Machine Design

* References

1- Mechanical Engineering Design
By: J.E. Shigley.

2- Machine Design, Theory & practice
By: A.D. Deutschmann, W.T. Michels and C.E. Wilson

3- Machine Design
By: R.L. Maleer and J.B. Hartman

4- Machine Design
By: Schaum's outline series

5- Design of machine elements
By: V.M. Fairs

6- A Textbook of Machine Design
By: R.S. Khurmi and J.K. Gupta

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* Definition

Machine Design is the creation of new and better machines and improving the existing ones.
A new or better machines have to be more economical in the overall cost of production and operation.

* General procedure in machine Design

1. Recognition of a need
2. Mechanism
3. Analysis of foces
4. Material selection
5. Design of elements (size and stresses)
6. Modifications
7. Detailed drawing
8. production

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* General Considerations in machine design

1. load
2. Motion
3. Material
4. size
5. use of standard parts
6. safety
7. work shop facilities
8. Cost of Construction
9. Assembly

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* Loads and Reactions

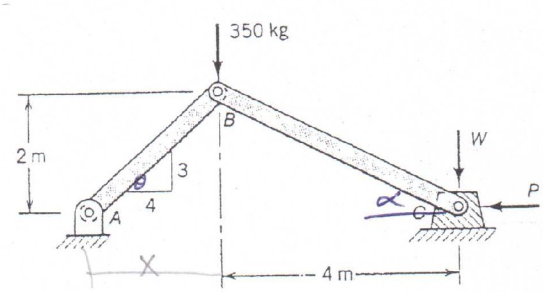
static

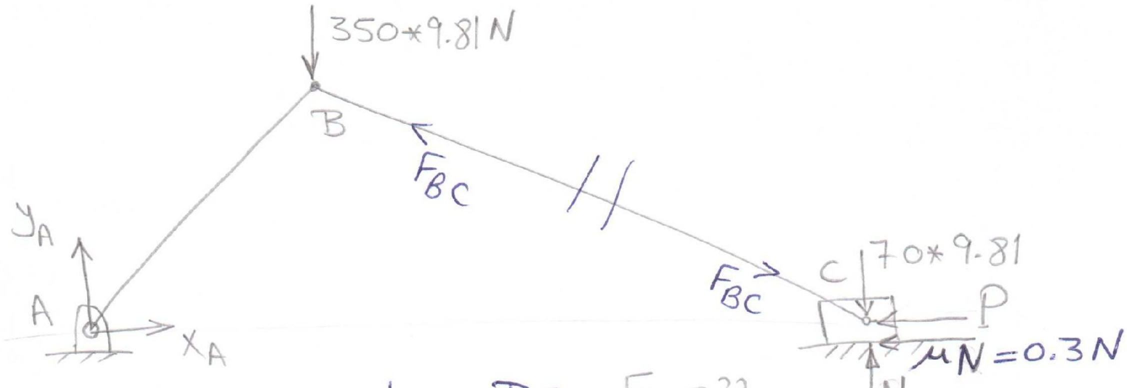
$$\left.\begin{array}{l}\Sigma F_x = 0 \\ \Sigma F_y = 0\end{array}\right\} \Sigma \vec{F} = 0$$

$$\Sigma M = 0$$

LOADS AND REACTIONS:

1- Given: The frame shown in the figure. Assume point A, B, and C to be frictionless hinges. If $W = 70\,kg$ and the coefficient of friction between W and the plane is *0.3*. Find: *(a)* The axial force in bar *BC*. *(b)* The magnitude of *P* necessary to keep the block from sliding to the right.





ⓐ The axial force in bar BC $F_{BC} = ??$

ⓑ $P = ??$ to keep the block from sliding to →

* for the whole body

$\Sigma M_A = 0$ (+↺)

