Introduction

design : formulate a plan for the satisfaction of a human need
for example, clothing design, interior design, highway design, landscape design, building design, ship design, bridge design, computer-aided design, heating system design, machine design, engineering design, process design

mechanical design : design of things and systems of a mechanical nature
mech. des. utilizes mathematics, the materials sciences, and the engineering-mechanics sciences

the design process is outlined as in Fig. 1-1.

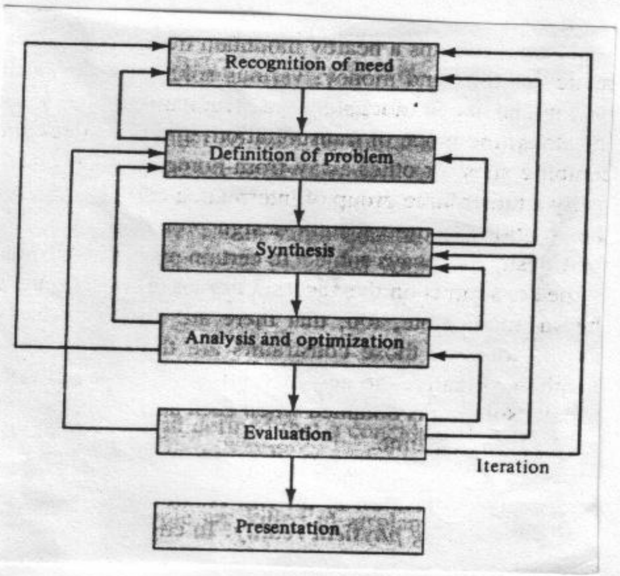


FIGURE 1-1
The phases of design.

- decision to do something about a need
- definition includes all the specifications
- synthesis requires both analysis and optimization (design is an iterative process)
- evaluation is the final proof of a successful design
- communicating the design to others

design consideration : some characteristic which influences the design of the element (for example, strength, reliability, thermal properties, corrosion, wear, friction, processing, utility, cost, safety, weight, life, noise, styling, shape, size, flexibility, control, stiffness, surface finish, lubrication, maintenance, volume, liability)

standard : set of specifications for parts, materials, or processes
code : set of specifications for the analysis, design, manufacture, and construction
organizations ⇒ American Gear Manufacturers Association (AGMA), American Society of Mechanical Engineers (ASME), etc.

Stress and strength considerations

strength : property of a material or of a mechanical element
metalworking and heat-treating processes (forging, rolling, and cold forming) cause variations in the strength from point to point
S : strength S_s : shear strength S_y : yield strength
S_u : ultimate strength $\bar{S}$: mean strength

A product design must be

- Functional: The product must perform to fill its intended need and customer expectation
- Safe: The product is not hazardous to the user, bystanders, or surrounding property. Hazards wiswhich can not be "designed out" are eliminated by guarding (a protective enclosure); if that is not possible, appropriate directions or warnings are provided.
- Reliable: Reliability is the conditional probability, at a given confidence level, that the product will perform its intended function satisfactorily or without failure at a given age.
- Competitive: The product is a contender in its market.
- Usable: The product is "user-friendly," accommodating to human size, strength, posture, reach, force, power, and control.
- Manufacturable: The product has been reduced to a "minimum" number of parts, suited to mass production, with dimensions, distorsion, and strength under control.
- Marketable: The product can be bought, and service (repair) is available.

⟷

Computer can remember data and programs, can calculate, can branch conditionally or unconditionally, can iterate, can read and write both alphabetic and numerical information, can draw, can pause and wait for external decisions or thoughtful input, does not tire.

Humans can understand the problem, can judge what is important or unimportant, can plan strategies and modify them in the light of experience, can weigh intangibles, can be skeptical, suspicious and unconvinced, can program computers.

stress allowables, allowable stresses, allowables

tension $0.45\, S_y \le \sigma_{all} \le 0.60\, S_y$

shear $\tau_{all} = 0.40\, S_y$

bending $0.60\, S_y \le \sigma_{all} \le 0.75\, S_y$

bearing $\sigma_{all} = 0.90\, S_y$

Factor of safety

$$n_d = \frac{\text{strength}}{\text{stress}}$$

Reliability

The statistical measure of the probability that a mechanical element will not fail in use is called the reliability of that element.

