MIDAS FEA NX

Documentation on

Fatigue Analysis

This guide is made for non-experienced FEA users. It provides the basic knowledge needed to start working on fatigue analysis. Experienced FEA can also use this guide to get used to FEA NX workflow.

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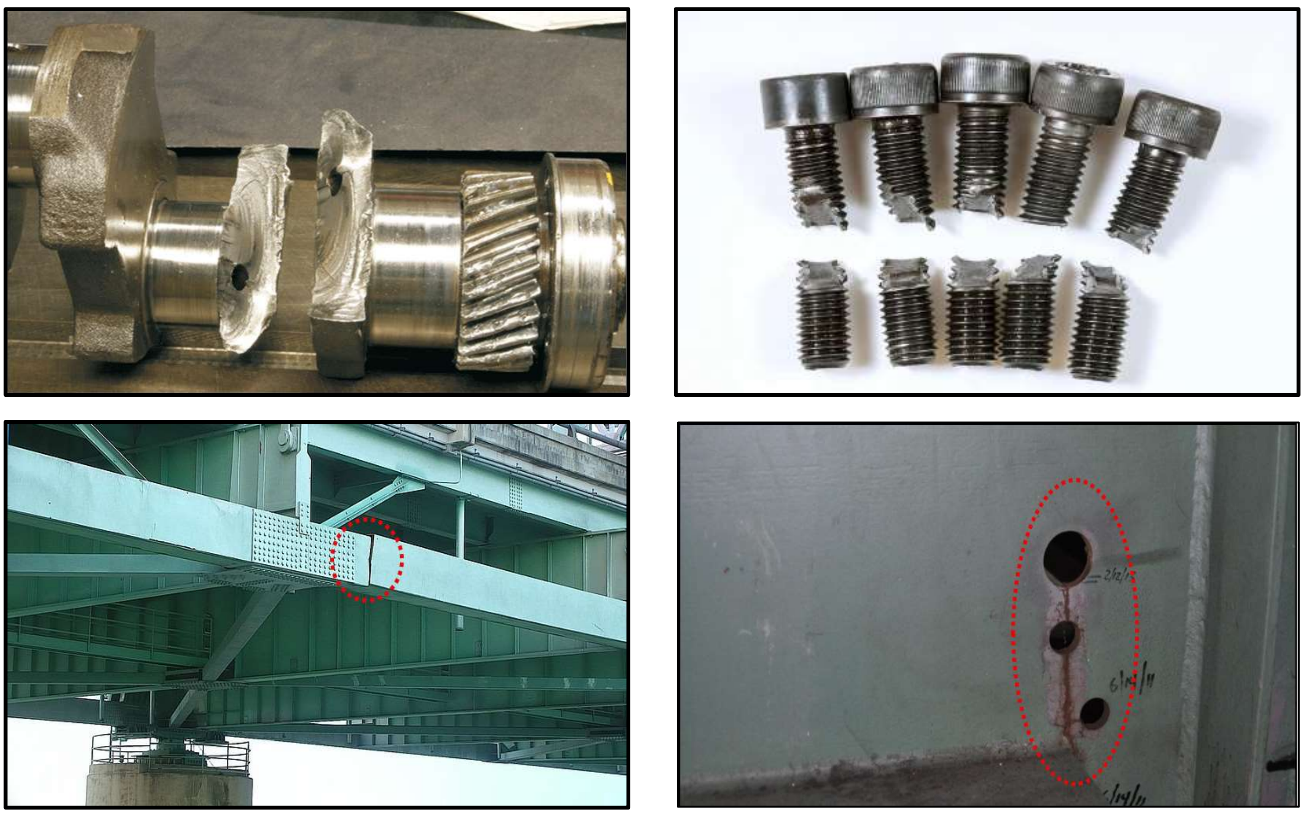
1. Fatigue Definition

Fatigue is a phenomenon associated with variable loading or more precisely cyclic stressing or straining of a material.

Fatigue failure is defined as the tendency of a material to fracture through progressive cracking under repeated alternating or cyclic stresses of an intensity considerably below the normal strength. Although the fracture is of a brittle type, it may take some time to propagate, depending on both the intensity and frequency of the stress cycles.



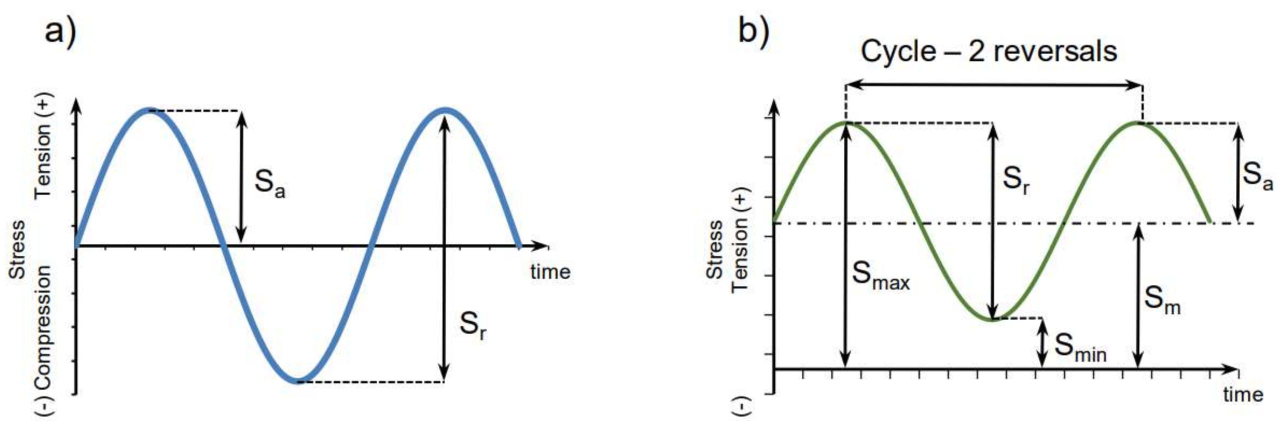
Examples of fatigue failure

All structural and mechanical components that are cyclically loaded can fail due to fatigue.
Fundamental requirements during design and manufacturing to avoid fatigue failure are different for each different case and should be considered during the design phase.