$-350 * 9.81 * X - 70 * 9.81 * (X+4) + N * (X+4) = 0$

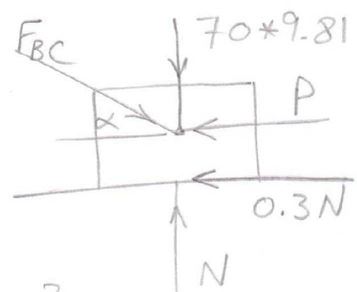
as $\theta = \tan^{-1} \frac{3}{4} = 36.87°$ $\tan\theta = \frac{2}{X}$ $\therefore X = 2.67\,m$

sub. in moment eqn $\therefore N = 2059.2$ Newton

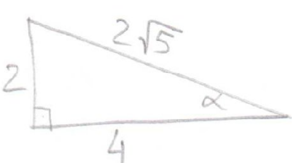
* for the block at C

$\Sigma F_y = 0$ ↑+

$-70 * 9.81 + N - F_{BC} \sin\alpha = 0$



$\sqrt{2^2+4^2} = \sqrt{20} = 2\sqrt{5}$



$\sin\alpha = \frac{2}{2\sqrt{5}}$

$\cos\alpha = \frac{4}{2\sqrt{5}}$

sub. in eqn

$$-70 * 9.81 + 2059.2 = F_{BC} * \frac{1}{\sqrt{5}}$$

$$\therefore F_{BC} = 3069 \text{ Newton}$$ Compression

$\Sigma F_x = 0 \quad \xrightarrow{+}$

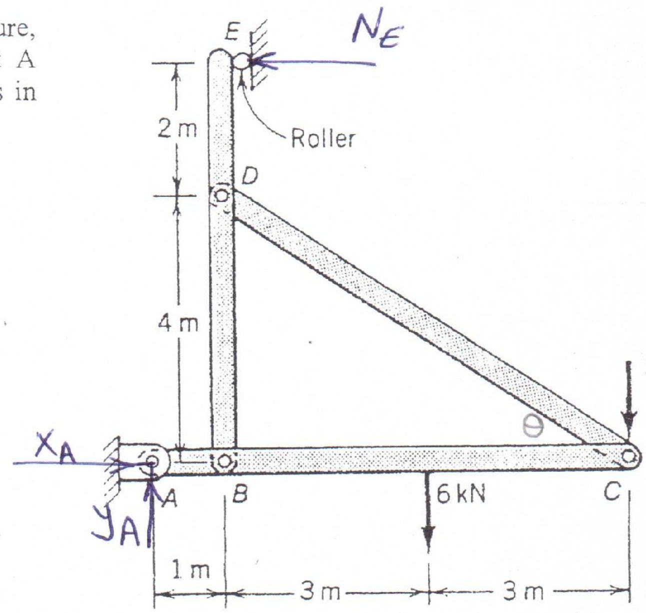
$$-P - 0.3N + F_{BC} \cos\alpha = 0$$

$$P = F_{BC} \cos\alpha - 0.3N$$

$$= 3069 * \frac{2}{\sqrt{5}} - 0.3 * 2059.2$$

$$= 2127.24 \text{ Newton}$$

3- For the frame shown in the figure, determine *(a)* The reactions at A and E, and *(b)* The axial forces in the members AC, DC, and EB.



