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# ISO

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

# ISO RECOMMENDATION
# R 373

## GENERAL PRINCIPLES FOR FATIGUE TESTING OF METALS

1st EDITION
August 1964





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# BRIEF HISTORY

The ISO Recommendation R 373, *General Principles for Fatigue Testing of Metals*, was drawn up by Technical Committee ISO/TC 17, *Steel*, the Secretariat of which is held by the British Standards Institution (BSI).

Work on this question by the Technical Committee began in 1958 and led, in 1961, to the adoption of a Draft ISO Recommendation.

In October 1962, this Draft ISO Recommendation (No. 516) was circulated to all the ISO Member Bodies for enquiry. It was approved subject to a few modifications of an editorial nature, by the following Member Bodies:

| | | |
|---|---|---|
| Australia | France | Norway |
| Austria | Germany | Poland |
| Belgium | Greece | Portugal |
| Bulgaria | Hungary | Romania |
| Burma | India | Spain |
| Canada | Ireland | Sweden |
| Chile | Italy | Switzerland |
| Czechoslovakia | Japan | Turkey |
| Denmark | Morocco | United Kingdom |
| Egypt | Netherlands | U.S.S.R. |
| Finland | New Zealand | Yugoslavia |

One Member Body opposed the approval of the Draft: U.S.A.

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council, which decided, in August 1964, to accept it as an ISO RECOMMENDATION.

ISO Recommendation R 373 August 1964

# GENERAL PRINCIPLES FOR FATIGUE TESTING OF METALS

## 1. SCOPE

This ISO Recommendation consists mainly of general recommendations for the definitions of the terms used, for the preparation of fatigue test pieces, their subsequent testing procedure and the presentation of results. The recommendations are intended to apply mainly to fatigue tests under tension-compression (direct stress), bending or torsion of plain or notched test pieces of simple forms. It does not cover, for example, fatigue under repeated impact or thermal fatigue. In this ISO Recommendation, the term "fatigue" applies to changes in properties which can occur in a metallic material due to the repeated application of stresses or strains, although usually this term applies specially to those changes which lead to cracking or failure.

## 2. OBJECT

The object of fatigue testing is to provide data relating to the behaviour of materials or structural components, when subjected to stresses or strains which vary repeatedly with time.

## 3. DEFINITIONS AND SYMBOLS

3.1 **General.** Stresses in service may be of simple form, for example, tension-compression, bending or torsion, or they may occur in combination. According to the information required, the stresses applied in fatigue tests may similarly be one of those modes or a combination of two or more of them. Whatever the mode of stress, whether applied singly or in combination, the direct and/or shear stress to which the test specimen is subjected will usually vary approximately sinusoidally with time, as illustrated in Figure 1.



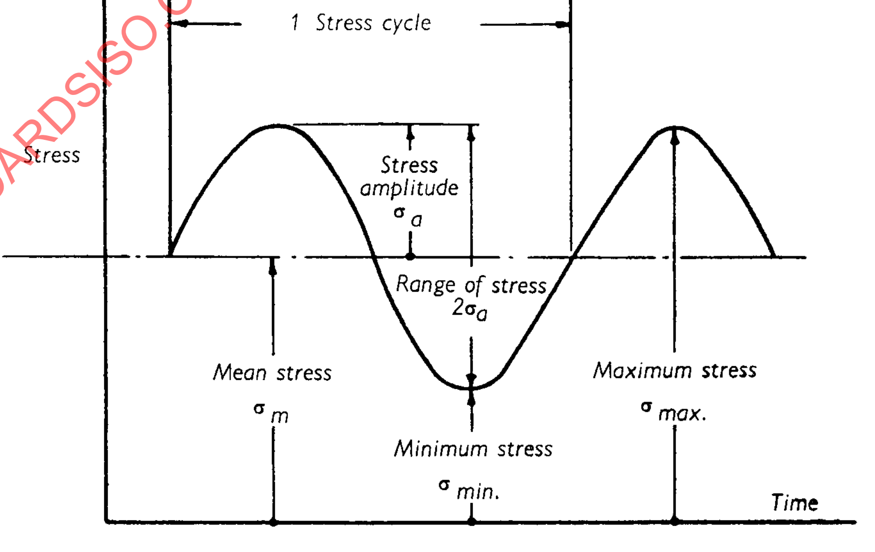


Fig. 1. — **Fatigue stress cycle**

NOTE. — Range of stress = 2 (Stress amplitude).

The statements in the following clauses are thus applicable whatever the mode of stressing, although, for reasons of simplicity, reference will be made generally to simple stress systems.

**3.2** **Stress.** In general, the stress will be a nominal stress calculated by reference to the net area under consideration. It will usually be calculated by the use of conventional elastic formulae.
It should be noted that in some instances tests may be conducted and the results expressed entirely in terms of strain; in particular, where strains beyond the elastic limit are employed, it is undesirable to calculate stresses from them.

**3.2.1** *Applied stress cycle.* It will be seen from Figure 1 that the smallest section of the stress-time function which is repeated periodically is *the stress-cycle.* Any stress varying periodically over a given range can be regarded as comprising a variable stress component alternating between two values opposite in sign but equal in magnitude (the stress amplitude) and a static stress component (the mean stress) superimposed. The recommended notation is algebraic as in Figure 2.