2. Fatigue Loading

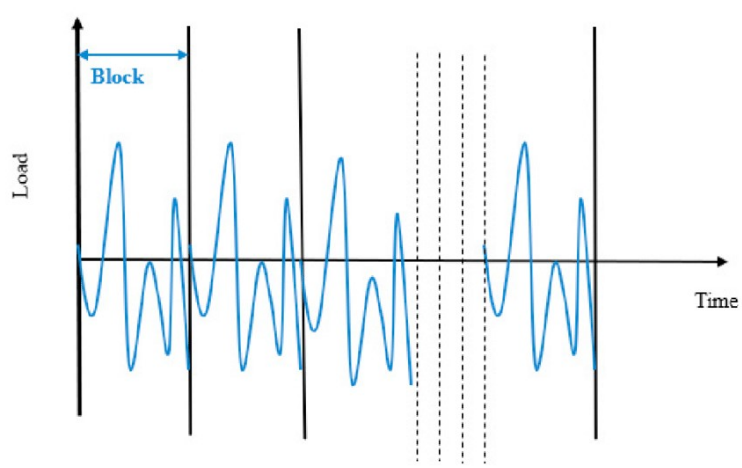
Fatigue loading is primarily the type of loading that causes cyclic variations in the stress or strain on a component.
The cyclic loading can be uniform or non-uniform in nature.
For simple cases, constant amplitude loading is used to obtain material fatigue behavior/properties for fatigue design.
Some real-life load histories can occasionally be modeled with constant amplitude as well.

Constant amplitude cycle



Uniform loading cycle
(a) Fully reversible uniform stress cycle (b) Fully reversible uniform stress cycle with offset

