

Combined Loading Cheat Sheet

Axial + bending + torsion, Mohr's circle and failure theories

ENGINEERING
CHEAT SHEET

Key equations

Quantity	Equation	Notes
Axial stress	$\sigma_{\text{axial}} = P / A$	Tension positive, compression negative (confirm your convention)
Bending stress	$\sigma_{\text{bending}} = M c / I$	c = distance from the neutral axis
Combined normal stress	$\sigma = P / A \pm M c / I$	Check both the tension and compression faces
Eccentric load	$M = P \cdot e$	e = offset from the centroidal axis
Torsional shear	$\tau = T r / J$	J = polar moment of inertia
Principal stresses	$\sigma_{1,2} = \sigma_{\text{avg}} \pm R$	$\sigma_{\text{avg}} = (\sigma_x + \sigma_y)/2$; $\tau_{\text{max}} = R$
Mohr's circle radius	$R = \sqrt{[(\sigma_x - \sigma_y)/2]^2 + \tau_{xy}^2}$	Center at σ_{avg} , radius R
Max shear (Tresca)	$\tau_{\text{max}} = \sigma_y / 2$	Failure when max shear reaches half of yield. Conservative
von Mises (plane stress)	$\sigma' = \sqrt{(\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{xy}^2)}$	Yield when $\sigma' \geq \sigma_y$. Matches ductile metals well

Key takeaways

- **Superposition:** solve each load alone, then add the stresses at the point of interest.
- Normal stress is perpendicular to the cross-section (axial and bending). Shear stress acts parallel to it. Real parts see both.
- A yield criterion lets you compare a multi-axis stress state with the uniaxial yield strength.
- Mohr's circle gives principal stresses, maximum shear and their orientation from the stresses at a point.
- Typical combined-load parts: engine crankshafts (torsion + bending), bridge towers, off-road chassis.
- Worked example: 100 × 150 mm column, $P = 50$ kN, $e = 20$ mm gives **6.00 MPa** on the near face and **0.67 MPa** on the far face (both compression, since the load stays inside the kern).
- Repeated combined loading drives fatigue failure well below static strength.