Autodesk Inventor Engineer s Handbook

هندبوک مهندسی نرم افزار Autodesk Inventor

انجمن اینونتور ایران

www.irinventor.com

Email: irinventor@chmail.ir irinventor@hotmail.com

Tel: 09352191813 &

021-46088862

Engineer s Handbook

Beam and Column Calculator

Calculation formulas for beams

These formulas are used to solve either a shaft (with one or more sections) or a beam (with one constant section) with multiple supports and loads.

The shaft / beam axis is aligned with the Z axis. If the impact of the material density is included in the calculation, the gravity vector is aligned with the Y axis.

Shear forces:

$$T(z) = -\int q(z)dz + \sum_{0}^{n} F$$

Bending moments:

$$M_B(z) = \int T(z)dz + \sum_{0}^{n} M_B$$

Deflection angle:

$$\varphi(z) = -\int \frac{M_B(z)}{E * J(z)}\, dz + \varphi(0) + \frac{\beta}{G * S(z)}$$

where:

E modulus of elasticity in tension

J moment of inertia

G modulus of rigidity

β shear displacement ratio

Deflection:

$$y(z) = \int \varphi(z)\, dz + y(0)$$

Bending stress:

$$\sigma_B(z) = \frac{M_B(z)}{W_B(z)}$$

Shear stress:

$$\tau_S(z) = \frac{T(z)}{S(z)}$$

Torsion stress:

$$\tau(z) = \frac{M_{torq}(z)}{W_{torq}(z)}$$

Tension stress:

$$\sigma_T(z) = \frac{\sum_0^n F_z}{S(z)}$$

Reduced stress:

$$\sigma_{red} = \sqrt{(\sigma_B + \sigma_T)^2 + \alpha * (\tau^2 + {\tau_S}^2)}$$

where:

σ_B bending stress

σ_T tension stress

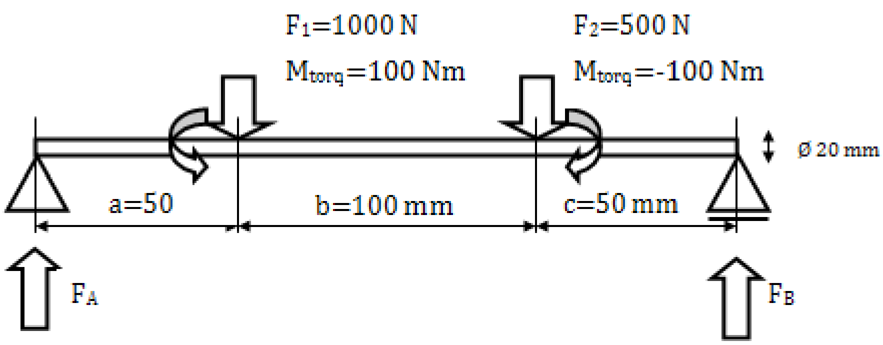
τ torsion stress

τ_S shear stress

αα = 3 for HMH

α = 4 for Tresca-Guest

Sample Calculation



Modulus of elasticity E = 210 000 MPa

Modulus of rigidity G = 81 000 MPa

Shear displacement ratio β = 1.118

Mode of reduced stress: HMH

Do not include the material density.

Support Forces:

$$F_A = \frac{F_1 * (b+c) + F_2 * b}{a+b+c} = \frac{1000 * 150 + 500 * 50}{200} = \underline{875\ N}$$

$$F_B = \frac{F_1 * a + F_2 * (a+c)}{a+b+c} = \frac{1000 * 50 + 500 * 150}{200} = \underline{625\ N}$$

Maximal shear stress:

$$\tau_{S\ max} = \frac{F_a}{\frac{\pi * d^2}{4}} = \frac{875}{\frac{\pi * 0.02^2}{4}} = \underline{2.78521\ MPa}$$

Maximal torsion stress:

$$\tau = \frac{M_{torq}}{W_{torq}} = \frac{M_{torq}}{\frac{\pi * d^3}{16}} = \underline{63.662\ MPa}$$

Maximal moment:

$$M_{B\,max} = F_A * a = 875 * 0{,}05 = \underline{43{,}75\ Nm}$$

Maximal bending stress:

$$\sigma_{B\,max} = \frac{M_{B\,max}}{W_B} = \frac{M_{B\,max}}{\frac{\pi * d^3}{32}} = \frac{43{,}75}{\frac{\pi * 0.02^3}{32}} = \underline{55.7042\ MPa}$$