$0 \le R < 1$ for example, total $\Rightarrow$ 1000, 6 of them fails

$$R = 1 - \frac{6}{1000} = 0.994 \quad \text{or} \quad 99.4\%$$

Economics

cost plays an important role in the design decision process

using standard sizes reduces cost

"large tolerances" reduce cost

breakeven point: a point corresponding to equal cost

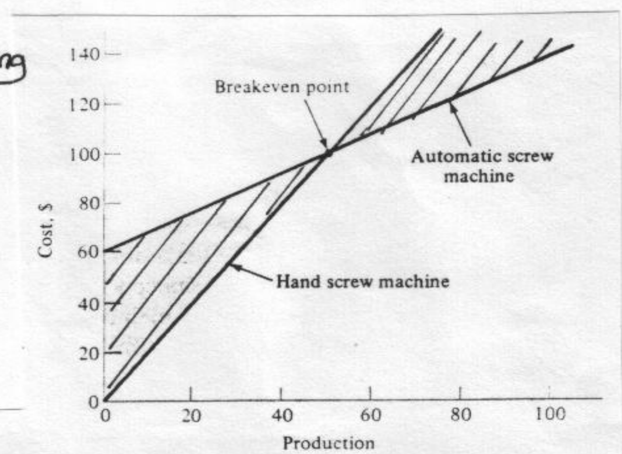


FIGURE 1-2

Units

In the English-speaking countries,

$$M = \frac{FT^2}{L} = \frac{(\text{pound-force})(\text{second})^2}{\text{foot}} =$$

$$= lbf \cdot s^2/ft = slug$$

(gravitational system)

$$F = \frac{M.L}{T^2} = \frac{(\text{kilogram})(\text{meter})}{(\text{second})^2} = kg \cdot m/s^2 = N$$

(absolute system)

Octahedral stresses

cut the stress element by a plane that forms equal angles with each of the three principal stresses ⇒ octahedral plane (Fig. 2-6)

octahedral normal stress }
octahedral shear stress } two components

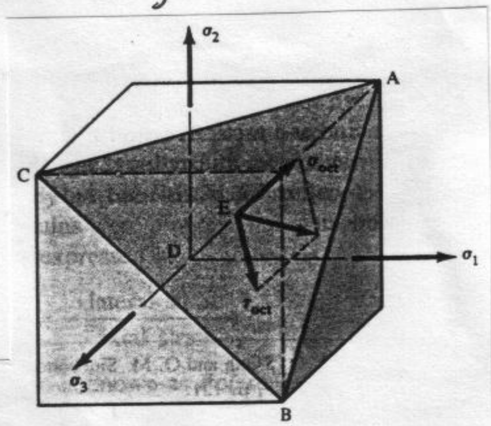


FIGURE 2-6
The octahedral plane.

Uniformly distributed stresses

Many time we assume that the stress is uniformly distributed. For example, pure (simple) tension, pure compression, pure shear.

Elastic strain

The amount of stretch, or elongation, is called strain, when a bar is subjected to a tensile load.

The elongation per unit length is unit strain, but we use "strain" instead of "unit strain".

$$\varepsilon = \frac{\delta}{L}$$

regains its original shape and dimensions when the load is removed ⇒ elasticity

Hooke's law: there is a linear relation between stress and strain ($\sigma = E\varepsilon$ $\tau = G\gamma$)

Poisson's ratio $\nu = -\dfrac{\text{lateral strain}}{\text{axial strain}}$ $E = 2G(1+\nu)$

Free-body diagrams

let's consider a typewriter, a bridge, a tractor

isolate a portion of a system in our imagination, then replace the original effect of the system on the segment is replaced by the interacting forces