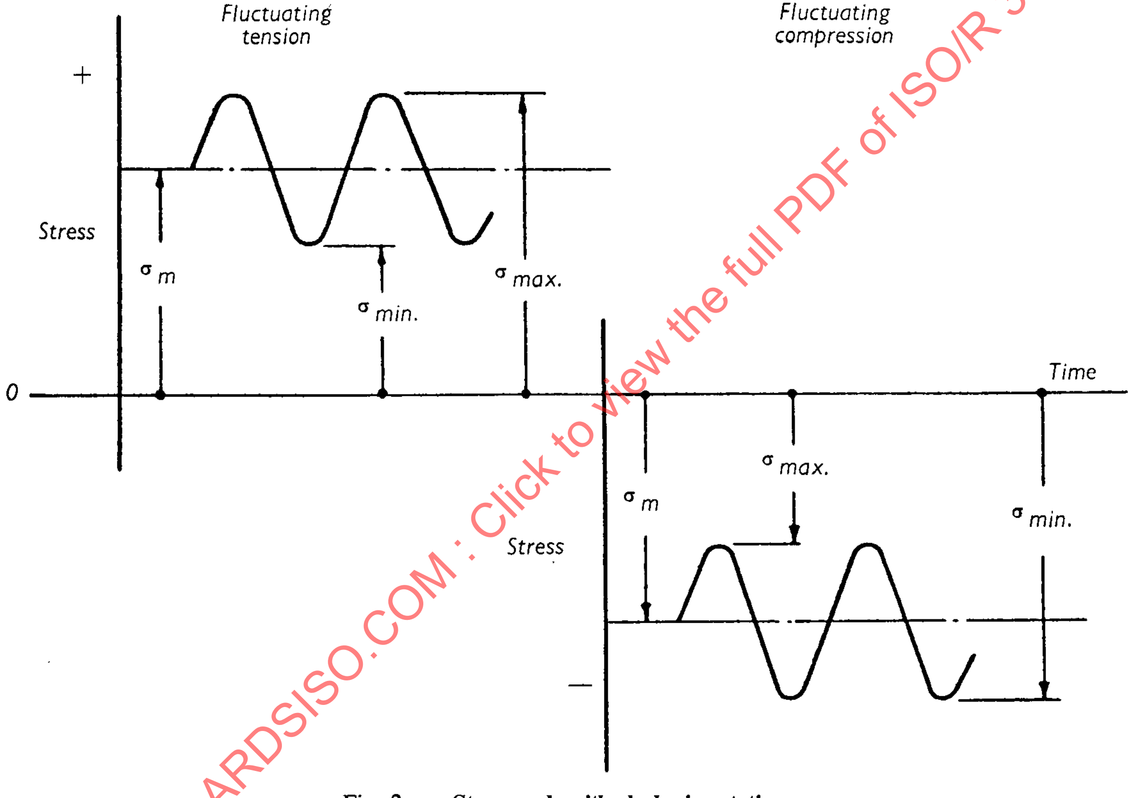


Fig. 2. — **Stress cycle with algebraic notation**

**3.2.2** *Symbols, designations and definitions*

| Symbol | Designation | Definition |
|---|---|---|
| $\sigma_{max.}$ | *Maximum stress* | The highest algebraic value of stress in the stress cycle; tensile stress is considered positive and compressive stress negative. |
| $\sigma_{min.}$ | *Minimum stress* | The lowest algebraic value of stress in the stress cycle; tensile stress is considered positive and compressive stress negative. |
| $\sigma_m$ | *Mean stress* | Static component of the stress. It is one half of the algebraic sum of the maximum and minimum stresses. |
| $\sigma_a$ | *Stress amplitude* | Variable component of stress. It is one half of the algebraic difference between the maximum stress and the minimum stress. |
| $2\sigma_a$ | *Range of stress* | Algebraic difference between the maximum stress and the minimum stress in the stress cycle. |

NOTE. — For shear stress, the symbol $\tau$ will be used instead of $\sigma$.

| Symbol | Designation | Definition |
|---|---|---|
| $n$ | *Number of the stress cycles* | Number of cycles applied at any stage during the test. |
| $f$ | *Frequency of cycles* | Number of applied cycles per unit time (cycles per minute or cycles per second). |
| $K_t$ | *Theoretical stress concentration factor* | Geometric stress concentration factor based on net area and calculated in accordance with the elastic theory. |
| $R_s$ | *Stress ratio* | Algebraic ratio of the minimum stress to the maximum stress in one cycle. $\frac{\sigma_{min.}}{\sigma_{max.}}$ |

3.2.3 *Types of stress cycles.* The stress cycle may take any of the forms shown in Figure 3.

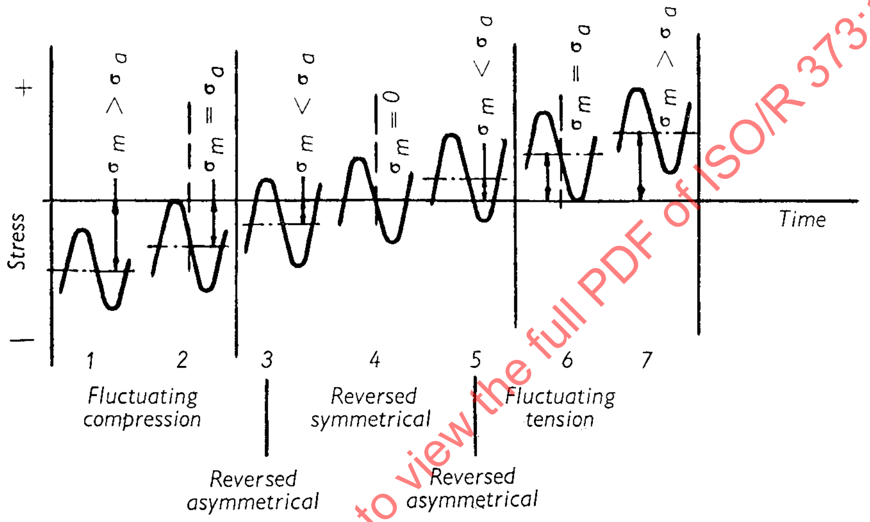


Fig. 3. — **Types of cyclic stress**

## 3.3 Fatigue strength

3.3.1 *Symbols, designations, and definitions*

| Symbol | Designation | Definition |
|---|---|---|
| $N$ | *Endurance or fatigue life* | Number of stress cycles to failure, generally stated as decimal fractions or multiples of $10^6$. |
| $\sigma_N$ | *Fatigue strength at N cycles or fatigue strength for finite life (sometimes known as endurance limit)* | Value of the stress condition under which the test-piece would have a life (which may be statistically determined) of $N$ cycles. |
| $\sigma_D$ | *Fatigue limit* | Value which may be statistically determined of the stress condition below which a material may endure an infinite number of stress cycles. If $\sigma_A$ is the stress amplitude at fatigue limit, then, for a particular value of the mean stress $\sigma_m$, $\sigma_D = \sigma_m \pm \sigma_A$ NOTE. — Certain materials and environments preclude the attainment of fatigue limits. |

| Symbol | Designation | Definition |
|---|---|---|
| $n/N$ | *Cycle ratio* | Ratio of the applied stress cycles (see clause 3.2.2) to cycles to failure: used in multi-level tests with reference to the Woehler curve. |
| $K_f$ | *Fatigue strength reduction factor (based on the net area)* | Ratio of fatigue limit for plain polished test pieces to the fatigue limit for test pieces with a stress-concentration. The term "stress-concentration" is here used in a general sense, to denote not only the effect of a mechanical notch, but also, for example, the influence of corrosion or of an unmachined surface.<br>Values of fatigue strength at $N$ cycles ($\sigma_N$) may be employed in the calculation of this factor. The ratio will vary with the value of $N$ chosen. |

## 4. PROCEDURE AND CRITERIA OF FAILURE

4.1 **Design of specimen.** The design of the specimen has to provide for all the variables that have to be investigated, and should be undertaken with a view to satisfying the conditions of the test programme.
For tests of materials, the test piece may be of simple shape, but for fatigue tests on structural components and assemblies, the design of the specimen should reproduce as closely as possible the true condition and distribution of the loads.

