-84.27	85.89	44.66
-83.43	-60.91	-93.29	12.22	76.78	9.51
24.06	69.28	11.17	39.57	39.80	18.49
-65.69	-22.15	-8.10	-13.47	-0.22	-9.95
5.89	67.73	-68.40	1.50	-31.62	-0.12
-33.65	69.14	-31.57	-24.10	-90.74	-22.86
52.05	91.81	82.99	81.17	33.08	75.07
-62.81	63.54	42.85	-78.96	82.91	-42.24
-73.86	-54.90	5.87	-52.50	12.04	39.37
-5.84	-68.86	-48.66	30.53	-35.55	-25.94
56.25	17.94	-20.06	53.71	62.13	-45.46
-88.16	46.99	-7.94	-79.37	88.86	-94.46
-82.46	-3.53	11.24	44.62	-41.23	-3.43
-38.64	58.46	-10.21	-79.57	21.95	-29.01
-6.98	43.10	-66.55	99.44	9.04	97.08
67.24	-40.88	68.55	10.29	-58.67	25.58
-51.86	1.42	-3.09	23.56	-76.24	94.57
-79.55	86.71	-61.31	-84.43	-65.10	-99.59
1.35	-10.11	-91.38	-29.41	-57.20	-5.85

separator between stress values can be ***TAB***, ***COMMA*** or ***SPACE*** indifferently

Figure 17: Stress input data format in the .sig file

For a uniaxial analysis, the User can enter the stress-tensor with the only σ_{XX} non-zero component, setting to zero the other five. MULTIFAT in this case performs a classical Rainflow calculation on this component.

σ_{xx}	σ_{yy}	σ_{zz}	τ_{xy}	τ_{yz}	τ_{xz}
64.704	0.0	0.0	0.0	0.0	0.0
-48.029	0.0	0.0	0.0	0.0	0.0
-71.065	0.0	0.0	0.0	0.0	0.0
-71.121	0.0	0.0	0.0	0.0	0.0
-41.055	0.0	0.0	0.0	0.0	0.0
-66.680	0.0	0.0	0.0	0.0	0.0
-77.772	0.0	0.0	0.0	0.0	0.0
71.942	0.0	0.0	0.0	0.0	0.0
-1.509	0.0	0.0	0.0	0.0	0.0
1.646	0.0	0.0	0.0	0.0	0.0
67.584	0.0	0.0	0.0	0.0	0.0
-11.617	0.0	0.0	0.0	0.0	0.0
-32.968	0.0	0.0	0.0	0.0	0.0
63.946	0.0	0.0	0.0	0.0	0.0
49.778	0.0	0.0	0.0	0.0	0.0
-33.349	0.0	0.0	0.0	0.0	0.0

Figure 18: Stress input data for uniaxial analysis

9.2 Input for Stress linear combination analysis

Stress linear combination

9.2.1 Nodal stress input data

The text file named **NAME_OF_THE_PROJECT.nds** contains the six components of the stress-tensor for each node and for each unit fatigue load case, in the following format. This file must be in the working directory.

