Static loading failure introduction

Static strength

Ideally, when an engineer designs a part, she has the resources to test these parts under the required loading and environment. Since there is variation in each part's qualities (e.g. yield strength), large data sets are often needed to get a sufficiently sized sample for statistical analysis.

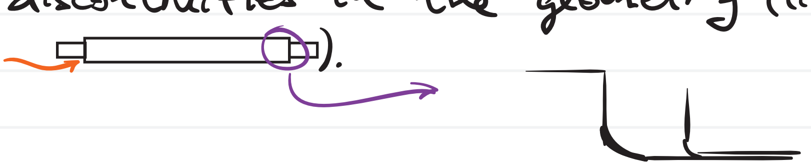
However, this is usually only feasible when the stakes for the part's failure — its ceasing to function properly — would have serious repercussions (e.g. death, environmental impact, significant financial cost).

When data cannot be gathered for the specific design, we can use standard data and the analytical methods that follow.

Several different meanings of "failure" are significant to an engineer. Here, we will focus on predicting and preventing permanent distortion or separation.

We will focus for now on the situation of static loading — that is, loading which is time-invariant.

Stress concentration

Stress concentration is the local increase of stress due to geometric irregularities in a part. These may be designed discontinuities in the geometry (like a shaft's shoulder ).

The theoretical or geometric stress concentration factors K_t (normal) and K_{ts} (shear) are defined as the ratios of maximum normal + shear stresses (σ_{max}, τ_{max}) to the nominal values (σ_0, τ_0):

$$K_t \equiv \frac{\sigma_{max}}{\sigma_{nom}} \qquad K_{ts} \equiv \frac{\tau_{max}}{\tau_{nom}} .$$

These are used to compute the maximum stresses due to stress concentration by solving the definitions of the concentration factors for

$$\sigma_{max} = K_t \sigma_{nom} \qquad \tau_{max} = K_{ts} \tau_{nom} .$$

Stress concentration in ductile materials

Ductile materials strain-strengthen under most conditions. This means that they plastically deform locally, yet can globally withstand higher stresses without failure. For such materials and situations, the stress concentration factor is usually set to unity. I.e. for ductile materials, we usually set $K_t = 1$.

Stress concentration in brittle materials

Brittle materials can be considered in the usual manner for stress concentration. However, microdiscontinuity stress concentration effects — those from microscopic discontinuities due to, for instance, air pockets — may already be present in some materials (like cast iron's graphite flakes), such that macroscopic stress concentrations are negligible. In these cases, $K_t = 1$.

Failure theories

Several theories of failure have been developed. In current engineering practice, there are six generally accepted theories.

Ductile material failure theories

Materials with failure strain $\varepsilon_f \geq 0.05$ and identifiable yield strength (usually equal in tension + comp.) $S_y = S_{yt} = S_{yc}$, are called ductile materials.

Three generally accepted failure theories for statically loaded ductile materials are

maximum shear stress (MSS),
distortion energy (DE), and
ductile Columb-Moore (DCM).

Each of these is used for different situations.

Brittle material failure theories

Materials with failure strain $\varepsilon_f < 0.05$ are brittle materials. These usually exhibit no clear yield stress and are characterized by ultimate tensile strength S_{ut} and ultimate compression strength S_{uc}.

Three generally accepted failure theories for statically loaded brittle materials are

maximum normal stress (MNS),
brittle Columb-Moore (BCM), and
modified Moore (MM).