4.2 **Test piece preparation.** The majority of fatigue failures originate at a free surface in the metal, and, as a consequence, the fatigue strength of a test piece or of a structural or mechanical component may be profoundly influenced by conditions at the surface. The method of preparation of a series of test pieces for a fatigue determination should take account of this in relation to the purpose for which the fatigue determination is being undertaken.
Thus, in preparing test pieces without any deliberately introduced stress-concentration, the machining and polishing technique employed to form the test portion should be designed to minimize surface imperfections and residual surface stresses and other effects, such as overheating.
Where the test piece being prepared contains an intentional stress-concentration (for example, a discontinuity such as a notch, a change in cross-section or a hole), the precautions noted above will apply to the machining process employed in forming the stress-concentration.

4.3 **Mounting the test piece in the testing machine.** Each test piece should be mounted in the testing machine in such a manner that operation of the machine does not subject the test piece to appreciable stresses additional to the required stress.
As examples, a rotating beam test piece should be clamped co-axially with the rotating shaft of the machine to avoid vibration; similarly, misalignment of an axial tension or compression stress test piece will result in the superimposition of bending stress.

4.4 **Application of the load.** The general procedure adopted in arriving at full load-running conditions should be the same for each test piece tested in a fatigue determination, and will be controlled by the type and conditions of the test being undertaken. The speed of a rotating test piece in a bending fatigue test should be increased to a value approximating to that required for the test before any load is applied. The load is then raised incrementally or continuously, but without shock, to the required value as quickly as is convenient. In general, tests will then be run continuously until failure of the test piece occurs.
Taking into account the volume of the material being stressed, the frequency of the stress cycles should be so chosen as to avoid overheating the test piece during testing. If, for any reason, this is inconvenient, the test piece may be continuously cooled by any appropriate method which does not influence the result (for example, by inducing corrosion).

**4.5 Test procedure.** The number of test pieces employed in a fatigue determination may vary over a wide range, according to the nature of the information being sought. Where the experiment is of a statistical nature, the number may be very large; if, on the other hand, each "test piece" is a costly machine component, the number will necessarily be small. If the number is less than 6, it may be desirable to adopt a special procedure.

Many fatigue determinations employ at least 10 similar test pieces, each of them being subjected to a particular stress amplitude until either failure (for criteria of failure, see clause 4.6) occurs, or until a predetermined number of cycles have been reached without failure. The values of the stress amplitudes applied to the individual test pieces should be so chosen as to result in one test piece * remaining unbroken at the predetermined endurance and one test piece broken at a very slightly different value. The remaining test pieces should be subjected to stress amplitudes which result in them falling over a range of endurances sufficiently wide to be plotted against the stress amplitude so that a curve may be drawn through the points. This curve is generally referred to as the Woehler curve. The range of endurances covered by the tests will depend upon the information being sought from the determination.

In some cases, the object of a fatigue determination may not be to plot a Woehler curve; for example, a fatigue limit may be obtained by a statistically designed procedure, such as the "staircase" method (see Section 7).

**4.6 Criterion of the failure.** In the majority of fatigue determinations, the criterion of failure is either the occurrence of a visible fatigue crack or complete failure.

It should be noted, however, that in particular applications, other criteria, for example, plastic deformation of the test piece or rate of crack propagation, may be adopted to determine the end of the test.

**4.7 Endurance.** The predetermined number of cycles at which a test will be discontinued will generally depend on the material being tested.

Commonly employed endurances are for example:

- $10^7$ for commonly used structural steels,
- $10^8$ for other steels and non-ferrous metals; also for high temperature and corrosion fatigue tests.

## 5. SPECIAL FATIGUE TESTS

**5.1 Environment.** Fatigue tests may be conducted under conditions other than in air at normal temperatures, for example, at elevated or at low temperatures, in vacuo or in a controlled atmosphere. In these cases, it is essential to ensure that the auxiliary apparatus does not adversely affect the stressing system.

A special case of environmental fatigue testing is that in which corrosive conditions, chemical or electro-chemical, are likely to be present simultaneously with the alternating stresses. This is generally referred to as corrosion fatigue testing. In elevated temperature fatigue tests in air, continuous oxidation of the surface of the test piece may occur, giving conditions analogous to those in corrosion fatigue testing. In tests at elevated temperatures employing a mean stress other than zero, a time-dependent elongation (creep) of the test piece may occur under the influence of the mean stress.

One feature of all such tests is that the Woehler curve is still falling at very large endurances (see Fig. 5, p. 11). Hence it is necessary to report the stress conditions corresponding to a stated endurance. Another feature of these tests is that the results obtained are dependent on frequency of stress cycling, since the extent of corrosion, of oxidation or of creep elongation is time-dependent.

* Additional information can sometimes be obtained by employing an "unbroken" test piece for a subsequent test at a higher stress amplitude. The stress amplitude in the second test should be appreciably higher than that employed in the initial test. In considering the results of the later test, possible effects of the earlier test should not be ignored.

5.2 **Combined stress tests.** Fatigue tests may also be made in special machines, under conditions of combined stress, for example, bending and torsion, or conditions of pulsating internal pressure.

5.3 **Bending or torsion stress tests.** Where they are of different diameters, bending (rotating or flat) or torsion test pieces do not always give comparable results.