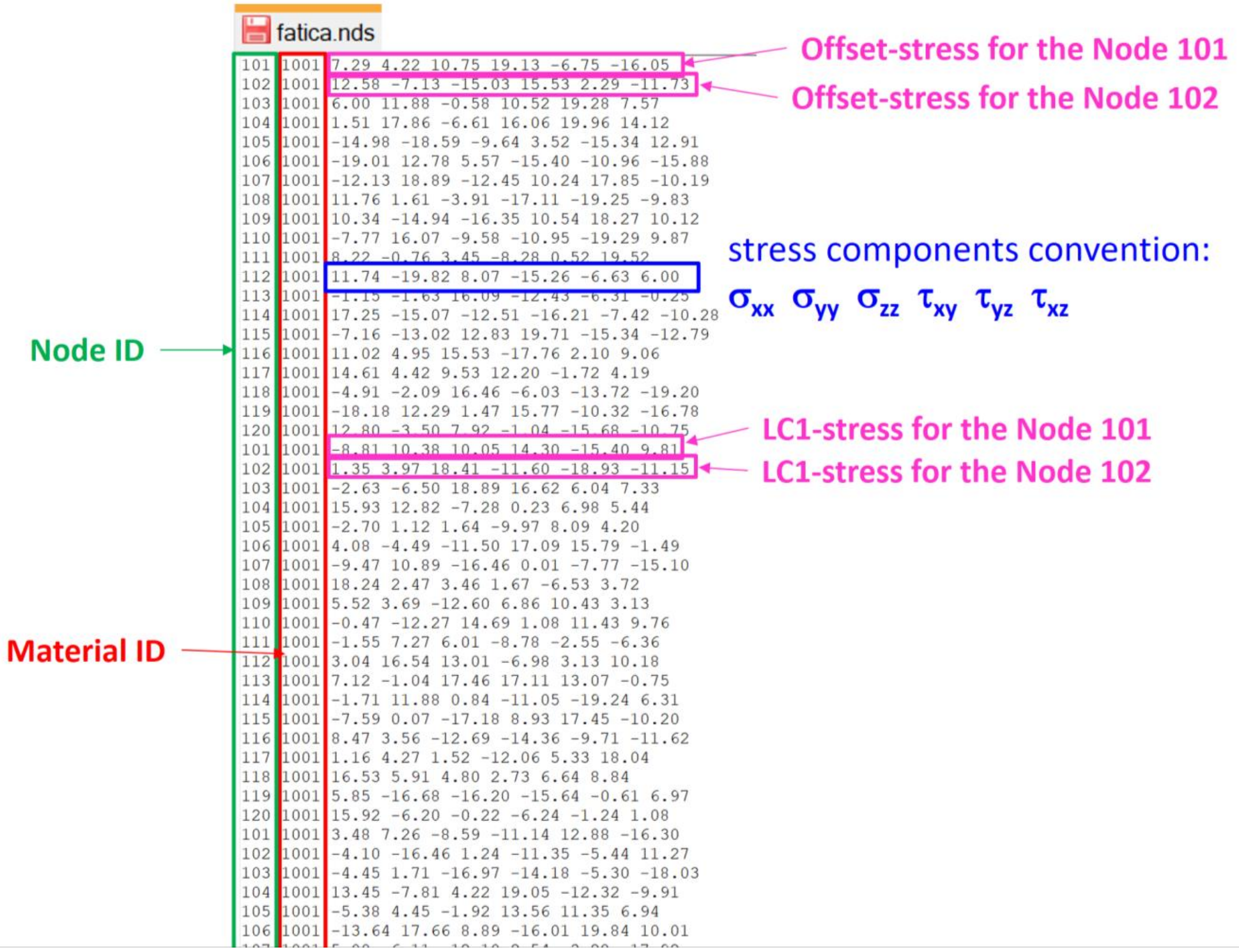


Figure 19: Nodal stress input data format in the .nds file

NOTES

- The input list must be built by blocks with the same sequence of Nodes ID and Materials ID, that must be identically repeated N_{LC} + 1 times, where N_{LC} is the number of Load Cases.
- MULTIFAT will check whether in the different blocks the same sequence of Nodes ID and Materials ID is respected: if it is not, it will stop with an error message.
- The Material ID for a given node must be the same for all the lines having the same Node id: if it is not like this, MULTIFAT will stop with error
- The first block of stress values represents the constant offset-stress $\sigma_{ij}^0(N)$, see § 9.2.2, of each node.
- The other blocks of stress values represents the stress $\sigma_{ij}(N)$ for each of the Load Cases, see § 9.2.2, of each node.

REMARK: Since the separators between the input data can be anyone among *TAB*, *COMMA* or *SPACE* (see as an example Figure 17), the numerical input can be easily copied and pasted for example from MS-Excel, as illustrated in Figure 20 without any need of reformatting the data.

