Design of Steel Structures

Short notes for B.Tech Civil · GATE CE

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1. Introduction and Limit State Design

- Steel: high strength-to-weight ratio, ductile, fast to build, recyclable. Drawbacks: corrosion, poor fire resistance, buckling of thin parts.
- Code: **IS 800:2007** (limit state method). Loads: IS 875 (dead, live, wind, snow), IS 1893 (earthquake).
- Common structural steel: E250 (fy = 250 MPa, fu = 410 MPa). Es = 2 × 10^5 MPa, G about 0.77 × 10^5 MPa, μ = 0.3.
- Rolled sections: ISMB, ISJB, ISLB (beams), ISMC (channels), ISA (angles), tubes, plates.

➤ Partial safety factors for material (IS 800)

Failure mode	Factor
Yielding / buckling γ_{m0}	1.10
Ultimate (rupture) γ_{m1}	1.25
Bolts γ_{mb}	1.25
Shop welds γ_{mw}	1.25
Field welds γ_{mw}	1.50

- Load factors (collapse): 1.5 (DL + LL), 1.2 (DL + LL + WL / EL), 1.5 (DL + WL) — check all combinations.

➤ Section classification

Class	Behaviour
Plastic (Class 1)	Forms plastic hinge with large rotation
Compact (Class 2)	Reaches Mp but limited rotation
Semi-compact (Class 3)	Reaches only My (first yield)
Slender (Class 4)	Local buckling before yield

- Limits are given in terms of b/t and d/t ratios multiplied by ε = sqrt(250 / fy).

2. Bolted Connections

- Types: bearing type bolts (black bolts, grade 4.6) and **HSFG bolts** (friction grip, grade 8.8 / 10.9).
- Bolt grade 4.6 means fub = 400 MPa and fyb = 0.6 × 400 = 240 MPa.
- Hole diameter d0 = d + 2 mm (for d = 14 to 24 mm). Minimum pitch = 2.5 d. Minimum edge distance about 1.5 d0 (rolled edge) to 1.7 d0 (sheared edge).

FORMULA Shear capacity: Vdsb = fub (nn Anb + ns Asb) / (sqrt3 x γmb). Net tensile area Anb = 0.78 x πd²/4 (about).

FORMULA Bearing capacity: Vdpb = 2.5 kb d t fu / γmb, kb = smaller of e/(3d0), p/(3d0) - 0.25, fub/fu, 1.0.

FORMULA HSFG slip resistance: Vdsf = μf ne Kh F0 / γmf, F0 = 0.7 fub Anb (proof load).

EXAMPLE M20 bolt, grade 4.6, single shear, threads in shear plane. Anb = 0.78 x 314.2 = 245 mm². Vdsb = 400 x 245 / (1.732 x 1.25) = 98000/2.165 = 45.3 kN. Bearing on 10 mm plate (fu = 410, take kb = 0.5): Vdpb = 2.5 x 0.5 x 20 x 10 x 410 / 1.25 = 82 kN. Bolt value = 45.3 kN.

- Failures of bolted joints: shear of bolt, bearing of bolt / plate, tearing of plate at net section, shear-out of plate end.
- **Prying force**: extra tension in bolts of a flexible T-stub connection.

3. Welded Connections

- Types: butt (groove) weld and fillet weld. Fillet welds are most common.
- **Effective throat** of a fillet weld tt = K × s; for a 90° joint, K = 0.7.
- Effective length = actual length − 2s (end returns). Minimum effective length = 4 × size.

FORMULA Fillet weld design strength = Lw tt fu / (sqrt3 x γmw), fu = smaller of weld and parent metal.

EXAMPLE 6 mm shop fillet weld, length 200 mm, fu = 410 MPa. tt = 0.7 x 6 = 4.2 mm. Strength = 200 x 4.2 x 410 / (1.732 x 1.25) = 344400/2.165 = 159.1 kN.

Bolted joint	Welded joint
Easy to inspect and dismantle	Permanent, neat, rigid
Holes reduce area	No reduction of area
Less skill on site	Skilled welders, inspection needed
Slip and noise possible	Residual stresses, distortion

➤ Eccentric connections

- Load not passing through the centroid of the bolt / weld group causes direct shear + torsional shear.
- Bracket type 1 (load in plane of group): resultant force on the farthest bolt from direct and torsional parts.

FORMULA Direct shear per bolt F1 = P / n. Torsional shear on bolt at distance r: F2 = P e r / Σr². Resultant R = sqrt(F1² + F2² + 2 F1 F2 cos θ).

- Bracket type 2 (load out of plane): bolts carry shear + tension; check the interaction of both.
- Connection types by rigidity: simple (shear only), semi-rigid, rigid (moment) connections.

4. Tension Members

- Design strength Td = least of: gross yielding Tdg, net section rupture Tdn, block shear Tdb.

FORMULA Gross yielding Tdg = Ag fy / γm0. Net rupture (plates) Tdn = 0.9 An fu / γm1.

FORMULA Net area with staggered holes An = [b - n d0 + Σ p² / (4g)] t (p = stagger pitch, g = gauge).

- Angles: $T_{dn} = 0.9 A_{nc} f_u / \gamma_{m1} + \beta A_{go} f_y / \gamma_{m0}$ (connected leg + outstanding leg). Shear lag reduces efficiency of outstanding legs.
- **Block shear**: failure along a shear plane plus a tension plane around the bolt group.