5.4 **Stress concentrations.** The effect of notches, fillets, holes or other forms of discontinuities is a further branch of special fatigue testing. To obtain information on the sensitivity in fatigue of a material or structure to notches, it is usual to determine the Woehler curves for test pieces with and without the notch. In the case of zero mean stress tests, the fatigue strength reduction factor is obtained by dividing the fatigue strength of the unnotched test pieces by the fatigue strength of the notched test pieces. In investigations employing a mean stress other than zero, tests on notched and unnotched test pieces are often made using the same nominal value of mean stress. The fatigue strength reduction factor is then calculated from the stress amplitudes obtained in each case. The calculation then takes no account of the local distribution of the mean stress in the vicinity of the notch. It is not possible to specify the precise form of the notch or other discontinuity; this will depend primarily on the particular application considered where fatigue conditions exist. Welded joints are special types of discontinuities and, frequently, their fatigue properties are compared with those of unwelded material to determine the effect of stress concentrations associated with the form and quality of the joint. In a similar way, riveted joints and screwed joints are compared with unjointed material.

5.5 **Other special tests.** Many other types of fatigue tests requiring special techniques and procedures are frequently made: for example, consideration of fretting, programme loading, coaxing, etc. The majority of tests on structural components come within this category.



## 6. PRESENTATION OF RESULTS

6.1 **General.** The design of the investigation and the use to be made of the results, govern the choice of the most suitable method of presenting the results from the many available, graphical and otherwise. The results of fatigue tests are usually presented graphically. In reporting fatigue data, the test conditions should be clearly defined.

6.2 **Woehler curve.** The most general method of presenting the results graphically is to plot the number of cycles to failure (see clause 4.6, "Criterion of failure") as abscissa and the values of stress amplitude or, depending on the type of stress cycle, those of any other stress, as ordinate. A logarithmic scale is used for the number of cycles and the choice of whether a linear or logarithmic scale is used for the stress axis lies with the experimenter. One Woehler curve can be plotted for each set of tests under one mean stress or, as is sometimes convenient, one curve can be plotted for each value of a simple function of the mean stress and the alternating stress. Examples of these graphical representations are shown in Figures 4 to 7, pages 11 and 12).

Figure 4 illustrates a Woehler curve where a linear stress scale is used.

Figure 5 illustrates two curves where a logarithmic stress scale is used, one of which shows corrosion fatigue tests where no fatigue limit can be obtained.

Figure 6 illustrates several curves, each corresponding to a particular mean stress, where a linear stress scale is used.

Figure 7 illustrates several curves, each corresponding to a particular stress ratio $R_s$, i.e.

$$\frac{\text{minimum stress}}{\text{maximum stress}}$$

where a logarithmic scale is used.

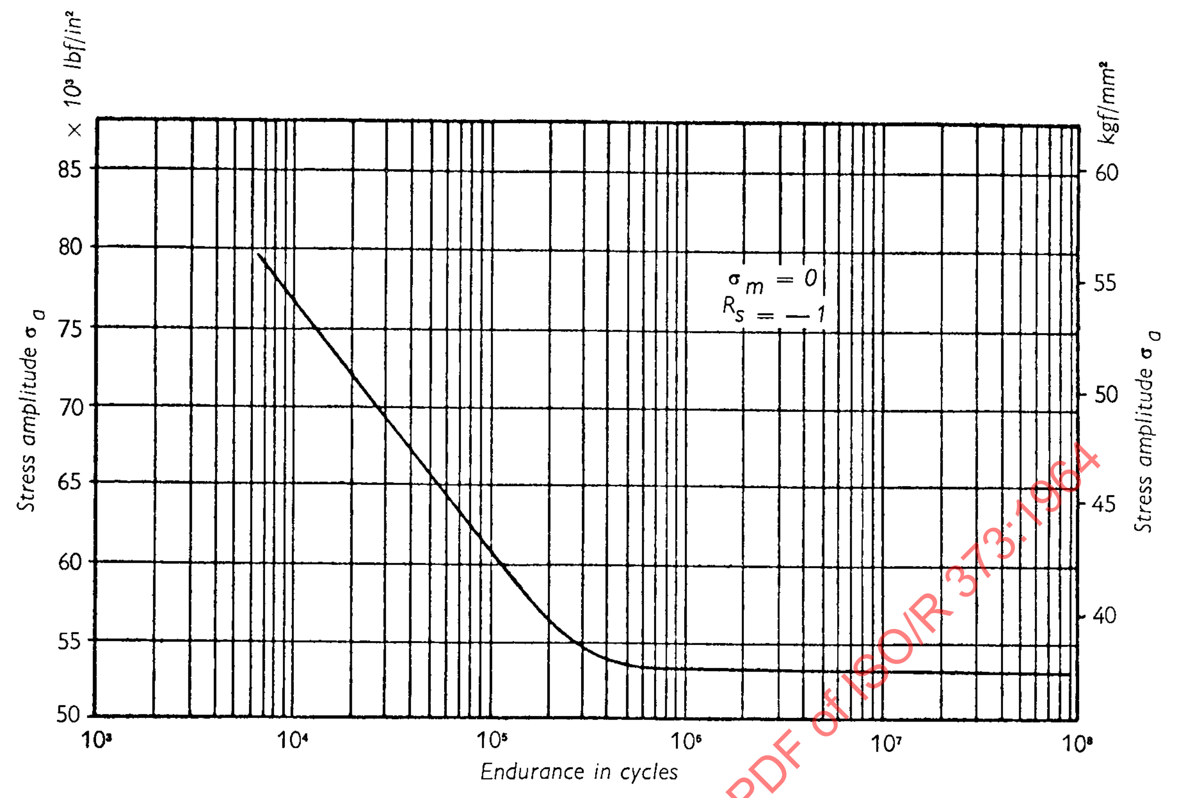


Fig. 4. — S/N curve (linear stress scale)

