MADE EASY PUBLICATIONS

# POSTAL BOOK PACKAGE 2026

# MECHANICAL ENGINEERING

## CONVENTIONAL Practice Sets

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## MACHINE DESIGN

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CHAPTER

# Design Against Fluctuating Load

## Practice Questions : Level-I

**Q.1** During a high cycle fatigue test, a metallic specimen is subjected to cyclic loading with a mean stress of +140 MPa, and a minimum stress of –70 MPa. Determine the R-ratio (minimum stress to maximum stress) for this cyclic loading.

**Solution:**

$$\sigma_{min} = -70 \text{ MPa}$$
$$\sigma_{mean} = 140 \text{ MPa}$$
$$\frac{\sigma_{min}}{\sigma_{max}} = ?$$

We know that,
$$\sigma_{mean} = \frac{\sigma_{max} + \sigma_{min}}{2}$$
$$140 = \frac{\sigma_{max} - 70}{2}$$
$$280 + 70 = \sigma_{max}$$
$$\sigma_{max} = 350 \text{ MPa (Tensile)}$$
$$\frac{\sigma_{min}}{\sigma_{max}} = -\frac{70}{350} = -0.2$$

**Q.2** Fatigue life of a material for a fully reversed loading condition is estimated from $\sigma_a = 1100\,N^{-0.15}$ where $\sigma_a$ is the stress amplitude in MPa and $N$ is the failure life in cycles. Determine the maximum allowable stress amplitude for a life of $1 \times 10^5$ cycles under the same loading condition.

**Solution:**

$$\text{Stress amplitude } (\sigma_a) = \frac{\sigma_{max} - \sigma_{min}}{2} = 1100\ N^{-0.15}$$
$$\frac{\sigma_{max} - (-\sigma_{max})}{2} = 1100\,N^{-0.15} \qquad [\because \text{ for reversal loading } \sigma_{max} = -\sigma_{min}]$$
$$\frac{2\sigma_{max}}{2} = 1100\,N^{-0.15}$$
$$\sigma_{max} = 1100\ N^{-0.15} = 1100 \times (10^5)^{-0.15}$$
$$= 1100 \times (10)^{-0.75}$$
$$= \frac{1100}{5.62}$$
$$\boldsymbol{\sigma_{max} = 195.61\ \text{MPa}}$$

**Q.3** A small element at the critical section of a component in biaxial state of stress with the two principal stresses being 360 MPa and 140 MPa. Determine the maximum working stress according to distortion energy theory.

**Solution:**

Given: $\sigma_1 = 360$ MPa, $\sigma_2 = 140$ MPa

According to distortion energy theory,

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2} = 314 \text{ MPa}$$

**Q.4** A machine component made of a ductile material is subjected to a variable loading with $\sigma_{min} = -50$ MPa and $\sigma_{max} = 50$ MPa. If the corrected endurance limit and the yield strength for the material are $\sigma_e' = 100$ MPa and $\sigma_y = 300$ MPa, respectively, determine the factor of safety.

**Solution:**

Variable loading is a completely reversed fatigue or variable loading because

$$\sigma_{max} = -\sigma_{min}$$

Hence, $\sigma_{mean} = \sigma_m = 0$; $\sigma_{variable} = \sigma_v = \sigma_{max}$

For completely reversed fatigue loading Soderberg, Goodman, Gerber and strength criterion will give same results.

As per strength criterion,

$$\sigma_{max} \le \sigma_{per} \quad \text{or} \quad \frac{\text{Failure stress}}{\text{F.O.S.}}$$

$$\sigma_{max} = \frac{\text{Endurance limit}}{N}$$

$$N = \frac{\text{Endurance limit}}{\text{Maximum stress}} = \frac{100}{50} = 2$$

**Q.5** A thin spherical pressure vessel of 200 mm diameter and 1 mm thickness is subjected to an internal pressure varying from 4 to 8 MPa. Assume that the yield, ultimate, and endurance strength of material are 600, 800 and 400 MPa respectively. Find the factor of safety as per Goodman's relation.

**Solution:**

Stress induced, $$\sigma_1 = \sigma_2 = \frac{pr}{2t}$$

$$\sigma_{1max} = \frac{8 \times 100}{2 \times 1} = 400 \text{ MPa}$$

$$\sigma_{1min} = \frac{4 \times 100}{2 \times 1} = 200 \text{ MPa}$$

$$\sigma_{2max} = 400 \text{ MPa}$$

$$\sigma_{2min} = 200 \text{ MPa}$$

$$\sigma_{1m} = \frac{\sigma_{1max} + \sigma_{1min}}{2} = 300 \text{ MPa}$$

$$\sigma_{1a} = \frac{\sigma_{1max} - \sigma_{1min}}{2} = 100 \text{ MPa}$$

$$\sigma_{2m} = 300 \text{ MPa}$$

$$\sigma_{2a} = 100 \text{ MPa}$$

Equivalent Stresses

$$\sigma_{me} = \sqrt{\sigma_{1m}^2 + \sigma_{2m}^2 - \sigma_{1m}\sigma_{2m}} = \sqrt{300^2 + 300^2 - 300 \times 300} = 300 \text{ MPa}$$

