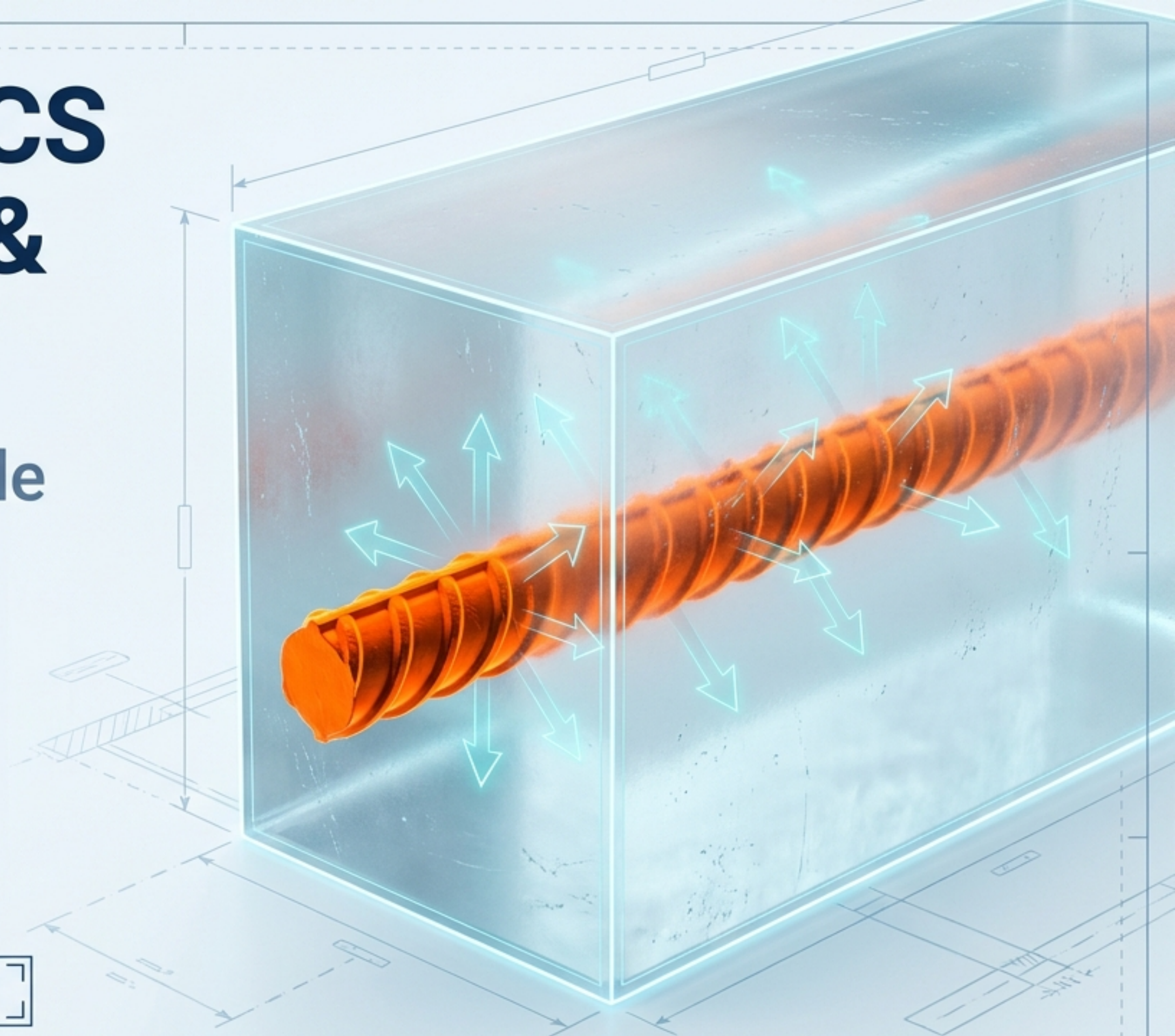


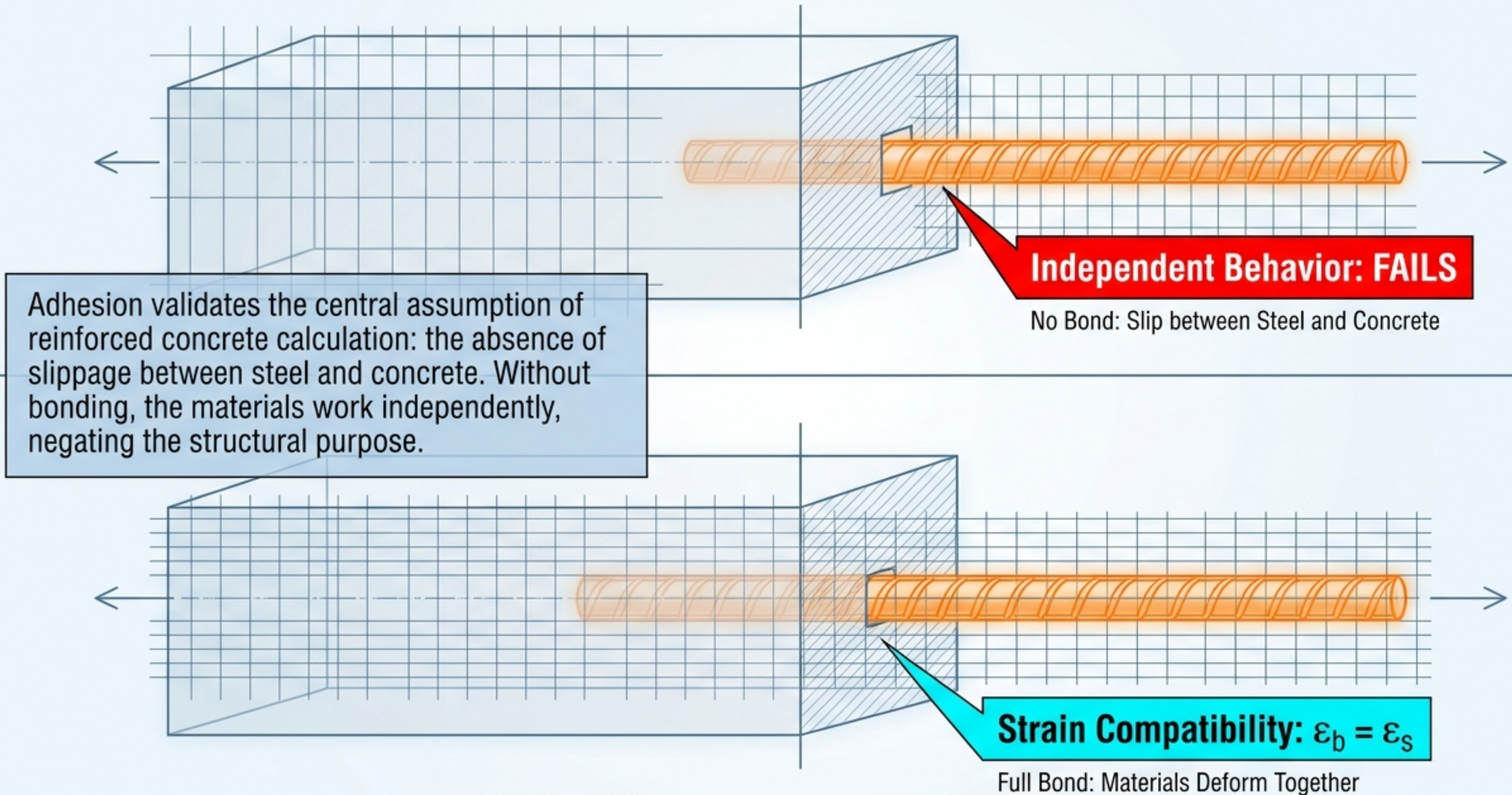
THE MECHANICS OF ADHESION & ANCHORING

A Visual Reference Guide
to BAEL Reinforced
Concrete Standards



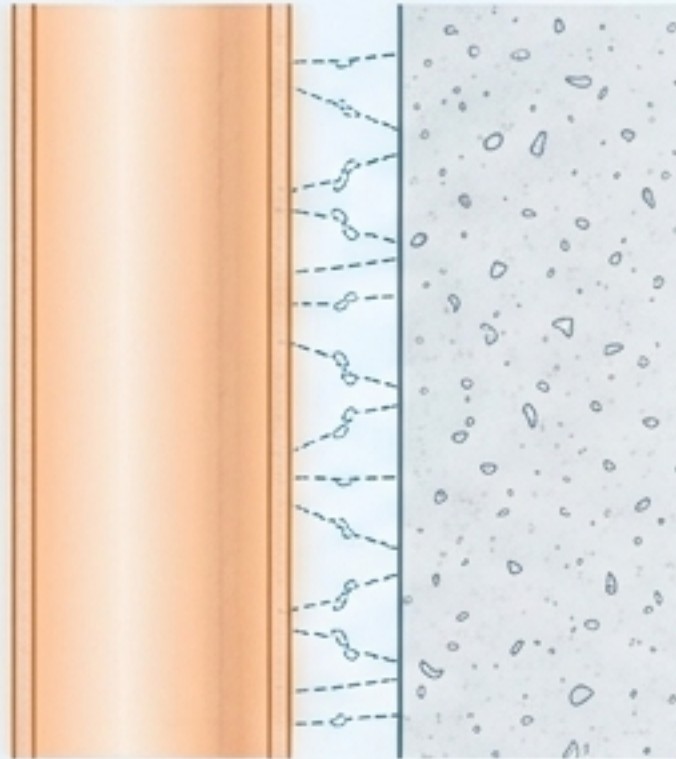