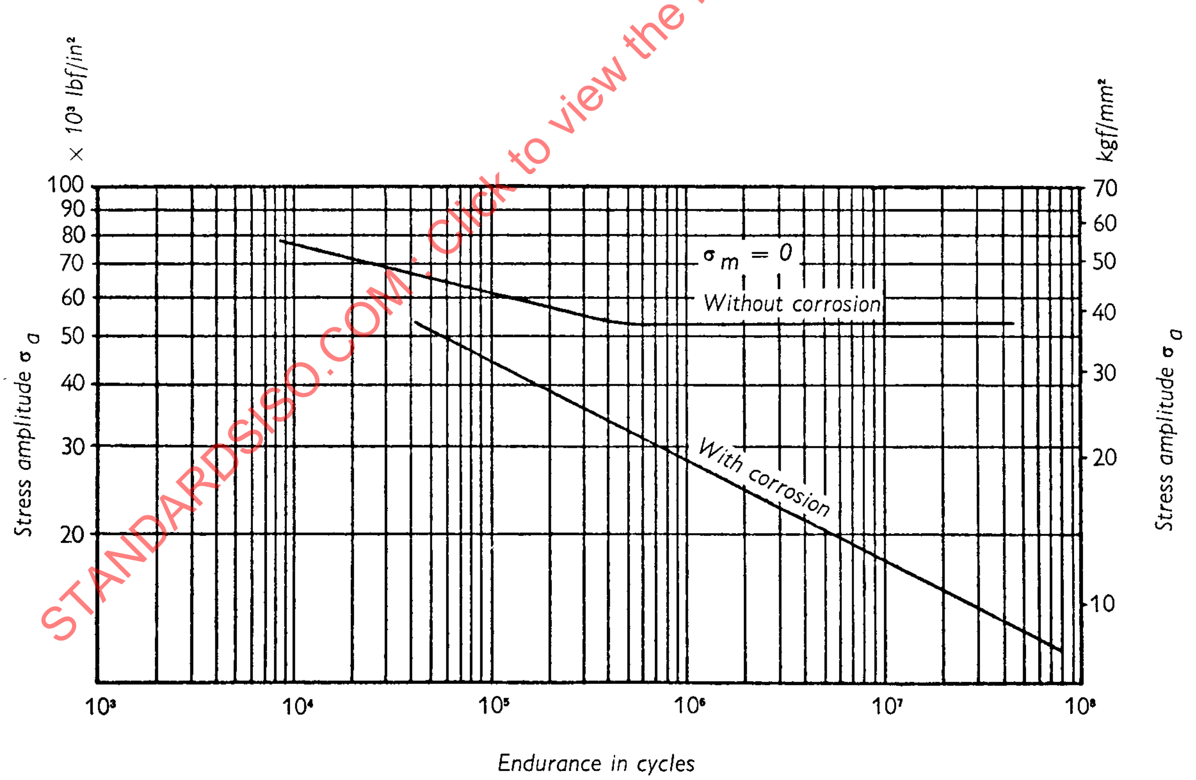


Fig. 5. — S/N curves (logarithmic stress scale)

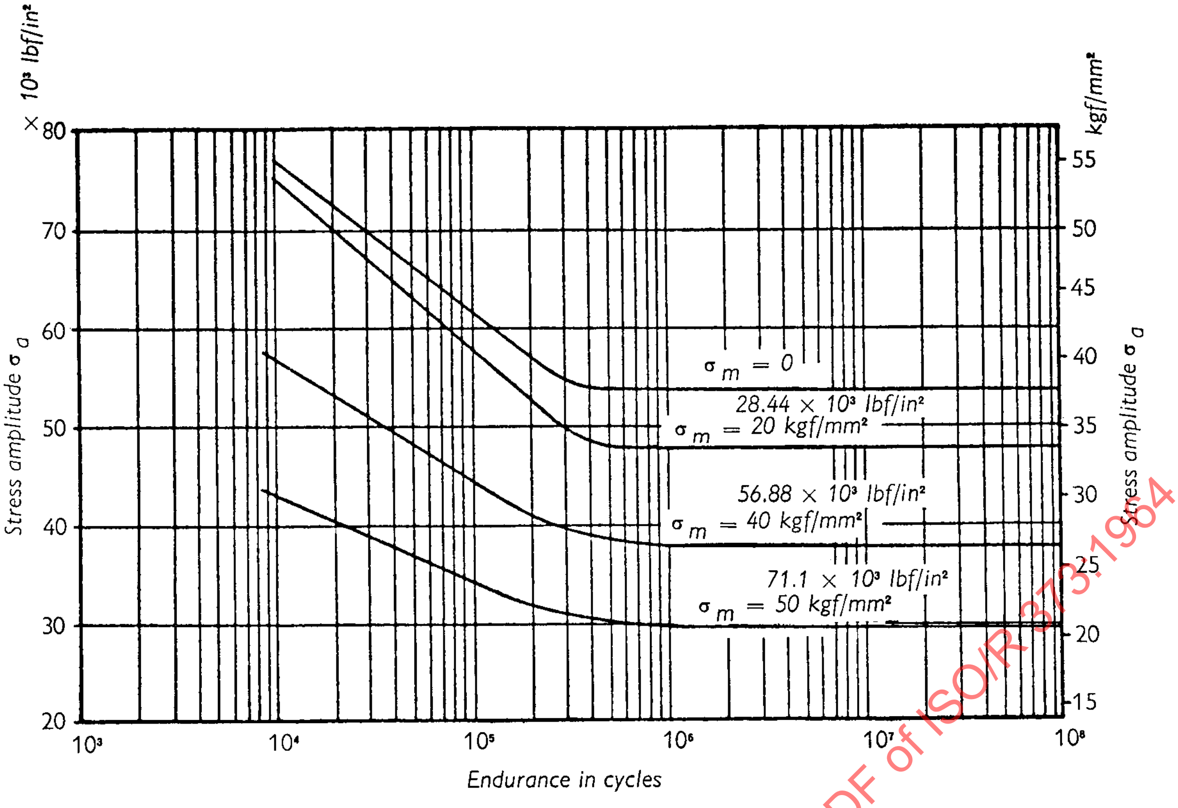


Fig. 6. — S/N curves corresponding to particular mean stresses (linear stress scale)

