Midas Intro Session

Fatigue Analysis for Structural Connections

Midas North American Office
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3:00 PM – 4:00 PM EST

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midas FEA NX

- Concrete Crack Analysis
- Static Analysis
- Fatigue Analysis
- Construction Stage Analysis
- Reinforcement Analysis
- Buckling Analysis
- Eigenvalue Analysis
- Response Spectrum Analysis
- Time History Analysis(Linear/Nonlinear)
- Static Contact Analysis
- Interface Nonlinearity Analysis
- Nonlinear Analysis(Material/Geometric)
- Heat of Hydration Analysis
- Heat Transfer Analysis
- Slope Stability Analysis
- Seepage Analysis
- Consolidation Analysis
- Coupled Analysis(Fully/Semi)

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Fatigue in Structural Materials

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses. Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load.

The term "fatigue" is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling. Fatigue is important as it is the single largest cause of failure in metals, estimated to comprise approximately 90% of all metallic failures. Furthermore, it is catastrophic and insidious, occurring very suddenly and without warning.

Fatigue failure is brittle-like in nature even in normally ductile metals, in that there is very little, if any, gross plastic deformation associated with failure. The process occurs by the initiation and propagation of cracks, and ordinarily the fracture surface is perpendicular to the direction of an applied tensile stress. (Callister, 1997)

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Bridge Fatigue

Fatigue specifications for the design of new, and evaluation of existing, highway bridges are provided by AASHTO in the LRFD Bridge Design Specifications (LRFD) and the Manual for Bridge Evaluation (MBE). (Zhou, 2013) And since the 70s, portions of the AASHTO fatigue specifications have been adopted by AISC. Therefore, the general application of the AASHTO fatigue provisions to the design examples are equally applicable to other structures. (Fisher, 1977)

The occurrence of the fatigue is usually resulted from conditions that were not accounted for in design. These conditions includes:

- The addition of welded plates or attachment without considering their reduction in fatigue strength
- Unaccounted for out-of-plane displacement induced stresses
- Details that have changed the structure's behavior such as connections which provided fixity when simple supported were assumed in the design.

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Bridge Fatigue

A method for estimating equivalent design life for use with constant cycle fatigue stresses is described for highway bridges. This permits the potential cumulative damage of random truck traffic to be accounted for in design. (Fisher, 1977)

Fatigue damage on steel bridges has been categorized as either load-induced or distortion-induced. Load-induced fatigue is due to the primary in-plane stresses in the steel plates that comprise bridge member cross-sections. The stresses for load induced fatigue can be directly correlated with the bridge live load using conventional design theories and are typically calculated and checked in the fatigue design or evaluation process. Distortion-induced fatigue is due to secondary stresses in the steel plates that comprise bridge members. These stresses, which are typically caused by out-of-plane forces, can only be calculated with refined methods of analysis or measured by strain gages, far beyond the scope of a conventional bridge design or evaluation. (Zhou, 2013)

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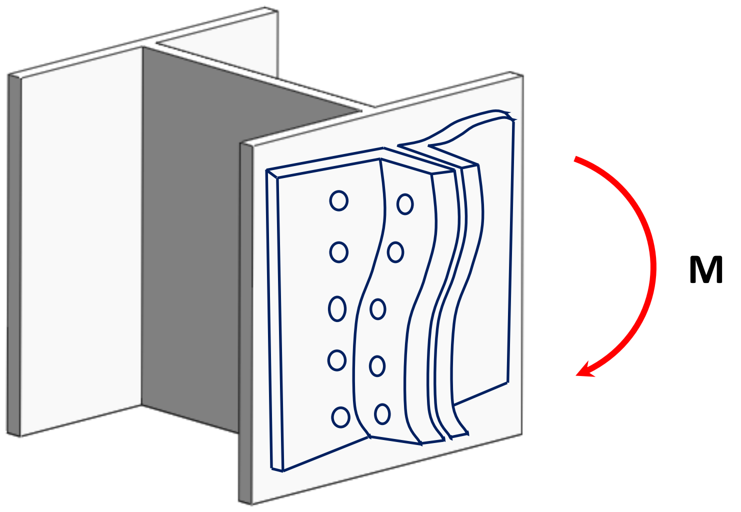
Primary and Secondary Stresses

Primary Stress is induced by in-plane behaviors, while secondary stress is usually induced by out-of-plane displacement and bending.