This applies generally to all the MULTIFAT data input files

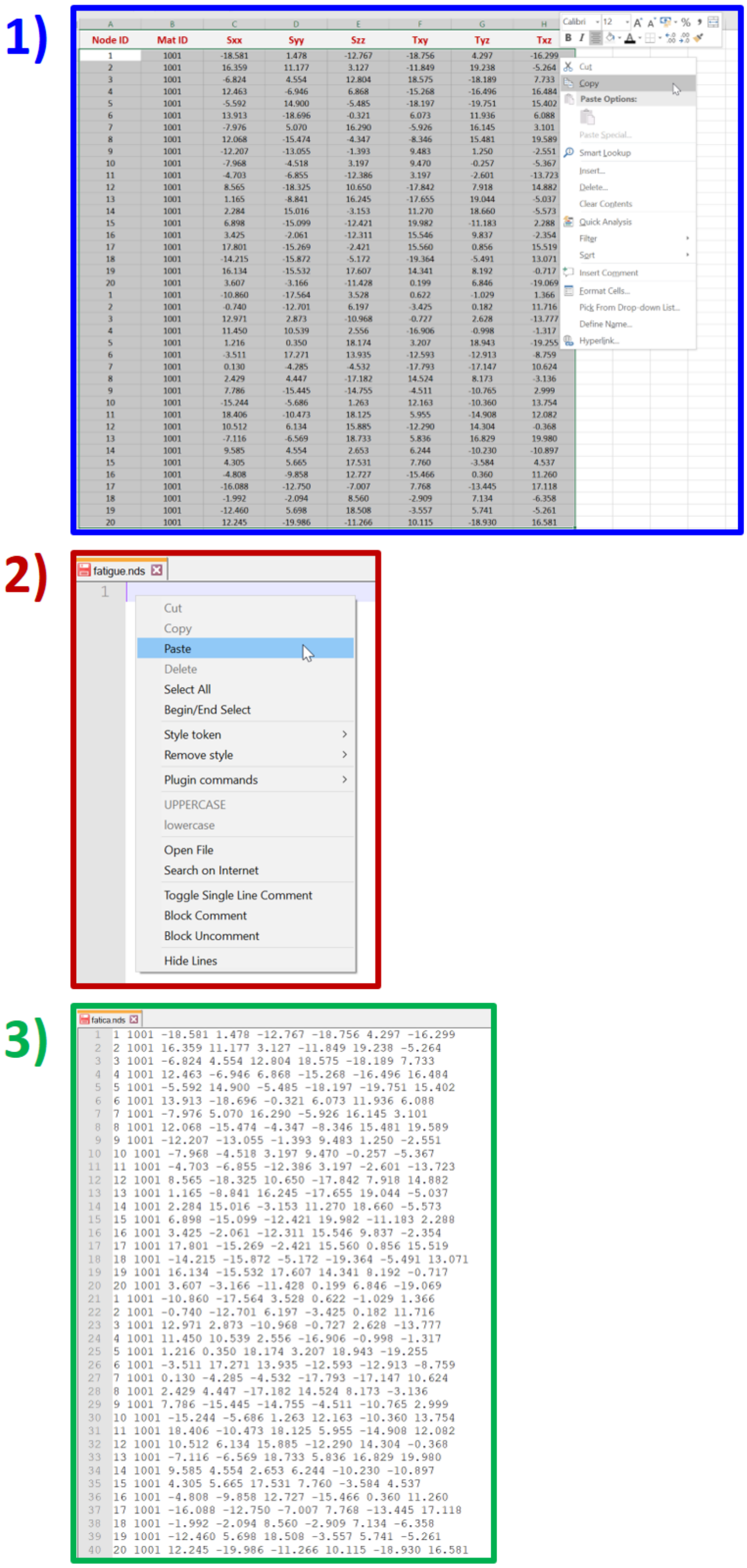


Figure 20: Input data manually copied from MS-Excel

9.2.2 Linear combination coefficients input data

The text file named **NAME_OF_THE_PROJECT.cmb** contains the sequence of the stress history given in terms of coefficients that, for each line, define the linear combination to be applied to the Unit Fatigue Load Cases defined in the **NAME_OF_THE_PROJECT.nds** file. This file too must be in the working directory.


```
1.795,-0.472,-1.421,-1.697,1.773,-0.892,-1.628,1.874,0.467
-1.340,-1.257,-0.978,-1.253,0.009,0.605,0.763,-1.872,-1.213
-1.076,0.056,0.661,0.201,-1.022,-1.992,1.117,-1.828,-0.153
-1.183,-0.604,-1.229,-0.112,1.170,-1.607,-0.371,1.037,-1.038
-0.630,-1.832,-0.801,-0.410,-0.987,0.071,0.273,-1.995,1.624
-1.204,-0.943,-0.566,-1.164,-0.245,1.116,-1.945,1.884,0.601
1.851,-1.691,0.822,1.916,1.260,1.289,1.577,1.625,-0.102
-1.483,1.324,-1.863,0.127,-1.185,-1.654,-0.734,-1.106,0.751
0.669,1.560,-0.515,0.871,-1.764,0.630,1.621,-1.771,0.235
-0.372,-1.551,-0.751,-0.734,1.534,-1.802,-1.096,-1.442,-1.521
0.053,-0.892,1.626,0.728,1.068,0.130,-0.235,1.227,1.764
1.456,-0.571,0.975,-0.486,-1.409,-0.644,-1.002,1.279,0.597
-1.819,-1.286,-1.875,-1.419,1.823,-1.635,-1.330,0.293,-1.509
-1.659,-0.728,1.075,-1.250,1.117,-1.694,-1.335,1.174,1.401
-0.368,-1.495,-0.510,-0.072,1.314,-1.955,-0.346,-0.612,-1.138
1.822,1.206,0.043,-0.844,0.519,0.650,-1.944,0.801,0.214
0.337,-0.503,-1.239,0.824,-0.710,1.277,1.310,-0.656,0.428
-1.292,1.547,-0.122,-0.367,-1.868,-1.522,-1.464,1.944,-1.242
1.766,-0.878,-0.830,1.856,-0.597,0.623,-0.082,0.898,0.755
0.458,0.314,1.618,1.200,1.566,-0.653,-1.740,-0.588,-0.641
0.934,-1.537,0.725,-1.729,1.178,0.018,0.542,-0.364,1.715
-1.606,0.908,-1.470,-0.848,-1.271,-1.931,-1.056,0.209,-1.829
1.118,1.674,-0.006,0.274,1.899,0.090,-1.705,-1.715,0.395
0.091,-0.659,-1.901,1.713,0.024,0.871,1.814,0.912,-1.821
0.711,-0.898,1.385,-0.653,-1.679,0.566,0.830,-0.933,1.473
0.800,1.572,-1.311,1.993,1.047,1.005,1.294,1.074,1.017
```

Figure 21: Linear combination coefficients data format in the .nds file

The formula that gives for a given node N the stress at the instant "t" of the time-history is the following

$$\sigma_{ij}(t,N) = A\left(\sigma^0_{ij}(N) + B\sum_{k=1}^{N_{LC}} c_k(t)\sigma_{k,ij}(N)\right) \tag{9.1}$$

where:

- $\sigma_{k,ij}(t, N)$ is the stress on the Node "N" of a given set of nodes obtained when applying the k^th *Unit Fatigue Load Case* (UFLC): this is given in the file **NAME_OF_THE_PROJECT.nds**. Note that $\sigma_{k,ij}(t, N)$ is the stress-difference with respect to the pre-stress condition $\sigma_{ij}^0(N)$ (see here below): i.e., $\sigma_{k,ij}(t, N)$ does not contain the pre-stress.
- $c_k(t)$ is a sequence of coefficients representing the linear combination to be applied for the k^{th} of the N_{LC} Load Cases at each instant on the same UFLC. These are given at the t^{th} line and in the k^{th} column of the file **NAME_OF_THE_PROJECT.cmb**
- $\sigma_{ij}^0(N)$ is a constant offset-stress (or "pre-stress") for each node: this is given in the file **NAME_OF_THE_PROJECT.nds**
- A, B are two scalar scaling-parameters given in the file **NAME_OF_THE_PROJECT.inp**
- k represents the k^{th} Load Case and N_{LC} is the total number of Load Cases, i.e. the number of lines with the same node id, in the file **NAME_OF_THE_PROJECT.nds**

MULTIFAT calculates for each node the fatigue damage and life.