Structural Engineering Field Manual — Chapter 3

The Foundational Assumption: Strain Compatibility



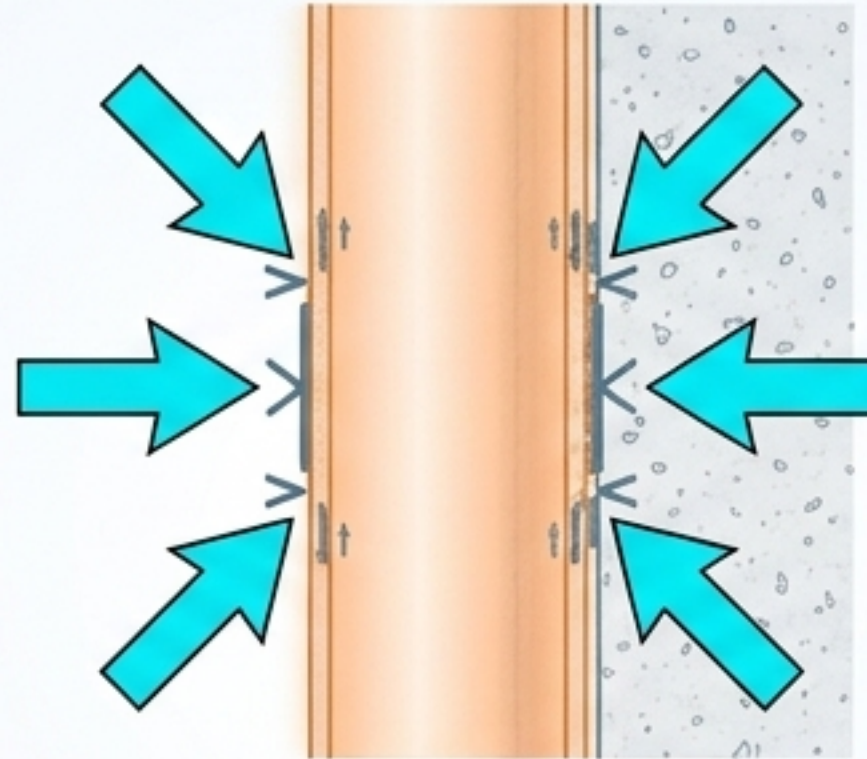
Physical Origins of Adhesion

Stage 1: Chemical Adhesion (Bonding)



