2. Equivalent Static Load Method

طريقة الحمل الإستاتيكي المكافئ

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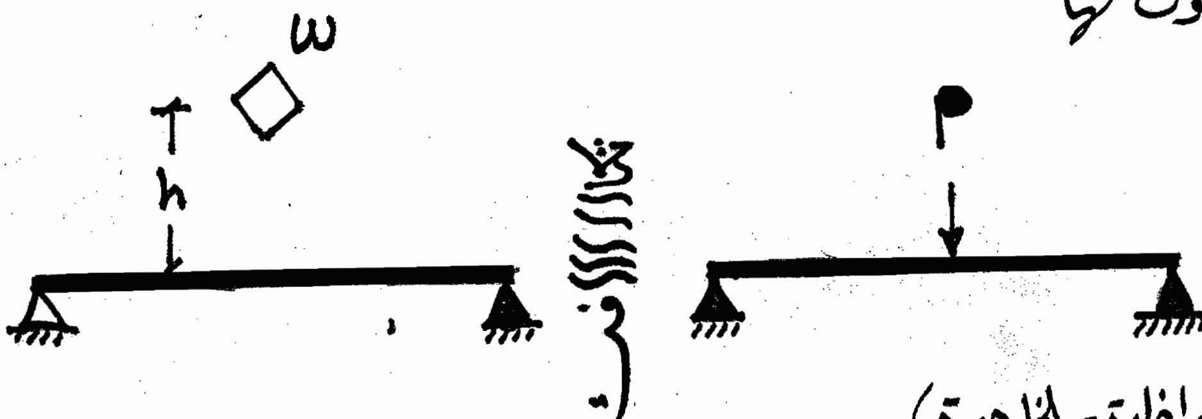
هي أحدى طرق التعامل مع أحمال الصدم :

لكل طريقة مجموعة فروض للوصول لها

فروض النظرية :



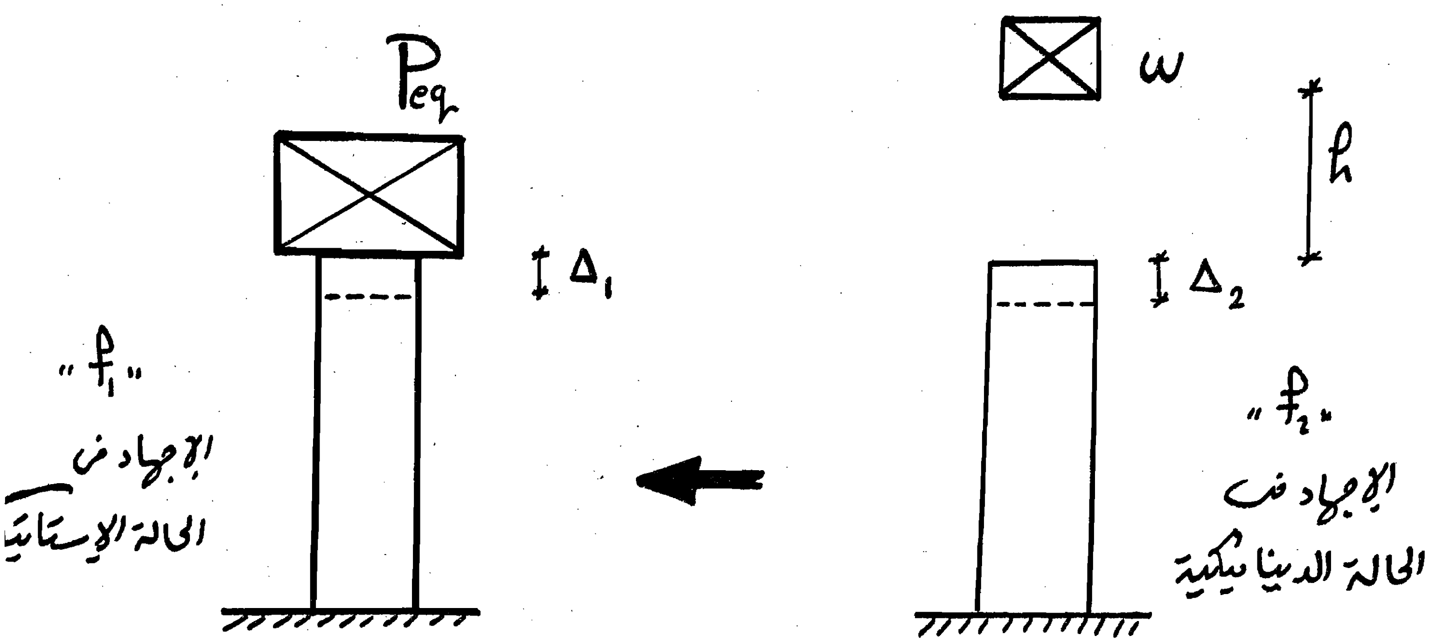
1. المادة في منطقة المرونة.
2. إهمال أي فواقد في الطاقة (الطاقة الداخلية = الخارجية).
3. إهمال وزن الكمرة المعرضة للصدم بالنسبة لحمل الصدم.

طريقة الحمل الإستاتيكي المكافئ

Equivalent Static Load (E.S.L)

* الحمل الإستاتيكي المكافئ :

هو الحمل الإستاتيكي الذي يسبب إجهاد و إنفعال يكافئ الإجهاد و الإنفعال الناتج من الصدم .



$$\Delta_1 = \Delta_2$$

$$f_1 = f_2$$

P_{eq} = الحمل الإستاتيكي المكافئ ∴

w = حمل الصدم

h = إرتفاع السقوط للحمل (w)

المعادلة العامة :

$$W(h+\Delta) = \frac{1}{2} P_{eq} \Delta$$

Look

كده وبس ؟!