Similarly,

$$\sigma_{ae} = \sqrt{\sigma_{1a}^2 + \sigma_{2a}^2 - \sigma_{1a}\sigma_{2a}} = 100 \text{ MPa}$$

Goodman equation,

$$\frac{\sigma_{ae}}{S_e} + \frac{\sigma_{me}}{S_{ut}} = \frac{1}{N}$$

$$\Rightarrow \quad \frac{100}{400} + \frac{300}{800} = \frac{1}{N}$$

$$N = \mathbf{1.6}$$

**Q.6** A forged steel link with uniform diameter of 30 mm at the centre is subjected to an axial force that varies from 40 kN in compression to 160 kN in tension. The tensile ($S_u$), yield ($S_y$) and corrected endurance ($S_e$) strengths of the steel material are 600 MPa, 420 MPa and 240 MPa respectively. Determine the factor of safety against fatigue endurance as per Soderberg's criterion.

**Solution:**

Diameter, $d = 30$ mm

$F_{max} = +160$ kN (Tension)

$F_{min} = -40$ kN (Compression)

Tensile strength, $S_u = 600$ MPa

Yield strength, $S_y = 420$ MPa

Corrected endurance, $S_e = 240$ MPa

Maximum stress, $$\sigma_{max} = \frac{F_{max}}{A} = \frac{160 \times 10^3 \text{ N}}{\frac{\pi}{4}(30)^2 \text{ mm}^2} = 226.47 \text{ MPa (Tensile)}$$

Minimum stress, $$\sigma_{min} = \frac{F_{min}}{A} = \frac{-40 \times 10^3 \text{ N}}{\frac{\pi}{4}(30)^2 \text{ mm}^2} = -56.62 \text{ MPa (Compression)}$$

Stress amplitude, $$\sigma_a = \frac{1}{2}(\sigma_{max} - \sigma_{min}) = \frac{1}{2}[226.47 - (-56.62)] = 141.54 \text{ MPa}$$

Mean stress, $$\sigma_m = \frac{1}{2}(\sigma_{max} + \sigma_{min}) = \frac{1}{2}[226.47 + (-56.62)] = 84.925 \text{ MPa}$$

Assume factor of safety is $n$ then

$$S_a = N\sigma_a = 141.54\, N$$

$$S_m = N\sigma_m = 84.925\, N$$

The equation of Soderberg line is as follows

$$\frac{S_a}{S_e} + \frac{S_m}{S_{yt}} = 1$$

$$\Rightarrow \quad \frac{141.54\, N}{240} + \frac{84.925\, N}{420} = 1$$

$$\Rightarrow \quad n = \mathbf{1.26}$$

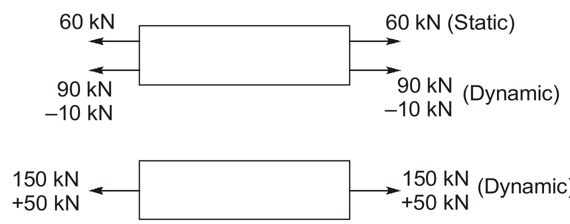
**Q.7** A bar is subjected to a combination of a steady load of 60 kN and a load fluctuating between –10 kN and 90 kN. The corrected endurance limit of the bar is 150 MPa. the yield strength of the material is 480 MPa and the ultimate strength of the material is 600 MPa. The bar cross-section is square with side *a*. If the factor of safety is 2, determine the value of *a* (in mm), according to the modified Goodman's criterion.

**Solution:**

Corrected endurance limit, $\sigma_e$ = 150 MPa; $S_y$ = 480 MPa $S_{ut}$ = 600 MPa; $N$ = 2

$$P_m = \frac{P_{max} + P_{min}}{2}$$

$$P_a = \frac{P_{max} - P_{min}}{2}$$




$$P_m = 100 \text{ kN}$$

$$P_a = 50 \text{ kN}$$

$$\sigma_m = \frac{100 \times 10^3}{a^2} \text{MPa}$$

$$\sigma_a = \frac{50 \times 10^3}{a^2} \text{MPa}$$

Solution by Goodman's equation,

$$\frac{\sigma_m}{S_{ut}} + \frac{\sigma_a}{\sigma_e} = \frac{1}{N}; \quad 1000\left[\frac{100}{a^2 \times 600} + \frac{50}{150a^2}\right] = \frac{1}{2}$$