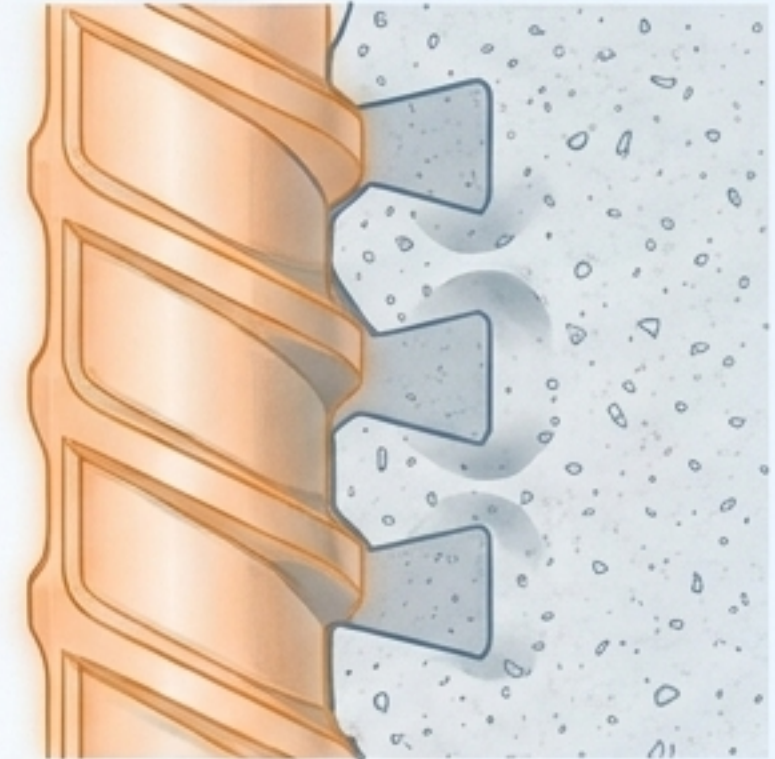
Produced by molecular forces. Weak and rapidly disappears due to micro-slip, cyclic loading, moisture, or temp changes. Significant only before loading or for smooth bars.

Stage 2: Friction



Stronger than chemical adhesion. Depends on bar surface roughness and transverse confinement (provided by surrounding concrete or transverse reinforcement).