Maximal reduced stress:

$$\sigma_{red} = \sqrt{(\sigma_B + \sigma_T)^2 + \ \alpha * (\tau^2 + {\tau_S}^2)}$$

$$\sigma_{red} = \sqrt{55.7^2 + 3 * (63.66^2 + 2.785^2)} = \underline{123.632\ MPa}$$

Angle of twist:

$$\alpha = \frac{180}{\pi} * \frac{M_{torq} * l}{G * J_{torq}} = \frac{180}{\pi} * \frac{M_{torq} * l}{G * \frac{\pi * d^4}{32}}$$

$$\alpha = \frac{180}{\pi} * \frac{100 * 0.1}{81 * 10^9 * \frac{\pi * 0.02^4}{32}} = \underline{0.45°}$$

Basic calculation of column buckling

For an axially loaded column, the calculation is in metric or imperial units, depending on the set standard. The ANSI standard uses the imperial units (with appropriate section dimensions).

Calculated parameters

Reduced length

$L_{red} = n\ L$

Slenderness ratio

$\lambda = L_{red} / j_{min}$

Radius of gyration

$$j_{min} = \sqrt{\frac{J_{min}}{S}}$$

Rankin critical stress

$$\sigma_R = \frac{Sy}{1 + \frac{Sy\,\lambda^2}{\pi^2 E}}$$

Rankin's critical force

$F_{crR} = \sigma_R\ S$

Rankin's maximal force

$F_{maxR} = F_{crR} / k_S$

Rankin's calculated safety factor

$k_{sR} = F_{crR} / F_a$

Johnson critical stress

$$\sigma_J = Sy\left(1 - \frac{Sy\,\lambda^2}{4\pi^2 E}\right)$$

Johnson's critical force

$F_{crJ} = \sigma_J S$

Johnson's maximal force

$F_{maxJ} = F_{crJ} / k_s$

Johnson's calculated safety factor

$k_{sJ} = F_{cr} J / F_a$

Euler's critical stress

$\sigma_E = \pi^2 E / \lambda^2$

Euler's critical force

$F_{crE} = \sigma_E S$

Euler's maximal force

$F_{maxE} = F_{crE} / k_s$

Euler's calculated safety factor

$k_{sE} = F_{crE} / F_a$

Pressure stress

$\sigma_p = F_a / S$

Critical force

$F_{crP} = S_y S$

Maximal force

$F_{maxP} = F_{crP} / k_s$

Calculated safety factor in pressure

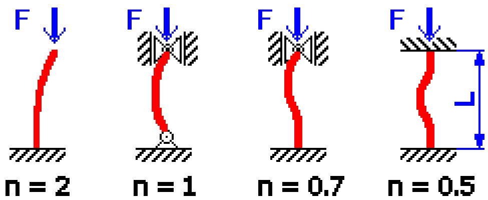
$k_{sP} = F_{crP} / F_a$

Strength check

$k_s \leq \min(k_{sR}, k_{sJ}, k_{sE}, k_{sP})$

Coefficient for end conditions

Factor for reduced (effective) length calculation,whose value depends on the conditions of end support of the column.



Meaning of used variables

F_a maximum load [lbforce, N]
n coefficient for end conditions
k_s required safety factor
E modulus of elasticity [psi, MPa]
L_{red} reduced length [in, mm]
S section area [in^2, mm^2]
j_{min} moment of inertia [in^4, mm^4]
λ Slenderness ratio
j_{min} least radius of gyration [in, mm]
σR Rankine's critical stress [psi, MPa]
F_{crR} Rankine's critical force [lbforce, N]
F_{maxR} Rankine's maximal force [lbforce, N]
k_{sR} Rankine's calculated safety factor
σ_j Johnson's critical stress [psi, MPa]
F_{crJ} Johnson's critical force [lbforce, N]
F_{maxJ} Johnson's maximal force [lbforce, N]
k_{sJ} Johnson's calculated safety factor
σ_E Euler's critical stress [psi, MPa]
J_{min} least moment of inertia
F_{crE} Euler's critical force [lbforce, N]
F_{maxE} Euler's maximal force [lbforce, N]
k_{sE} Euler's calculated safety factor
σ_P Pressure stress [psi, MPa]
F_{crP} Critical force [lbforce, N]
F_{maxP} Maximal force [lbforce, N]
J_{min} least moment of inertia
k_{sP} Calculated safety factor in pressure

Web: www.irinventor.ir
Email: irinventor@chmail.ir
& irinventor@hotmail.com

Tel: 09352191813 & 021-46088862

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