$$a^2 = 1000$$

$$a = 31.62 \text{ mm}$$

Solution by yield (Langer's) line equation,

$$\frac{\sigma_m}{S_{yt}} + \frac{\sigma_a}{S_{yt}} = \frac{1}{N}; \qquad 1000\left[\frac{100}{480a^2} + \frac{50}{480a^2}\right] = \frac{1}{2}$$

$$a^2 = 625$$

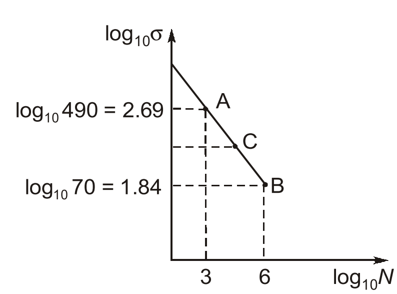
$$a = 25 \text{ mm}$$

Hence final answer by modified **Goodman's criterion is 31.62 mm**

**Q.8** A cylindrical shaft is subjected to completely reversed stress of amplitude 100 MPa. Fatigue strength to sustain 1000 cycles is 490 MPa. If the corrected endurance strength is 70 MPa, determine the estimated shaft life.

**Solution:**

Equation of straight line connecting (3, $\log_{10}$ 490) and (6, $\log_{10}$ 70)




$$\frac{y - 1.8451}{x - 6} = \frac{1.84 - 2.6902}{6 - 3}$$

$$y - 1.8451 = -0.2817\,(x - 6)$$

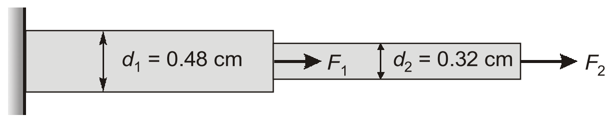
At $\quad y = \log_{10} 100 = 2$

$\Rightarrow \quad 2 - 1.8451 = -0.2817\,(x - 6)$

$$x = 5.4501$$

$\log_{10} N = 5.4501, \quad N =$ **281914 cycles**

**Q.9** For the stepped shaft shown in figure, which is acted by both fluctuating axial force $F_1$ between (–900 N) and 3600 N and a constant axial force $F_2$ of 2250 N. The ultimate and endurance limits are 735 MPa and 455 MPa. Also consider the factors which effect the endurance limit such as surface finish factor ($k_a = 0.90$), size factor ($k_b = 1$), reliability factor ($k_c = 0.868$), theoretical stress concentration factor and notch sensitivity are 1.18 and 0.8 respectively. As the load is axial so, axial load factor is 0.8. Determine the factor of safety using Goodman theory.




**Solution:**

$$S_{ut} = 735 \text{ MPa}, S_e = 455 \text{ MPa}$$

Corrected endurance limit,
$$k_t = 1.18, \; q = 0.8$$
$$k_f = 1 + q(k_t - 1) = 1 + 0.8(1.8 - 1) = 1.144$$
$$k_d = \frac{1}{k_f} = \frac{1}{1.144} = 0.874$$

Corrected endurance limit,
$$S_e' = 0.9 \times 1 \times 0.868 \times 0.874 \times 0.8 \times 455 = 248.527 \text{ MPa}$$

Maximum and minimum axial force,
$$F_{max} = F_1^{max} + F_2 = 3600 + 2250 = 5850 \text{ N}$$
$$F_{min} = F_1^{min} + F_2 = -900 + 2250 = 1350 \text{ N}$$

Mean axial force,
$$F_m = \frac{F_{max} + F_{min}}{2} = 3600 \text{ N}$$

Alternating axial force,
$$F_a = \frac{F_{max} - F_{min}}{2} = 2250 \text{ N}$$

where, $A$ = Area of the larger diameter (d) which experiences the fluctuating load.

$$\sigma_m = \frac{F_m}{A} = \frac{3600}{\frac{\pi}{4} \times d_1^2} = 198.9 \text{ MPa} \qquad (\text{where, } d_1 = 0.48 \text{ cm})$$

$$\sigma_a = \frac{F_a}{A} = \frac{2250}{\frac{\pi}{4} \times d_1^2} = 124.3 \text{ MPa}$$

According to Goodman theory,
$$\frac{1}{N} = \frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_{ut}}$$
$$\frac{1}{N} = \frac{124.3}{248.527} + \frac{198.9}{735}$$
$$N = 1.2974$$

**Q.10** A machine component is subjected to 2-dimensional stresses. The tensile stress in $x$ direction varies from 50 to 100 N/mm$^2$, tensile stress in $y$-direction varies from 10 to 80 N/mm$^2$ and shear stress ($\tau_{xy}$) varies from 10 to 50 N/mm$^2$. The frequency of variation of these stresses is equal. The corrected endurance limit of the component is 270 N/mm$^2$ and the yield tensile strength of material of component is 450 N/mm$^2$. Determine the factor of safety by using distortion energy theory.