Variable amplitude cycle



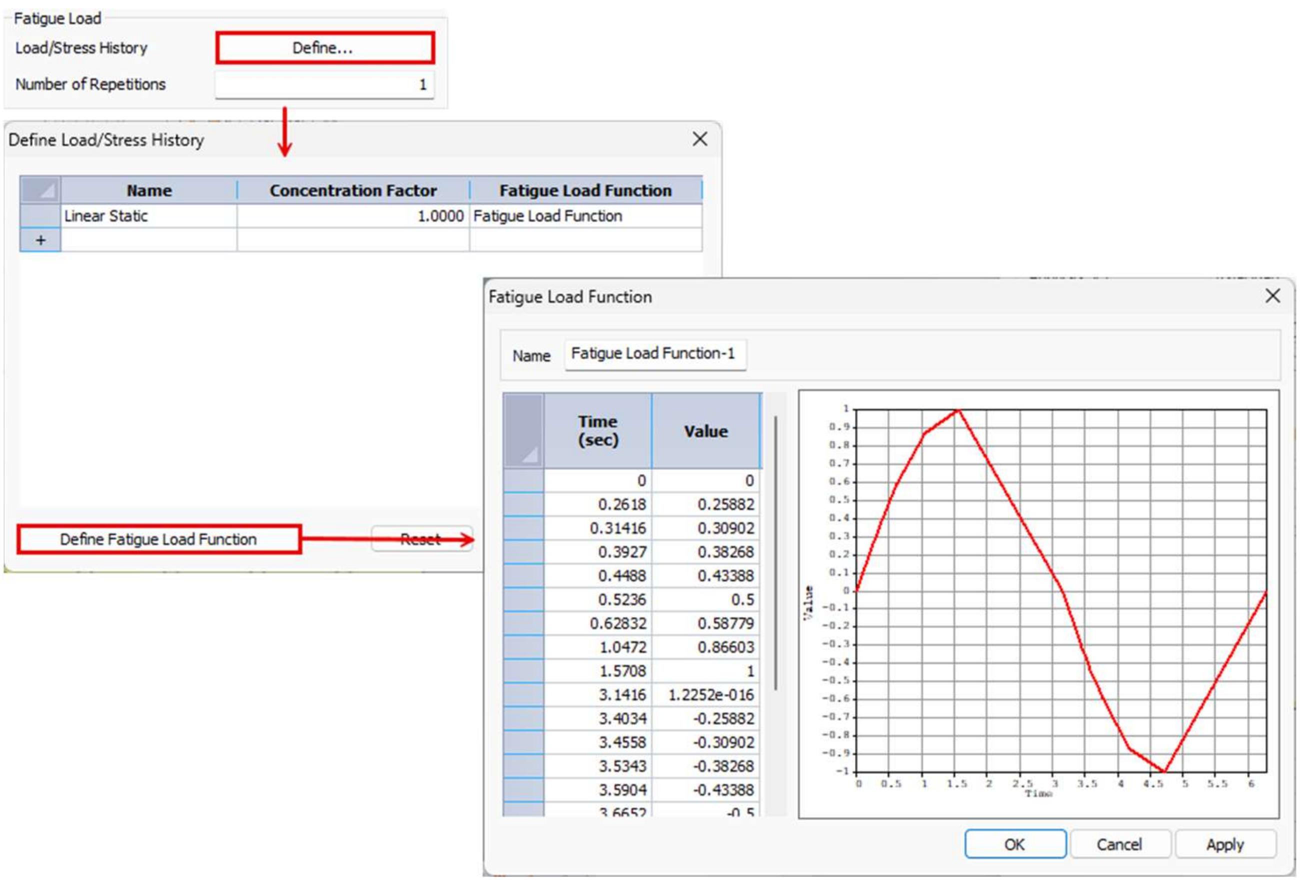
Non-uniform loading cycle

Concentration factor: it is the ratio of fatigue strength of the smooth member to that of the notched member. Depending upon the type of geometry of the detail the characteristic curve shall be modified by using concentration factor.

Number of Repetitions: the number of times the loading function should be repeated to complete one full loading cycle.

Fatigue loading function definition in FEA NX

Fatigue analysis> Fatigue load> Define> Define fatigue load function



3. Fatigue Life Estimation Method

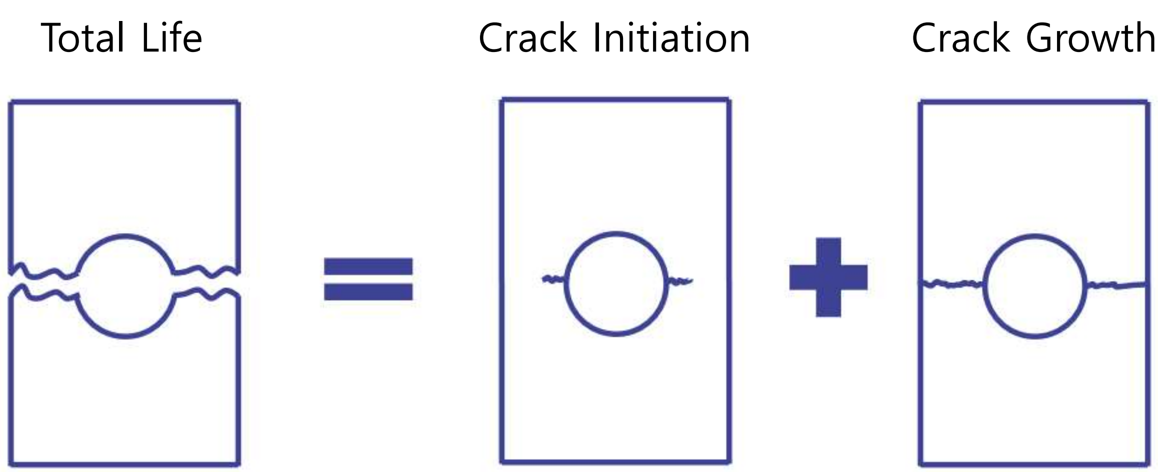
Fatigue analysis is usually carried out using the following methods of analysis:

1. S-N Method
2. E-N Method
3. Crack Growth