9.3 Input for Blocks of Cycles analysis

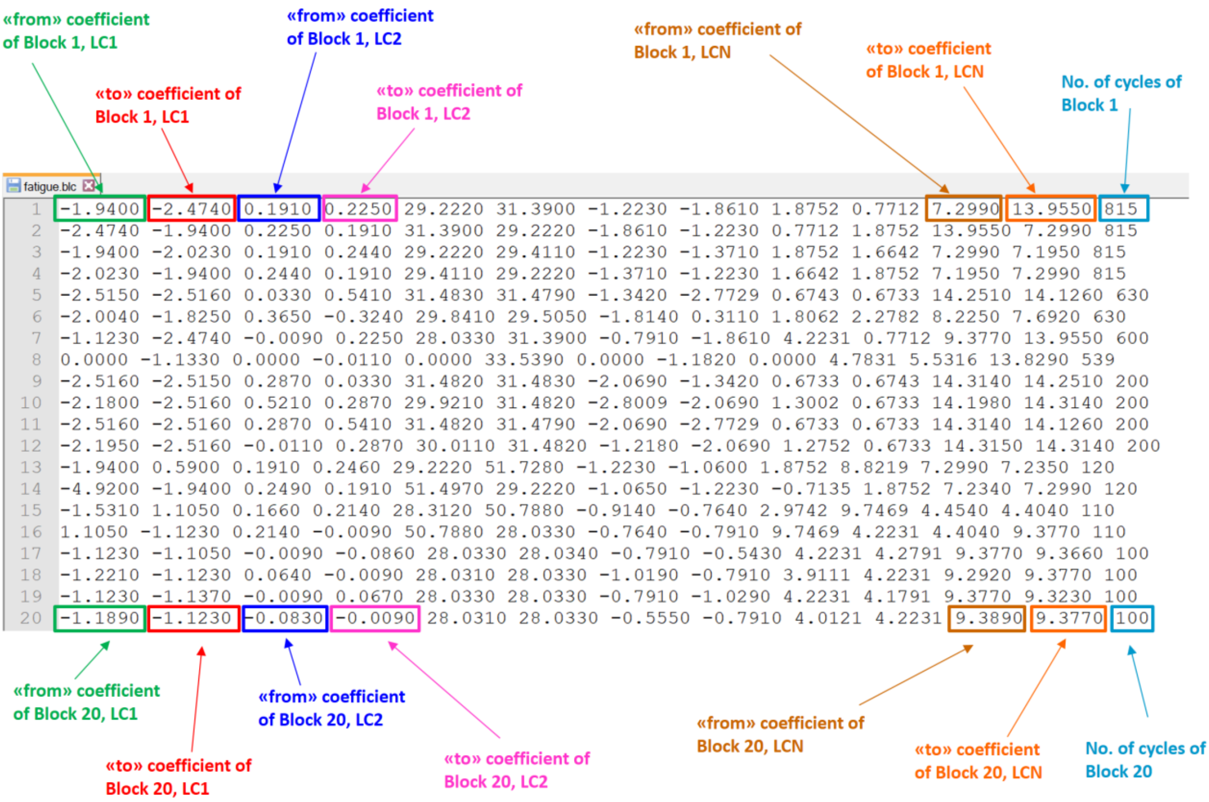
Blocks of cycles

9.3.1 Nodal stress input data

Identically to what indicated in the paragraph 9.2.1, the text file named **NAME_OF_THE_PROJECT.nds** contains the six components of the stress-tensor for each node and for each unit fatigue load case, in the following format. This file must be in the working directory. See the paragraph 9.2.1 for all details.

