

Safety and Regulatory Requirements

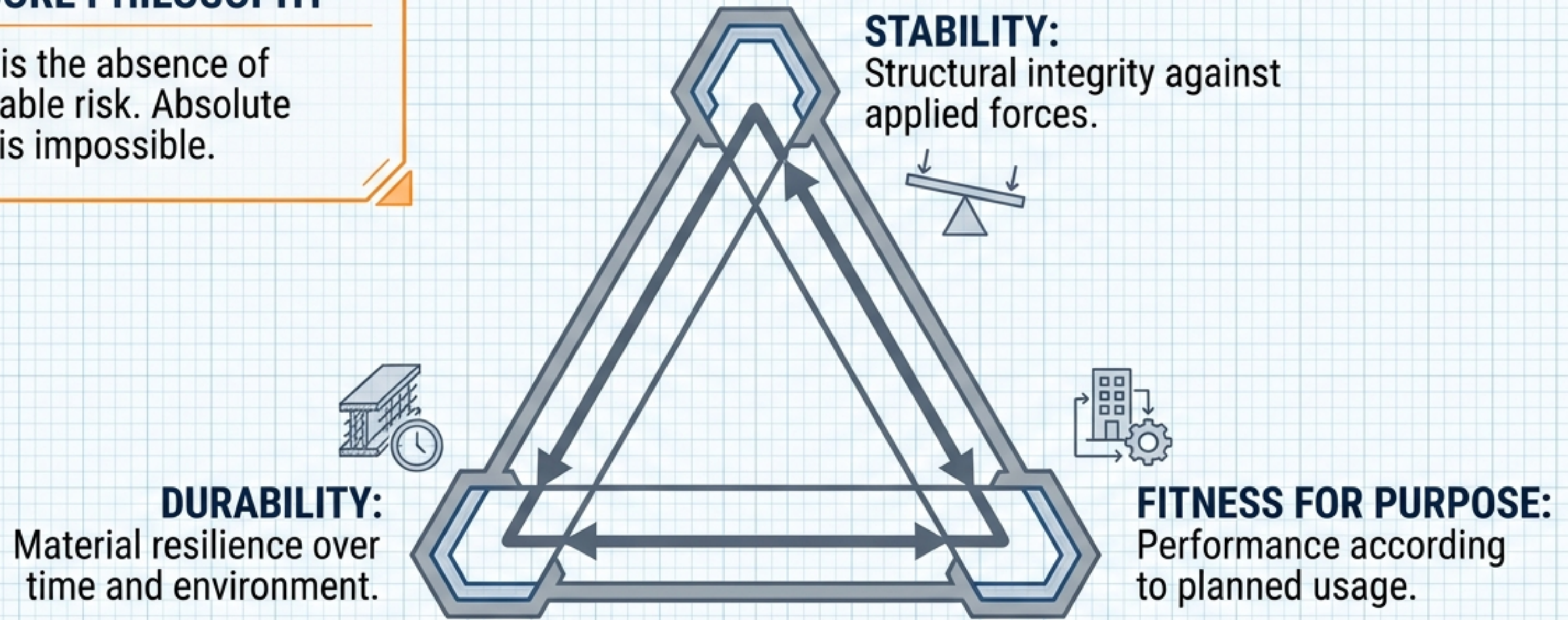
Reinforced Concrete 1 — Chapter 2 (BAEL 91 Framework)

University Level:
Licence Génie Civil

Document Type:
Comprehensive
Reference Manual

THE CORE PHILOSOPHY

Safety is the absence of acceptable risk. Absolute safety is impossible.



THE ENGINEERING MANDATE

Absolute safety is impossible; a residual risk must be integrated. Empirical approaches are insufficient. Sizing and verification **MUST** rely on **rigorous, codified calculation rules** to scientifically analyze mechanical, environmental, and usage constraints.

Classification of Actions (External loads and forced deformations)

 Permanent (G)	 Variable (Q)	 Accidental (FA)
Constant intensity.	Frequent variations.	Exceptional/unpredictable.
- Self-weight (Concrete density: 25 KN/m^3) - Fixed equipment (partitions, installations) - Earth/liquid thrusts at stable level - Continuous imposed deformations (prestressing, shrinkage)	- Operating costs (human traffic, mobile loads) - Climate loads (snow, wind dynamic pressure) - Thermal effects (expansion/contraction)	- Earthquakes (defined by zoning) - Shocks (vehicle impacts, explosions) - Rare phenomena (major fires, floods)

Requests: Internal forces (N = normal, T = shear) and moments (M_f = bending, M_t = torsional) generated in a structure. Determined by combining the most unfavorable actions to ensure safety.