للأجسام الساقطة تحت تأثير وزنها ←

- خطوات الحل :

(١) أوجد المجاهيل بدلالة "P_{eq}" .

(٢) عوض من المعادلة العامة .

(٣) أوجد P_{eq} ومنها Δ .

- هذه النظرية لها مجموعة فروض "Assumption" :

١. المادة فى منطقة المرونة " تحت الخط المستقيم فى العلاقة بين P & Δ ".

٢. إهمال أى فواقد خارجية فى الطاقة .

٣. إهمال وزن الكمرة المصدومة .

٤. تأثر المنشآت بالنسبة للأحمال الساقطة صغير جداً .

* In Axial Load :

$\because \quad f = \frac{P}{A} \longrightarrow P = f \cdot A$

$\because \quad \Delta = \frac{PL}{EA} \longrightarrow \Delta = \frac{f \cdot L}{E}$

- بالتعويض في المعادلة العامة : $\boxed{\left(w(h+\Delta) = \frac{1}{2} P \Delta \right)}$

$$\therefore \quad w \left[h + \frac{f_d \cdot L}{E} \right] = \frac{1}{2} \left[f_d \cdot A \right] \left[\frac{f_d \cdot L}{E} \right]$$

$$\therefore \quad \frac{w}{A} \left[h + \frac{f_d \cdot L}{E} \right] = \frac{1}{2} \frac{L}{E} f_d^2$$

as : $f_s = \frac{w}{A}$ بفرض الحمل "w" حمل إستاتيكي

وبحل المعادلة التربيعية :

Look

$$\therefore \quad f_d = f_s * \left[1 + \sqrt{1 + \frac{2h}{\Delta_s}} \right]$$

$\equiv \quad f_d =$ Stress of Impact الإجهاد الناشئ من الصدم

$f_s = \frac{w}{A}$ الإجهاد بفرض الحمل "w" حمل إستاتيكي

$\Delta_s =$ الإنضغاط بفرض الحمل w حمل إستاتيكي

$= \frac{w * L}{E A}$

$$\therefore \quad \Delta_d = \Delta_s \cdot \left[1 + \sqrt{1 + \frac{2h}{\Delta_s}} \right]$$

$\therefore$ Δ_d : الإنضغاط الناتج من الصدم

Δ_s : الإنضغاط لو كان الحمل إستاتيكي

$$\Delta_s = \frac{\omega L}{E \cdot A}$$

ـ لاحظ $\left(\left(1 + \sqrt{1 + \frac{2h}{\Delta_s}} \right) \right)$ يسمى الترم بمعامل الصدم "K_d"

$\therefore K_d = f_d / f_s =$

ـ حالات خاصة :

If : $h <<<<$ (إرتفاع السقوط صغير جدا)

الإجهاد الإستاتيكي $\Rightarrow$ $F = 2 F_s$ إجهاد الصدم

الإنضغاط الإستاتيكي $\Rightarrow$ $\Delta = 2 \Delta_s$ إنضغاط الصدم

If: $h >>>> \Delta_s$

$F = F_s \cdot \left[\sqrt{\frac{2h}{\Delta_s}} \right]$ إجهاد الصدم

$$\Delta = \sqrt{2h \Delta_s}$$

Look

هنعمل إيه بالكلام ده ؟!!!

- طاقة الصدم أثناء الحركة :

- الطاقة السابقة نتيجة سقوط جسم على الجسم "تحت تأثير وزنه".

$\therefore$ Energy $U = W(h+\Delta)$

- في حالة سير جسم بسرعة معينة وحدوث إصطدام :

- طاقة الحركة أثناء الصدم :

$\therefore$ Energy $= U = \frac{1}{2} m v^2$

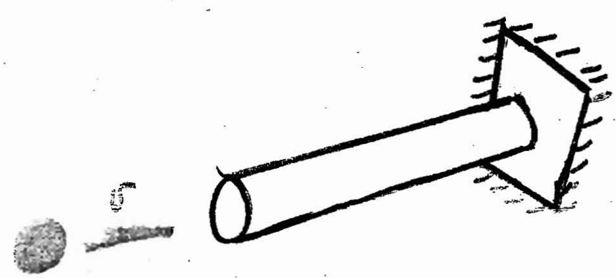
$\because$ m : mass الكتلة $= \frac{W}{g}$ $\frac{\text{الوزن}}{\text{عجلة الجاذبية}}$

v : السرعة

السرعة عند الصدم $v = \sqrt{2gh}$

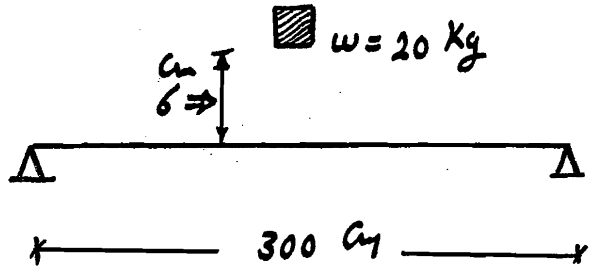
$\because$ g : عجلة الجاذبية الأرضية

h : المسافة بين الجسم والكتلة

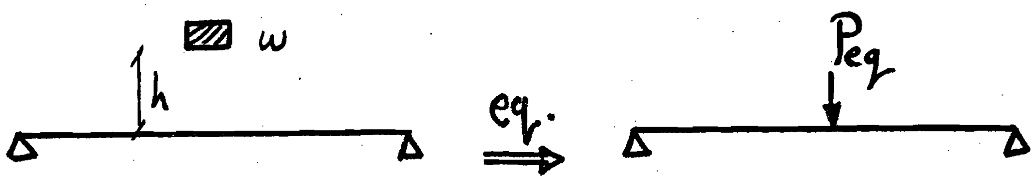


جسم يتحرك بسرعة "v"