The conventional nominal stress-based design methodology should be sufficient for structural details that are primarily subjected to in-plane stresses. However, for structures that undergoes out-of-plane distortion induced fatigue, local stress-based method is applicable. And the determination of local stress shall be determined from detailed linear FE analyses of a three-dimensional (3-D) model of the connection. (Appendix C, LRFD Specifications for Structural Supports)



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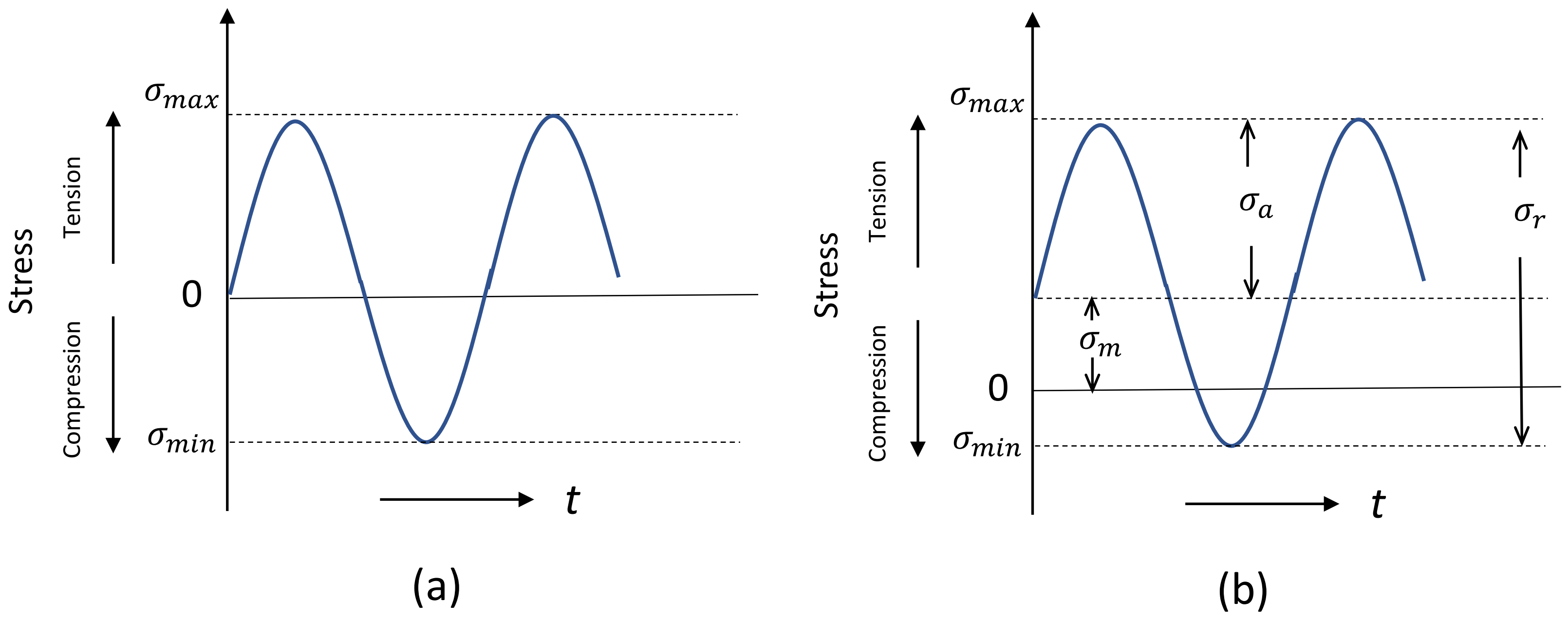
Cyclic Stresses

The applied stress may be axial (tension-compression), flexural (bending), or torsional (twisting) in nature. In general, three different fluctuating stress-time modes are possible. One is represented in (a) below. Its stress amplitude is symmetrical about a mean zero stress level, for example, alternating from a maximum tensile stress (σ_{max}) to a minimum compressive stress (σ_{min}) of equal magnitude. This is referred to as a reversed stress cycle. (Callister, 1997)



σ_m: mean stress
σ_r: range of stress
σ_a: stress amplitude

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

$$\sigma_r = \sigma_{max} - \sigma_{min}$$

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

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The S-N Curve

To determine the fatigue behavior of a material under a particular type of loading, Lab testing is used for a certain specimen to be subjected to σ_{max} cycles usually in the order of 2/3 of the tensile stress of the material. The number of cycles to failure is counted.