Nomenclature of Combinations

Permanent Actions (G)

G_{max} : Adverse (aggravating)

G_{min} : Favorable (reducing)

G : Neutral

Accompanying Variable Actions ($Q_i, i \geq 2$) (Secondary, reduced by coefficient ψ)

Q_r : Road bridges standard

Q_{RP} : Road bridges specific
(military/exceptional)

Principal Variable Actions (Q1) (Dominant 'basic' action)

Q_B : Building operating costs

W : Wind pressure

S : Snow load

Thermal Actions

T : Uniform temperature variation

Delta_Theta : Thermal gradient

Accidental & Modifiers

F_A : Accidental representative value

psi : Combination coefficients (ψ_0, ψ_1, ψ_2) for simultaneous occurrence probability

Ultimate Limit States (ULS)

Goal: Withstand extreme loads without breakage/instability.

Fundamental Equation

$$ELU = 1.35 * G_{\max} + 1.5 * Q_1 + \sum_i \gamma_{Qi} * \psi_{0i} * Q_i$$

Accidental Equation

$$Accidental = G + F_A + \psi_1 * Q_1 + \sum_i \psi_{2i} * Q_i$$

Example: Building ($G_{\max}$, Q_B , W)

$$ELU = 1.35 * G_{\max} + 1.5 * Q_B + 1.5 * 0.6 * W$$

(with $\psi_0 = 0.6$)

Service Limit States (SLS)

Goal: Guarantee user comfort and durability (limit deformation/cracking).

Characteristic Eq

$$Characteristic = G + Q_1 + \sum_i \psi_{0i} * Q_i$$

Frequent Eq

$$Frequent = G + \psi_1 * Q_1 + \sum_i \psi_{2i} * Q_i$$

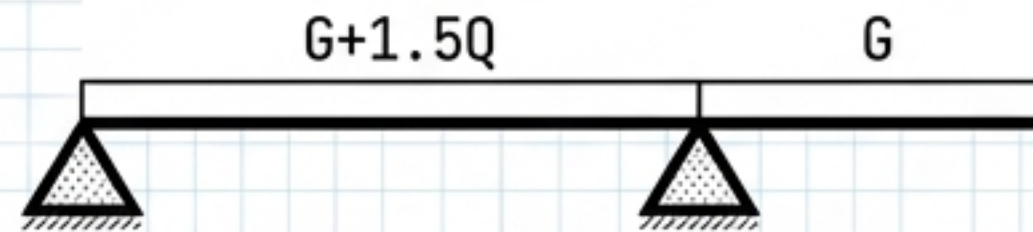
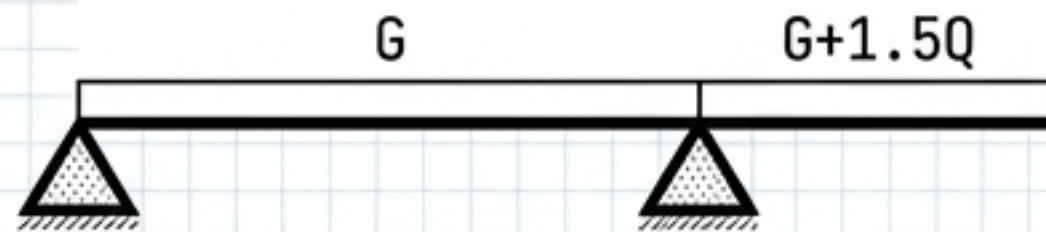
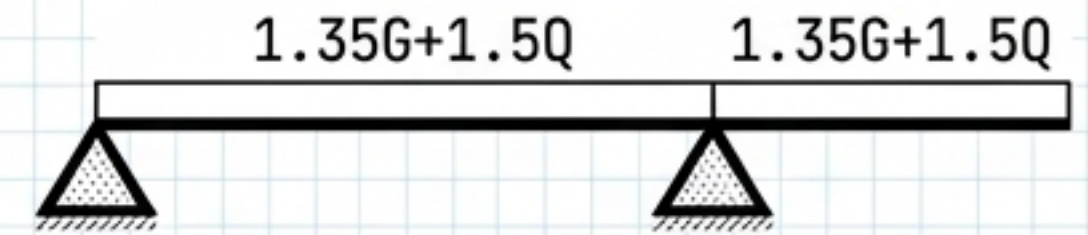
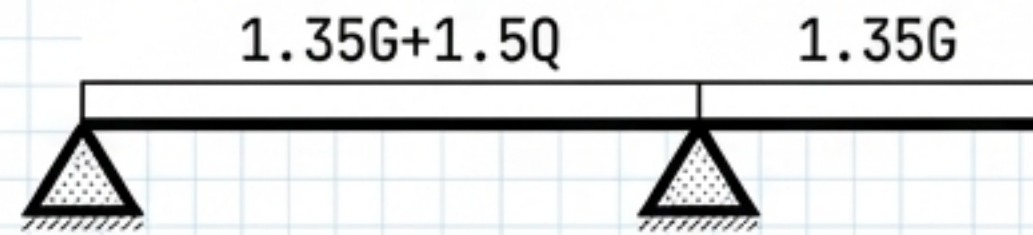
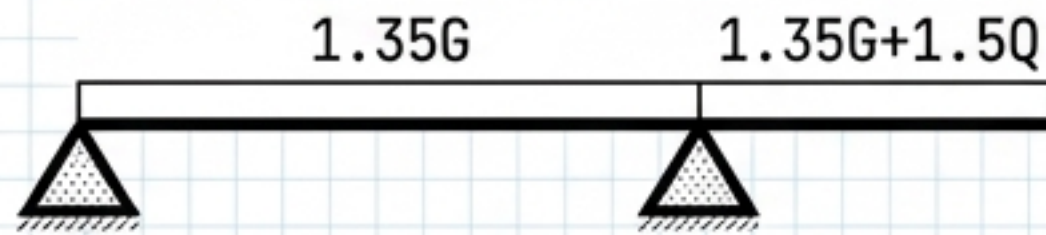
Quasi-Permanent Eq