FEA NX can consider the S-N and the E-N methods for fatigue analysis.

The stress-life (or S-N method), is commonly referred to as the total life method since it makes no distinction between initiating or growing a crack. This was the first fatigue analysis method to be developed and it provides satisfactory results for fatigue analysis.

The local-strain or strain-life (E-N) method, commonly referred to as the crack initiation method, was more recently developed and is intended to describe only the 'initiation' of a crack.

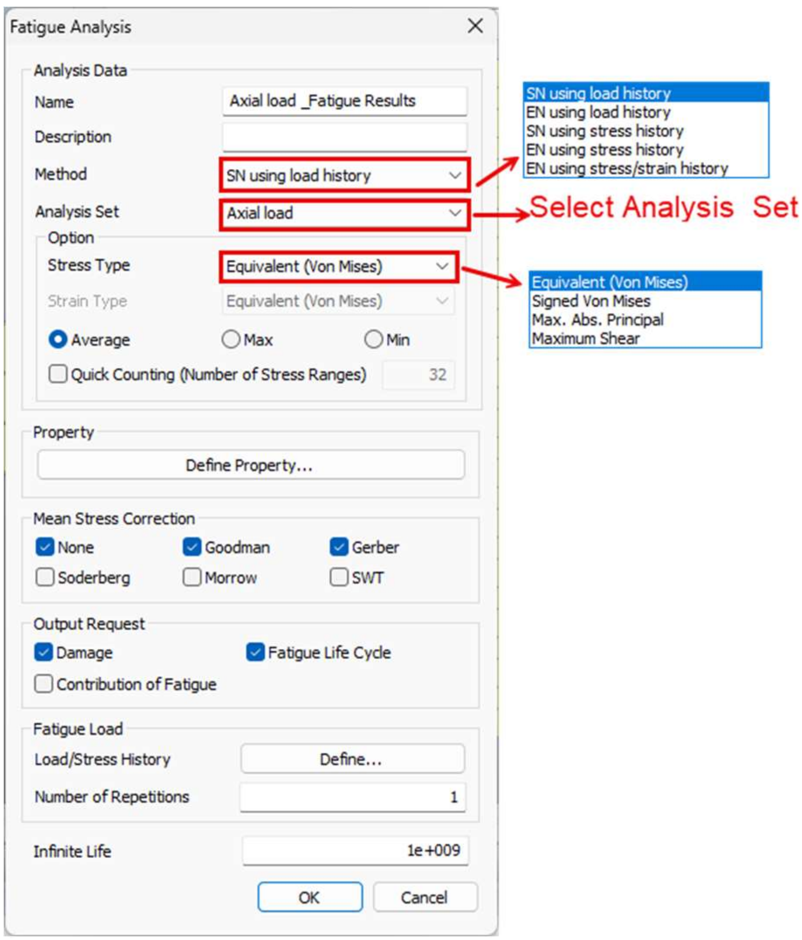


Idealization of fatigue design process

In FEA NX we can specify the S-N and E-N methods by using the loading, stress, or strain results based on the linear static analysis carried on the structure. Users can specify the following methods:

1. SN using loading history
2. EN using loading history
3. SN using stress history
4. EN using stress history
5. EN using stress/strain history

Fatigue analysis> Method or Analysis Set

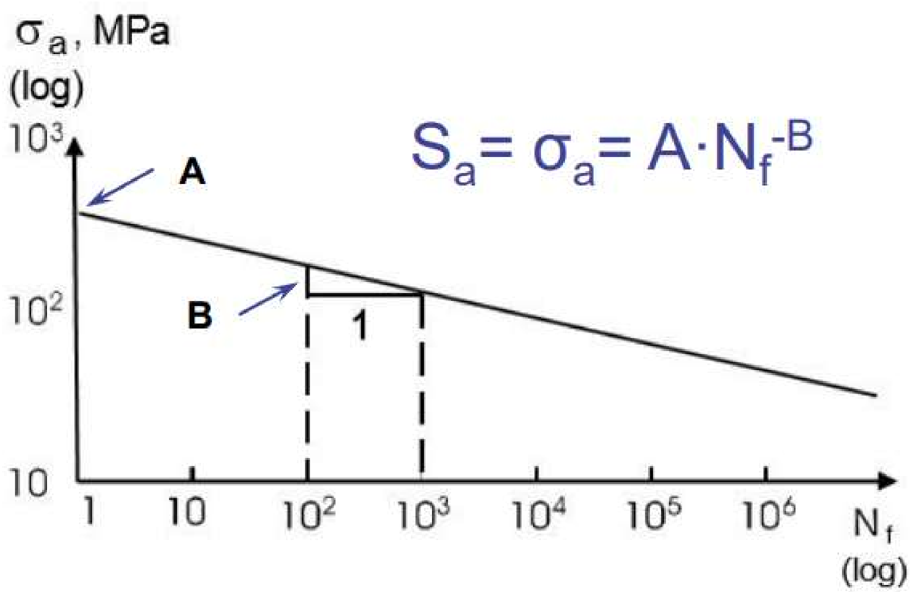


Experimental test data is mostly uniaxial whereas FE results are usually multiaxial. At some point, stress must be converted from a multiaxial stress state to a uniaxial one. In FEA NX Equivalent (Von Mises), Signed Von Mises, Absolute Maximum Principal, and Maximum Shear options are available for this purpose.

4. Stress Life Approach

The Stress life method, more commonly known as the **S-N** or **Nominal Stress method** is used for total life calculation.
It assumes the structure to be fully elastic. The initiation or growing phase of a crack is not considered in this method. Applicable to high cycle fatigue problems (low load-long life). This approach should not be used to estimate fatigue lives below 10,000 cycles.

The S-N Curve was developed by German August Wőhler for his systematic fatigue tests done in the 1870s. S-N Curve plots the diagram of the amplitude of nominal stress as a function of several cycles to failure for un-notched (smooth) specimens. Mathematical description of the material S-N curve:



σ_a – applied alternating stress

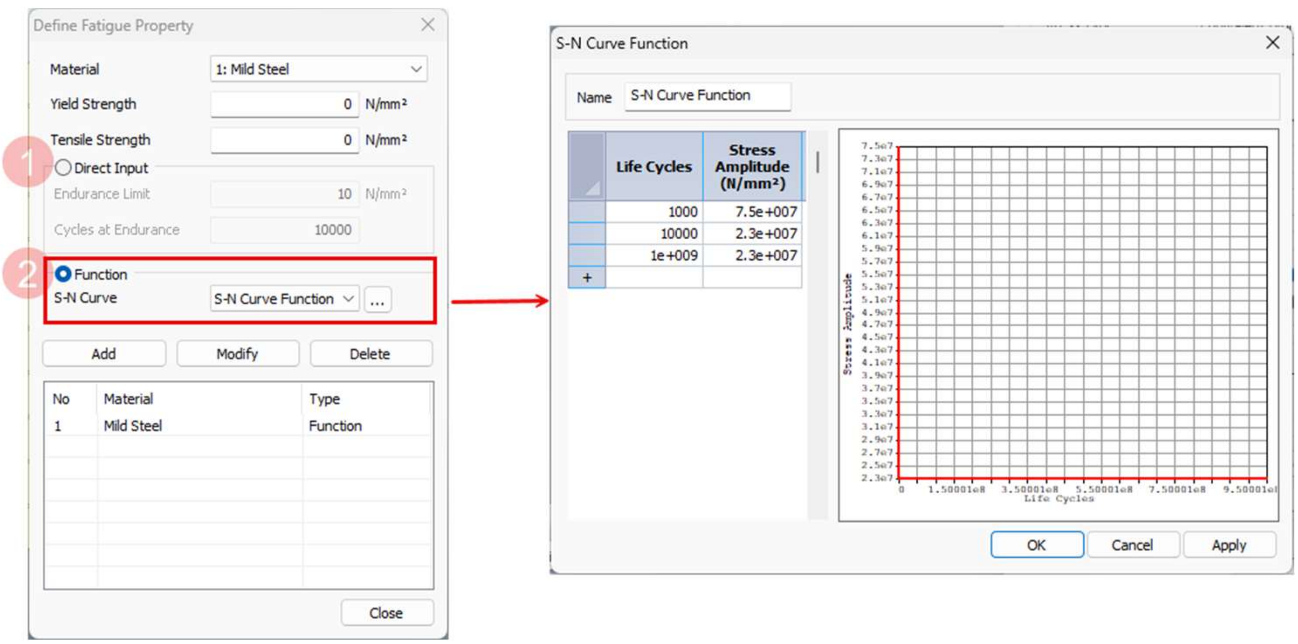
A – constant, value of σ_a at one cycle

B – Basquin's exponent, slope of the log-log curve

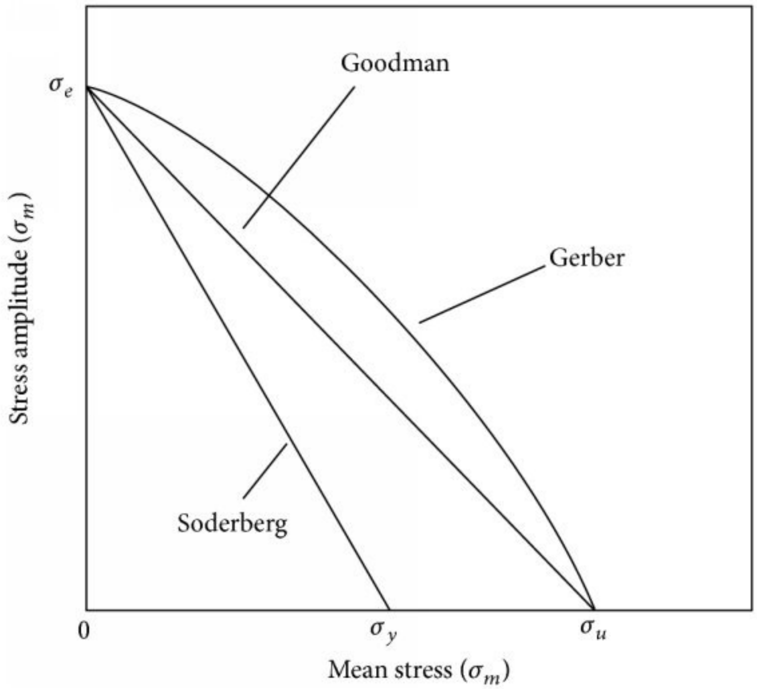
N_f - the number of cycles of stress that a specimen sustains before failure occurs

We can define the S-N curve for a particular material by using Direct Input or by defining a function as per our requirements. In direct input depending upon the Endurance limit and the Cycles at Endurance, the program automatically calculates the S-N curve.

Fatigue analysis> Property> Define Property…

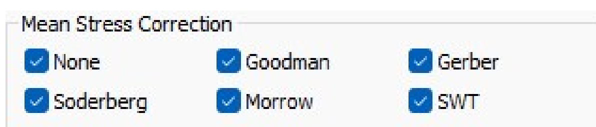


For the different combinations of mean stresses and alternating stresses, we can use the **Goodman**, **Gerber**, **Soderberg**, **Morrow**, or **SWT** method of fatigue life prediction in the case of the S-N approach. These methods can be chosen depending on the material properties and loading criteria.



Mean stress correction approach

Fatigue analysis> Mean stress correction



Note: If the stress cycle is fully reversible and alternating with no deviation then no mean stress correction is required and, in that case, **None** can be selected.

5. Strain Life Approach

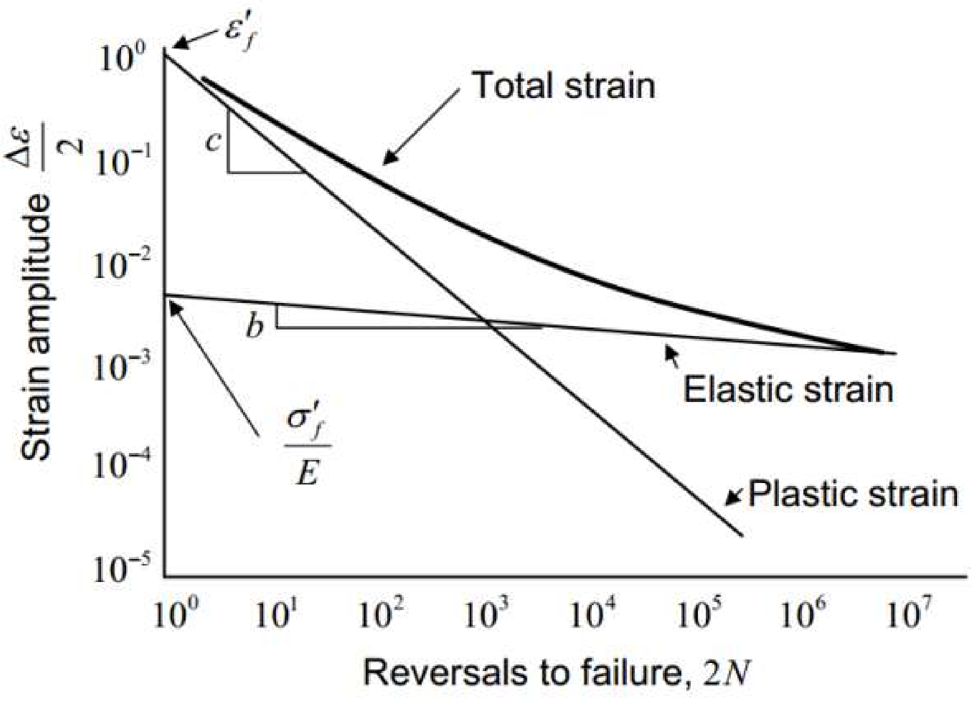
This method is also called the **Local Stress-Strain**, **E-N** or **Crack Initiation method**.