The same test is then performed on other specimen of the same material under incrementally smaller cyclic stress. Eventually, the test data is plotted as stress (S) versus the number of cycles (N). The S is normally taken as σ_a(stress amplitude)

Fatigue strength is the stress level at which the failure occurs at a certain number of cycles (N).
Fatigue life is the number of cycles that cause failure to happen at a certain stress level.
Fatigue limit/Endurance limit is the point when S-N curve becomes horizontal at higher N values. (only for some ferrous/titanium alloys).

Project 12-7 under the sponsorship of National Cooperative Highway Research Program (NCHRP) has shown that the two most important factors that affect the fatigue strength are the stress range and the structural details/designs.

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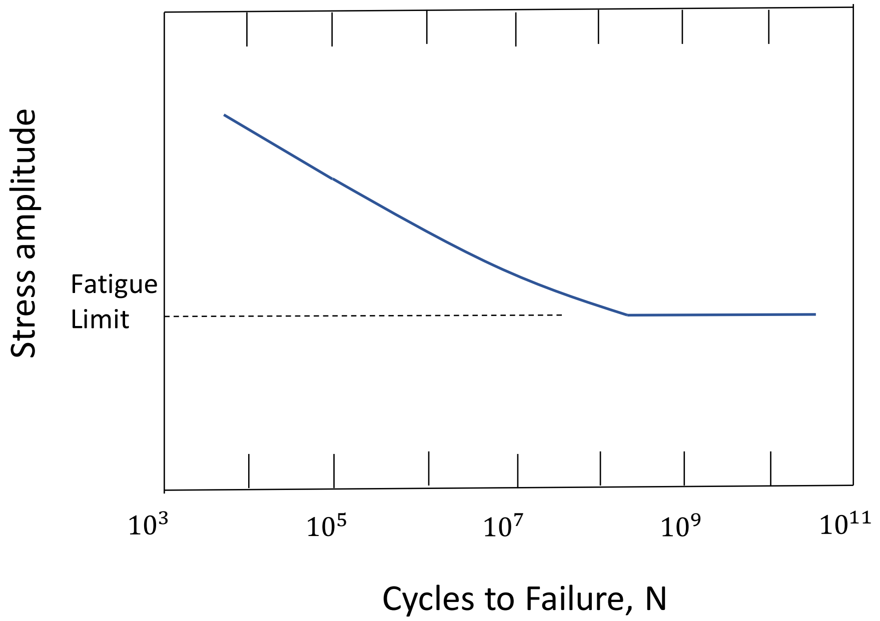
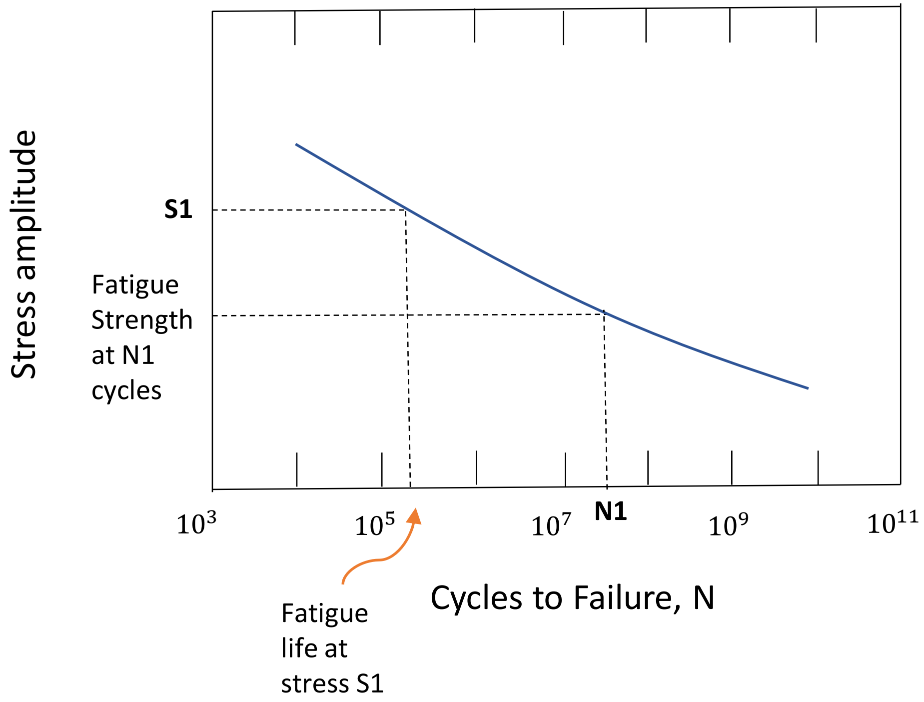
The S-N Curve