$$Quasi-Permanent = G + \sum_i \psi_{2i} * Q_i$$

Example: Bridge (Q_r , Delta_Theta)

$$Frequent = G + 0.7 * Q_r + 0.6 * Delta_Theta$$

Beams on two supports extended by a cantilever



Note: Combination 4 uses $0.9G$ instead of G in the span adjacent to the cantilever for the justification of static equilibrium.

Slabs & Multi-span Beams Matrix

State/Comb	Loaded bays	Unloaded bays
ULS Comb 1	$1.35 G + 1.5 Q$	$1.35 G$
ULS Comb 2	$G + 1.5 Q$	G
SLS Comb	$G + Q$	G

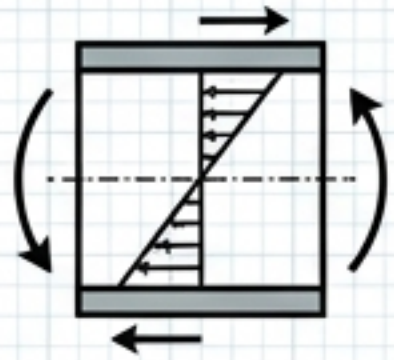
Posts & Foundations

Common Rule: $1.35G + 1.5Q$

Applies when the support point does not contribute to stability under wind action.

ULS Resistance: Calculation Assumptions

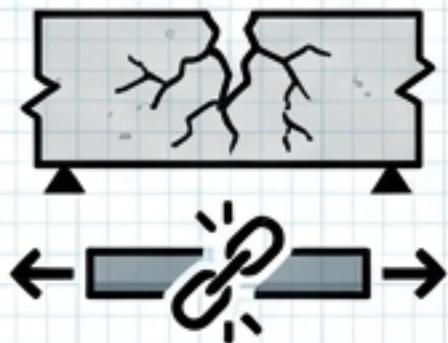
Theoretical Basis



Deformation compatibility:
Straight sections remain planar after deformation (Bernoulli hypothesis).



Perfect adhesion: No slippage between steel and concrete. Deformations are identical for both materials.



Neglected tensile strength:
Cracked concrete under tension contributes zero mechanical strength; steel handles all tension.

