



Soviet-era science, translated into English

Reports of the Academy of Sciences of the USSR

G. V. Uzhik and M. Ya. Galperin

1960

SovietRxiv

View the original and related papers at <https://sovietrxiv.org/items/ru-196001.02857>

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

Abstract

Full Text

Reports of the Academy of Sciences of the USSR
1960. Volume 131, No. 5

THEORY OF ELASTICITY

G. V. Uzhik and M. Ya. Galperin

ON THE DANGER OF INSTANTANEOUS FRACTURE OF STRUCTURAL ELEMENTS UNDER CYCLIC OVERLOADS

(Presented by Academician A. A. Blagonravov, 2 VII 1959)

Fracture under the action of cyclic loads occurs, as is known, in the following principal stages: first, as a result of repeated microplastic deformation, irreversible changes in the metal begin in individual, most heavily loaded regions; under certain conditions these changes may lead to an ultramicroscopic discontinuity. The increase in the number of regions with similar damage to the metal and their coalescence ends, in the second stage, with the formation of a crack and its emergence at the surface. In the third stage, the fatigue crack develops through the cross section. In the fourth stage, under the action of a load applied once, final fracture occurs in that part of the section to which the fatigue crack has not yet had time to spread.

The conditions on which the duration of each of the listed stages of fatigue fracture depends have been poorly studied. It is beyond doubt, however, that the duration of each of them depends on the resistance of the material and on the nature of the loading under which fatigue fracture may begin. It is known that in some cases, as, for example, with the under-hub portion of locomotive axles (¹), the development of a fatigue crack proceeded extremely slowly, so that the duration of the third stage amounted to hundreds of millions of cycles, and yet final fracture (the last stage) did not occur. It is also known that under certain conditions (periodic reduction of the acting loads, the presence of zones of increased resistance of the metal over the section, the influence of rest during periods of unloading, etc.) even a temporary cessation of crack growth is observed. However, such observations may lead to the erroneous conclusion that a fatigue crack must in general develop over a considerable period of time before final fracture occurs. A study of the causes of major failures of various machines and structures subjected to repeated loads (²) indicates the possibility of sudden instantaneous fracture of the most heavily loaded machine elements at the very earliest stage of crack development.

Fig. 1. Deformation and fracture diagrams in bending (steel 45).
 $\rho = 0.4$; $h = 94$

Figure 1: Fig. 1. Deformation and fracture diagrams in bending (steel 45).
 $\rho = 0.4$; $h = 94$

Since instantaneous fracture occurs under the action of a singly applied overload after the formation of a fatigue crack and is always brittle, in order to clarify the question of its possible causes it is necessary to investigate the conditions of brittle fracture in the presence of sharp stress concentrators.

Below are presented the results of an investigation (medium-carbon steel) of the causes of instantaneous fracture of steel beams of rectangular section in bending.

Each beam was loaded by alternating loads with one or another asymmetry of the cycles until the fatigue crack had propagated to a certain depth. After this, cyclic loading was stopped, and fracture was produced in the remaining part of the section, not occupied by the crack, by a singly applied load. In this process the character of the final fracture was determined, the magnitude of the breaking load was established, and the bending diagram was recorded. A series of typical dia-

bending diagrams is shown in Fig. 1. In each diagram the segment Oa corresponds to cyclic loading, the segment ab to single loading to fracture under load cb .* The upper row of curves corresponds to a very small area of fatigue fracture; the lower row, to a substantially larger one.

Consideration of Fig. 1 leads to the following conclusions:

Fig. 1. Deformation and fracture diagrams in bending (steel 45).
 $\rho = 0.4$; $h = 94$

1. Instantaneous fracture of a brittle character may occur at the very earliest stage of development of a fatigue crack. The preceding plastic deformation (segment ab) depends on the size of the area over which the crack has managed to propagate. However, this deformation proves to be very small even for comparatively small sizes of the fatigue-fracture area, amounting to only 3-5% of the entire cross-sectional area.
2. The possibility of instantaneous fracture under cyclic overloads depends on the width of the section. Apparently, there exists a critical width, different for different materials, at which (and below which) only delayed ductile fracture is possible under the action of overloads. For the investigated steel 45 this critical width was 5-7 mm. The existence of a critical section width is connected with the transition from a predominantly plane stress state (small width values) to triaxial tension in the vicinity of the crack bottom as the width increases beyond the critical value^(3,4). As further studies showed, the critical section width may vary depending on the magnitude of

Fig. 2

Figure 2: Fig. 2

the potential energy accumulated in the deforming system by the moment fracture begins.

The investigations carried out also showed that the magnitude of the maximum load causing instantaneous fracture depends little on the asymmetry of the cycle under which the fatigue crack is formed. Fig. 2 presents a comparison of static and cyclic (with different cycle asymmetries) fracture loads as a function of the area over which the crack has pro-

* For $t = 7$ mm the segment bc is delayed ductile fracture with the onset of fracture at point b .

the fatigue crack propagated. As can be seen, the static loads that fracture specimens with an artificially made sharp notch of various depths differ almost not at all from the cyclic loads causing instantaneous fracture in beams with a previously obtained fatigue crack, and depend only on the magnitude of the area over which the fatigue crack has managed to propagate.

Fig. 2. Change in the breaking loads as a function of the area of propagation of the fatigue crack or the notch area. **1** –specimens fractured after propagation of the fatigue crack to various depths under repeated bending (a $-\rho = 0.4$; b $-\rho = 0.12$); **2** –specimens with an applied notch of various depths; radius of curvature of the notch $R = 0.1-0.2$ mm. Height $h = 94$ mm.

On the basis of the results shown in Fig. 2, a calculation was made of the magnitudes of those overloads which cause instantaneous fracture at various cycle asymmetries (specimen with section width $t = 24$ mm). The results obtained are given in Fig. 3. They indicate that this kind of fracture is least probable under a symmetrical cycle, since in order to cause instantaneous fracture under this cycle, even with propagation of the fatigue crack over an area amounting to 10% of the area of the entire cross section of the beam, more than a twofold overload is necessary.

The danger of brittle fracture under overload increases as the asymmetry of the cycles increases. As can be seen from Fig. 3, at $\rho = \sigma_{\min}/\sigma_{\max} = 0.37$, instantaneous fracture may occur at the very earliest stage of development of the fatigue crack under an overload amounting to only 10-20%.

The results presented make it possible to draw the following basic conclusion: the significance of periodically repeated overloads under cyclic loading consists not only in the fact that they can cause irreparable damage to the metal, but also in the fact that the action of each of them at a certain stage of fatigue damage, or even before the onset of fatigue fracture in places of sharp stress concentrators, is associated with a very great danger of sudden, instantaneous fracture.

Fig. 3

Figure 3: Fig. 3

Fig. 3. Change in overloads causing instantaneous fracture, for various cycle asymmetries, as a function of the area of propagation of the fatigue crack. Cross-sectional area of the specimen $F_{\text{sec}} = 22.56 \text{ mm}^2$.

Institute of Machine Science
Academy of Sciences of the USSR

Received
30 VI 1959

CITED LITERATURE

1. T. V. Bukwalter, O. J. Horger, W. C. Sanders, *Trans. ASME*, **60**, No. 3-4, 335 (1938).
2. H. D. Emmert, *A.S.M.E.*, **78**, 1547 (1956).
3. G. V. Uzhik, *DAN*, **126**, No. 1 (1959).
4. G. V. Uzhik, M. J. Galperin, A. A. Zooykova, *Symposium on Large Fatigue Testing Machines and their Results*, A.S.T.M., 1958, p. 132.

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.