R_A

(a) $X_A, Y_A, N_E = ??$

(b) Axial forces in
AC
DC = ??
EB

* for the whole frame

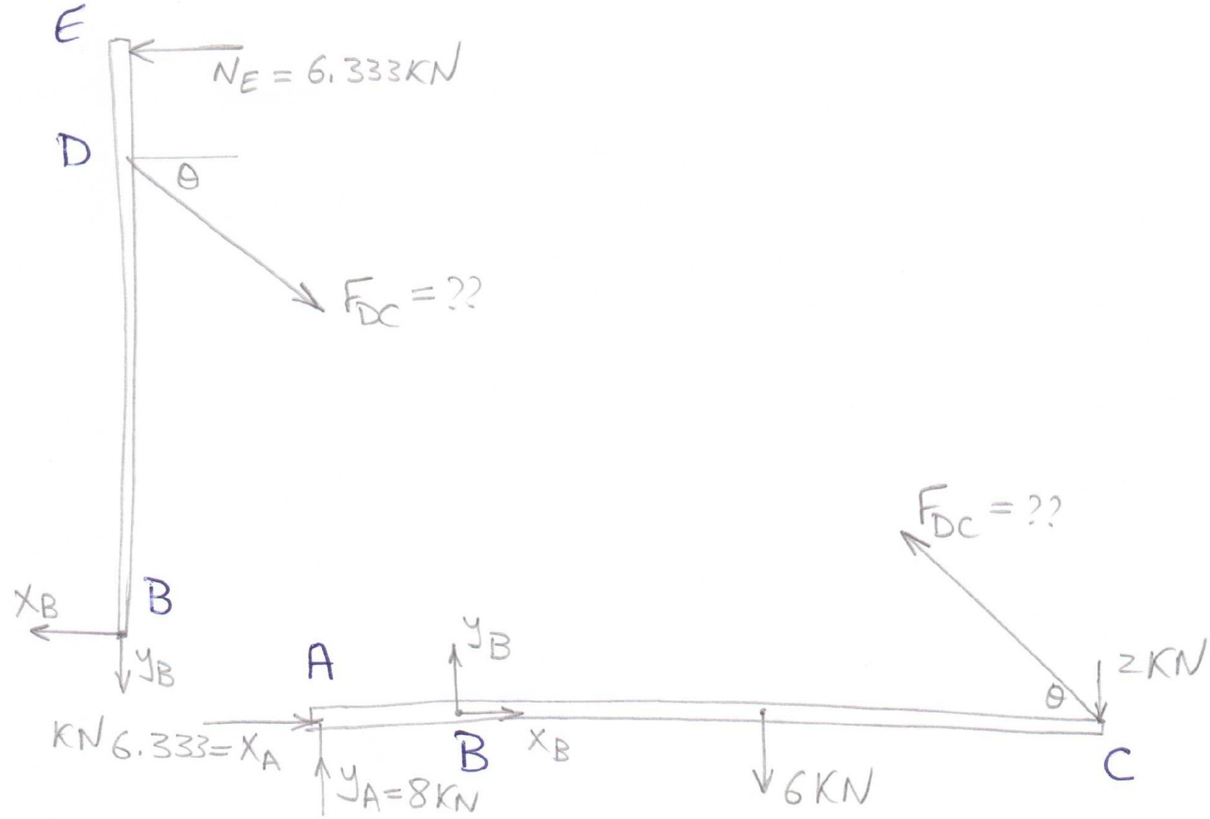
$\Sigma M_A = 0 \quad (+\circlearrowleft)$

$N_E * 6 - 2*7 - 6*4 = 0 \qquad \therefore N_E = 6.333 \text{ KN}$

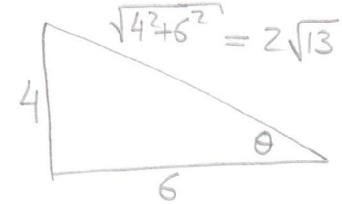
$\Sigma F_y = 0 \ \uparrow+ \qquad Y_A - 6 - 2 = 0 \qquad \therefore Y_A = 8 \text{ KN}$

$\Sigma F_x = 0 \ \xrightarrow{+} \qquad -N_E + X_A = 0 \qquad X_A = N_E = 6.333 \text{ KN}$

$$R_A = \sqrt{X_A^2 + Y_A^2} = 10.2 \text{ KN}$$



for member BDE



$\Sigma M_B = 0$ (+↺)

$-F_{DC} \cos\theta * 4 + N_E * 6 = 0$

$F_{DC} * \frac{3}{\sqrt{13}} * 4 = 6.333 * 6$

$F_{DC} = 11.417\ KN$ tension

$\sin\theta = \frac{4}{2\sqrt{13}} = \frac{2}{\sqrt{13}}$

$\cos\theta = \frac{6}{2\sqrt{13}} = \frac{3}{\sqrt{13}}$

$\Sigma F_x = 0$ (+→)