9.3.2 Definition of the Cycle Blocks

The text file named **NAME_OF_THE_PROJECT.blc** contains the coefficients defining each block of cycles, as well as the number of its occurrences.




```
-1.9400 -2.4740 0.1910 0.2250 29.2220 31.3900 -1.2230 -1.8610 1.8752 0.7712 7.2990 13.9550 815
-2.4740 -1.9400 0.2250 0.1910 31.3900 29.2220 -1.8610 -1.2230 0.7712 1.8752 13.9550 7.2990 815
-1.9400 -2.0230 0.1910 0.2440 29.2220 29.4110 -1.2230 -1.3710 1.8752 1.6642 7.2990 7.1950 815
-2.0230 -1.9400 0.2440 0.1910 29.4110 29.2220 -1.3710 -1.2230 1.6642 1.8752 7.1950 7.2990 815
-2.5150 -2.5160 0.0330 0.5410 31.4830 31.4790 -1.3420 -2.7729 0.6743 0.6733 14.2510 14.1260 630
-2.0040 -1.8250 0.3650 -0.3240 29.8410 29.5050 -1.8140 0.3110 1.8062 2.2782 8.2250 7.6920 630
-1.1230 -2.4740 -0.0090 0.2250 28.0330 31.3900 -0.7910 -1.8610 4.2231 0.7712 9.3770 13.9550 600
0.0000 -1.1330 0.0000 -0.0110 0.0000 33.5390 0.0000 -1.1820 0.0000 4.7831 5.5316 13.8290 539
-2.5160 -2.5150 0.2870 0.0330 31.4820 31.4830 -2.0690 -1.3420 0.6733 0.6743 14.3140 14.2510 200
-2.1800 -2.5160 0.5210 0.2870 29.9210 31.4820 -2.8009 -2.0690 1.3002 0.6733 14.1980 14.3140 200
-2.5160 -2.5160 0.2870 0.5410 31.4820 31.4790 -2.0690 -2.7729 0.6733 0.6733 14.3140 14.1260 200
-2.1950 -2.5160 -0.0110 0.2870 30.0110 31.4820 -1.2180 -2.0690 1.2752 0.6733 14.3150 14.3140 200
-1.9400 0.5900 0.1910 0.2460 29.2220 51.7280 -1.2230 -1.0600 1.8752 8.8219 7.2990 7.2350 120
-4.9200 -1.9400 0.2490 0.1910 51.4970 29.2220 -1.0650 -1.2230 -0.7135 1.8752 7.2340 7.2990 120
-1.5310 1.1050 0.1660 0.2140 28.3120 50.7880 -0.9140 -0.7640 2.9742 9.7469 4.4540 4.4040 110
1.1050 -1.1230 0.2140 -0.0090 50.7880 28.0330 -0.7640 -0.7910 9.7469 4.2231 4.4040 9.3770 110
-1.1230 -1.1050 -0.0090 -0.0860 28.0330 28.0340 -0.7910 -0.5430 4.2231 4.2791 9.3770 9.3660 100
-1.2210 -1.1230 0.0640 -0.0090 28.0310 28.0330 -1.0190 -0.7910 3.9111 4.2231 9.2920 9.3770 100
-1.1230 -1.1370 -0.0090 0.0670 28.0330 28.0330 -0.7910 -1.0290 4.2231 4.1791 9.3770 9.3230 100
-1.1890 -1.1230 -0.0830 -0.0090 28.0310 28.0330 -0.5550 -0.7910 4.0121 4.2231 9.3890 9.3770 100
```

Figure 22: Definition of the Blocks of Cycles in the .blc file

The formulae providing for a given node N the stress-cycle allowing calculating a damage for each block, are the following:

$$\sigma_{ij,FROM}(N) = A\left(\sigma_{ij}^{0}(N) + B\sum_{k=1}^{N_{LC}} c_{k,FROM}\sigma_{k,ij}(N)\right) \tag{9.2a}$$

$$\sigma_{ij,TO}(N) = A\left(\sigma_{ij}^{0}(N) + B\sum_{k=1}^{N_{LC}} c_{k,TO}\sigma_{k,ij}(N)\right)$$

(9.2b)

where:

- $\sigma_{k,ij}(t, N)$ is the stress for a certain number of *Unit Fatigue Load Cases* (UFLC) and for a given set of nodes: this is given in the file **NAME_OF_THE_PROJECT.nds**
- $c_{k,FROM}$ and $c_{k,TO}$ are coefficients providing the linear combination to be applied for the k^{th} Load Case and for each blocks, defining the two extremes of each cycle: they are given in the file **NAME_OF_THE_PROJECT.blc**
- $\sigma_{ij}^{0}(N)$ is a constant offset-stress for each node: this is given in the file **NAME_OF_THE_PROJECT.nds**
- A, B are two scalar scaling-parameters
- k represents the k^{th} Load Case and N_{LC} is the total number of Load Cases, i.e. the number of lines with the same node id, in the file **NAME_OF_THE_PROJECT.nds**

- MULTIFAT calculates the fatigue damage for each node and for each cycle of a block between "FROM" and "TO". The damage of one block is then obtained by multiplying it by the number of cycles in a block, given in the last column of the file **NAME_OF_THE_PROJECT.blc**. Finally, the total damage D_{TOT} of one node is the sum of the damages of all the blocks, and the life in terms of repeats of the whole set of cycle-blocks is equal to $1/D_{TOT}$.

10 The material input-data

Stress linear combination

Blocks of cycles

This kind of input applies only for "Stress linear combination analysis" and to "Blocks of cycles". The Material ID for each calculated node is indicated in the second column of the **NAME_OF_THE_PROJECT.nds** file, see § 9.2.1.

In the file **NAME_OF_THE_PROJECT.mtr** the Material ID appears together with all the necessary input coefficients of this material: there meaning is illustrated in the Figure 23.

fatica.mtr

```
Materials list
MID   fty    E        ftu     A%  SNid p1      p2     p3    p4    SMexp SMid  SmMAX
1001 680.0 105000.0 900.0    6.0 1     9.0    -3.0  50.0 500.0   1.0   2    900.0
1003 800.0 210000.0 1100.0   8.0 2   380.0  1040.0   4.0   4.5   1.0   2   1100.0
1004 680.0 105000.0 900.0    6.0 2   220.0   800.0   3.5   3.9   1.0   2    900.0
1010 340.0 71000.0  420.0   14.0 2    50.0   410.0   5.0   3.9   1.0   2    420.0
1002 190.0 71000.0  280.0    2.0 1    15.0    -5.0   0.0  10.0   1.0   2    280.0
```

Figure 23: Nodal stress input data format in the .mtr file

The parameters defining the material properties have the following meaning:

1)	**MID**	Material ID
2)	**fty**	yielding stress
3)	**E**	Young's modulus
4)	**ftu**	ultimate tensile stress
5)	**A%**	total elongation at ftu, in %
6)	**SNid**	S-N curve Palmgren (1) or Weibull (2)
7)	**p1**	S-N curve parameter : L1 for Palmgren, sainf for Weibull
8)	**p2**	S-N curve parameter : p for Palmgren, sasup for Weibull
9)	**p3**	S-N curve parameter : C for Palmgren, alfaw for Weibull
10)	**p4**	S-N curve parameter : EndLim for Palmgren, betaw for Weibull
11)	**SMexp**	Goodman exponent in the mean-stress correction
12)	**SMid**	Goodman method in the mean-stress correction
13)	**SmMAX**	Static Max in the mean-stress correction

11 Run MULTIFAT

The binary file *multifat.exe* can be run as command line from Windows Command Prompt or by double clicking the *multifat.exe* icon in Windows.