It applies when the structure's durability depends on the stress amplitude of local strain at the crack initiation place. The strain-life design method is based on relating the fatigue life of notched parts to the life of unnotched specimens cycled to the same strains as the material at the notch root.

This approach is best suited for low-cycle fatigue problems, where the applied stresses have a significant plastic component.

E-N curve shows the relationship between the strain and the number of cycles causing fatigue failure as expressed in the equation below.

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E} \cdot (2N_f)^b + \varepsilon_f' \cdot (2N_f)^c$$



$\Delta\varepsilon/2$ – total strain amplitude = ε_a

N_f - the number of cycles of stress that a specimen sustains before failure occurs

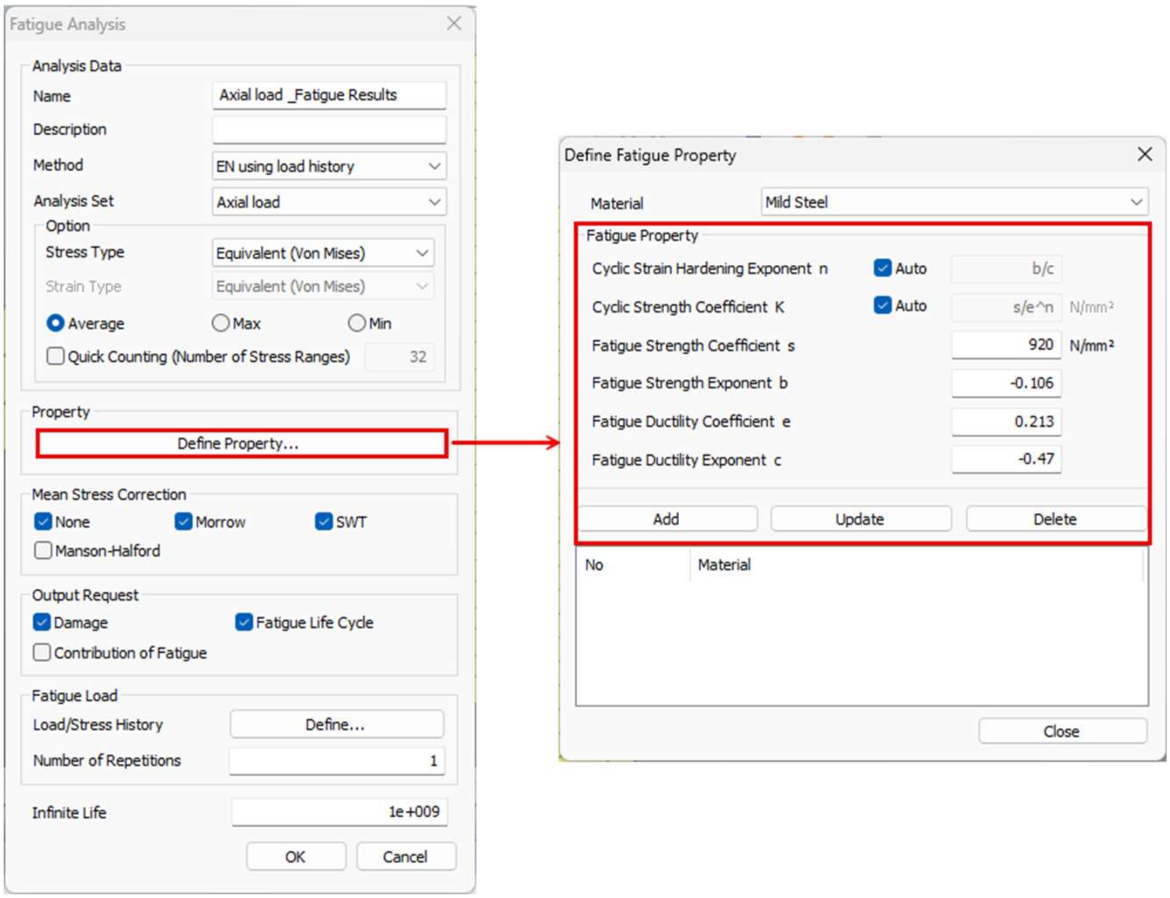
E – modulus of elasticity

σ_f' – fatigue strength coefficient

ε_f' – fatigue ductility coefficient

C – fatigue ductility exponent

Fatigue analysis> Property> Define Property…



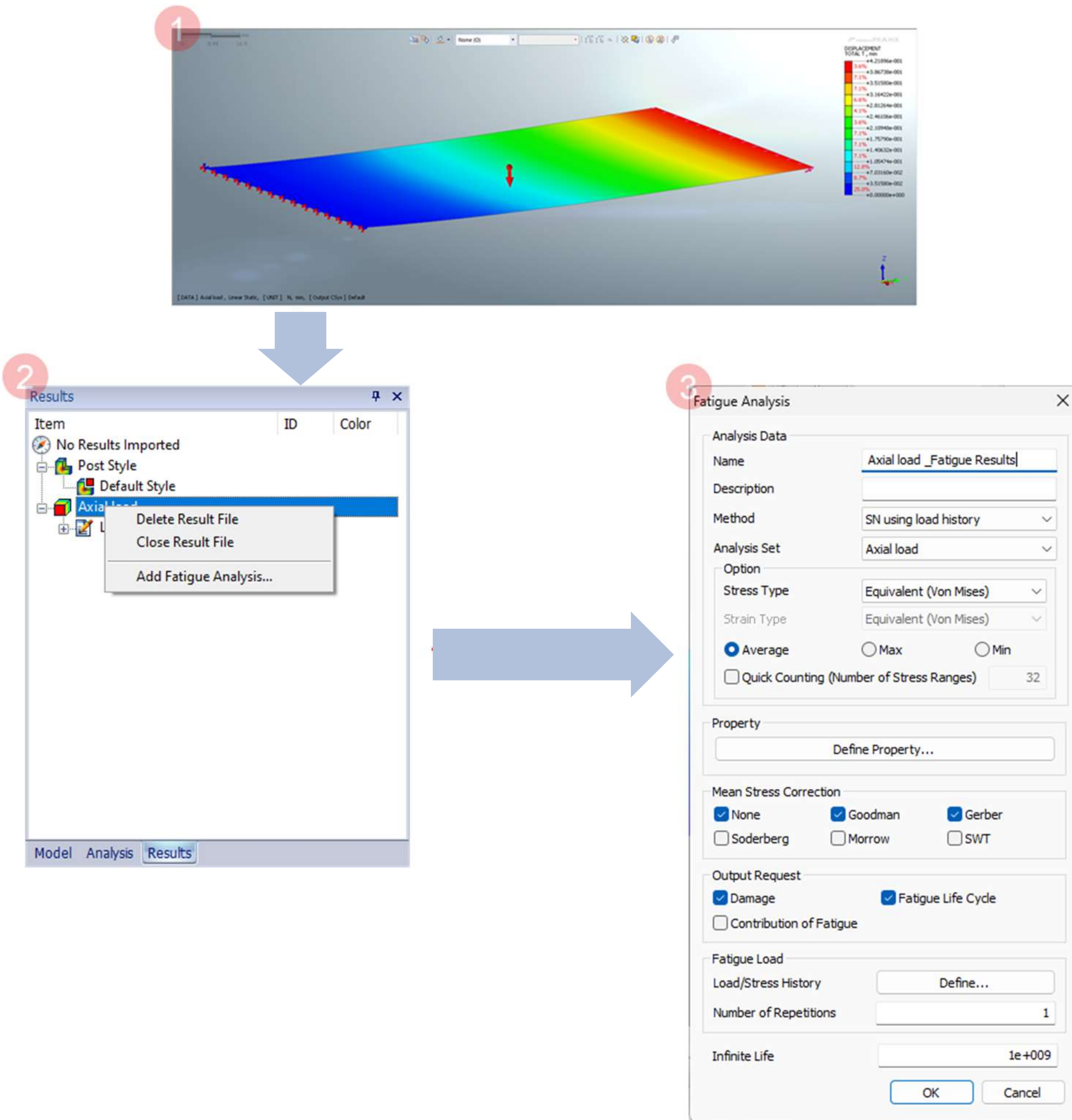
By applying several individual strain amplitudes to the E-N curve, which has been extracted through rain flow counting, each number of cycles and the corresponding individual damage level are obtained.

We can use the **Morrow**, **SWT**, and **Manson-Halford** method of fatigue life prediction in the case of the E-N approach.