Ex (1): Find the max Stress equiulante By APPLING (**E.S.L**) method. (Given $E = 2000^{t/cm^2}$)



Sol

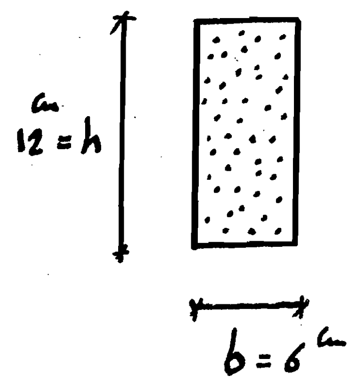


$$\therefore \quad \Delta = \frac{P_{eq} L^3}{48 EI}$$

$$= \frac{P_{eq} \cdot (300)^3}{48 \cdot 2000 \cdot 1000 \cdot 864}$$

للتحويل لـ Kg

$$\therefore \quad \Delta = \frac{P_{eq}}{3072} \longrightarrow (1)$$



$$I = \frac{b h^3}{12} = \frac{6 (12)^3}{12}$$

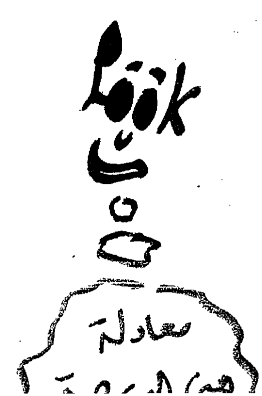
$$I = 864 \ cm^4$$

from General equ.:

$$w (h + \Delta) = \tfrac{1}{2} \cdot P_{eq} \cdot \Delta$$

$$\therefore \quad 20 \left(6 + \frac{P_{eq}}{3072} \right) = \frac{1}{2} \cdot P_{eq} \cdot \frac{P_{eq}}{3072}$$

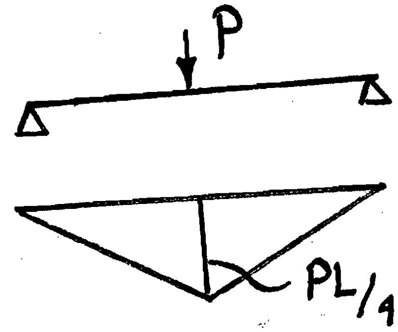
$$\therefore \quad P_{eq}^2 \qquad 5 P_{eq} \qquad - 120 = 0.0 \Rightarrow$$



$\therefore$ Solve this equ. :

$$\therefore P_{eq} = 878.9 \text{ kg}$$

$$\because \quad f_{(stress)} = \frac{M}{I} \cdot y$$



$$= \frac{P.L/4}{I} \cdot y$$

$$= \frac{(878.9 + 300)/4}{864} \cdot \left(\frac{12}{2}\right) = \underline{\underline{457.76 \text{ Kg/cm}^2}}$$

→ **Find Dynamic factor (K_d):** "معامل الصدم"

$$K_d = \frac{f_d}{f_s} = \frac{P_d}{P_s = W} = \frac{878.9}{20} = 43.95$$

لاحظ

معامل الصدم "K_d" لا يقل عن 2

$$K_d \not< 2$$

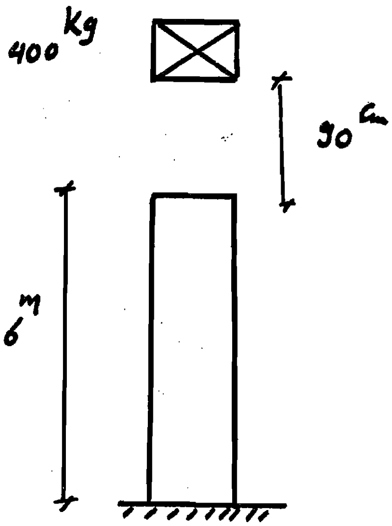
A weight W = 400 kg falls from a height h= 90 cm upon a vertical wooden pole 6 m long and 30 cm in diameter and fixed at the lower end. Determine the maximum compressive stress in the pole, assuming that $E_{wood} = 100\ t/cm^2$.

* Given :

$w = 400\ kg$, $h = 90\ cm$

$L = 6\ m$, $D = 30\ cm$, $E = 100\ t/cm^2$

Sol



Axial

$$A = \frac{\pi}{4}(D)^2$$

$$= \frac{\pi}{4}(30)^2 = 706.9\ cm^2$$

للتحويل لل Cm

$$\therefore \Delta = \frac{P \cdot L}{E \cdot A} = \frac{6 * 100 * P_{eq}}{100 * 706.9}$$

$$= 8.488 * 10^{-3}\ P_{eq}$$

$$\therefore w(h + \Delta) = \frac{1}{2} P_{eq}\ \Delta$$

$$\frac{400}{1000} * (90 + 8.488 * 10^{-3} P_{eq}) = \frac{1}{2} P_{eq} \cdot (8.488 * 10^{-3} P_{eq})$$

$$\therefore P_{eq}^2 - 0.8 P_{eq} - 8482.56 = 0.0$$

$$\therefore P_{eq} = 92.5\ \text{ton}$$

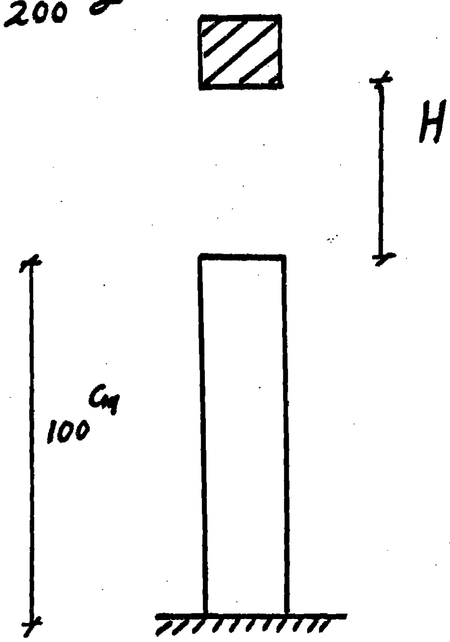
$$\therefore f_{max} = \frac{P_{eq}}{A} = \frac{92.5}{706.9} = 0.13\ t/cm^2$$