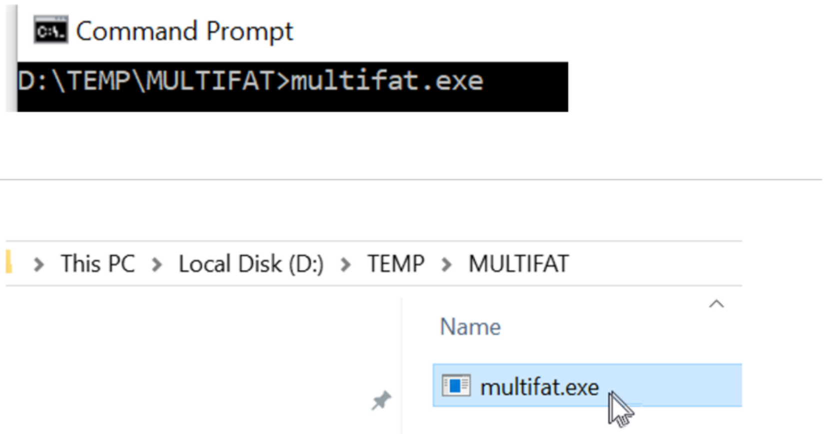


Figure 24: MULTIFAT run

In case of multifat.exe is run by double-clicking the Windows icon, then possibly some messages if any - like for example runtime errors information or unexpected stop - that would be printed at the screen if using the Windows Command Prompt, are written in a file named *multifat.adv*, as shown for example in Figure 25:

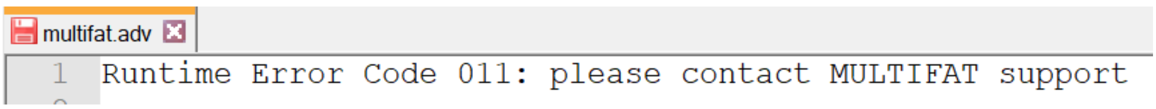


Figure 25: Example of *multifat.adv* file

12 Output data

12.1 Screen output

A summary of some basic output information and data is given already when MULTIFAT is run from the Windows Command Prompt.

N.B. Depending on the MULTIFAT version and type of analysis, the screen output can be different from what shown in Figure 26.

```
Runtime begin 15:51:53
You are running MULTIFAT version v22.03
License expires in 54 days
Executing MULTIFAT version 22.03 ...
Name of input file :        .\fatigue.inp
MULTIFAT version v22.03 for               PROFESSIONAL
License expires in 54 days
The following parameters define the elasto-plastic behavior of the material:
Yielding stress              470
Young's modulus              71000
Static strength              500
Total strain at failure (%)  20.1
Analysis performed without elasto-plastic correction
The following unique set of material properties has been used for the analysis:
The S-N curve format is the Palmgren's equation, with the following parameters:
L1 =           8.62074
p =           -2.0475
C =            2170
Endurance limit =            92.25
Parameters for the mean-stress correction:
Goodman exponent             1
Goodman method               2
Goodman SmMAX                600
Total damage is equal to     0.00142917694474O783
Number of Life Repeats       699.703422784626
End of MULTIFAT
Runtime end   15:51:53
```

Figure 26: MULTIFAT screen output data example

The same type of output data is written also to the file in the working directory:

NAME_OF_THE_PROJECT.sum

This output allows namely the User to check if the data given as input has been correctly read by MULTIFAT.

```
MULTIFAT version v22.03 for                    PROFESSIONAL
License expires in 54 days
The following parameters define the elasto-plastic behavior of the material:
Yielding stress               470
Young's modulus               71000
Static strength               500
Total strain at failure (%)   20.1
Analysis performed without elasto-plastic correction
The following unique set of material properties has been used for the analysis:
The S-N curve format is the Palmgren's equation, with the following parameters:
L1 =           8.62074
p =           -2.0475
C =            2170
Endurance limit =             92.25
Parameters for the mean-stress correction:
Goodman exponent              1
Goodman method                2
Goodman SmMAX                 600
Total damage is equal to      0.00142917694474O783
Number of Life Repeats        699.703422784626
```

Figure 27: Example of output file .sum

N.B. Depending on the MULTIFAT version and type of analysis, the output can be different from what shown in Figure 27.