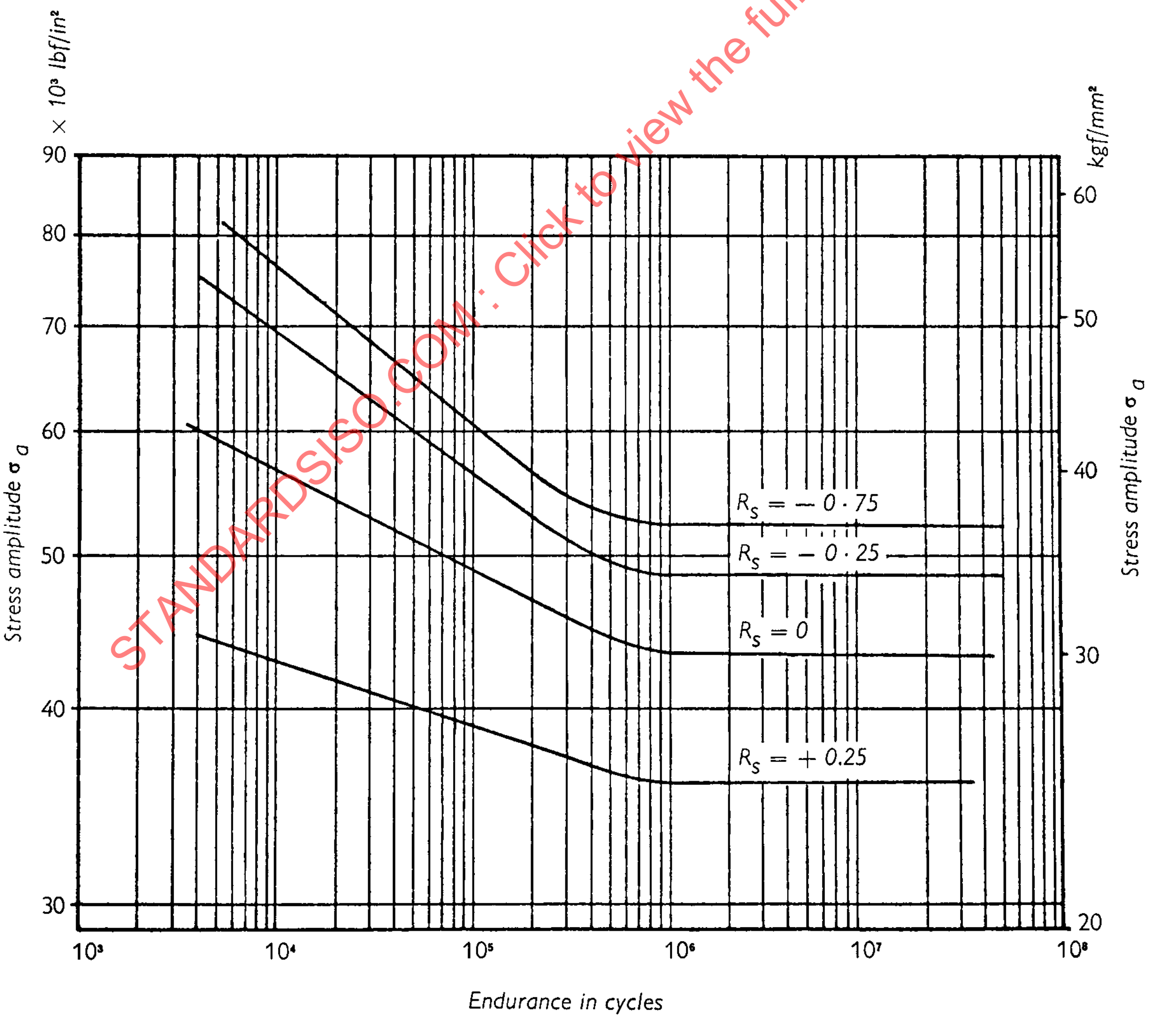


Fig. 7. — S/N curves corresponding to particular stress ratios (logarithmic stress scale)

Other variants of this forms of plot are occasionally used, for example, the maximum stress plotted against the number of cycles, or the stress amplitude plotted against a function of the number of cycles. It is occasionally useful to indicate on the diagram the width of the scatter band of the results (see clause 7.2.).

6.3 **Mean stress diagrams.** The fatigue limits derived from the Woehler curves are plotted in fatigue limit diagrams. The results can be represented by a graph giving directly, for particular endurances, the stress amplitude against the mean stress, as shown in Figures 8 and 9 (Haigh diagrams), or by plotting the maximum and minimum stresses against the mean stresses, as shown in Figures 10 and 11 (Smith diagrams). Figures 8 and 10 are theoretical diagrams, whilst Figures 9 and 11 represent diagrams taken from actual experimental test results.
Another method consists in plotting the maximum stress against the minimum stress, and this gives the Roš diagram (Fig. 12 and 13, p. 17 and 18).
Other systems have been used for expressing the relationship between stress amplitude and mean stress; these are chiefly diagrams giving the maximum stress against a function of a quantity dependent on the stress amplitude and the mean stress; this quantity being, for example,

$$\text{the relationship} \quad \frac{\text{mean stress}}{\text{maximum stress}}$$

$$\text{or the relationship} \quad \frac{\text{minimum stress}}{\text{maximum stress}}$$



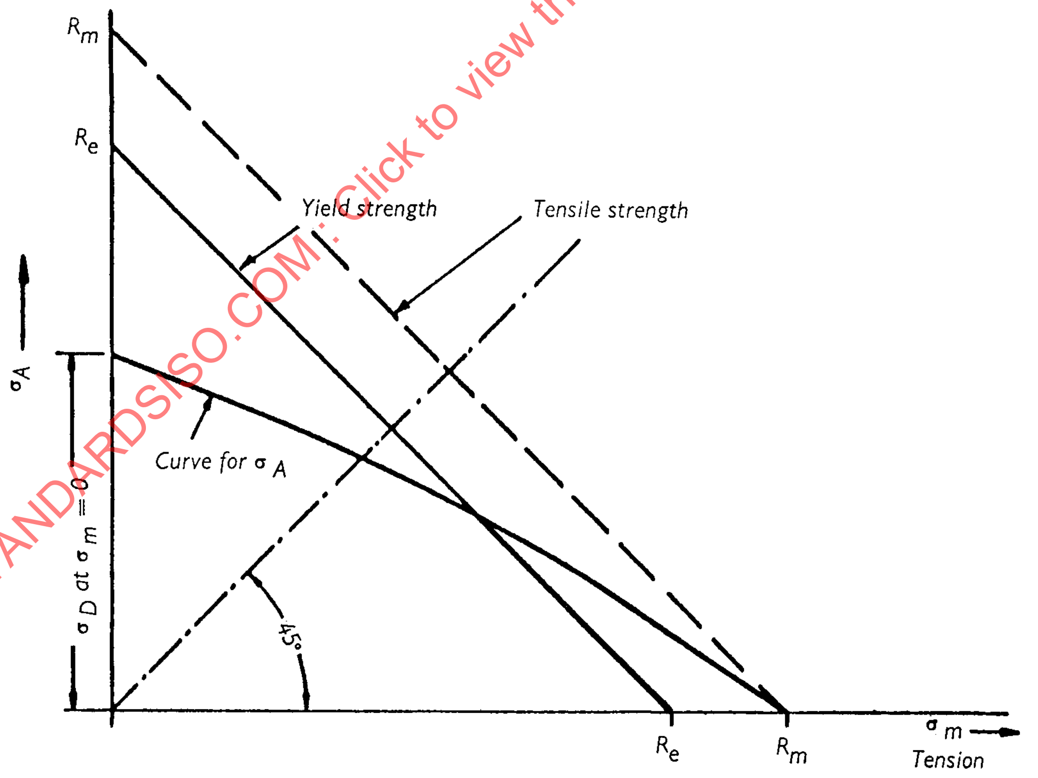


Fig. 8. — **Axial load fatigue test results (theoretical results)**
**Haigh diagram**