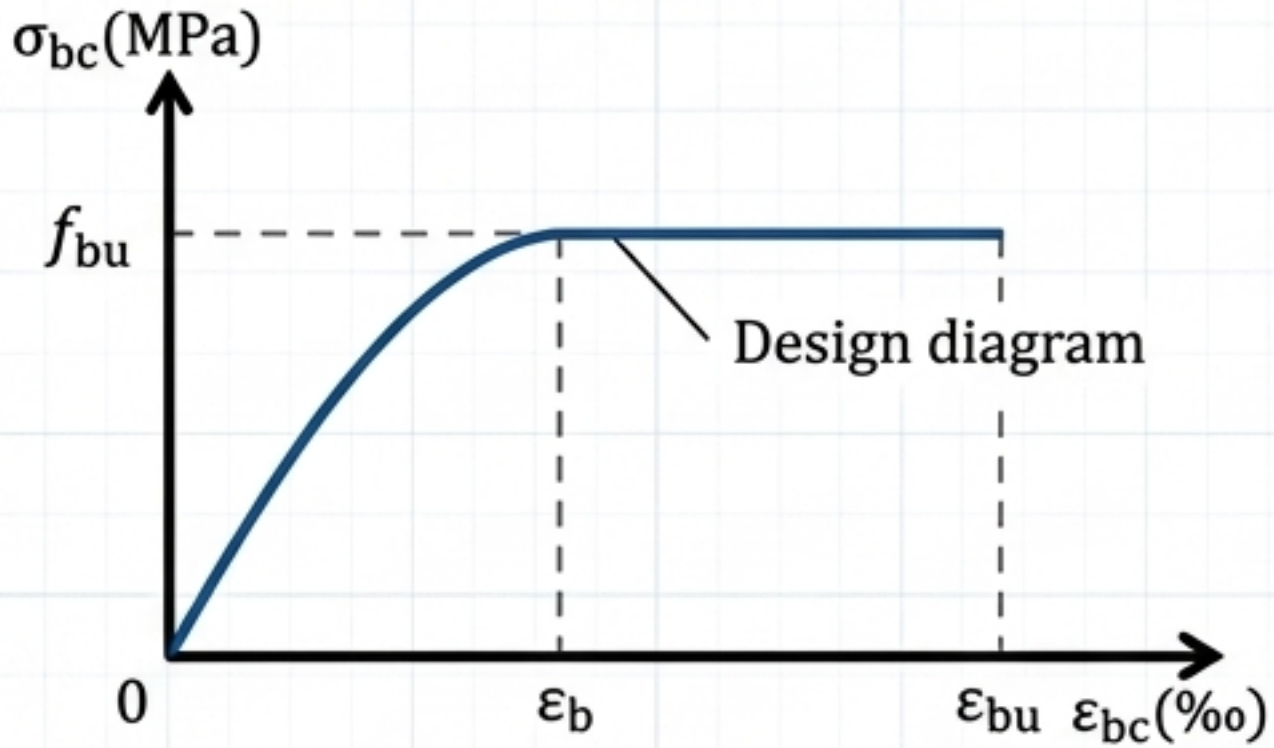
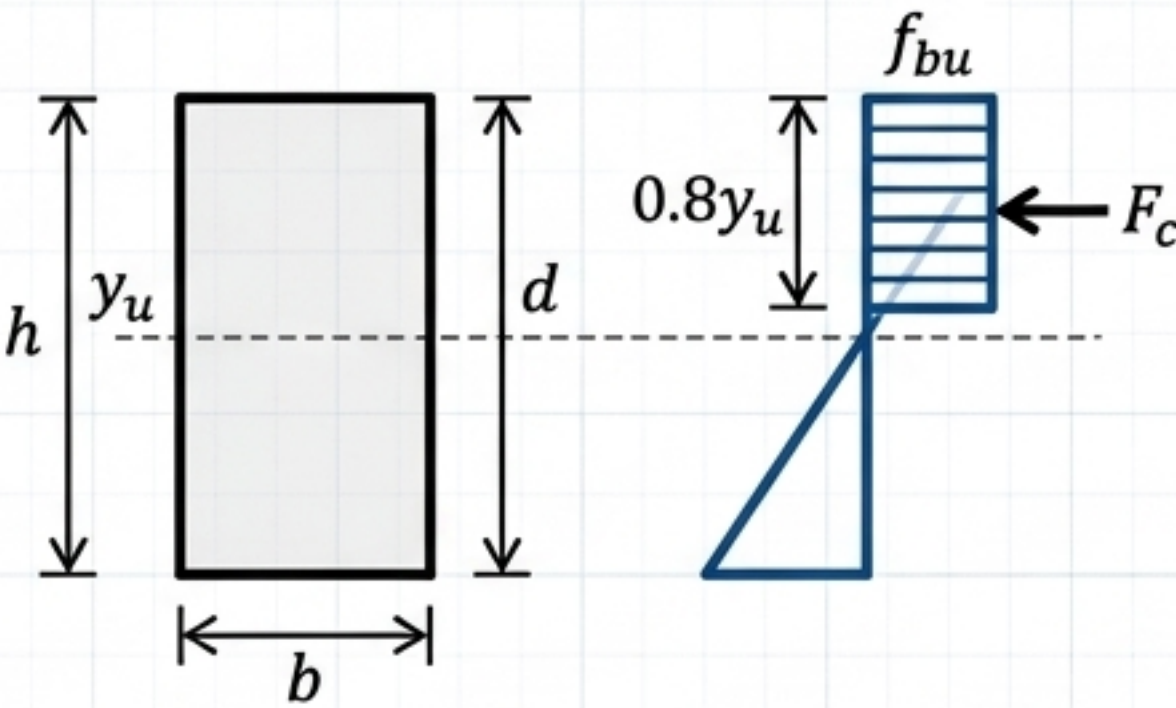
Deformation Limits

Steel: Maximum elongation **10%** (prevents excessive plasticity).