12.2 Output file .cyc for Stress sequence analysis

Stress sequence

A text file named **NAME_OF_THE_PROJECT.cyc** is written as output. Its columns of data for each of the generated cycles are:

Column 1 σ_m = mean stress of the cycle

Column 2 σ_a = stress-amplitude of the cycle

Column 3 DMG = damage of the cycle

Column 4 Static Failure: indicates if static failure occurred for the cycle and which type (see Sect. 13)

fatigue.cyc

σ_m σ_a DMG Static Failure

Fatigue cycles

Mean Stress	Amplitude	Damage	Static Failure
-3.880000e+02	3.716383e+02	1.820266e-03	0
8.969257e+01	3.716383e+02	1.000000e+00	2
1.283105e+01	1.195586e+02	2.616402e-05	0
3.000000e+01	3.650685e+01	2.293946e-06	0
-3.450000e+01	3.618701e+01	8.005382e-07	0
-6.485135e+01	1.364578e+00	0.000000e-01	0
3.409588e+01	1.063353e+02	3.955710e-05	0
1.396893e+02	2.000732e+02	1.000000e+00	1
4.794167e+01	9.264250e+01	5.123119e-05	0
6.950000e+01	6.902898e+01	1.022143e-04	0
9.164154e+01	5.032816e+01	1.000000e+00	2
2.820157e+02	1.610724e+02	1.000000e+00	1

Figure 28: Output file .cyc for Stress sequence

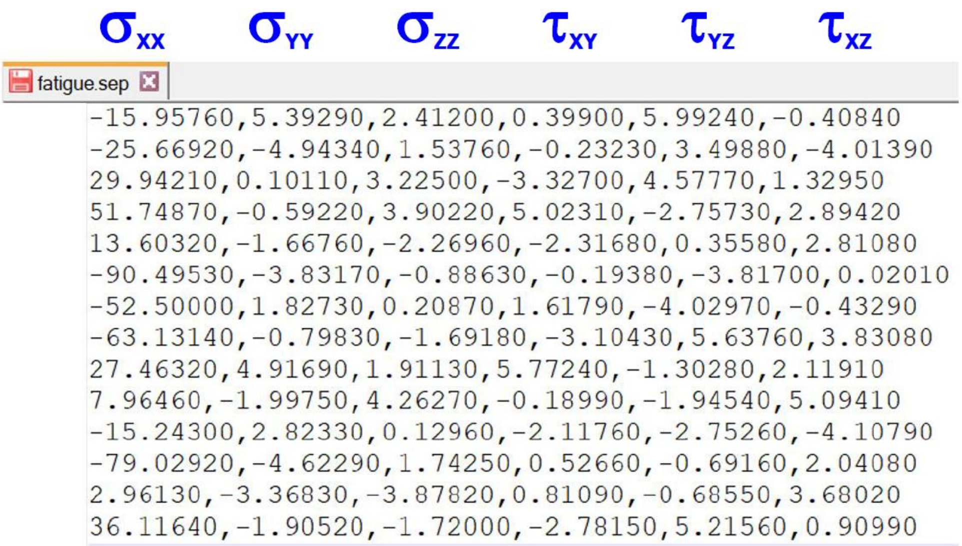
12.3 Output file .sep for Stress sequence analysis

Stress sequence

For a Stress sequence analysis, if the elasto-plastic correction is performed, a text file named **NAME_OF_THE_PROJECT.sep** is written as output.

Its columns are the six stress-components calculated after performing the elasto-plastic correction. The stress components are given in the following order (same as the already illustrated file **NAME_OF_THE_PROJECT.inp**):

σ_{XX}, σ_{YY}, σ_{ZZ}, τ_{XY}, τ_{YZ}, τ_{XZ}




```
-15.95760,5.39290,2.41200,0.39900,5.99240,-0.40840
-25.66920,-4.94340,1.53760,-0.23230,3.49880,-4.01390
29.94210,0.10110,3.22500,-3.32700,4.57770,1.32950
51.74870,-0.59220,3.90220,5.02310,-2.75730,2.89420
13.60320,-1.66760,-2.26960,-2.31680,0.35580,2.81080
-90.49530,-3.83170,-0.88630,-0.19380,-3.81700,0.02010
-52.50000,1.82730,0.20870,1.61790,-4.02970,-0.43290
-63.13140,-0.79830,-1.69180,-3.10430,5.63760,3.83080
27.46320,4.91690,1.91130,5.77240,-1.30280,2.11910
7.96460,-1.99750,4.26270,-0.18990,-1.94540,5.09410
-15.24300,2.82330,0.12960,-2.11760,-2.75260,-4.10790
-79.02920,-4.62290,1.74250,0.52660,-0.69160,2.04080
2.96130,-3.36830,-3.87820,0.81090,-0.68550,3.68020
36.11640,-1.90520,-1.72000,-2.78150,5.21560,0.90990
```

Figure 29: Output file .sep for Stress sequence

12.4 Output file .ndd for “Stress linear combination” and “Blocks of cycles”

Stress linear combination

Blocks of cycles

For “Stress linear combination” and “Blocks of cycles” analyses, a text file named **NAME_OF_THE_PROJECT.ndd** is written as output. Its columns of data for each of the generated cycles are:

Column 1 Node id

Column 2 DMG = total damage at the node

Column 3 LIFE = fatigue life at the node in terms of repeats of the time history or set of blocks

Column 4 Static Failure: indicates if static failure occurred for the node and which type (see Sect. 13)

Nd	DMG	LIFE	Static Failure
Node ID	Damage	Life	Static Failure
1	1.564234e-04	6.392904e+03	0
2	1.000000e-18	1.000000e+18	0
3	1.000000e-18	1.000000e+18	0
4	2.633320e-06	3.797488e+05	0
5	1.000000e-18	1.000000e+18	0
6	1.000000e-18	1.000000e+18	0
7	5.747415e-06	1.739913e+05	0
8	1.000000e-18	1.000000e+18	0
9	6.022941e-05	1.660318e+04	0
10	1.000000e-18	1.000000e+18	0

Figure 30: Output file .ndd for Stress linear combination

12.5 Output files .cyc and .sep for Stress linear combination analysis

Stress linear combination

Blocks of cycles

The two text files named **NAME_OF_THE_PROJECT.cyc** and **NAME_OF_THE_PROJECT.sep** already described at § 12.2 and 12.3 can be written as output also for Stress linear combination analysis, but only for one specified node. The ID of the node appears in the file **NAME_OF_THE_PROJECT.inp** as already shown in Figure 7.