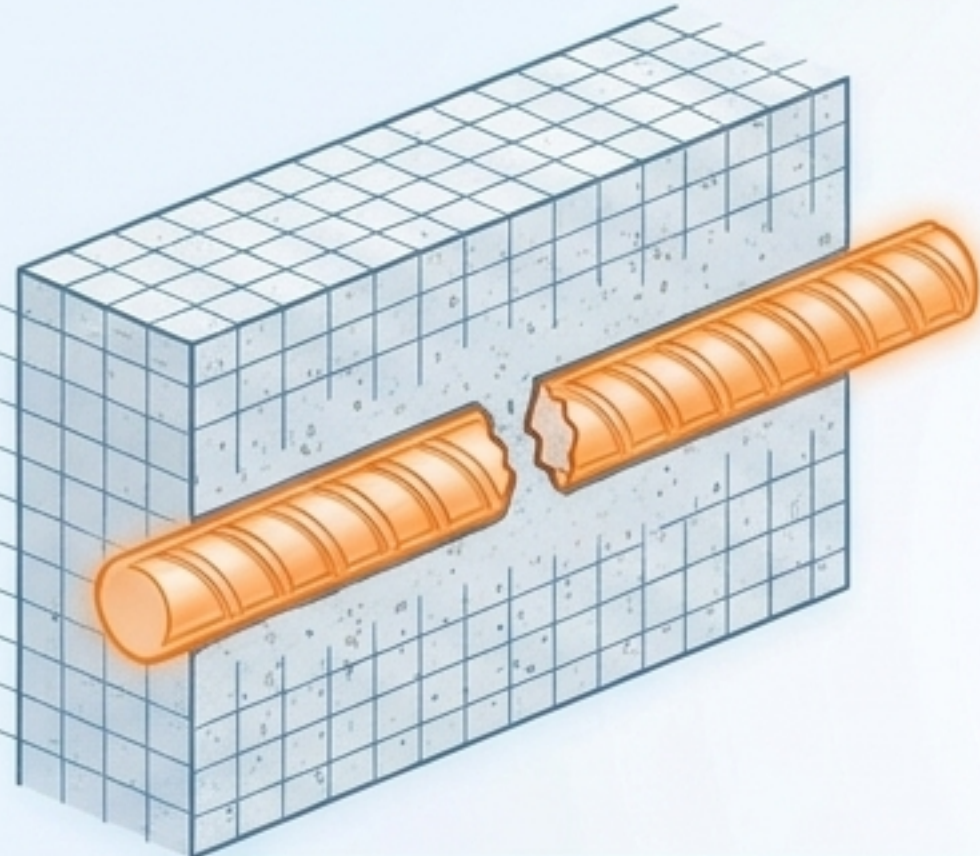
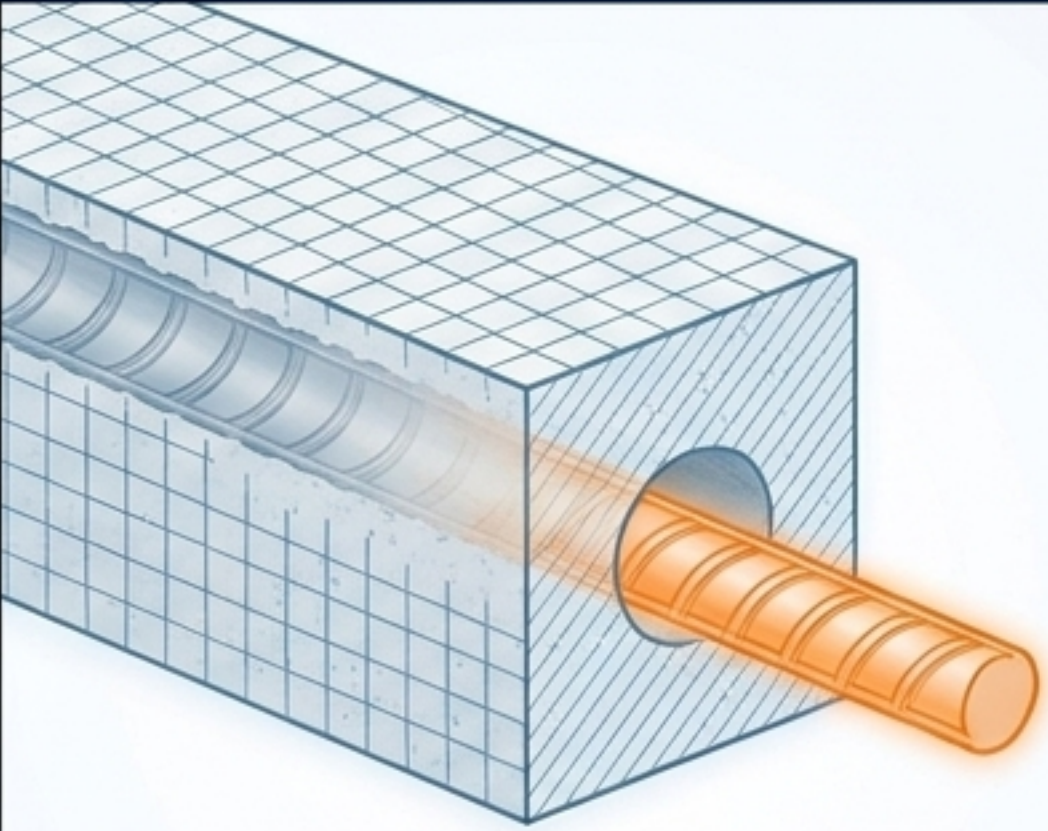
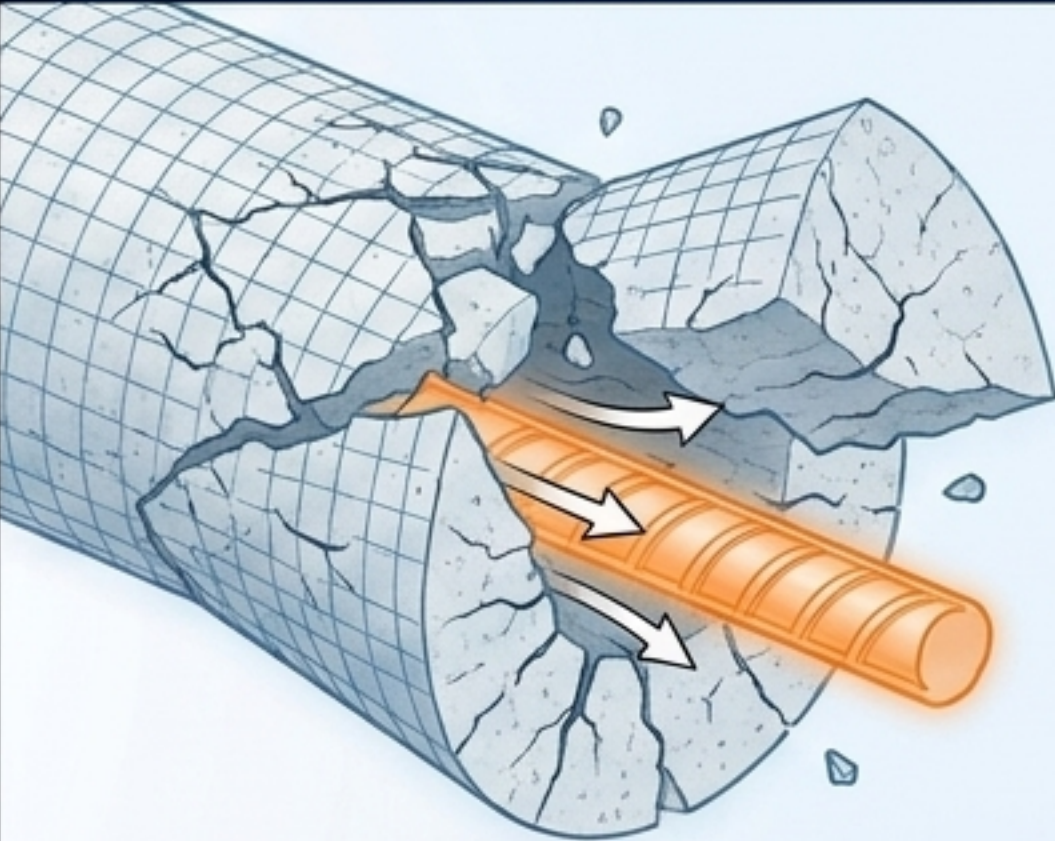
Stage 3: Mechanical Meshing (Stamping)



Main bonding mechanism for HA bars. Transfers forces through compression and shear. Provides highest strength but risks radial cracking.