Concrete (Bending):
Maximum shortening **3.5%** (limit before crushing).

Concrete (Compression):
Maximum shortening **2%** (pure axial compression in columns).

MATHEMATICAL MODELS FOR CONCRETE: A SIDE-BY-SIDE DIAGRAMMATIC COMPARISON

Model 1: Parabola-Rectangle Diagram	Model 2: Simplified Rectangular Diagram
 • Parabolic phase: Stress rises to max strength ($\epsilon_b \sim 2\text{‰}$). • Rectangular phase: Constant stress f_{bu} to ultimate failure ($\epsilon_{bu} \sim 3.5\text{‰}$).	 • Constant stress block f_{bu} over height $0.8y_u$. • Simplified model approximates the parabolic curve perfectly for bending verification without integration.

	Parabola-Rectangle	Simplified Rectangular
Use Cases	Complex sections, columns under axial compression (requires integration).	Simple bending in beams (Force = $0.8y * b * f_{bu}$).

EQUATION DEEP-DIVE: ULTIMATE CONVENTIONAL COMPRESSIVE STRENGTH

f_{cj} = Characteristic compressive strength of concrete at day j .

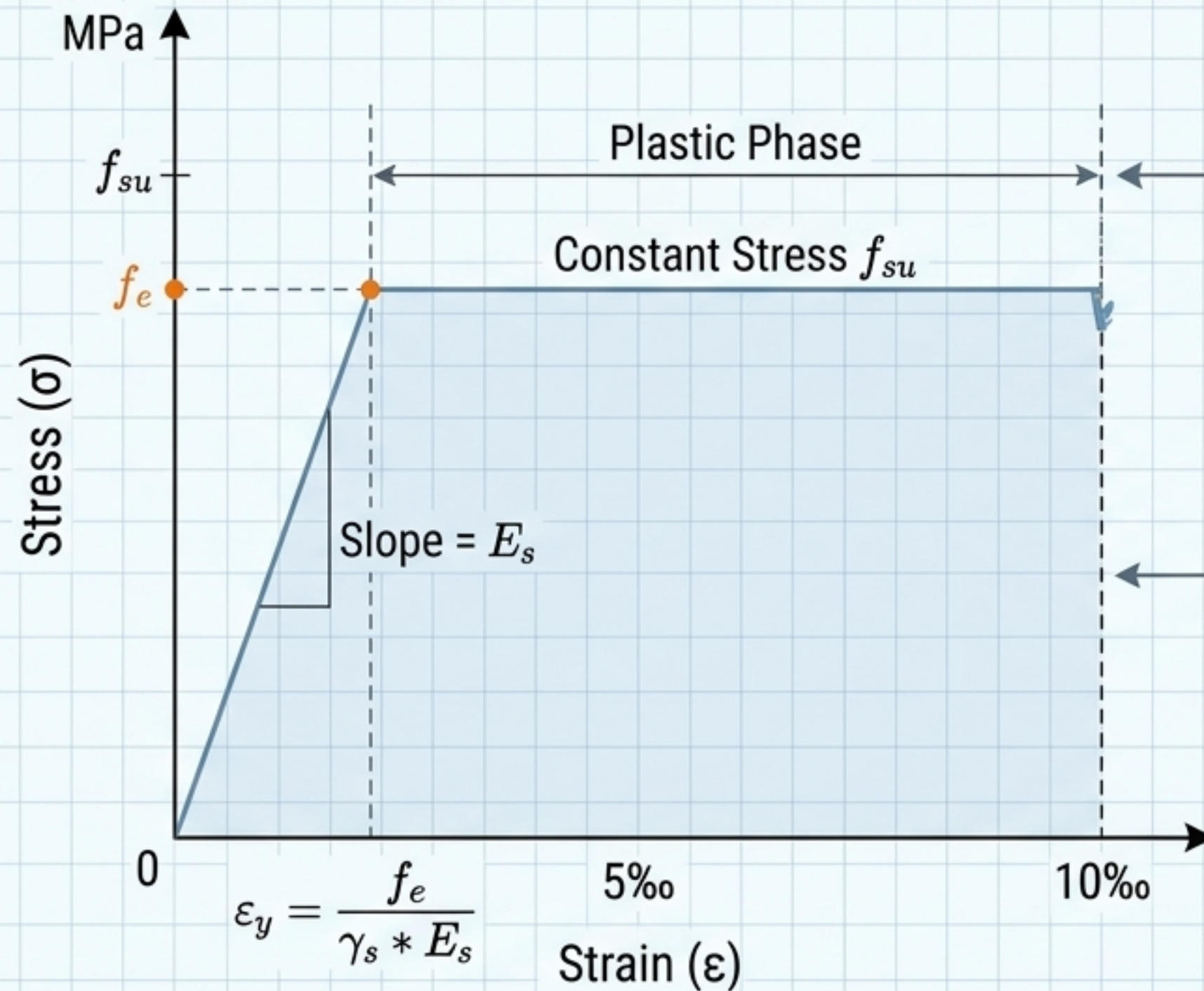
$$f_{bu} = \frac{0.85 * f_{cj}}{\theta * \gamma_b}$$

