

MODULE II • ALL 8 OUTLINE TOPICS

Strength of Materials Formula Cheat Sheet

Every formula has its symbols and SI units, and the situation it is for. Work in **newtons and millimetres**: stresses then come out in N/mm^2 . A formula only earns marks when you choose the right one, so read the last column first.

UNITS YOU WILL NEED

$$1 \text{ N/mm}^2 = 1 \text{ MN/m}^2 = 1 \text{ MPa}$$

$$1 \text{ GN/m}^2 = 1000 \text{ N/mm}^2$$

$$\text{steel: } E \approx 200\,000, G \approx 80\,000 \text{ N/mm}^2$$

$$1 \text{ kNm} = 10^6 \text{ Nmm}; 1 \text{ kN/m} = 1 \text{ N/mm}$$

$$1 \text{ m}^4 = 10^{12} \text{ mm}^4$$

$$1^\circ = \pi/180 \text{ rad}; \omega = 2\pi N/60$$

1 STRESS, STRAIN AND ELASTIC CONSTANTS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\sigma = \frac{P}{A}, \quad \varepsilon = \frac{\delta L}{L}$	P axial load (N); A area (mm^2); δL change in length; L original length (mm). ε has no unit	a load acts along a bar's axis
$E = \frac{\sigma}{\varepsilon} \Rightarrow \delta L = \frac{PL}{AE}$	E Young's modulus (N/mm^2)	finding extension or E ; elastic range only
$\tau = \frac{Q}{A}, \quad G = \frac{\tau}{\gamma}$	Q shear force (N); γ shear strain (rad); G modulus of rigidity (N/mm^2)	a force slides one face over another
$\nu = \frac{\delta d/d}{\delta L/L}, \quad \delta d = \nu \delta L$	ν Poisson's ratio, no unit, between 0 and 0.5; d width or diameter	change in diameter or width
$\frac{\delta V}{V} = \varepsilon(1 - 2\nu)$	$\delta V/V$ volumetric strain	change in volume of a loaded bar
$E = 2G(1 + \nu) = 3K(1 - 2\nu)$	K bulk modulus (N/mm^2)	finding one constant from two others
$k = \frac{AE}{L}, \quad \delta = \frac{T}{k}$	k stiffness of a wire (N/mm); T its tension	bars or wires sharing a load: statics plus equal (or related) extensions
$\text{FoS} = \frac{\sigma_u}{\sigma_w}$	σ_u ultimate stress; σ_w working stress	choosing a safe working stress

2 SHEAR FORCE AND BENDING MOMENT

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\frac{dV}{dx} = -w, \quad \frac{dM}{dx} = V$	V shear force (kN); M bending moment (kNm); w load per metre (kN/m)	sketching diagrams; $M_{\max}$ is where $V = 0$
$V = \Sigma F_{\text{one side}}, \quad M = \Sigma (F x)_{\text{one side}}$	take forces on one side of the section only	SF or BM at any point

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
UDL: wL at its centre	UVL (triangle): $\frac{1}{2}wL$ at $L/3$ from the large end	reactions and moments of distributed loads

Signs used: SF + when forces to the left add up to an upward result; BM + when *sagging*. Contraflexure: where M changes sign. **Standard maxima:** cantilever, end load W : $M = -WL$ at wall; cantilever UDL: $M = -wL^2/2$; simply supported, central W : $M = WL/4$; simply supported UDL: $M = wL^2/8$, reactions $wL/2$.

3 BENDING STRESS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$	M moment (N mm); I second moment of area (mm^4); y distance from neutral axis (mm); R radius of curvature (mm)	stress at any layer, or curvature
$\sigma_{\max} = \frac{M}{Z}, \quad Z = \frac{I}{y_{\max}}$	Z section modulus (mm^3)	greatest stress; safe load
Rect: $I = \frac{bd^3}{12}, \quad Z = \frac{bd^2}{6}$	b width; d depth (perpendicular to the axis)	rectangular sections
Circle: $I = \frac{\pi d^4}{64}, \quad Z = \frac{\pi d^3}{32}$	hollow: $I = \pi(D^4 - d^4)/64$	round bars and tubes
$\bar{y} = \frac{\Sigma Ay}{\Sigma A}, \quad I = \Sigma(I_G + Ah^2)$	h distance from each part's centroid to the neutral axis	T, I and built-up sections

The neutral axis passes through the centroid. In unsymmetric sections the face further from the neutral axis has the larger stress.