Increasing Bond Strength

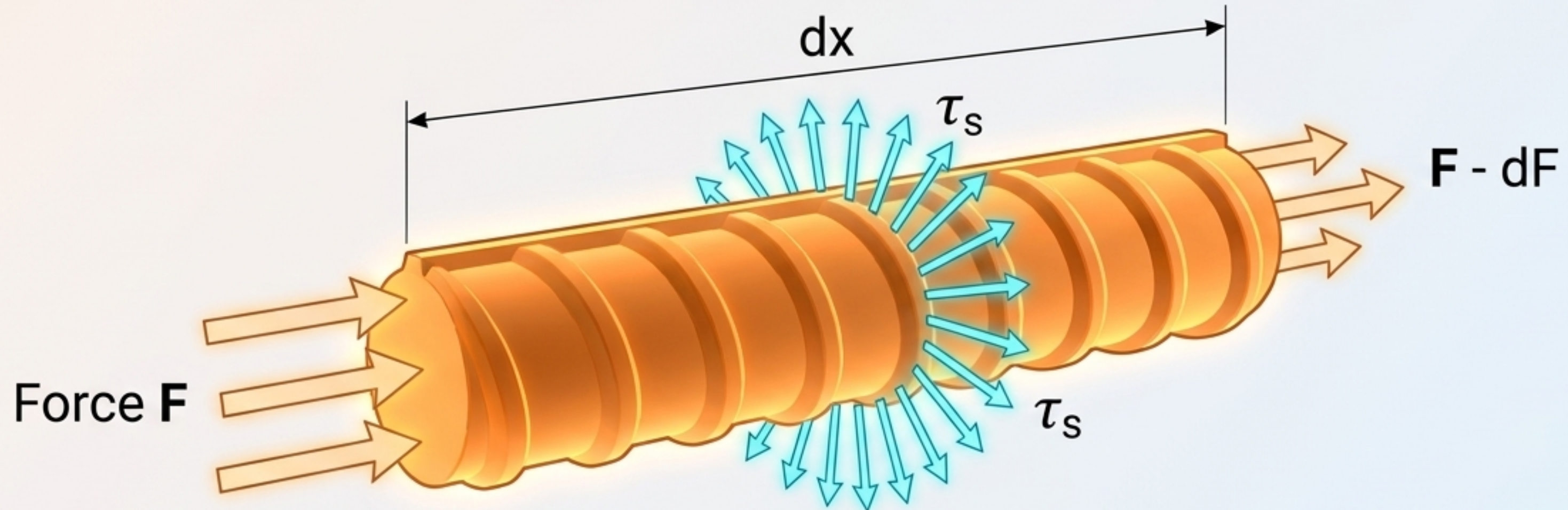
Failure Diagnostic Matrix

Tensile Fracture of Steel	Pull-Out Failure	Splitting Failure
		
Verdict: Perfect Anchorage Cause	Verdict: Avoid (Pull-Out) Cause	Verdict: Avoid (Splitting) Cause
Steel reaches yield/ultimate strength before bond fails. Anchorage length is sufficient.	Bond strength exceeded due to insufficient length, weak concrete, or poor bond conditions.	High bond stresses cracking concrete. Promoted by low cover, low concrete strength, or insufficient transverse reinforcement.

Adhesion Modifiers

HA bars, Rib geometry, Wide spacing, high f_{cj} , transverse compression, and adequate cover all increase bond resistance.

The Infinitesimal Equilibrium (dx)



$$\tau_s = \frac{\frac{dF}{dx}}{u}$$

Average bond stress (MPa) — τ_s

— $\frac{dF}{dx}$ Axial force gradient (tensile force transfer)

— u Effective perimeter of the steel (For isolated bar: $u = \pi \cdot \phi$)

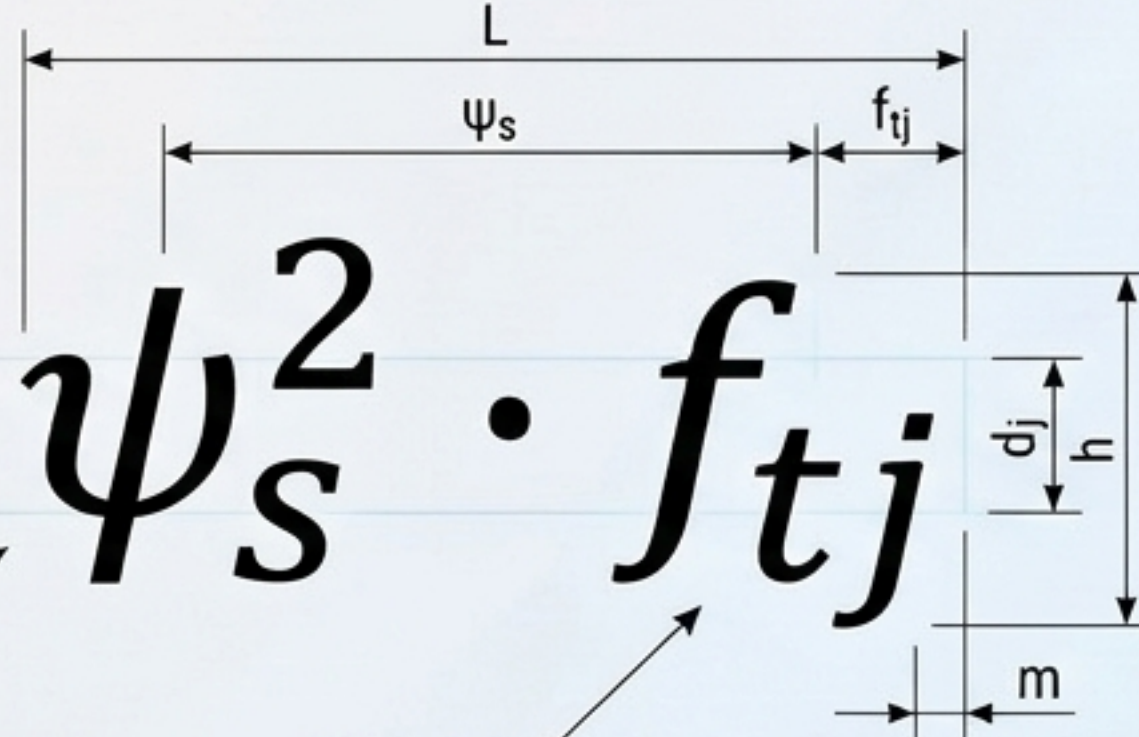
Key insight

A larger bar perimeter u provides a greater contact area, reducing the bond stress τ_s required to transfer a given force.

