

1.7 Fatigue of steel structures

A component or structure, which is designed to carry a single monotonically increasing application of static load, may fracture and fail if the same load or even smaller load is, applied cyclically a large number of times. For example a thin rod bent back and forth beyond yielding fails after a few cycles of such repeated bending. This is termed as the 'fatigue failure'. Examples of structures, prone to fatigue failure, are bridges, cranes, offshore structures and slender towers, etc., which are subjected to cyclic loading. The fatigue failure is due to progressive propagation of flaws in steel under cyclic loading. This is partially enhanced by the stress concentration at the tip of such flaw or crack. As we can see from Fig. 1.22, the presence of a hole in a plate or simply the presence of a notch in the plate has created stress concentrations at the points 'm' and 'n'. The stress at these points could be three or more times the average applied stress. These stress concentrations may occur in the material due to some discontinuities in the material itself. These stress concentrations are not serious when a ductile material like steel is subjected to a static load, as the stresses redistribute themselves to other adjacent elements within the structure.

At the time of static failure, the average stress across the entire cross section would be the yield stress as shown in Fig.1.23. However when the load is repeatedly applied or the load fluctuates between tension and compression, the points m, n experience a higher range of stress reversal than the applied average stress. These fluctuations involving higher stress ranges, cause minute cracks at these points, which open up progressively and spread with each application of the cyclic load and ultimately lead to rupture.

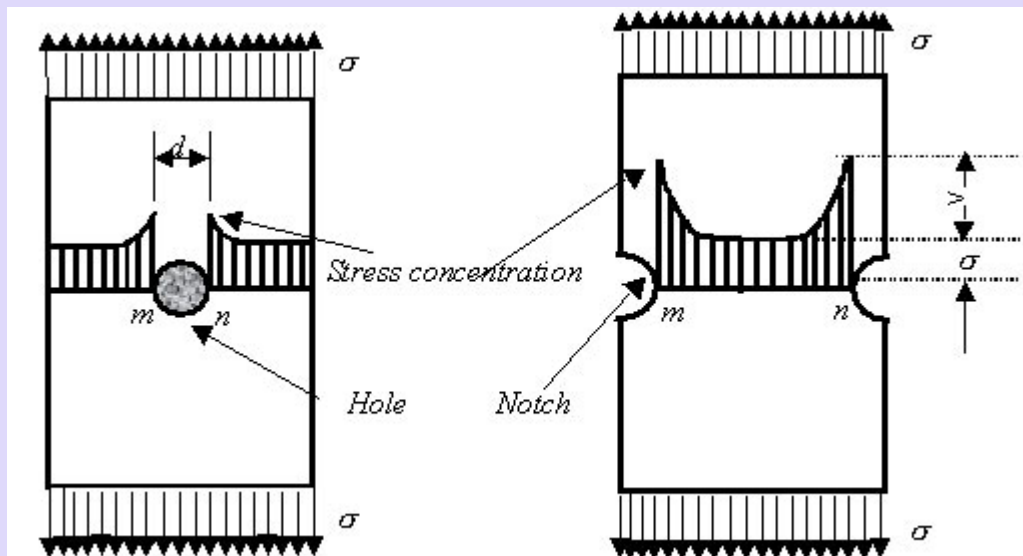


Fig 1.22 Stress concentrations in the presence of notches and holes

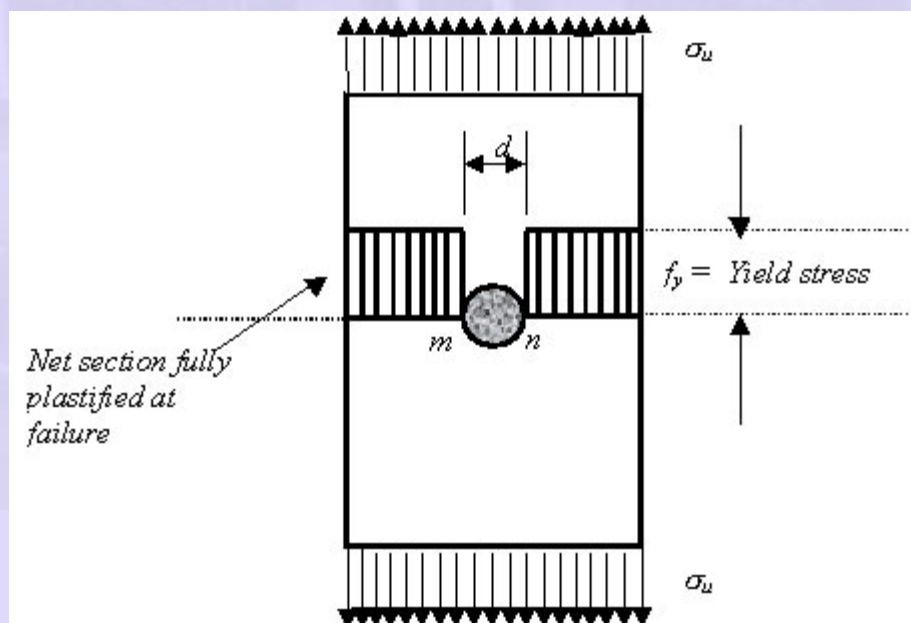


Fig 1.23 Stress pattern at the point of static failure

The fatigue failure occurs after four different stages, namely:

1. Crack initiation at points of stress concentration
2. Crack growth
3. Crack propagation
4. Final rupture

The development of fatigue crack growth and the various stages mentioned above are symbolically represented in Fig. 1.24. Fatigue failure can be defined as the number of cycles and hence time taken to reach a pre-defined or a threshold failure criterion. Fatigue failures are classified into two categories namely the high cycle and low cycle fatigue failures, depending upon the number of cycles necessary to create rupture. Low cycle fatigue could be classified as the failures occurring in few cycles to a few tens of thousands of cycles, normally under high stress/ strain ranges. High cycle fatigue requires about several millions of cycles to initiate a failure. The type of cyclic stresses applied on structural systems and the terminologies used in fatigue resistant design are illustrated in Fig. 1.25.

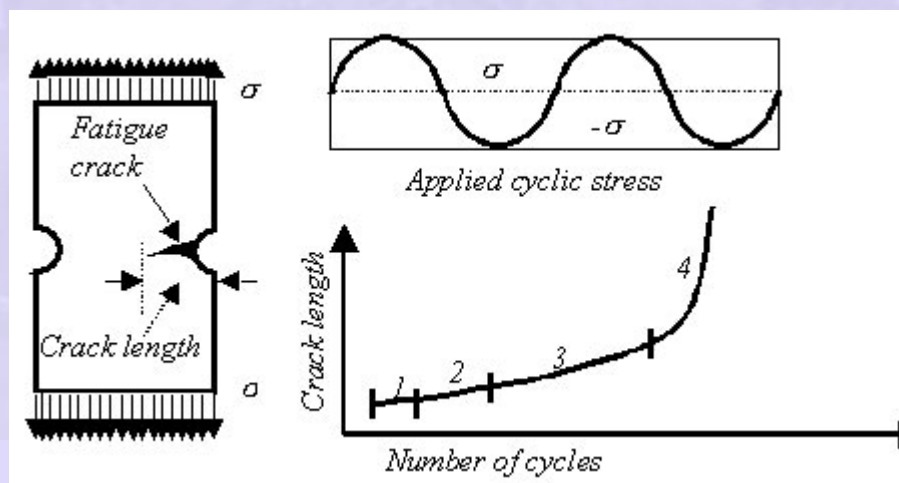


Fig 1.24 Crack growth and fatigue failure under cyclic load

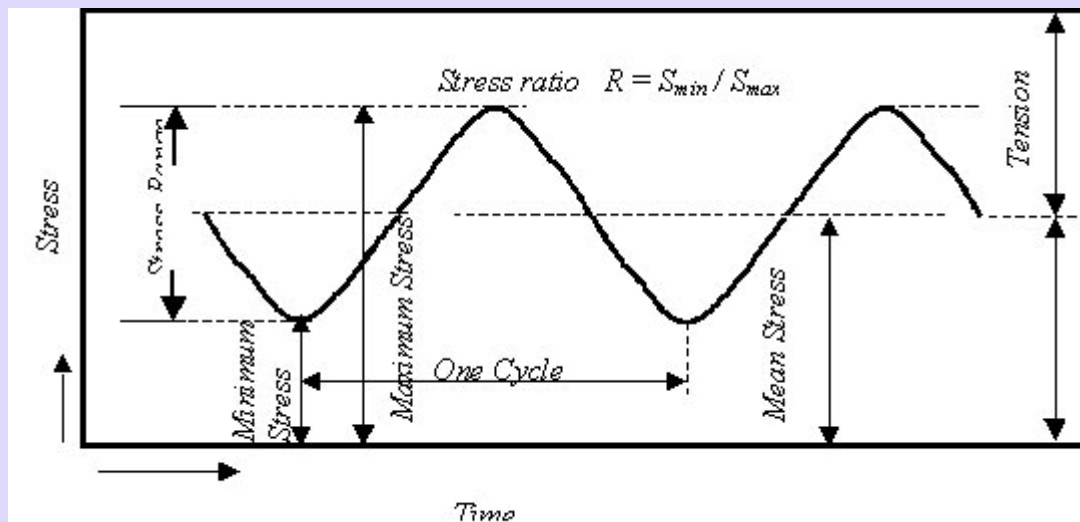


Fig 1.25 Terminology used in fatigue resistant design of structural steel work

S-N curves and fatigue resistant design

The common form of presentation of fatigue data is by using the S-N curve, where the total cyclic stress (S) is plotted against the number of cycles to failure (N) in logarithmic scale. A typical S-N curve is shown in Fig. 1.26.