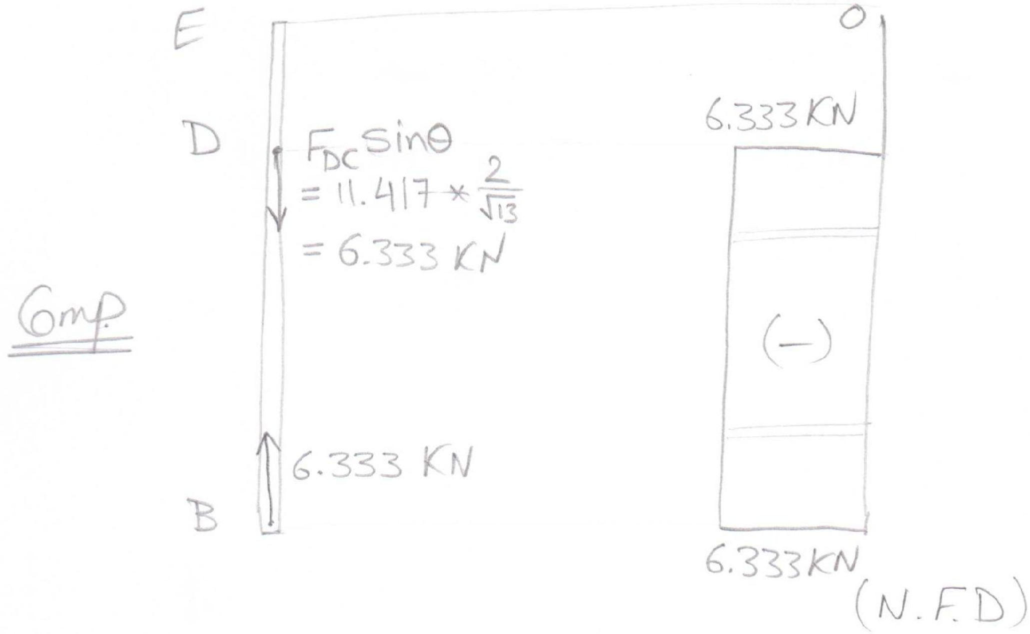
$-N_E + F_{DC} \cos\theta - X_B = 0$

$-6.333 + 11.417 * \frac{3}{\sqrt{13}} = X_B$ $\quad \therefore X_B = 3.167 KN$

$\Sigma F_y = 0$ (↑+)

$-F_{DC} \sin\theta - y_B = 0$

$\therefore y_B = -11.417 * \frac{2}{\sqrt{13}}$ $\quad \therefore y_B = -6.333 KN$



for member ABC

Comp.