A weight W = 200 kg is dropped from a height H on the Steel bar with a circular cross section (Diameter = 5 cm) and length =100cm with a modulus of Elasticity = 2000 t/cm2. Find the m maximum height (h) so that the total deformation in the bar doesn't exceed 0.10 cm.

* Given :

$D = 5$ cm $\qquad w = 200$ kg

$E = 2000\ t/cm^2 \qquad 6\ \Delta = 0.1$ cm



Sol

$$\Delta = \frac{P_{eq} * L}{E * A}$$

$$\therefore\ 0.1 = \frac{P_{eq} * 100}{2000 * 19.65}$$

Area = $A = 19.65\ cm^2$

$$\therefore\ P_{eq} = 39.3\ \text{ton}$$

$$\therefore\ w(h + \Delta) = \frac{1}{2} P_{eq}\, \Delta$$

$$\therefore\ 200/1000\ [H + 0.1] = \frac{1}{2} * [39.3] * 0.1$$

$$\therefore\ H = 9.72\ \text{cm}$$

تم سقوط الحمل 200 Kg من على إرتفاع 9.72 سم

ليحقق إنضغاط 0.1 سم.

Design a simple beam with a rectangular cross section to sustain the impact of a failing weight from a height of 50 cm on the mid-span of the beam. Use the following information:

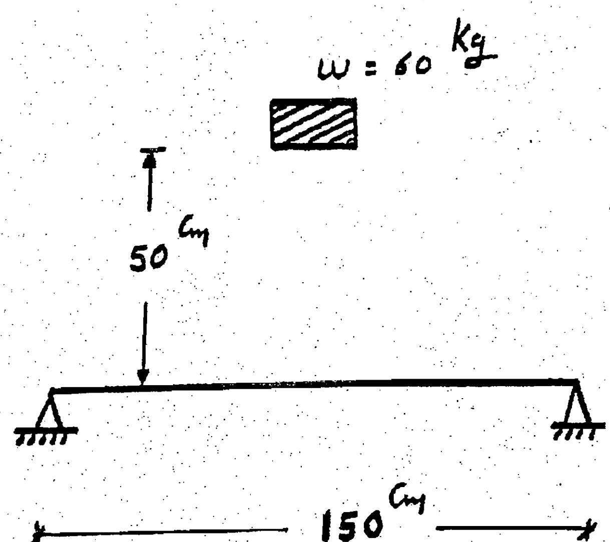
- The beam height = 30 cm
- The span of the beam = 150 cm.
- The dropped weight = 600kg.
- The flexural strength of the beam material = 2000 kg/cm2
- Design factor of safety = 2.
- Material modulus of elasticity = 2200 t/cm2

Given : $H = 50$ cm

$w = 60$ kg , $F.O.S = 2$

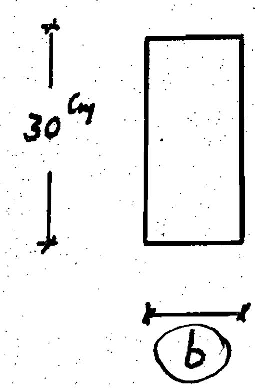
$E = 2200\ t/cm^2$

$f_u = 2000\ kg/cm^2$



Sol

$$f_{all} = \frac{f_u}{F.O.S} = \frac{2000}{2} = 1000\ kg/cm^2$$



$$\therefore\ 1000 = \frac{M}{I} \cdot y$$

$$= \frac{P \cdot L}{4 \cdot I} \cdot \left(\frac{30}{2}\right)$$

$$= \frac{P}{I} \cdot \frac{150}{4} \cdot \left(\frac{30}{2}\right)$$

$$\therefore\ \frac{P}{I} = 1.78 \longrightarrow (1)$$

$$\therefore \quad \Delta = \frac{P \cdot L^3}{48\, E\, I}$$

$$= \frac{P}{48\, I} \cdot \frac{(150)^3}{2200 \cdot 1000} = 1.78 \cdot \frac{(150)^3}{2200 \cdot 1000 \cdot 48}$$

$$\therefore \quad \Delta = 0.057 \text{ cm}$$

From General equ. :-

$$w \cdot (h + \Delta) = \frac{1}{2} \cdot P \cdot \Delta$$

$$\therefore \quad 600 \cdot (50 + 0.057) = \frac{1}{2} \cdot P \cdot 0.057$$

$$P = 1053800 \text{ kg}$$

$$\therefore \quad \frac{P}{I} = 1.78 \implies I = \frac{1053.8}{1.78} = 594 \text{ cm}^4$$

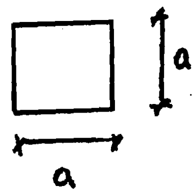
$$\therefore \quad I = \frac{b\, h^3}{12} \implies 594 = \frac{b \cdot (30)^3}{12}$$