Limit Bond Stress Threshold (BAEL)

Overall Safety Factor:

Incorporates material variability and force transmission uncertainties.


$$\tau_{su} = 0.6 \cdot \psi_s^2 \cdot f_{tj}$$

Concrete Tensile Strength (MPa):

$$f_{tj} = 0.6 + 0.06 \cdot f_{cj}$$

Sealing Coefficient:

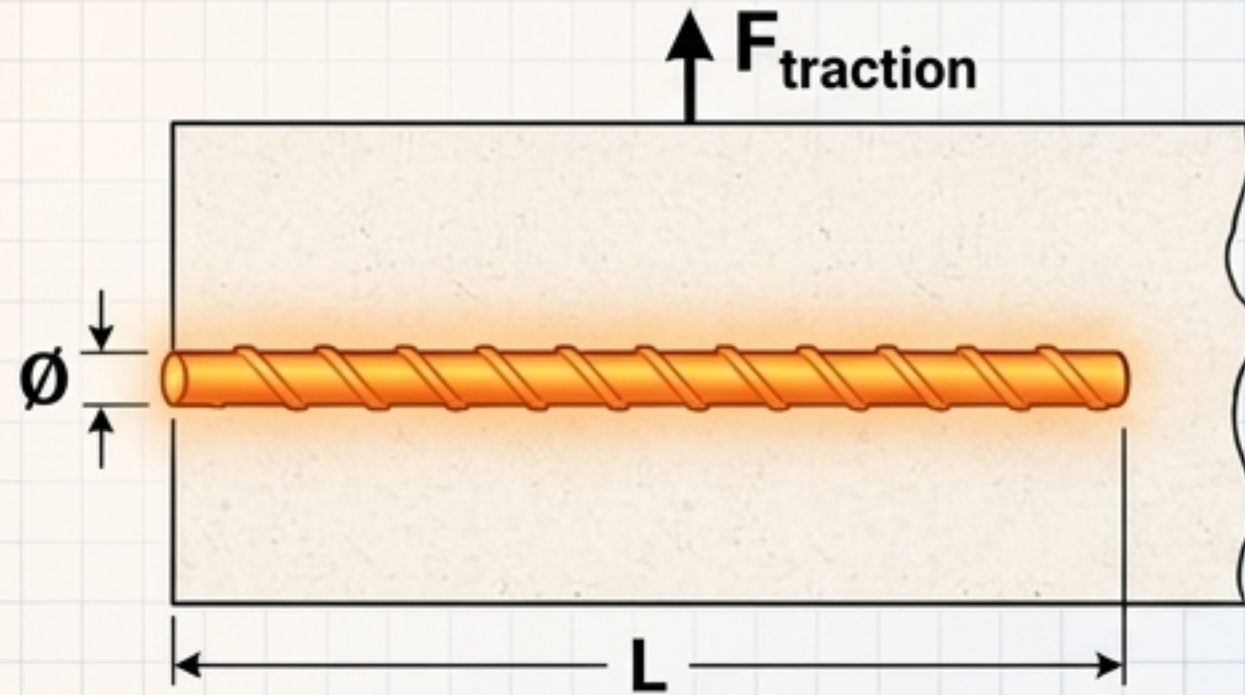
Smooth Steel = 1.0
(friction reliant)



HA Steel = 1.5
(mechanical interlocking)

Ultimate bond stress (τ_{su}) is the maximum allowable stress before slippage. It relies entirely on the steel's surface condition and the concrete's tensile strength.

Straight Anchorage (l_s)



$$\Rightarrow F_{\text{traction}} = F_{\text{adherence}}$$
$$\frac{\pi \varnothing^2}{4} \cdot f_e = \pi \varnothing \cdot l_s \cdot \tau_{su}$$

$$l_s = \frac{\varnothing \cdot f_e}{4 \cdot \tau_{su}}$$

Practical Design Standards (BAEL Rules of Thumb)