4 DEFLECTION OF BEAMS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$EI \frac{d^2y}{dx^2} = M$	y deflection (up +); EI flexural rigidity (N mm^2 or kN m^2)	integrate twice; constants from the supports
Macaulay: $[x - a]$	a bracket counts only when $x > a$; never expand it	several point loads on one beam

BEAM AND LOAD	MAX DEFLECTION	END SLOPE
Cantilever, point load W at free end	$\frac{WL^3}{3EI}$	$\frac{WL^2}{2EI}$
Cantilever, UDL w over the length	$\frac{wL^4}{8EI}$	$\frac{wL^3}{6EI}$
Simply supported, central load W	$\frac{WL^3}{48EI}$	$\frac{WL^2}{16EI}$
Simply supported, UDL w	$\frac{5wL^4}{384EI}$	$\frac{wL^3}{24EI}$

Fixing moments (superposition): propped cantilever with UDL: prop force $3wL/8$, wall moment $wL^2/8$.
 Beam fixed at both ends: $wL^2/12$ (UDL), $WL/8$ (central load).

5 THIN CYLINDERS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\sigma_c = \frac{pd}{2t\eta_L}, \quad \sigma_L = \frac{pd}{4t\eta_c}$	p pressure (N/mm ²); d internal diameter; t wall thickness (mm); η joint efficiency (η_L longitudinal joint, η_c circumferential)	stresses or plate thickness; thin if $t < d/20$
$\varepsilon_c = \frac{\sigma_c - \nu\sigma_L}{E} = \frac{\delta d}{d}$	hoop strain	change in diameter
$\varepsilon_L = \frac{\sigma_L - \nu\sigma_c}{E} = \frac{\delta L}{L}$	longitudinal strain	change in length
$\frac{\delta V}{V} = 2\varepsilon_c + \varepsilon_L$	volumetric strain	extra fluid to be pumped in

6 TORSION OF SHAFTS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{L}$	T torque (N mm); J polar second moment (mm ⁴); τ shear stress at radius r ; θ twist (rad); L length	strength (τ) or stiffness (θ)
$P = \frac{2\pi NT}{60}$	P power (W); N speed (rev/min); T in N m	torque from power and speed
$J = \frac{\pi d^4}{32}$ (solid)	d shaft diameter (mm)	any solid shaft
$J = \frac{\pi(D^4 - d^4)}{32}$ (hollow)	D, d outside and inside diameters (mm)	any hollow shaft
$\tau_{\max} = \frac{16T}{\pi d^3}$ (solid)	hollow: $\tau_{\max} = 16TD/\pi(D^4 - d^4)$	designing for strength
$\theta = \frac{TL}{GJ} = \frac{2\tau L}{Gd}$	GJ torsional rigidity	designing for stiffness

Stepped shaft (series): same T ; twists add. **Composite shaft (parallel):** same θ ; $T = T_1 + T_2$, shared in proportion to GJ . **Design:** find d from strength and from stiffness; use the larger.

7 STRAIN ENERGY

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$U = \frac{1}{2}P\delta = \frac{\sigma^2}{2E}V$	U strain energy (N mm = mJ); V volume (mm ³)	energy in a bar under direct load
$\frac{\sigma_e^2}{2E}$	σ_e stress at the elastic limit	modulus of resilience (per unit volume); $\times V$ = proof resilience
$\sigma = \frac{P}{A} \left[1 + \sqrt{1 + \frac{2AEh}{PL}} \right]$	h height of drop (mm); sudden load ($h = 0$): $\sigma = 2P/A$	falling or suddenly applied loads
$\frac{\tau^2}{2G}V; \quad \frac{\tau^2}{4G}V = \frac{T^2L}{2GJ}$	shear; solid shaft (τ at the surface). Hollow: $\times (D^2 + d^2)/D^2$	energy in shear and torsion