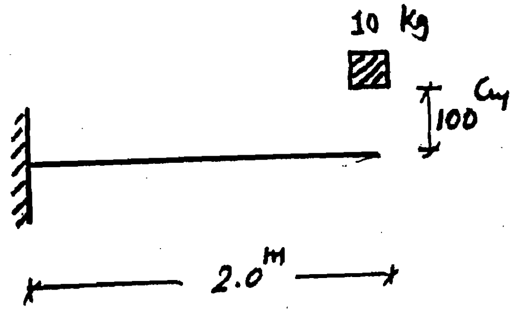
$$\therefore \quad b = 26.3 \text{ cm}$$

Final 2007

c- Calculate the minimum dimensions of a **square** cross section of **2.0 meter** long cantilever made of steel grade **40/60** knowing that the steel modulus of elasticity (E) is **2000 t/cm²**, and an impact load **W =10 kg** that dropped from a height **100 cm** on the free end of the cantilever to cause the yield stress. **Calculate also, the equivalent static load and the corresponding deflection.** (F.o.S = 2)

* Given :





Grade (40/60)

$E = 2000 \ t/cm^2$

$W = 10 \ kg$

Sol

$$\therefore \quad w(h+\Delta) = \frac{1}{2} P_{eq} \Delta$$

$$\therefore \quad \Delta = \frac{P_{eq} \cdot L^3}{3EI} = \frac{P_{eq}}{I} * \frac{(200)^3}{3*2000} = 1333.33 * \frac{P_{eq}}{I} \rightarrow ①$$

$$\therefore \quad f_y = 40 \ kg/mm^2 \longrightarrow \underset{\rightarrow cm}{f_{all}} = f_y / F.o.S = 40/2 = 20$$

$$\therefore \Rightarrow F_y = \frac{20 * (10)^2}{1000} = 2 \ t/cm^2$$

$$\therefore \quad F_y = \frac{\overset{(P.L)}{M}}{I} * Y = \frac{P_{eq} * 200}{I} * \left(\frac{a}{2}\right)$$

$$\therefore \quad 2 = \frac{200 \ P_{eq}}{I} * \left(\frac{a}{2}\right) \Rightarrow \frac{P_{eq}}{I} = (0.02/a)$$

$$\therefore \; P_{eq} = \frac{0.02}{\cancel{\alpha}} * \frac{\cancel{\alpha} * a^3}{12} = \frac{a^3}{600} \rightarrow ②$$

from ①

$$\therefore \; \Delta = 1333.33 * \frac{0.02}{a} = \frac{26.6}{a} \rightarrow ③$$

$$\therefore \; w(h + \Delta) = \frac{1}{2} * P_{eq} * \Delta$$

$$\therefore \; \frac{10}{1000} \left(100 + \frac{26.6}{a}\right) = \frac{1}{2} * \frac{a^3}{600} * \frac{26.6}{a}$$

للتحويل لل "ton"

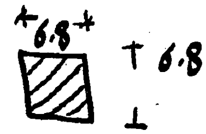
$1 + \frac{0.266}{a} = a^2 \; 0.02217$

← بحل المعادلة بالآلة :

$$\therefore \; a = 6.85 \; cm$$

$a + 0.266 = a^3 \; 0.02217$

$\therefore$ Cross section $(6.8 * 6.8 \; cm)$



$$\therefore \; P_{eq} = \frac{(6.8)^3}{600} = 0.524 \text{ ton}$$

$$\therefore \; \Delta = \frac{26.6}{6.8} = 3.9 \; cm$$

$D = \frac{PL}{AE}$ $D = \frac{PL^3}{48EI}$ $F = \frac{M}{I} y$

$w(h + D) = U$

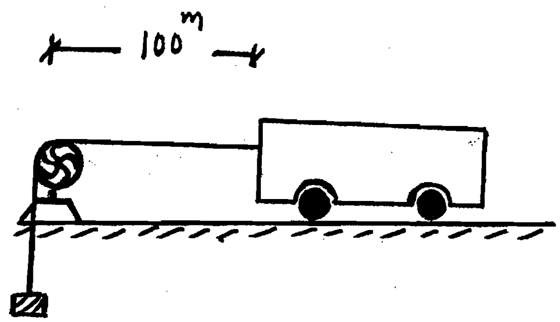
$U = \frac{1}{2} P D = w(h + D)$

~ Sheet 2 ~

a. A truck of weight ~~10~~ 6 tons is traveling at a constant speed of ~~12~~ 8 km/hr with engine stopped and the rear of the truck is connected to one end of a wire of diameter 3 cm and the other end is connected to a pulley. Suddenly, the wire gets jammed at the pulley and the truck stopped. Calculate the stress in the wire and its elongation due to wire jamming. Given that the elastic modulus of the wire material is 1500 t/cm2, wire length = ~~100~~ 120 m, g=980 cm / sec2.

Given :

$W = 10 \text{ ton}$

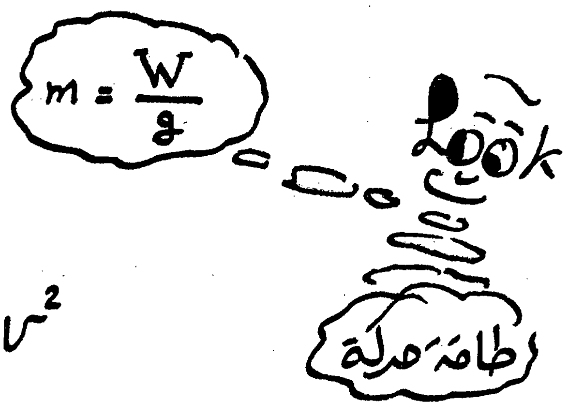


$V = 12 \text{ Km/hr}$

$\therefore V = \dfrac{12 \times 10^5}{60 \times 60} = 333.33 \text{ cm/sec}$

$D = 3 \text{ cm}$, $E = 1500 \text{ t/cm}^2$

$L = 100 \text{ m}$, $g = 980 \text{ cm/sec}^2$



Sol

$\because U = \frac{1}{2} m V^2$

$= \frac{1}{2} \cdot \dfrac{10 \times 1000^{\text{"kg"}}}{980} \cdot (333.33)^2$

$= 566893.4 \text{ Kg.cm}$

$\because U = \frac{1}{2} P.\Delta = \frac{1}{2} P^2 . \dfrac{L}{E.A} = \frac{1}{2} f^2 . \dfrac{LA}{E}$