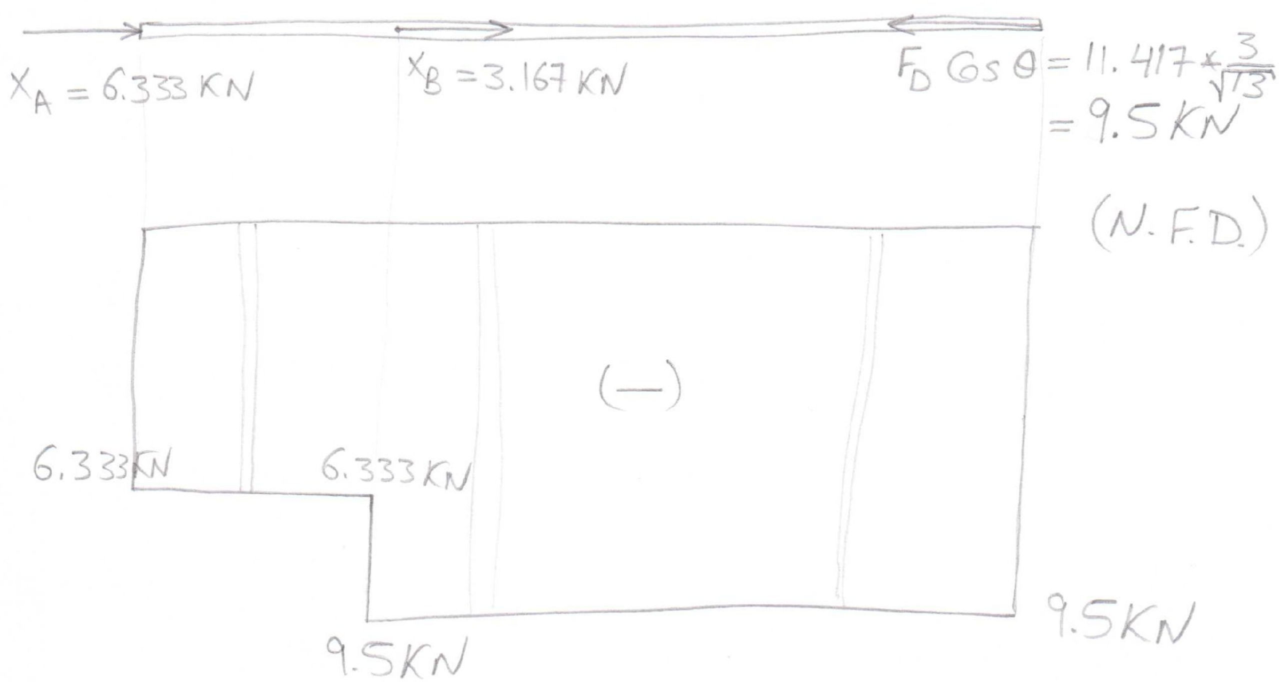


Table 2.1. Physical properties of metals.

Metal	*Density* (kg/m³)	*Melting point* (°C)	*Thermal conductivity* (W/m°C)	*Coefficient of linear expansion at* 20°C (μm/m/°C)
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11 400	327	33.5	29.1
Monel metal	8600	1350	25.2	14.0
Nickel	8900	1453	63.2	12.8
Silver	10 500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Tungsten	19 300	3410	201	4.5
Zinc	7200	419	113	33.0
Cobalt	8850	1490	69.2	12.4
Molybdenum	10 200	2650	13	4.8
Vanadium	6000	1750	—	7.75

2.5 Mechanical Properties of Metals

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness. We shall now discuss these properties as follows:

1. *Strength.* It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called *stress.

2. *Stiffness.* It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. *Elasticity.* It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

4. *Plasticity.* It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. *Ductility.* It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper, aluminium, nickel, zinc, tin and lead.

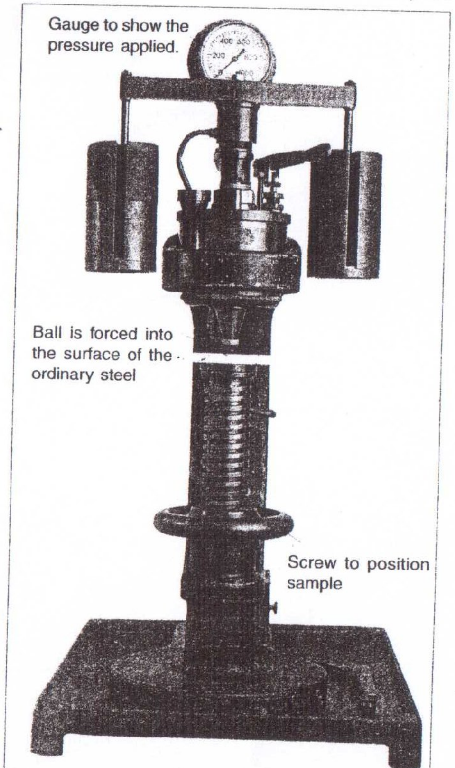
Note : The ductility of a material is commonly measured by means of percentage elongation and percentage reduction in area in a tensile test. (Refer Chapter 4, Art. 4.11).

* For further details, refer Chapter 4 on Simple Stresses in Machine Parts.

6. *Brittleness.* It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads, snap off without giving any sensible elongation. Cast iron is a brittle material.

7. *Malleability.* It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminium.

8. *Toughness.* It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed upto the point of fracture. This property is desirable in parts subjected to shock and impact loads.



Brinell Tester : Hardness can be defined as the resistance of a metal to attempts to deform it. This machine invented by the Swedish metallurgist Johann August Brinell (1849-1925), measure hardness precisely.

9. *Machinability.* It is the property of a material which refers to a relative case with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel.

10. *Resilience.* It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

11. *Creep.* When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called ***creep***. This property is considered in designing internal combustion engines, boilers and turbines.

12. *Fatigue.* When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as ****fatigue***. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

13. *Hardness.* It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal. The hardness is usually

* For further details, refer Chapter 6 (Art. 6.3) on Variable Stresses in Machine Parts.