the isolated subsystem together with all forces and moments is free-body diagram

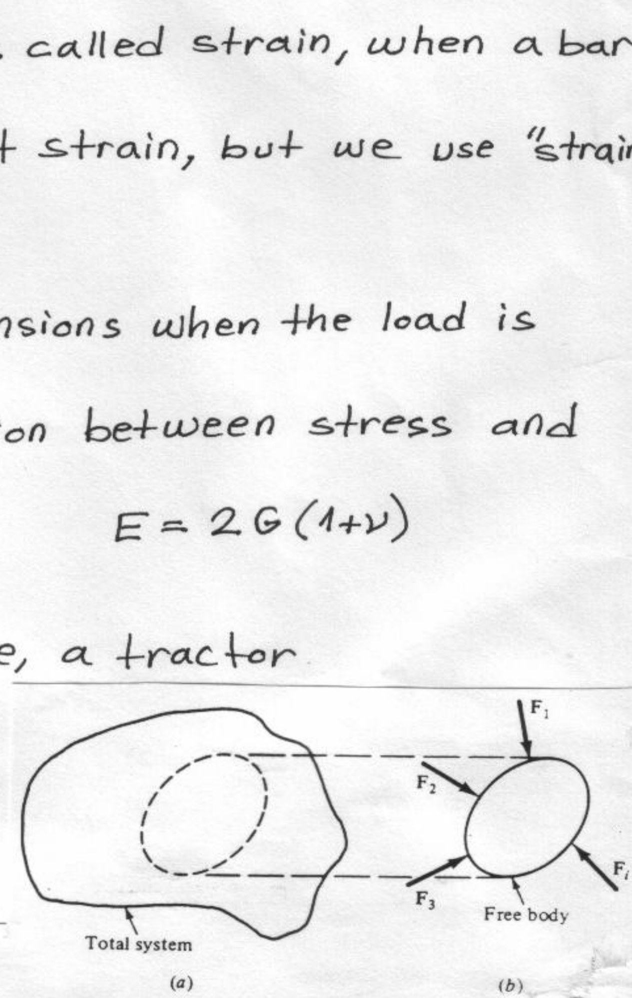


FIGURE 2-7
The isolation of a subsystem.

Shear and moment

the relation between shear and moment is given by $V = \frac{dM}{dx}$

if the bending is caused by a distributed load, then

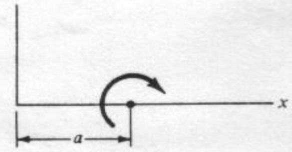
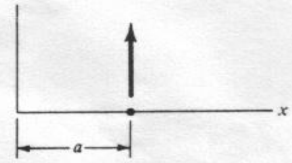
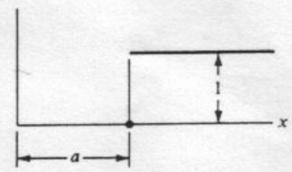
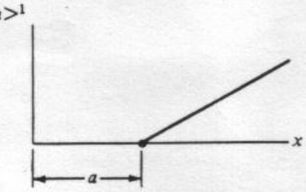
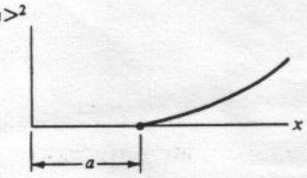
$$\frac{dV}{dx} = \frac{d^2M}{dx^2} = -w$$

w → force per unit length

Singularity functions

There are five singularity functions (Table 2-2)

TABLE 2-2
Singularity and Macaulay Functions

FUNCTION	GRAPH OF $f_n(x)$	MEANING
Concentrated moment (unit doublet)	$\langle x-a\rangle^{-2}$ 	$\langle x-a\rangle^{-2} = 0 \quad x \neq a$; $\int_{-\infty}^{x} \langle x-a\rangle^{-2}\,dx = \langle x-a\rangle^{-1}$; $\langle x-a\rangle^{-2} = \pm\infty \quad x = a$
Concentrated force (unit impulse)	$\langle x-a\rangle^{-1}$ 	$\langle x-a\rangle^{-1} = 0 \quad x \neq a$; $\int_{-\infty}^{x} \langle x-a\rangle^{-1}\,dx = \langle x-a\rangle^{0}$; $\langle x-a\rangle^{-1} = +\infty \quad x = a$
Unit step	$\langle x-a\rangle^{0}$ 	$\langle x-a\rangle^{0} = \begin{cases} 0 & x < a \\ 1 & x \geq a \end{cases}$; $\int_{-\infty}^{x} \langle x-a\rangle^{0}\,dx = \langle x-a\rangle^{1}$
Ramp	$\langle x-a\rangle^{1}$ 	$\langle x-a\rangle^{1} = \begin{cases} 0 & x < a \\ x-a & x \geq a \end{cases}$; $\int_{-\infty}^{x} \langle x-a\rangle^{1}\,dx = \frac{\langle x-a\rangle^{2}}{2}$
Parabolic	$\langle x-a\rangle^{2}$ 	$\langle x-a\rangle^{2} = \begin{cases} 0 & x < a \\ (x-a)^2 & x \geq a \end{cases}$; $\int_{-\infty}^{x} \langle x-a\rangle^{2}\,dx = \frac{\langle x-a\rangle^{3}}{3}$

