For ductile materials, assumed to have the same ultimate and yield stress in both tension and compression, we say

\[ N_e(\text{design}) = \frac{\text{ultimate stress}}{\text{working or design stress}} \quad (1-1) \]

\[ N_y(\text{design}) = \frac{\text{yield stress}}{\text{working or design stress}} \quad (1-2) \]

Most often, equation (1-2) is used because mechanical equipment is frequently considered nonfunctional if some important component has yielded. A typical example of such a failure would be the local permanent yield that might be caused by a cam follower on a cam surface.

If a machine or mechanical component has already been sized (that is, its dimensions are known), then the factor of safety is defined as

\[ N_e(\text{actual}) = \frac{\text{ultimate stress}}{\text{calculated stress}} \quad (1-3) \]

\[ N_y(\text{actual}) = \frac{\text{yield stress}}{\text{calculated stress}} \quad (1-4) \]

For nonlinear types of problems, such as columns or rods subject to failure by buckling, the yield or ultimate stress can no longer be used. Instead, the actual failure load is used as the basis for a factor of safety. Thus, we have

\[ N(\text{actual}) = \frac{\text{failure load}}{\text{calculated load}} \quad (1-5) \]

Mechanical components subject to a continuously varying load have their factor of safety based upon the endurance limit of the material. However, because of the cyclic and static load that may exist, the definition depends upon the Soderberg fatigue analysis, which is covered in Chapter 6, Section 6-5.

Joseph P. Vidosic [15] suggests the following factors of safety as being reasonable. These factors are based on yield strength.

1. \( N = 1.25 - 1.5 \) for exceptionally reliable materials used under controllable conditions and subjected to loads and stresses that can be determined with certainty. Used almost invariably where low weight is a particularly important consideration.
2. \( N = 1.5 - 2 \) for well-known materials, under reasonably constant environmental conditions, subjected to loads and stresses that can be determined readily.
3. \( N = 2 - 2.5 \) for average materials operated in ordinary environments and subjected to loads and stresses that can be determined.
4. \( N = 2.5 - 3 \) for less tried or for brittle materials under average conditions of environment, load, and stress.
5. \( N = 3 - 4 \) for untried materials used under average conditions of environment, load, and stress.
6. \( N = 3 - 4 \) should also be used with better known materials that are to be used in uncertain environments or subjected to uncertain stresses.
7. Repeated loads: the factors established in items 1 to 6 are acceptable but must be applied to the endurance limit rather than the yield strength of the material.
8. Impact forces: the factors given in items 3 to 6 are acceptable, but an impact factor should be included.
9. Brittle materials: where the ultimate strength is used as the theoretical maximum, the factors presented in items 1 to 6 should be approximately doubled.
10. Where higher factors might appear desirable, a more thorough analysis of the problem should be undertaken before deciding upon their use.

In some cases, the selection of the factor of safety is stipulated by code or contract requirements. For example, the ASME\(^3\) Unfired and Fired Pressure Vessel Code, the ASME Pressure Vessel Code for Nuclear Vessels, various building codes and specific values that are stipulated in contracts for both civilian and governmental designs.

It is apparent that the selection of an appropriate factor is rather empirical and very much dependent upon an individual's or industry's accumulated experience. Where a product or device has a long history of use, the factors based upon such a history are reliable. In fact, one may still depend upon such data even though modifications in design and materials have been made.

Statistical methods [16, 17] have also been employed in establishing a factor of safety. Here, account is taken of the variance in both the dimensions and strength of a mechanical component. This approach results in a factor of safety that, in general, is smaller than that based upon pure judgement. However, this method also requires estimation of possible load and strength variations, thereby making the method somewhat less than rational. Nevertheless, the statistical approach should be more than just of passing interest to the modern designers, particularly in those areas where experience data for certain components have been accumulated. Moreover, this method permits the use of a relatively low factor, if a small percentage of failure is acceptable. Unfortunately, space limitations do not permit a detailed discussion, but the reader is urged to investigate the given references.

\(^3\) American Society of Mechanical Engineers.