$\therefore 566893.4 = \frac{1}{2} \times f^2 \times \dfrac{(100 \times 100)^{\text{cm}} \times \frac{\pi}{4}(3)^2}{1500 \times 1000_{\text{kg}}}$

$\therefore f = 4905 \text{ Kg/cm}^2 \longrightarrow$ find $\Delta = \checkmark$

If the allowable stress for the wire material is 1200 kg/cm2, what do you suggest to handle this problem of operation?

∵ $f_{all} = 1200$ kg/cm²

- الإجهاد المسموح به في الحبل أقل من الفعلي $f = 4905$ kg/cm²

Look

كل جامع سنة ٢٠١٢

المعادلة العامة

- لتلاشي انهيار الحبل :

① تقليل السرعة "V" .

② زيادة مقطع الـ "Wire" .

③ تقليل وزن الـ "Truck" .

لاحظ

- المعادلة العامة :

$$U = \frac{1}{2} P \cdot \Delta = \frac{1}{2} f^2 \cdot \frac{LA}{E} = \frac{1}{2} m v^2$$

- الحلول السابقة من المعادلة :

① $f^2 \propto v^2$ "تناسب طردي"

② $f^2 \propto 1/A$

③ $f^2 \propto W$

b. A huge chandelier (نجفة كبيرة) of 1600 kg weight is hanged to the ceiling using an old wire of current length (while hanging the chandelier) of 300 cm. There is doubt (شك) about the safety of the wire carrying the chandelier; however, it is extremely difficult to change the wire due to the relatively heavy weight of the chandelier. Thus it is decided to secure the system through putting two wires parallel to the existing one. Due to the difficulty in securing the new two wires with the same length as the old one, it is found that these wires should be of 304 cm in length. Calculate the required diameter of the new wires and the expected elongation at the time of failure of the old wire if the allowable stress of the wire material is 1200 kg/cm2 and its elastic modulus is 2000 t/cm2.

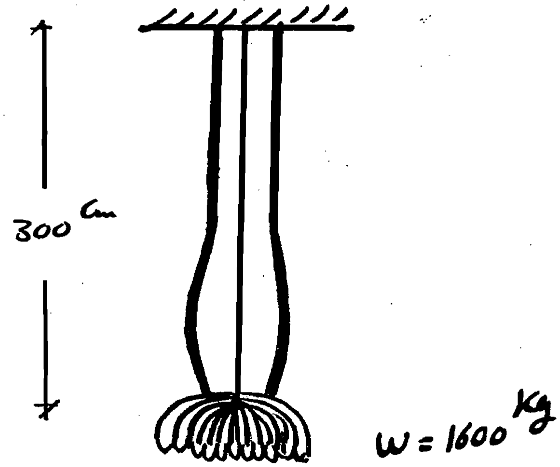
800

: Given

$f_{all} = 1200 \ kg/cm^2$

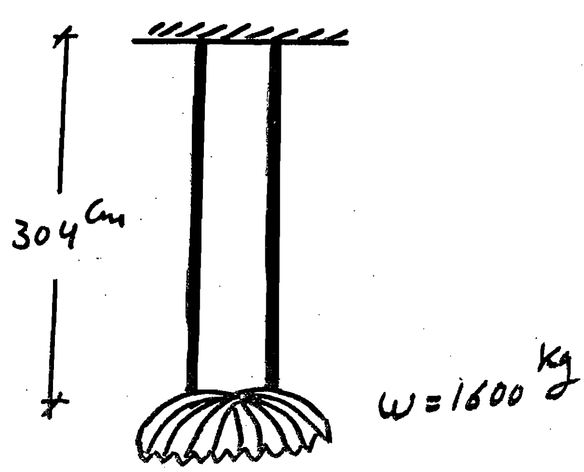
$W = 1600 \ kg$ s.

$E = 2000 \ t/cm^2$.



- Find :

Diameter for new wire.



Look

النجفة بعد نهاية
التحميل ل 2 wire

Sol

$\because \quad f_{all} = \dfrac{P}{A} \Rightarrow 1200\,A = P$

Look

$\therefore P = 1200\,A \rightarrow (1)$

طول السلك الجسيد

$\because \quad \Delta = \dfrac{PL}{EA} \Rightarrow = \dfrac{P * (304)}{2000 * 1000 * A}$

لم للتحويل "Kg"

from (1) $\boxed{P = 1200\,A}$

$\therefore \quad \Delta = \dfrac{1200 * 304\ \cancel{A}}{2000 * 1000 * \cancel{A}} = \underline{0.1824\ cm}$

← المعادلة العامة :

$\because \quad W(h + \Delta) = \frac{1}{2} P \Delta$

$1600\ (4 + 0.1824) = \frac{1}{2} \cdot P \cdot (0.1824)$

$\therefore \quad P = 73375.4\ Kg$

Look

from (1) $\Rightarrow \boxed{A = 61.14\ cm^2}$

المساحة لـ "2 wire" 2

$\therefore \quad A_{wire} = \dfrac{A}{2} = 30.57\ cm^2$

$\therefore \quad A_{wire} = \dfrac{\pi}{4}(D)^2 \Rightarrow \boxed{D = 6.23\ cm \simeq 6.25\ cm}$

Determine the number of persons can be carried by an elevator which is lifted by one steel cable of 16 mm. diameter and 30 m long. Knowing that the cable is made of steel of grade (28/40) and it has an elastic modulus E= 2000 t/cm2 .Consider the elevator's dead load is 720 kg, the average person weight = 85 kg and the design factor of safety = 2.5.