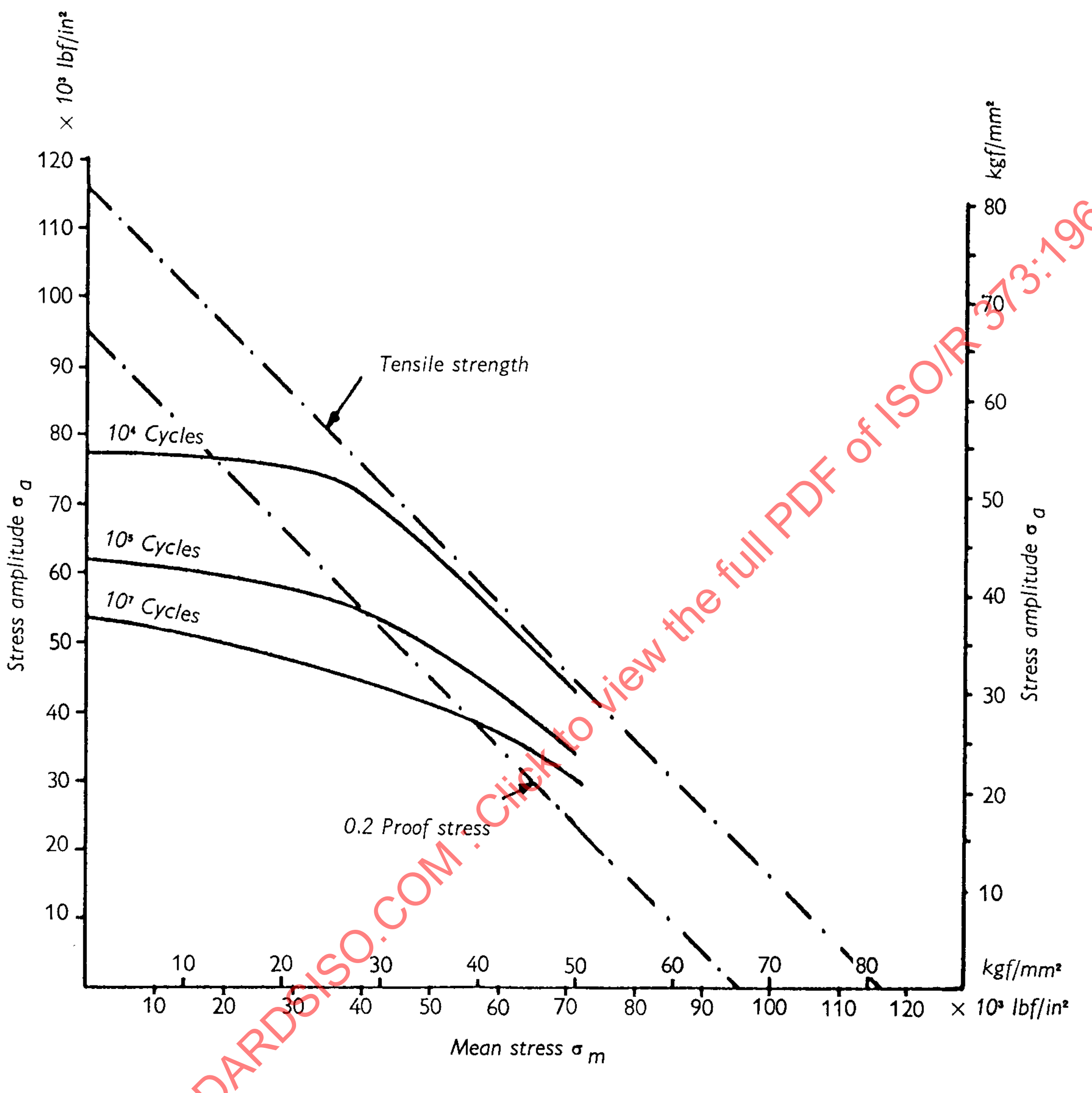




Fig. 9. — **Axial stress fatigue test results (practical results)**
**Haigh diagram**