For HA Fe E 400 bars

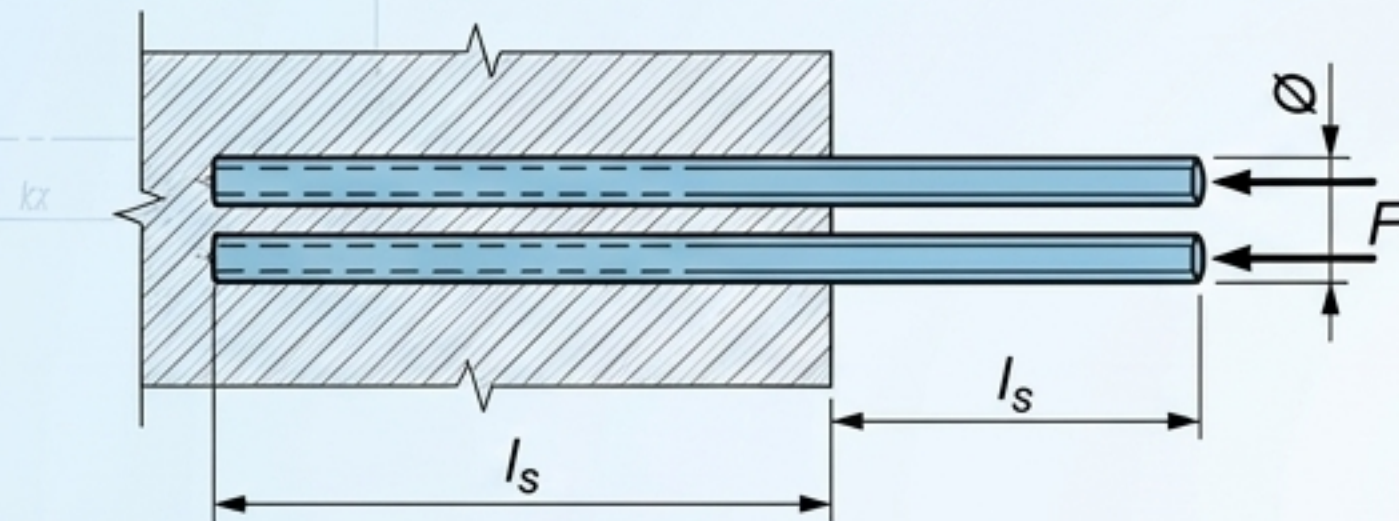


For HA Fe E 500 & Smooth bars

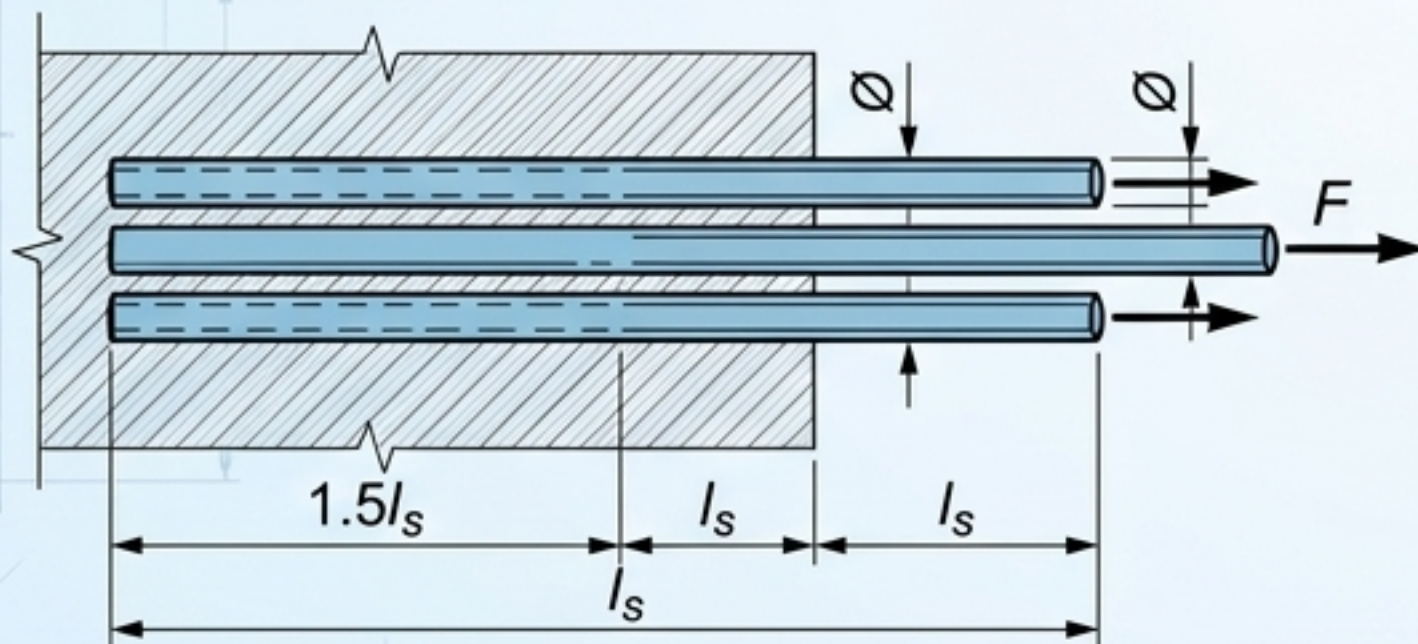
Required length l_s increases with bar diameter ($\varnothing$) and steel yield (f_e), but decreases as bond strength (τ_{su}) improves

Straight Anchorage for Bar Bundles

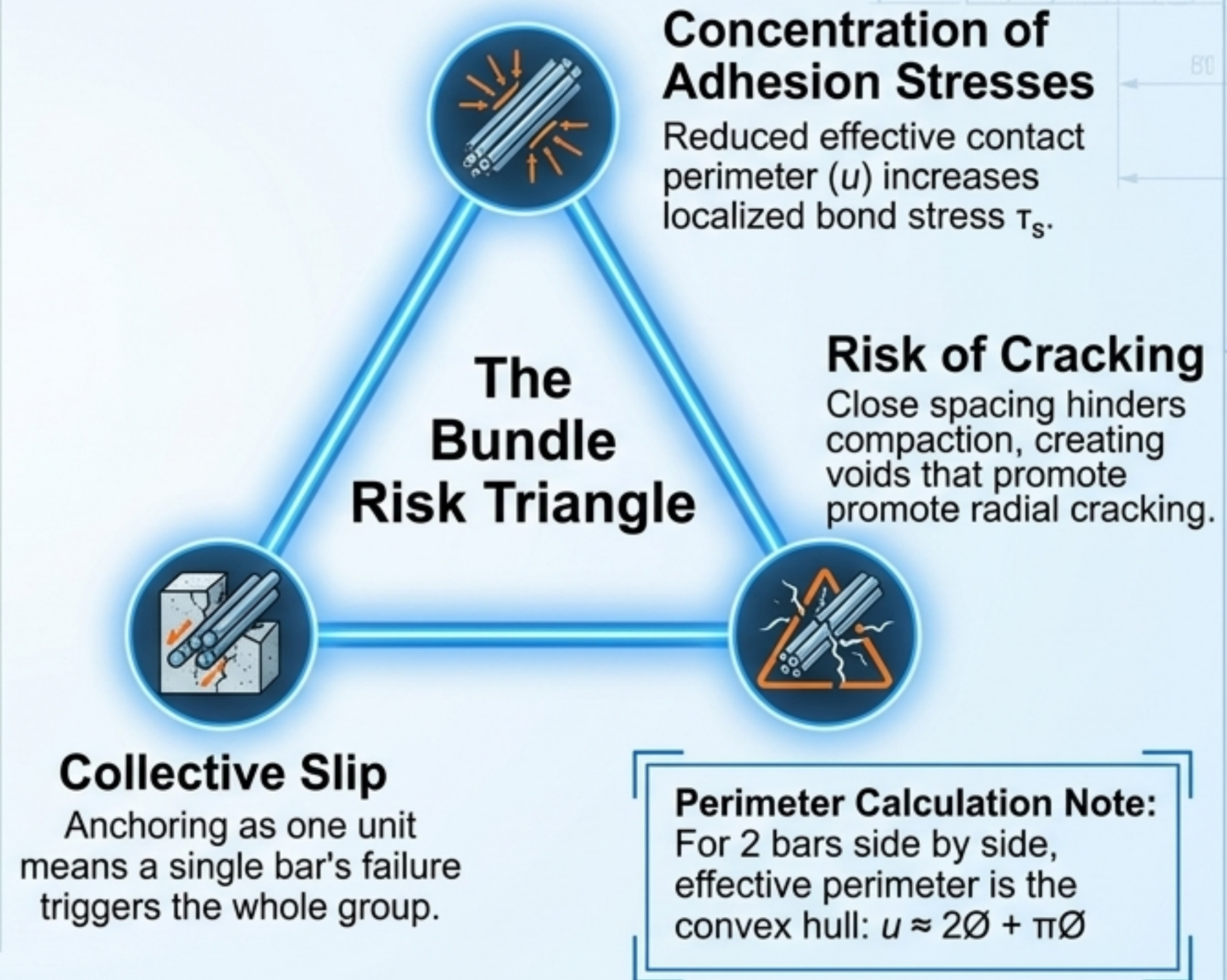
BAEL Article A.6.1.21 demands individual anchorage adjustments.