*Mechanical properties of Metals

(1) strength — قابلية المادة مقاومة القوى الخارجية بدون كسر أو استطالة

~ ~ ~ التغير تحت تأثير الاجهاد

(2) stiffness

خاصية للمادة لاستعادة الطول الأصلي بعد ازالة القوى المؤثرة

(3) Elasticity

~ لبقاء التغير الناتج عن الاحمال بشكل دائم ~ stamping forging images in coi

(4) plasticity

قابلية المادة للسحب إلى أسلاك تحت تأثير قوى شد

(5) Ductility

خاصية للمادة عكس ال ductility وهي كسر المادة بأقل تغير في الشكل

(6) Brittleness

حالة خاصة من ال ductility وهي خاصية للمادة التي يمكن تحويلها إلى thin sheets

(7) Malleability

خاصية للمادة لمقاومة الكسر الناتج عن الحمل الصدمي (مثل الطرق بالمطرقة)

(8) Toughness

خاصية للمادة تعكس امكانية تشغيلها

(9) Machinability

خاصية للمادة تمتص الطاقة وتقاوم الصدمات والحمل الصدمي

(10) Resilience

عند تعرض جزء لاجهاد ثابت عند درجة حرارة عالية لفترة زمنية كبيرة يحدث لها تغير بطئ دائم

(11) creep

عند تعرض مادة لاجهاد متكرر ويحدث لها انهيار تحت اجهاد أقل من yield

(12) Fatigue :

خاصية مهمة ولها معان مختلفة وهي مقاومة التآكل والخدش والتغير والتشغيل

(13) Hardness — وتعني أيضا قابلية مادة لقطع مادة أخرى.

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* Simple stresses in machine parts

Load: N — هو القوى الخارجية التي تؤثر على جزء الماكينة

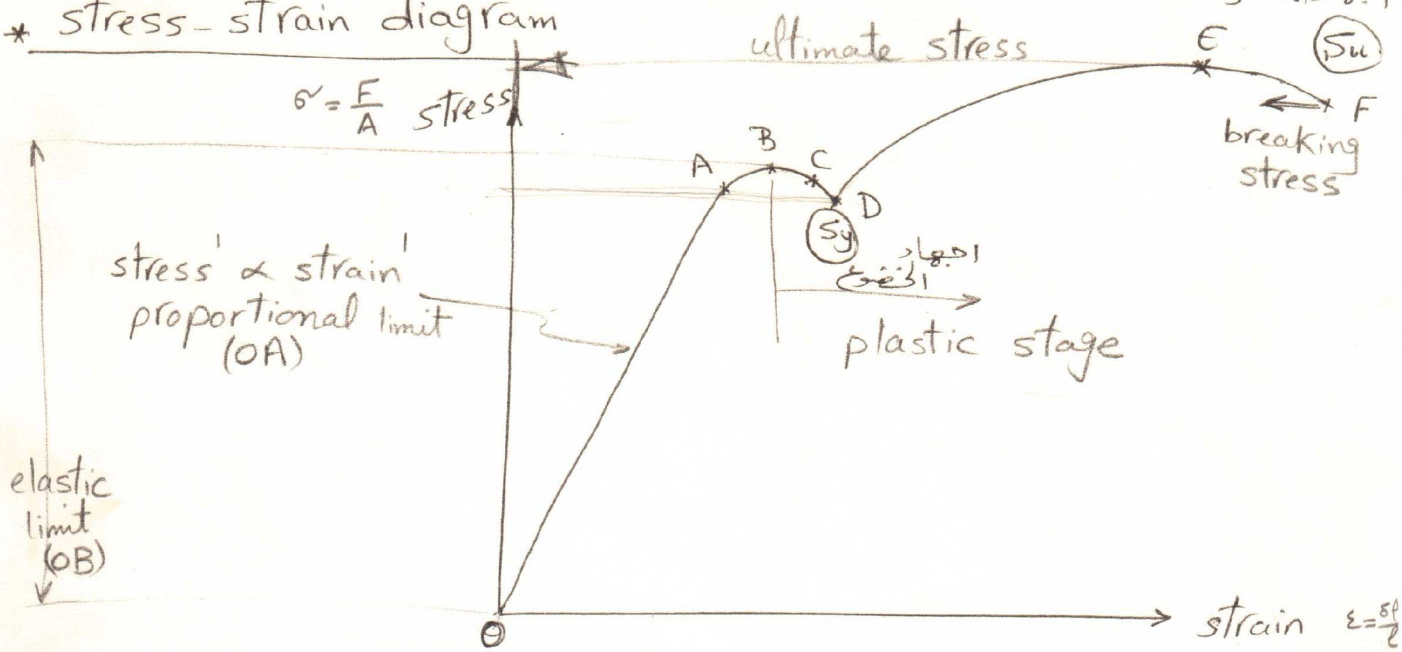
stress: $\left[\frac{N}{m^2} = (Pa)\right]$ — عندما تؤثر قوى خارجية على جسم تتولد قوى داخلية مساوية وعكس اتجاه القوى الخارجية وتتواجد في القطاعات المختلفة