★ Given :

$D = 16$ mm

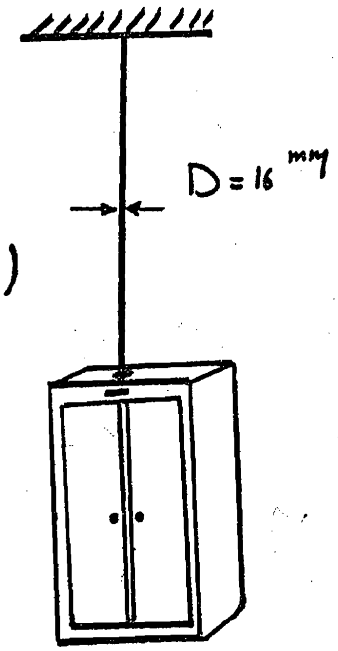
$L = 30$ m

$E = 2000 \; t/cm^2$; Grade (28/40)

Dead Load = 720 Kg

Person wt. = 85 Kg

F.O.S = 2.5



Sol

$$F_y = 28 \; Kg/mm^2 \rightarrow F_{all} = \frac{F_y}{F.O.S} = \frac{28}{2.5} = 11.2$$

$$\therefore F_{all} = \frac{P_{eq}}{A} \rightarrow P_{eq} = F_{all} * Area$$

$$\therefore P_{eq} = 11.2 * \frac{\pi}{4}(16)^2 = 2251.9 \; Kg$$

التحويل لـ Cm

(ج) $$\Delta = \frac{P_{eq} * L}{E * A} = \frac{2251.9 * 30 * 100}{2000 * 1000 * \frac{\pi}{4}\left(\frac{16}{10}\right)^2}$$

التحويل لـ Kg

$$\therefore \Delta = 1.68 \; cm$$

→ <u>from general equ. :</u>

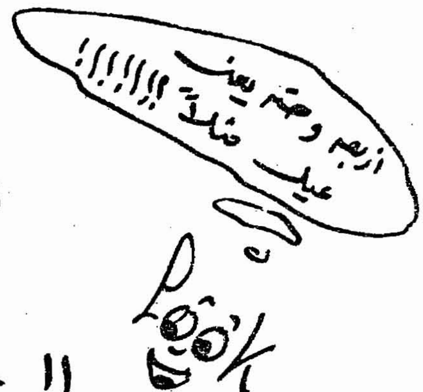
$$w\,(h+\Delta) = \frac{1}{2}\,P\,\Delta$$

$$\therefore\; w * (0.0 + 1.68) = \frac{1}{2} * 2251.9 * 1.68$$

$$\therefore\; w = 1125.95 \text{ kg}$$

ـ لحساب عدد الأشخاص "n" :

$$\therefore\; w = 720 + n * 85$$



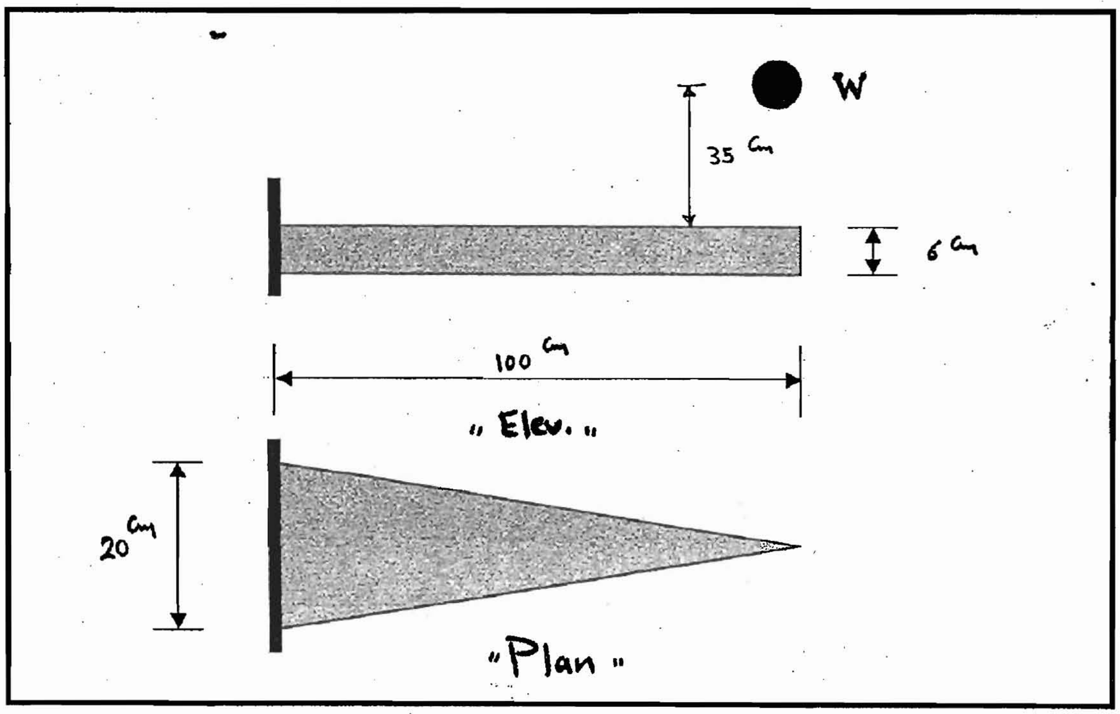
$$\therefore\; 1125.95 = 720 + n * 85$$

$$\therefore\; n = \underline{4.78} \text{ Person !!}$$

$$\therefore\; n = 4 \text{ Person}$$

" *H. W.* "

a. Calculate the maximum weight W that can be dropped from a height of 35 cm on a cantilever beam in the configuration shown next to cause a allowable stress 1200 kg/cm² knowing that the modulus of elasticity for the material is 2000 t/cm² and a cross section of beam is available.