12.6 Output file .cif for a Stress sequence analysis

Stress sequence

The text file named **NAME_OF_THE_PROJECT.cif** contains the list of all the half cycles extracted with the multiaxial rainflow, in case of Stress sequence analysis type, and for each half cycle, the 6x2 stress components of its initial and final points.

fatigue.cif

```
 Fatigue half-cycles
 sigA(1,...,6)  ,  sigB(1,...,6)
2.361085e+02  -1.184710e+01 0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01  6.510378e+01  2.050618e+02  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01
2.096562e+02  1.466114e+01  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01  2.270239e+02  -4.200460e+00 0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01
2.270239e+02  -4.200460e+00 0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01  2.096143e+02  1.461923e+01  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01
1.594235e+02  6.997160e+01  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01  1.679738e+02  5.824691e+01  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01
1.679738e+02  5.824691e+01  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01  1.577599e+02  6.833218e+01  0.000000e-01  0.000000e-01  0.000000e-01  0.000000e-01
```

Figure 31: Output file .cif for Stress sequence

The option to write as an output the file **NAME_OF_THE_PROJECT.cif** is selected by putting "1" in the corresponding line of the **NAME_OF_THE_PROJECT.inp** file:

```
For Stress Sequence only: extract cycles (1) or not (0)
1
```

Figure 32: Input line in the file .inp to get the information of all half-cycles

13 Damage calculation and static failure definition

From a general standpoint, in MULTIFAT the damage of every cycle extracted by the multiaxial rainflow, is calculated entering in the S-N curve with the equivalent stress Seq, previously obtained via the specified mean stress correction applied on the alternate stress Sa and the mean stress Sm calculated from the cycle. This is symbolically represented in the Figure 33

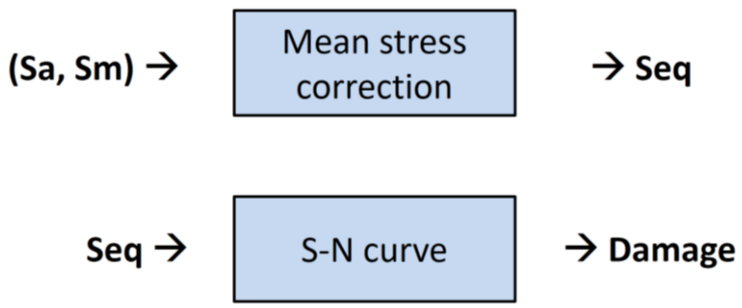


Figure 33: Process to calculate the damage

This process can be mathematically performed only if:

1) $Sm < Sm_{MAX}$ in the Goodman-like mean stress correction (see Sect. 8)
   Note: $Sm \geq Sm_{MAX}$ then Seq cannot be calculated

2) Seq < Sa0 in the S-N curve formulation, where Sa0 is the stress for N=1 cycles.

If for a given cycle one of these two conditions is not respected, MULTIFAT considers it as a "Static Failure" condition, respectively of "type 1" and "type 2" for the two cases.

This is specified in the files **NAME_OF_THE_PROJECT.cyc** (see § 12.2 and § 12.5) for each extracted half-cycle and as a summary in the file **NAME_OF_THE_PROJECT.ndd**, when Stress Linear Combination is performed (see § 12.4).

Namely for a given node, the column "Static Failure" in the file .ndd will have value:

= 1 if cycles with static failure of "type 1" but not of "type 2" are present for the node

= 2 if cycles with static failure of "type 2" but not of "type 1" are present for the node

= 12 if cycles with static failure of both "type 1" and "type 2" are present for the node

When a Static Failure condition happens, the damage of the corresponding half-cycle is put equal to 1.0 indicating that static rupture occurs with this half-cycle.

If a static failure occurs, this is indicated also in the screen output and in the file **NAME_OF_THE_PROJECT.sum**

Blocks of cycles

NOTE: In the case of Blocks of cycles, every cycle is considered as a fully reversed cycle and not a half-cycle.

14 Specific User requests

MULTIFAT can be easily adapted on demand to particular needs of a Customer in terms for example of input and output format, usage of proprietary fatigue-data or standards, …

<u>The MULTIFAT Team is glad to take into consideration all Users opinions and suggestions to make the Tool evolving</u>

Do not hesitate to contact us via the MULTIFAT website

www.multiaxialfatigue.com

MULTIFAT is also on YouTube

https://www.youtube.com/channel/UCVt4RaDmjH-QU-1ix22O0hg

<u>A heartfelt thanks to all those who want to support this project through our PATREON page</u>

This will allow us to keep MULTIFAT as a low-cost tool

https://www.patreon.com/multifat

15 References

[Ref 1] MULTIFAT Theory Manual https://multiaxialfatigue.com/multifat/

[Ref 2] Handbuch Strukturberechnung (HSB)