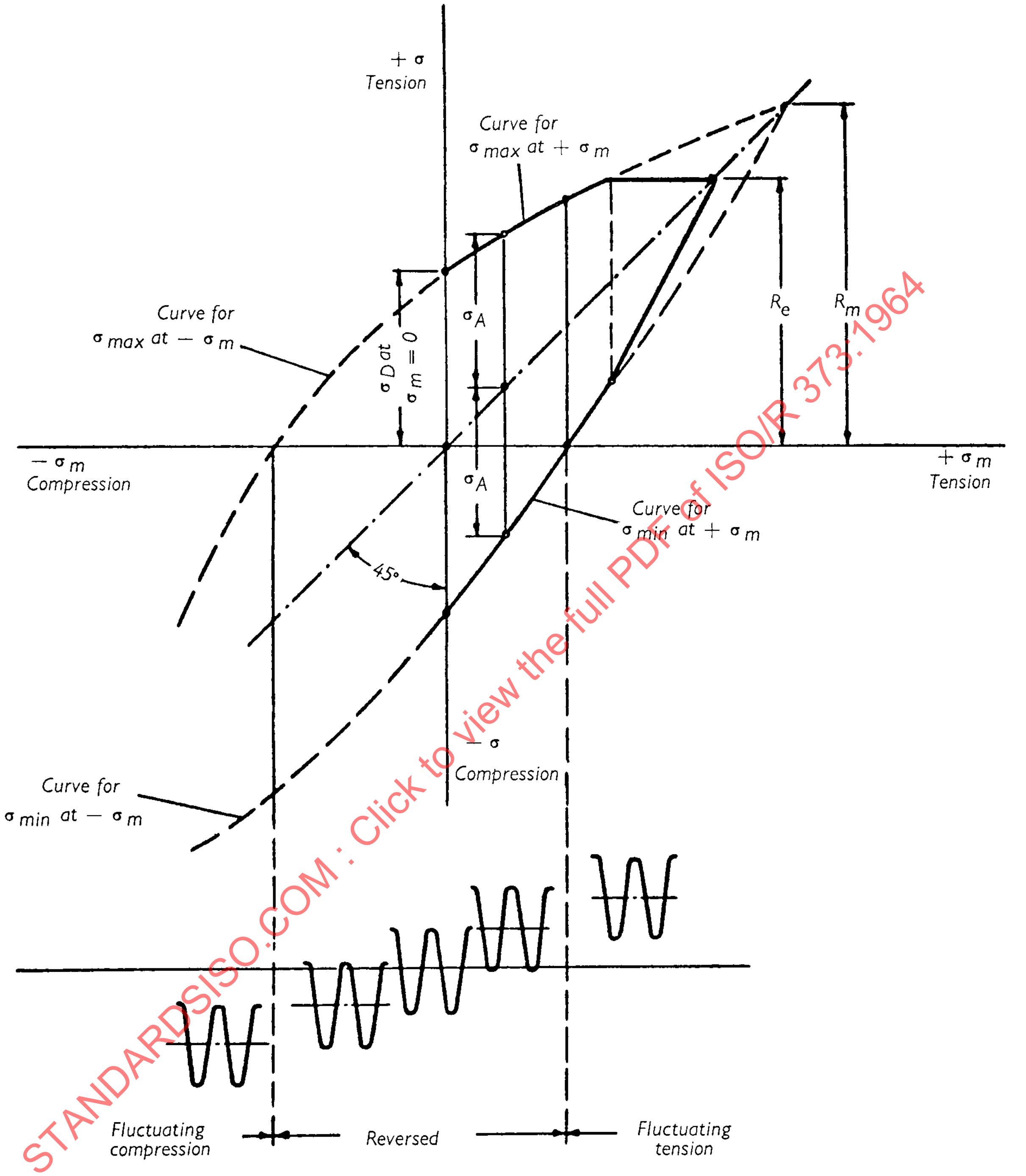




**Fig. 10. — Maximum and minimum stresses ($\sigma_{max.}$ and $\sigma_{min.}$) against mean stress ($\sigma_m$) (theoretical results) Smith diagram**

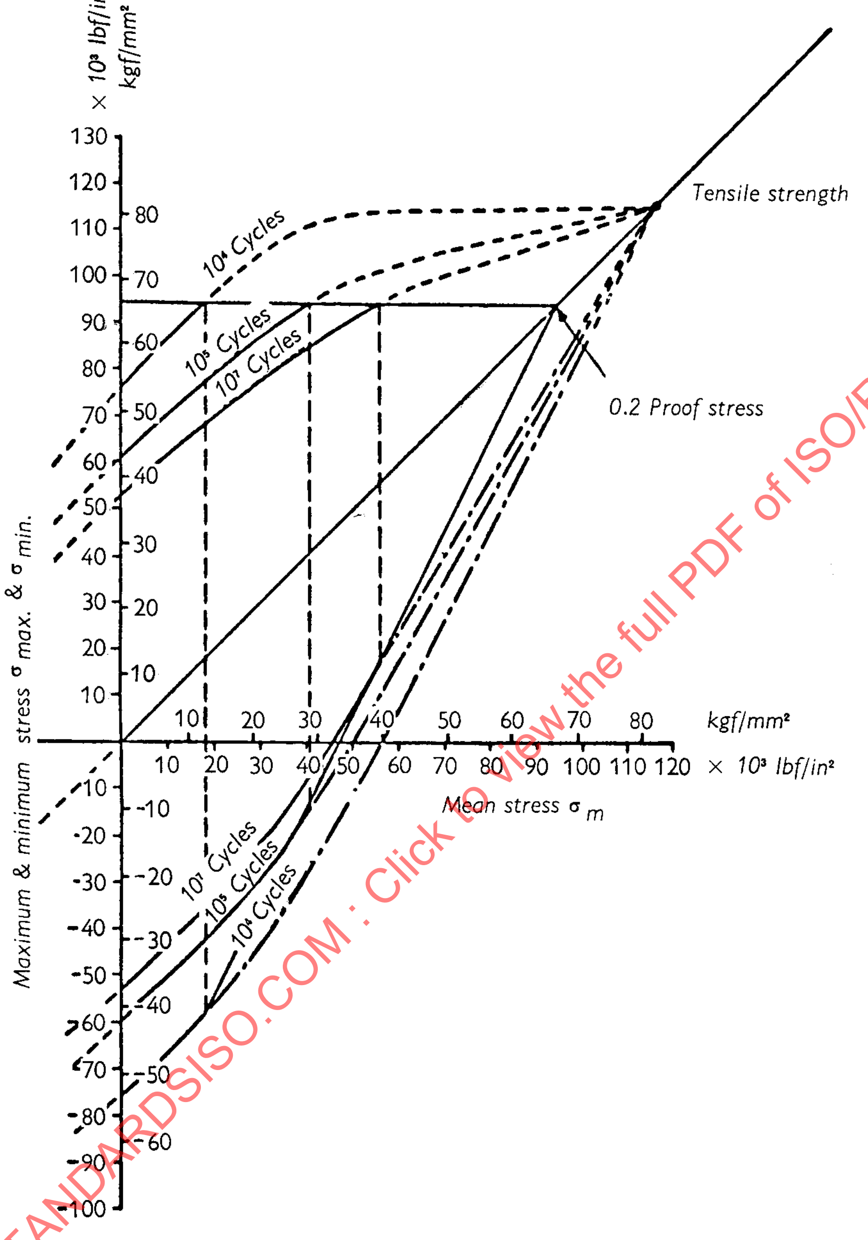


Fig. 11. — **Maximum and minimum stresses ($\sigma_{max.}$ and $\sigma_{min.}$) against mean stress ($\sigma_m$) (practical results) Smith diagram**