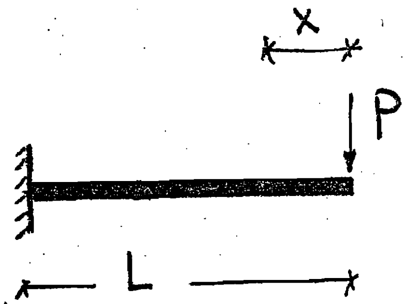


(1)

d) A three- point bending test is performed on a metallic beam that is made of steel and has a span of 150 cm and a rectangular cross section of width of 6.0 cm and depth of 9.0 cm. The load is applied at mid span of the beam. The mid span deflection is 0.20 cm of 2.0 ton concentrated load. This beam is subjected to impact bending due to dropped weight (w) of 10.0 kg from a height of 80.0 cm in the middle of span. Determine the maximum stress due to the impact load and also the absorbed energy of beam providing that the stress due to the two cases is less than the proportional limit stress of material beam.

(2)

(1) Prove that : $\Delta = \dfrac{PL^3}{3EI}$ for shown beam



Sol

$$M_x = P \cdot x \quad \rightarrow \quad (0 \rightarrow L)$$

$$\because \quad U = \int_0^L \frac{(M_x)^2}{2EI} \cdot dx$$

$$= \int_0^L \frac{P^2 x^2}{2EI} \cdot dx = \frac{P^2}{2EI}\left[\frac{x^3}{3}\right]_0^L$$

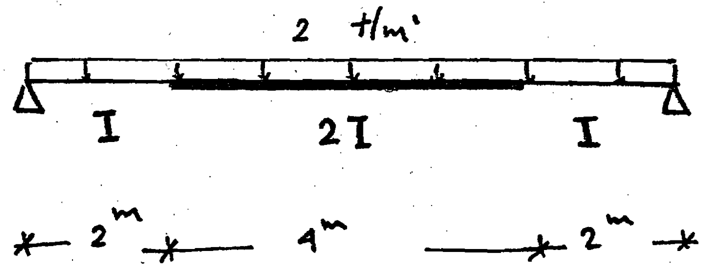
$$\therefore \quad U = \frac{P^2 \cdot L^3}{6EI}$$

Look

$$\boxed{\because \; U = \tfrac{1}{2} P \Delta} \Rightarrow \cancel{\tfrac{1}{2}}\cancel{P}\Delta = \frac{P^{\cancel{2}} L^3}{{}_3\cancel{6}\, EI}$$

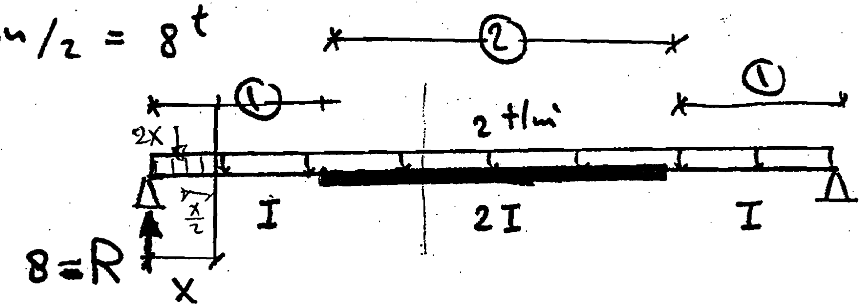
$$\boxed{\therefore \; \Delta = \frac{PL^3}{3EI}}$$

(2) Calculate Elastic Energy in this beam



Sol

$R = 2 \times 8 = 16 \text{ ton}/2 = 8^t$



* Part 1

$\therefore M_x = 8 \times x - 2 \times x^2/2 = 8x - x^2$

$(0 \rightarrow 2)$

* Part 2

$\therefore M_x = 8x - \cancel{2} \times \frac{x^2}{\cancel{2}} = 8x - x^2$

$(2 \rightarrow 6)$

$\therefore U = 2U_1 + U_2$

$$\therefore U_1 = \int_0^2 \frac{(8x - x^2)^2}{2EI} \cdot dx$$

$$\therefore \quad U_1 = \int_0^2 \frac{64x^2 + x^4 - 16x^3}{2EI} \cdot dx$$

Look

عوض ب $x=2$

$$= \frac{1}{2EI}\left[64 \cdot \frac{x^3}{3} + \frac{x^5}{5} - 16 \cdot \frac{x^4}{4}\right]_0^2$$

$$\therefore \quad U_1 = 56.533 / EI \longrightarrow (1)$$

Look

عوضنا x مرة (6) واخرى مرة (2)

$$\therefore \quad U_2 = \int_2^6 \frac{(M_x)^2}{2EI} \cdot dx$$

$$= \frac{1}{2E(2I)}\left[64 \frac{x^3}{3} + \frac{x^5}{5} - 16 \cdot \frac{x^4}{4}\right]_2^6$$

$$\therefore \quad U_2 = 216.533 / EI \longrightarrow (2)$$

from (1),(2)

$$\therefore \quad U = 2U_1 + U_2$$

$$= 2 \cdot \frac{56.533}{EI} + \frac{216.533}{EI}$$

$$\therefore \quad U = 329.6 \quad t.m$$