γ_b = Safety factor.
- 1.5 (General case)
- 1.15 (Accidental combinations)

θ = Load duration coefficient.
- 1.0 : Loads applied > 24 hours
- 0.9 : Loads between 1 and 24 hours
- 0.85 : Loads < 1 hour

Note: This constraint defines the ultimate conventional compressive strength, applicable when concrete deformation is between 2‰ and 3.5‰ ([Equation 2.1](#)).

STEEL STRESS-STRAIN MODEL (ULS)



Fundamental Parameters

- f_e : Guaranteed yield strength (e.g., Fe 500 = 500 MPa).
- γ_s : Safety factor (1.15 common, 1.0 accidental).
- E_s : Longitudinal elasticity modulus (200,000 MPa).

Elastic Phase (Linear Deformation)

Equation: $\sigma = E_s * \epsilon_s$

Valid up to limit: $\frac{f_e}{\gamma_s * E_s}$

Plastic Phase (Unlimited Deformation)

Constant calculation constraint: $f_{su} = \frac{f_e}{\gamma_s}$

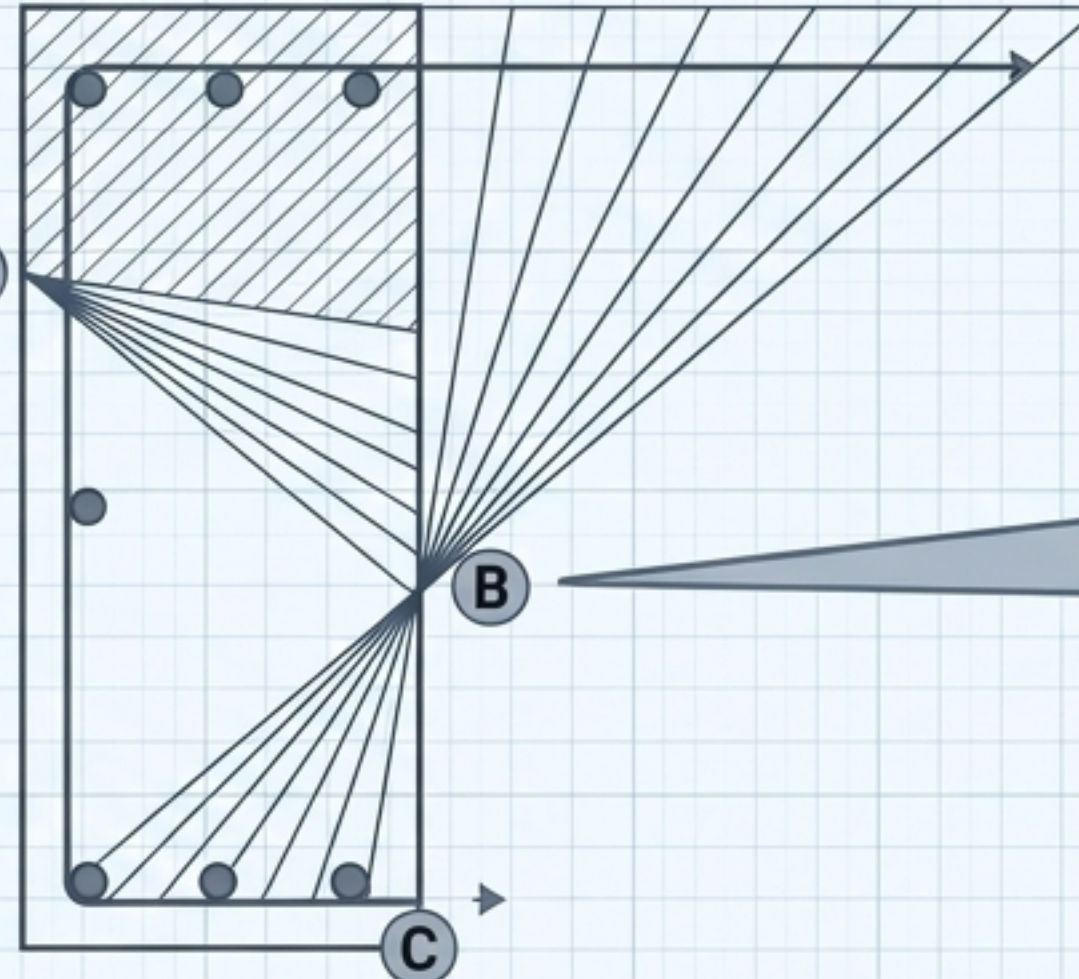
The stress remains constant until failure at 10‰ limit, ignoring work hardening.