It is seen from Fig. 1.26 that the fatigue life reduces with respect to increase in stress range and at a limiting value of stress, the curve flattens off. The point at which the S-N curve flattens off is called the 'endurance limit'. To carry out fatigue life predictions, a linear fatigue damage model is used in conjunction with the relevant S-N curve. One such fatigue damage model is that postulated by Wohler as shown in Fig.1.26. The relation between stress and the number of cycles for failure could be written as

$$\log N = \log C - m \log S \quad (1.8)$$

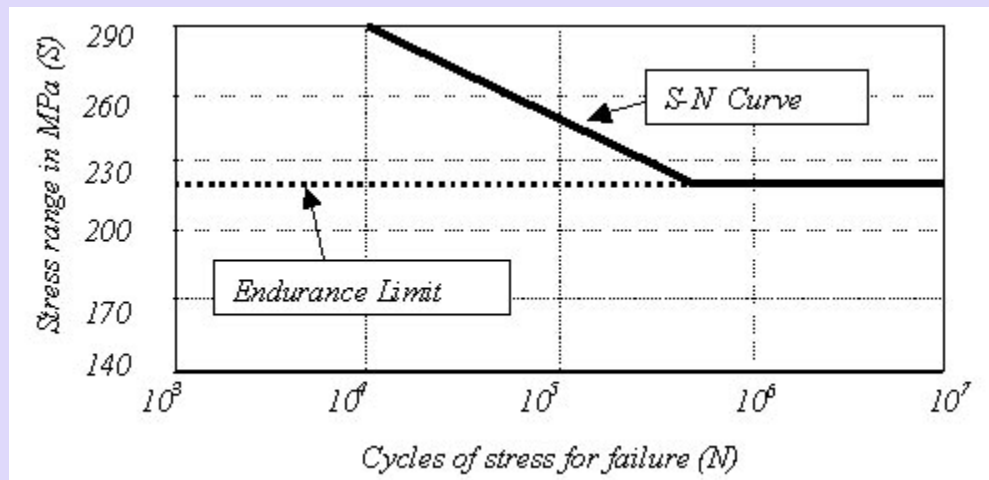


Fig 1.26 S-N diagram for fatigue life assessment

where 'N' is the number of cycles to failure, 'C' is the constant dependant on detailing category, 'S' is the applied constant amplitude stress range and 'm' is the slope of the S-N curve. For the purpose of design it is more convenient to have the maximum and minimum stresses for a given life as the main parameters. For this reason the modified Goodman diagram, as shown in Fig, is mostly used. The maximum stresses are plotted in the vertical ordinate and minimum stresses as abscissa. The line OA represents alternating cycle ($R = -1$), line OB represents pulsating cycle ($R = 0$) and OC the static load ($R = 1$). Different curves for different values of fatigue life 'N' can be drawn through point 'C' representing the fatigue strength for various numbers of cycles. The vertical distance between any point on the 'N' curve and the 45° line OC through the origin represents the stress range. As discussed earlier, the stress range is the important parameter in the fatigue resistant design. Higher the stress range a component is subjected to, lower would be its fatigue life and lower the stress range, higher would be the fatigue life.

It becomes very important to avoid any local structural discontinuities and notches by good design and this is the most effective means of increasing fatigue life. Where a structure is subjected to fatigue, it is important that welded joints are considered carefully. Indeed, weld defects and poor weld details are the major

contributors of fatigue failures. The fatigue performance of a joint can be enhanced by the use of techniques such as proper weld geometry, improvements in welding methods and better weld quality control using non-destructive testing (NDT) methods. The following general points are important for the design of a welded structure with respect of fatigue strength: (a) use butt welds instead of fillet welds (b) use double sided welds instead of single sided fillet welds (c) pay attention to the detailing which may cause stress concentration and (d) in very important details subjected to high cyclic stresses use any non-destructive testing (NDT) method to ensure defect free details. From the point of view of fatigue design, the codes of practice classify various structural joints and details depending upon their vulnerability to fatigue cracks.

Each categories denoted by a number which corresponds to the stress for 5×10^6 , IS: 800 classifies the detailing in the structural steel work in to several categories depending upon their vulnerability to stress concentrations. It provides S-N curves for all the categories. Using these curves the allowable stress (S) for a given life time (N) may be obtained. (Cl.13.5). The accuracy of any fatigue life calculation is highly dependent on a good understanding of the expected loading sequence during the whole life of a structure. Once a global load pattern has been developed, then a more detailed inspection of particular area of a structure where the effects of loading may be more important called the 'hot spot stresses' which are basically the areas of stress concentrations.