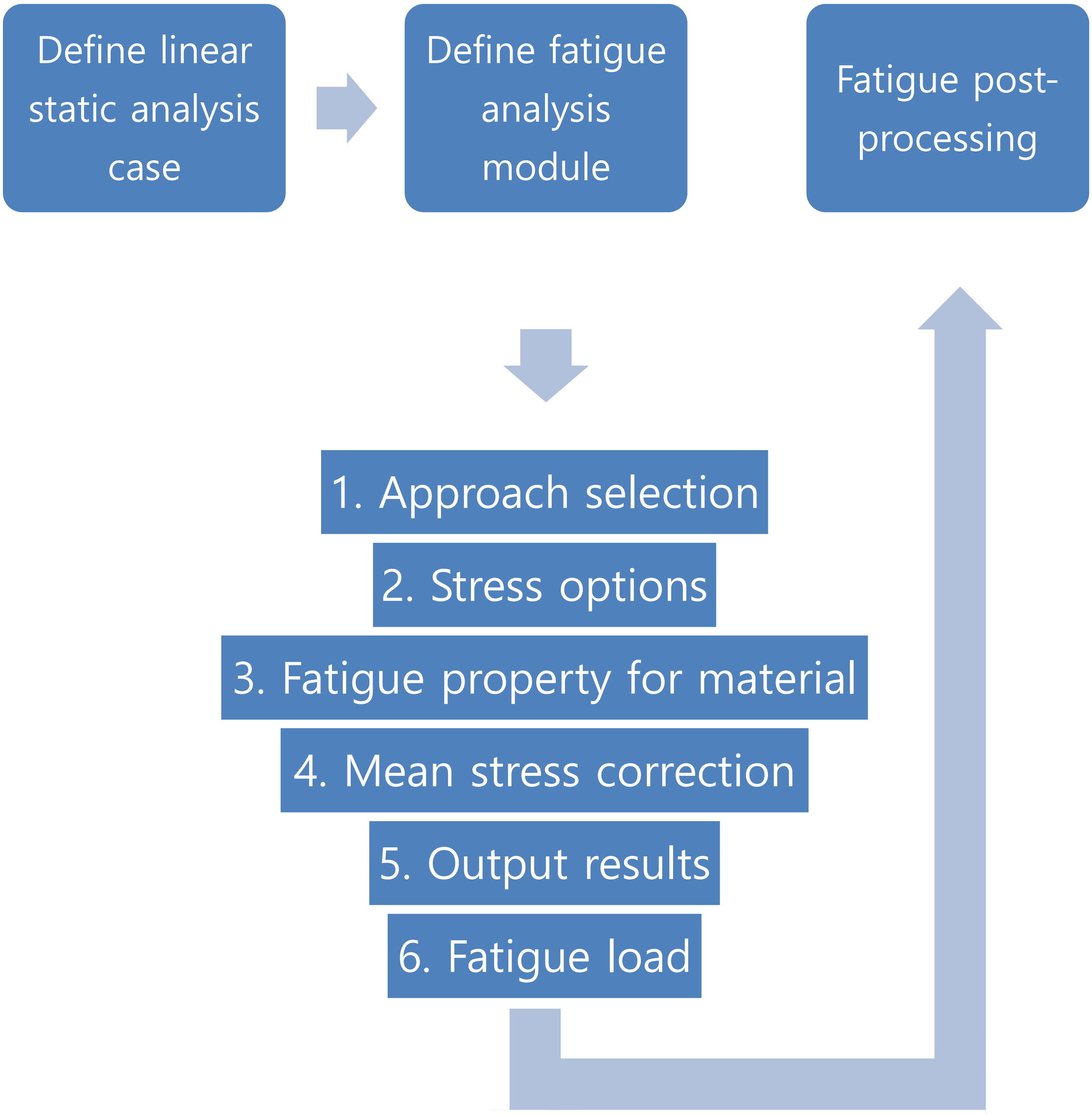
Fatigue analysis> Mean stress correction

6. Fatigue Analysis Workflow

To start your fatigue analysis setup, it is necessary to perform linear static analysis for your model. When the static results are loaded, you can enter the Fatigue Analysis dialog box.



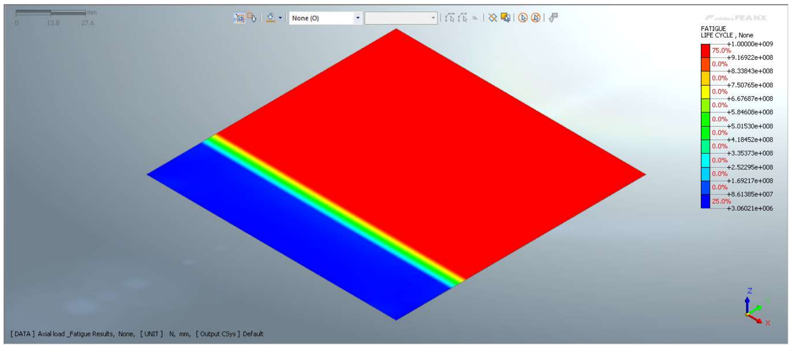
A flowchart of the fatigue setup in FEA NX can be described as shown in the image below:



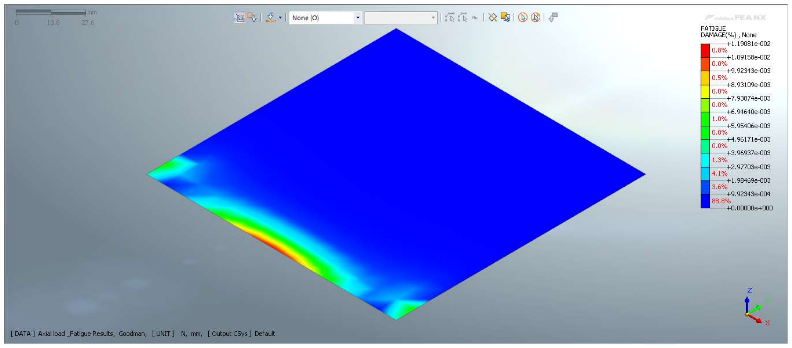
7. Fatigue Results

Fatigue results are calculated as Damage and Fatigue Life Cycle. Under Output Request required output vector can be selected.

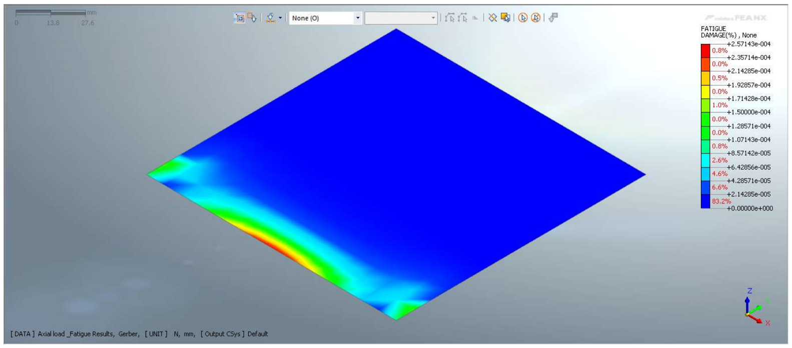
Fatigue analysis> Output results



Fatigue damage output vector.



Fatigue lifecycle according to Goodman mean stress correction.



Fatigue lifecycle according to Gerber mean stress correction.