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$U = \int \frac{M^2 dx}{2EI}$	M moment along the beam	energy in bending
$\delta = \frac{\partial U}{\partial P} = \int \frac{M}{EI} \frac{\partial M}{\partial P} ds$	Castigliano; $ds = R d\phi$ on a curved bar	deflection of bent or curved bars; dummy load $Q \rightarrow 0$

Three principal stresses $\sigma_1, \sigma_2, \sigma_3$: $\frac{U}{V} = \frac{1}{2E} [\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\nu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1)]$

8 SPRINGS

FORMULA	SYMBOLS AND UNITS	USE IT WHEN
$\tau = \frac{8WD}{\pi d^3} = \frac{16WR}{\pi d^3}$	W axial load (N); $D = 2R$ mean coil diameter; d wire diameter (mm)	close-coiled helical spring, stress
$\delta = \frac{8WD^3n}{Gd^4}, \quad S = \frac{W}{\delta} = \frac{Gd^4}{8D^3n}$	n active coils; S stiffness (N/mm); $C = D/d$ spring index	deflection, stiffness, design
$\sigma_b = \frac{32M}{\pi d^3}, \quad \phi = \frac{64MDn}{Ed^4}$	M axial torque (N mm); ϕ wind-up angle (rad)	close-coiled spring under axial torque
$\frac{1}{S} = \frac{1}{S_1} + \frac{1}{S_2}; \quad S = S_1 + S_2$	series (same load) ; parallel (same deflection)	combining springs
$\sigma = \frac{3WL}{2nbt^2}, \quad \delta = \frac{3WL^3}{8Enbt^3}$	n plates, each b wide and t thick; L span; plates formed to $R = L^2/8\delta$	semi-elliptic leaf spring, central load
$\sigma = \frac{6WL}{nbt^2}, \quad \delta = \frac{6WL^3}{Enbt^3}$	L length; W end load	quarter-elliptic leaf spring
$\sigma = \frac{12M}{bt^2}, \quad \theta = \frac{12M\ell}{Ebt^3}, \quad U = \frac{\sigma^2 V}{24E}$	M winding torque; ℓ strip length; θ turns $\times 2\pi$	flat spiral spring

Five mark-losers to avoid

1. **Mixed units.** kN with mm, or GN/m^2 with N, inside one formula. Convert everything to N and mm first.
2. **Degrees in $G\theta/L$.** The torsion and Castigliano formulas need radians.
3. **Wrong y or J .** Measure y from the neutral axis, not the base. Torsion uses $J = \pi d^4/32$, not the bending $\pi d^4/64$.
4. **Static stress for a dropped load.** A sudden or falling load gives at least $2P/A$.
5. **A formula without a reason.** Write the principle in words first (“taking moments about A”, “the torsion equation”). Examiners give method marks for it.

A formula sheet tells you *what*. It cannot show you *when* or *why*.

Most Strength of Materials marks go to choosing the right formula, setting it up correctly and showing the working. Many questions also ask you to **derive** a formula, such as $T/J = \tau/r = G\theta/L$, $M/I = \sigma/y = E/R$, $pd/2t$ or the spring results. A sheet like this cannot teach that. Here is how to build it, one step at a time:

YOUR NEXT STEPS

Step 1 – free: the **SOM Formula-to-Solution Starter**. A five-question method, 4 fully worked examples on stress, strain and torsion, and a self-test with worked answers. Get it at [LINK – to be confirmed].

Step 2 – the complete guide: the **SomaReady Strength of Materials Revision Guide** (36 pages). It covers all eight topics on this sheet, step by step:

- every derivation the past papers ask for, written out in full;
- 41 original examples, from direct to exam style, each explaining *why* each step is taken;
- worked answers to every practice question, plus common mistakes for every topic.

Price: **KSh 249** (launch price). **Get it at:** [LINK – to be confirmed].

Get the complete Strength of Materials guide: KSh 249

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