Normal stresses in flexure

assumptions made

- pure bending (no shear, torsion, or axial loads)
- material is isotropic and homogeneous
- material obeys Hooke's law
- constant cross section, straight beam
- axis of symmetry in the bending plane
- the beam is long enough (so it fails by bending, no crushing, wrinkling, or sidewise buckling)
- cross sections of the beam remain plane during bending

bending equation

$$\frac{1}{\rho} = \frac{M}{EI}$$

ρ → radius of curvature; E → modulus of elasticity; I → the second moment of the area

$$\sigma = -\frac{M}{I} \cdot y$$

Shear stresses in beams

$$V = \frac{dM}{dx} \qquad \tau = \frac{V}{Ib}\int_{y_1}^{c} y\,dA \qquad Q = \int_{y_1}^{c} y\,dA$$

Q → the first moment of the area

τ is maximum at the center of the cross section of the beam (symmetrical cross section)

Torsion

assumptions made

- pure torque
- cross sections are originally plane and parallel and they remain plane and parallel after twisting
- the material obeys Hooke's law

torque, T, from a consideration of power and speed of a rotating shaft, $H = T \cdot \omega$

- H → power (W)
- T → torque (N·m)
- ω → angular velocity (rad/s.)

Stress concentration

Any discontinuity in a machine part alters the stress distribution in the neighborhood of the discontinuity. Such discontinuities are called stress raisers, these regions are called areas of stress concentration.

$$K_t = \frac{\sigma_{max}}{\sigma_o}$$

σ_o → nominal stress

$$K_{ts} = \frac{\tau_{max}}{\tau_o}$$

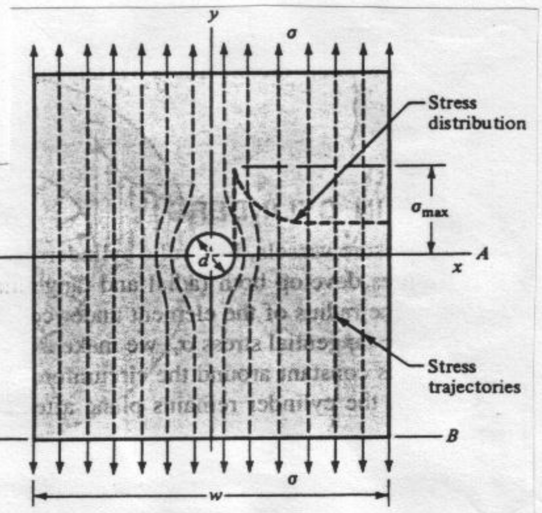


FIGURE 2-22

Stress distribution near a hole in a plate loaded in tension. The tensile stress on a section at *B-B*, remote from the hole, is $\sigma = F/A$, where $A = wt$ and t is the plate thickness. On a section at *A-A*, through the hole, the area is $A_0 = (w - d)t$ and the nominal stress is $\sigma_0 = F/A_0$. Note the difference between the nominal stress and the stress at a section remote from the discontinuity.

Stresses in cylinders

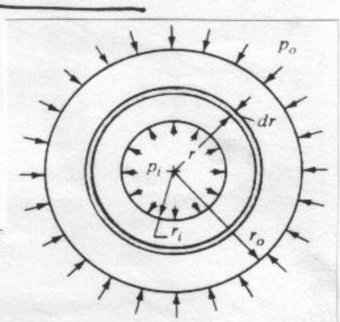


FIGURE 2-23

A cylinder subjected to both internal and external pressure.

cylindrical pressure vessels, hydraulic cylinders, gun barrels, pipes carrying fluids ⇒ develop both radial and tangential stresses

assumption ⇒ longitudinal elongation is constant around the circumference of the cylinder

$$\sigma_t = \frac{p_i r_i^2 - p_o r_o^2 - r_i^2 r_o^2 (p_o - p_i)/r^2}{r_o^2 - r_i^2}$$

$$\sigma_r = \frac{p_i r_i^2 - p_o r_o^2 + r_i^2 r_o^2 (p_o - p_i)/r^2}{r_o^2 - r_i^2}$$