stress is the internal force per unit area

stress Analysis
- simple بسيط
  - (σ) Normal
    - axial tension
    - axial Compression
    - Normal due to bending
  - Bearing (σ_{br})
  - shear (τ)
    - direct shear
    - shear due to torsion
- Combined مركب

strain [—] عندما تؤثر مجموعة من القوى على الجسم يحدث له تشوه بالنسبة للطول

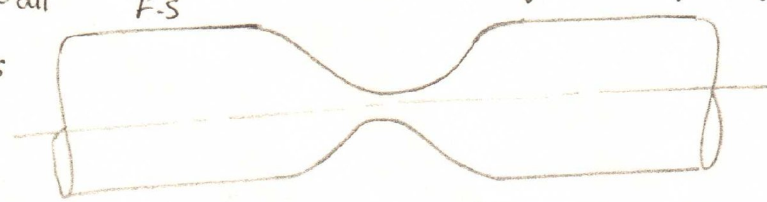
* stress_strain diagram



max. allowable stress $\sigma_{all} = \frac{S_y}{f.s}$ as f.s.: factor of safety عامل الامان (2~3)

~ ~ shear stress

$\tau_{all} = \frac{0.5\, S_y}{f.s.}$



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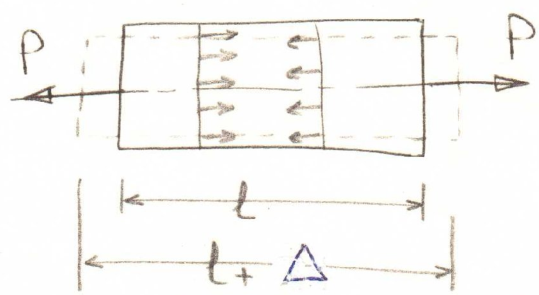
* Normal stresses الاجهادات العمودية (σ)

① Axial tension



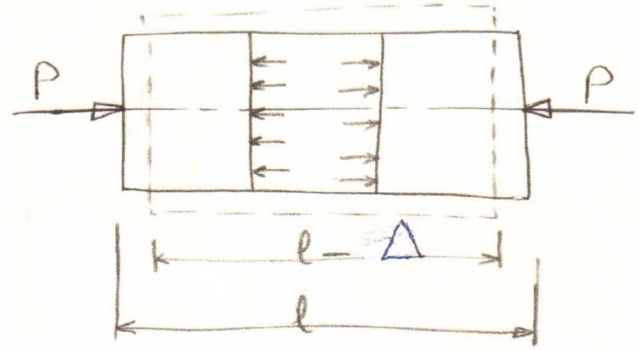
$\sigma = \frac{P}{A}$ Normal stress (N/m²) = Normal forces (N) / Area of failure (m²)

$\varepsilon = \frac{\Delta}{l}$ strain = change of length (m) / original length (m)

$\sigma = E\epsilon$ $\frac{F}{A} = E\frac{\Delta}{l}$ $\therefore \Delta = \frac{FL}{AE}$

E → modulus of Elasticity (young modulus) (Pa)

② Axial Compression



$\sigma_{tension}$ (+ve)

$\sigma_{Compression}$ (−ve)

* Area

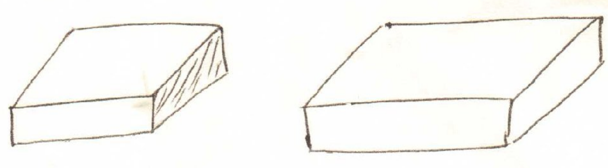
Cross-section area

① circular

$A = \frac{\pi}{4} d^2$

③ rectangular

A = length * width



② hollow circular

$A = \frac{\pi}{4}(d_o^2 - d_i^2)$

d_o → outer diameter

d_i → inner diameter