Pivot A (Tension Failure)

Neutral axis is close to the compressed face.

The tensioned steel reaches its maximum deformation (10‰) first.

A



Pivot B (Simultaneous Failure)

Neutral axis is at an intermediate position.

Concrete (3.5‰) and steel (10‰) simultaneously reach their limits.

B

Pivot C (Compression Failure)

Neutral axis is close to the tension face.
The compressed concrete crushes before the steel deforms plastically.

C

The **Three Pivots Rule** classifies fundamental failure modes based on neutral axis position.

SLS ASSUMPTIONS (NAVIER-BERNOULLI)

Plane sections & Perfect adhesion (no slippage).

Neglected tensile concrete.

Key Difference from ULS:
Linear elastic behavior
($\sigma = E * \epsilon$).

Equivalence coefficient $n = 15$.
$$n = \frac{E_s}{E_b}$$

(transforms steel section into equivalent concrete section).

CONCRETE COMPRESSION LIMIT STATE

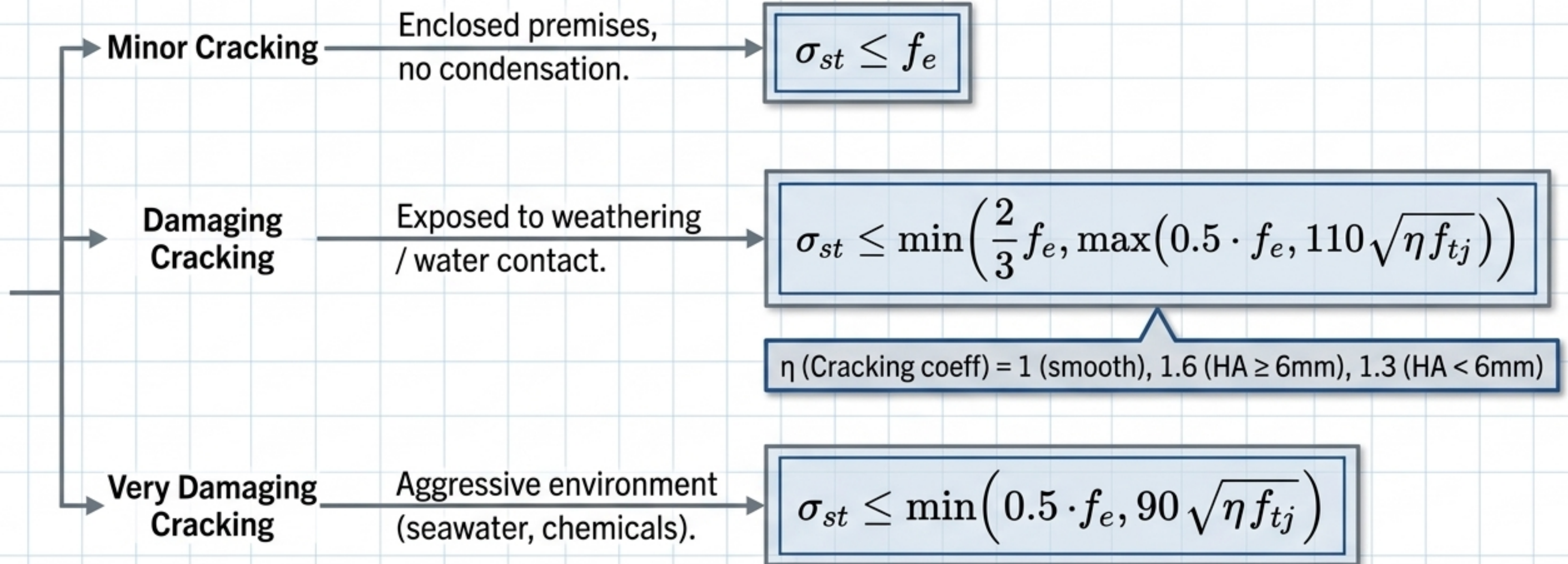
Goal: Avoid premature crushing, micro-cracking, and excessive creep under normal operational loads.