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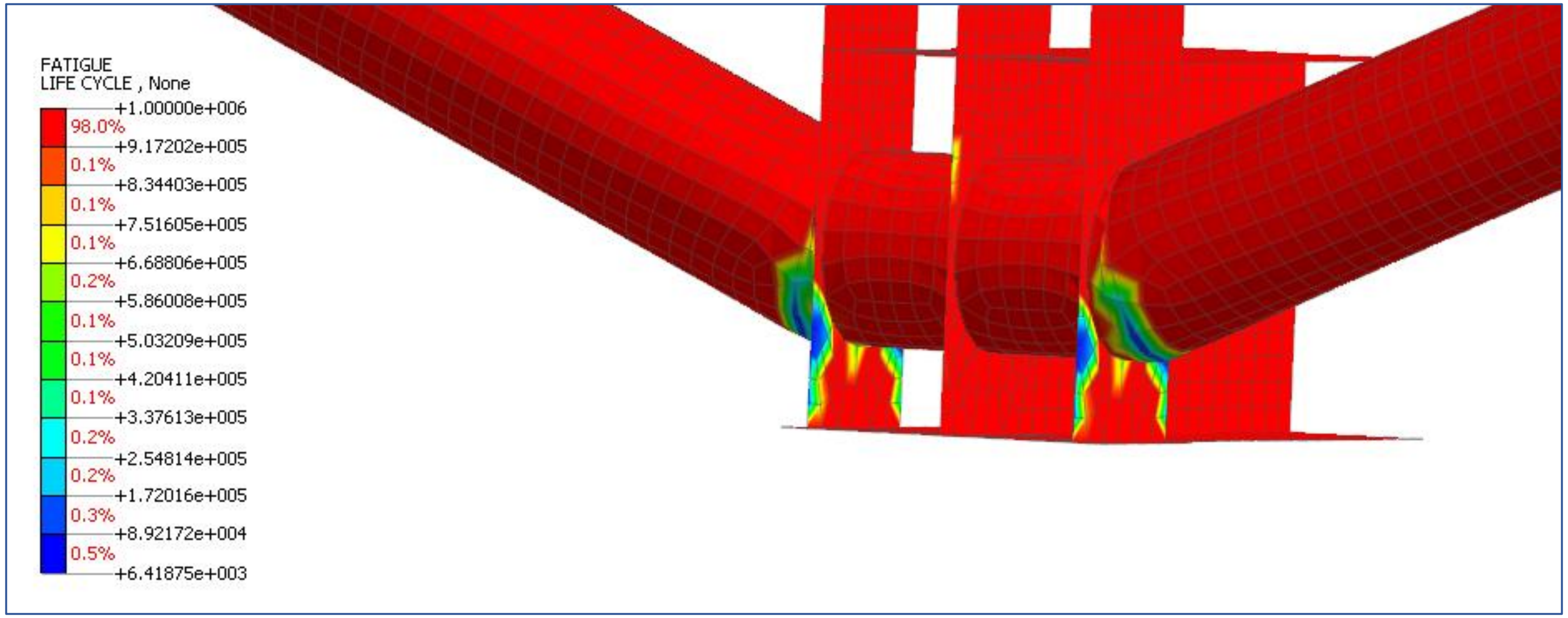
Stress-Life Method

The stress-life method predicts the extent of fatigue under a given loading history using the relationship between the number of loading cycles (N) and stress amplitude (S).

For a fatigue analysis using the stress-life method, a linear elastic analysis on the structure is performed first. Equivalent stresses such as Von Mises stresses or max/min principal stresses are obtained. There stresses are then applied to an S-N curve to predict the number of loading cycles required to reach the fatigue failure.



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References

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Callister, William D. *Material Science and Engineering and Introduction*, John Wiley & Sons, Inc., 1997

Zhou, Edward Y. *Bridge Fatigue*, Structure Magazine, Apr, 2013

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