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Design against fatigue
Design principles

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DESIGN AGAINST FATIGUE
DESIGN PRINCIPLES

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DESIGN AGAINST FATIGUE

DESIGN PRINCIPLES

1. INTRODUCTION

A very high proportion of recorded failures of engineering components and structures in service is the result of fatigue. This Item summarises some general design principles that should be observed to minimise the risk of fatigue failure. However, the success of a component or structure in service for its design life depends not only on the designer, but also on a chain of people which includes draughtsmen, machinists, assemblers, metallurgists, buyers, operators, inspectors, maintenance and service personnel, *et cetera*. Anyone in the chain, through either ignorance or carelessness, could create circumstances that would precipitate a fatigue failure.

Complementary to this Item are ESDU 75022, "Design against fatigue. Basic design calculations" and ESDU 70016 "Terms and notation for fatigue endurance data".

2. THE FATIGUE CRACK

In service, an engineering component that is subjected to repeated applications of loads much less than its static strength may develop a crack or cracks and, if the loading be continued, some of these cracks may grow and ultimately lead to complete rupture. This process is termed fatigue.

As long as each loading is light so that the deformation of the material remains everywhere perfectly elastic, there is no risk of fatigue failure; but when the loading is heavier, the range of strain imposed upon the material may be greater than that which the material can accommodate by elastic deformation. Continued deformation beyond this elastic range with each load application leads to the formation of minute cracks, termed micro-cracks. Micro-cracks are far too small to be seen by ordinary workshop means and can be studied only by high powered microscopy or by other sophisticated means.

Under the repeated applications of load the micro-crack will continue to grow, usually along planes subjected to the maximum range of shear stress, until it is of such length, in relation to material microstructure, that it will grow as if the material were a continuum*; it is then termed a macro-crack. The macro-crack is detectable by ordinary workshop methods and will usually grow along the planes normal to the maximum tension, although in detail there may be considerable deviations from these planes. The tension across a spreading macro-crack will help to extend it, whereas compression will tend to close it and retard its growth.

As the macro-crack grows the effective section of the component is reduced until eventually the part of the section remaining uncracked may become incapable of sustaining the maximum load in the cycle; at this point complete rupture will occur. Just prior to this rupture the rate at which the crack spreads under the cyclic loading increases enormously and this has to be recognised as another distinct stage in the fatigue process.

The whole fatigue process is of course governed by the stresses imposed, but the relative durations of the four stages, namely crack initiation, micro-crack, macro-crack and unstable crack, vary widely according to the nature of the material and to the degree of uniformity of the stress system imposed on the component.

* Reference to the material as a "continuum" means that the material may be treated as homogeneous and that, using the appropriate material properties, microscopic discontinuities, such as those that occur at grain boundaries or inclusions, may be ignored.

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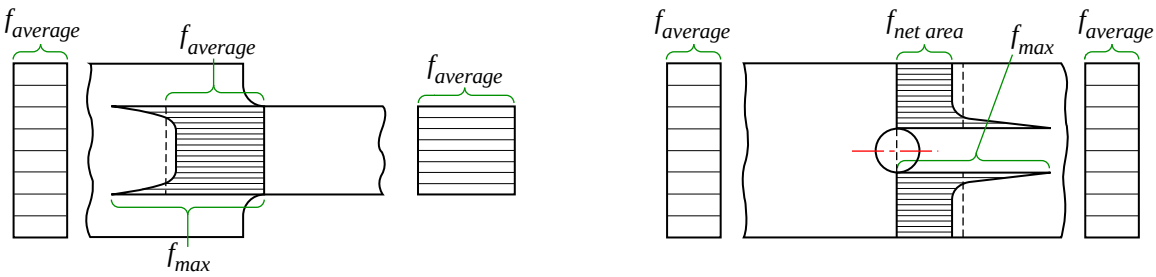
For example, in a plate or bar of hard material subjected to pulsating tension that is uniform across the section, nearly all the fatigue life may be taken up in the production and growth of micro-cracks; the rate at which a macro-crack will grow may be so fast that it is unlikely to be discovered before rupture occurs. By contrast, in a sharply notched piece of relatively soft material macro-cracks will start almost at once and practically the entire life will be taken up in their propagation.

3. THE STRESS IN A COMPONENT

In engineering practice few components can be designed so that they are uniformly stressed; the transmission of loads through screw threads, splines, bolt heads, collars, *et cetera*, and changes of cross-section, as at fillets and oil holes, necessarily set up stresses much larger than those based upon the nominal cross-section of the component. These concentrations of stress may be severe, but they affect only small regions close to the discontinuities, and, for a given discontinuity, the greater the stress concentration the smaller is the region affected by it. Two examples of geometry changes are shown in Sketch 3.1 together with the local stress distribution caused by them.



Sketch 3.1

At severe discontinuities the volume of material that is highly stressed may be very small and the material may not be able to accept the theoretically predicted stress. The stress will therefore be redistributed over a slightly larger region. The size of the region of high stress at which this effect becomes apparent depends upon the behaviour of the material which is determined by the general state of stress within some microscopic element representative of its microstructure. The size of this element varies widely according to the nature of the material but for the more usual engineering materials estimates of the appropriate size are available (see Section 5 of ESDU 75022). If the region affected by the high stress does not greatly exceed the size of the basic material element the effective stress concentration, represented by the average stress over the element, may be considerably less than the stress concentration factor represented by the maximum theoretical stress.

4. IMPROVEMENT OF FATIGUE LIFE BY THE REDUCTION OF STRESS

Reduction of stress can be achieved by increasing the size of a component. However, careful detail design of the component so as to reduce stress concentrations will significantly improve the fatigue life of the component and recourse to change of size can usually be avoided. When the worst stress concentration is reduced another stress concentration may become critical and in general practice the maximum loading will be set by a stress concentration that cannot reasonably be reduced further.

Many Data Items are provided to give the value and position of the stress concentration for a variety of geometries and each one shows the effect of varying the local geometry. These Items may be located by reference to the Engineering Sciences Data Index.

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