$$\sigma_{bc} \leq 0.6 * f_{cj}$$

Equation 2.2: Maximum allowable compressive stress.

SLS Limit State of Crack Opening

Goal: Control crack width to protect aesthetics, watertightness, and prevent reinforcement corrosion by limiting steel tensile stress.



The Condition of Non-Brittleness

A regulatory mandate requiring minimum longitudinal reinforcement to ensure a ductile transition. It prevents sudden, explosive failure when concrete cracks. The stress releasing into the steel must be $\leq f_e$.

Pathway 1: Simple Tension

$$A_{smin} * f_e \geq B * f_{t28}$$

B = Total cross-section of tensile concrete. Reinforcements must withstand the cracking force without exceeding elastic limit.

Pathway 2: Simple Bending (Rectangular Section)

$$A_{smin} \geq 0.23 * b * d * \left(f_{t28} / f_e \right)$$

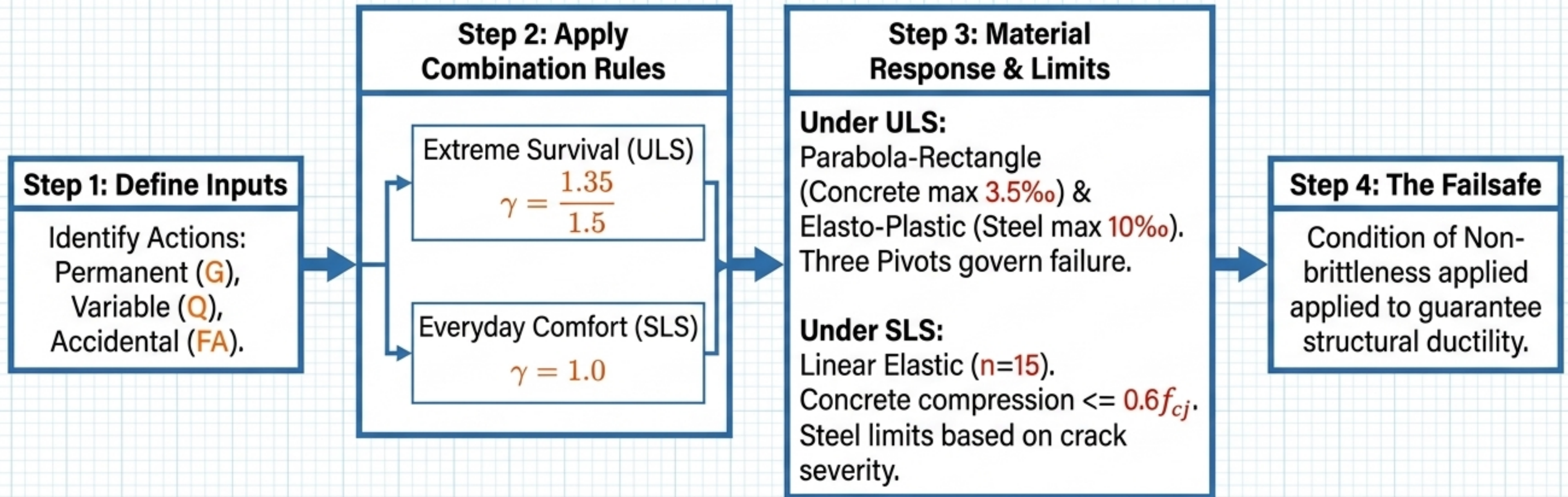
Origin of 0.23

Derived from force balance where

$$\text{Cracking Moment } M_{fs} = \frac{b * h^2}{6} * f_{t28}.$$

Using lever arm $z \sim 0.9d$ and $h \sim 1.1d$ yields the 0.23 coefficient.

Chapter 2: The Structural Blueprint Workflow



Conclusion: Absolute safety is impossible, but through codified combinations, strict material constraints, and built-in failsafes, residual risk is systematically engineered out.