EXAMPLE Plate 200 x 10 mm, E250, two 20 mm bolts in one row (d_0 = 22 mm). A_g = 2000 mm². A_n = (200 - 2 x 22) x 10 = 1560 mm². T_{dg} = 2000 x 250/1.1 = 454.5 kN. T_{dn} = 0.9 x 1560 x 410/1.25 = 460.5 kN. Design strength = 454.5 kN (yielding governs).

- Max slenderness ratio for tension members (no reversal) = 400 (IS 800).

5. Compression Members

- Short columns crush; long columns buckle. Real columns fail by **inelastic buckling**, so IS 800 uses column buckling curves.

FORMULA $f_{cd} = (f_y / \gamma_{m0}) / [\phi + \sqrt{(\phi^2 - \lambda^2)}]$, $\phi = 0.5 [1 + \alpha (\lambda - 0.2) + \lambda^2]$, $\lambda = \sqrt{(f_y / f_{cc})}$, $f_{cc} = \pi^2 E / (KL/r)^2$.

Buckling curve	Imperfection factor α
a	0.21
b	0.34
c	0.49
d	0.76

- Curve depends on section type and buckling axis (e.g. angles, channels and built-up sections use curve c).

➤ Effective length (IS 800, Table 11)

End conditions	K
Both ends fixed	0.65
One fixed, one hinged	0.80
Both ends hinged	1.00
One fixed, one free	2.00

EXAMPLE Column, KL/r = 100, fy = 250, curve c. fcc = π^2 x 2 x 10^5 / 100^2 = 197.4 MPa. λ = sqrt(250/197.4) = 1.125. ϕ = 0.5 [1 + 0.49 x 0.925 + 1.266] = 1.360. fcd = 227.3 / (1.360 + sqrt(1.850 - 1.266)) = 227.3 / 2.124 = 107 MPa.

- Max slenderness ratio for members carrying DL + LL compression = 180.
- **Built-up columns**: lacing (angle 40° to 70°, single or double) or battens; designed for a transverse shear of 2.5% of axial load.
- **Column bases**: slab base for axial load; gusseted base for heavy loads / moments.

FORMULA Slab base thickness ts = sqrt[2.5 w (a^2 - 0.3 b^2) $\gamma m0$ / fy] (w = base pressure, a and b = larger and smaller projections).

6. Beams (Flexural Members)

- **Laterally supported** beam: compression flange restrained, no lateral-torsional buckling (LTB).

FORMULA Laterally supported, low shear: Md = βb Zp fy / $\gamma m0$ (βb = 1 for plastic / compact). Limit for simply supported: Md ≤ 1.2 Ze fy / $\gamma m0$.

FORMULA Shear strength Vd = Av fy / (sqrt3 x $\gamma m0$), Av = h tw for I-sections (major axis). High shear if V > 0.6 Vd (moment capacity reduced).

EXAMPLE Laterally supported beam, plastic section, Zp = 1.0 x 10^6 mm^3, fy = 250. Md = 1.0 x 10^6 x 250 / 1.1 = 227.3 kN·m. Max UDL on 6 m simple span: wu = 8 x 227.3 / 36 = 50.5 kN/m (factored).

- **Laterally unsupported** beam: design bending strength = βb Zp fbd, where fbd depends on elastic critical moment Mcr (LTB).
- Web checks: web buckling and web crippling under concentrated loads; stiffeners if needed.
- Deflection limit for simply supported floor beams: span / 300 (elements not susceptible to cracking), span / 360 (susceptible).

➤ Plate girders and gantry girders

- **Plate girder**: built-up I-section for large spans and loads; parts are flanges, web, stiffeners (bearing, intermediate), splices.
- Thin webs use **tension field action** after shear buckling.
- **Gantry girder**: carries crane loads; designed for vertical wheel loads + impact, lateral surge and longitudinal drag.

7. Plastic Analysis and Roof Trusses

- Shape factor S = Zp / Ze: rectangle 1.5, circle 1.7, I-section about 1.12 to 1.15.
- Collapse loads: fixed beam with central load Wc = 8Mp/L; fixed beam with UDL wc = 16Mp/L².

➤ Roof trusses

- Types: Pratt, Howe, Fink, North-light, King post, Queen post; tubular trusses for large spans.
- Pitch for steel sheeting: often 1/4 to 1/6 of span.
- **Purlins**: angle, channel or cold-formed Z / C sections; designed for biaxial bending under wind.
- Wind load (IS 875 Part 3): Vz = Vb k1 k2 k3 k4, pz = 0.6 Vz² (N/m²). Design force F = (Cpe − Cpi) A pd.

> **REMEMBER** k1 = risk (life) factor, k2 = terrain and height factor, k3 = topography factor, k4 = importance factor for cyclonic regions.

8. Most Asked Questions (practice)

1. Explain partial safety factors and section classification in IS 800.
2. Find bolt value of a bearing type bolt in single and double shear.
3. Explain HSFG bolts and their slip resistance.
4. Design a fillet-welded lap joint for a given load.
5. Find design tensile strength of a plate / angle (yield, rupture, block shear).
6. Find design compressive strength of a column using buckling curves.
7. Design a laced or battened built-up column.
8. Design a slab base for an axially loaded column.

9. Design a laterally supported beam with shear and deflection checks.
10. Explain lateral-torsional buckling and plate girder components.

> **TIP** GATE CE asks γ_{m0} / γ_{m1} values, bolt and weld strength, net area with stagger, effective length factors, shape factor and Md of beams. Practise one full tension and one compression design.