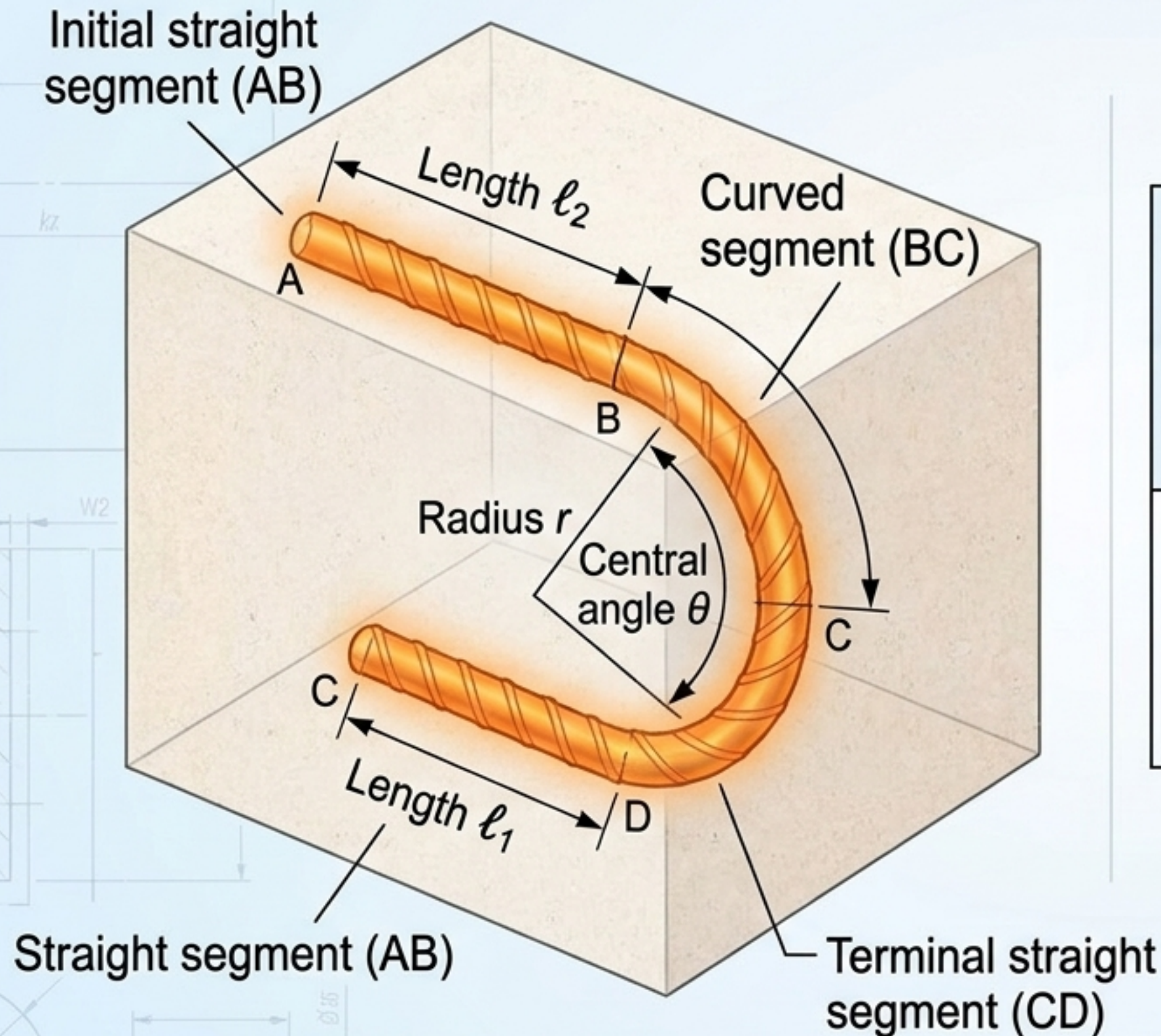
2-bars bundle



3-bars bundle



Curved Anchors (Hooks): Geometry & Constraints

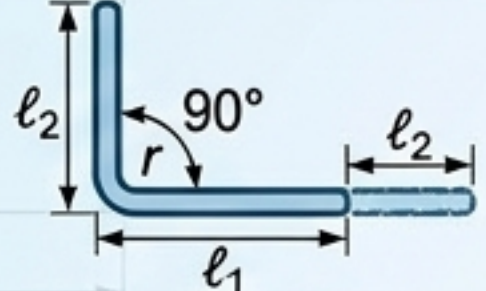
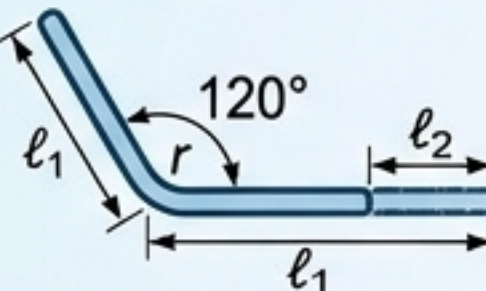
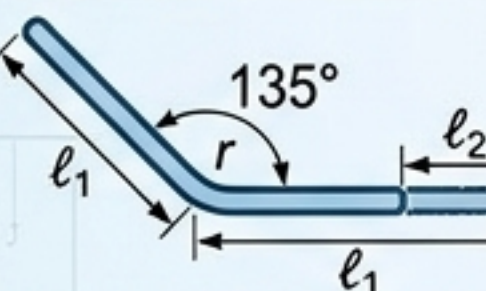
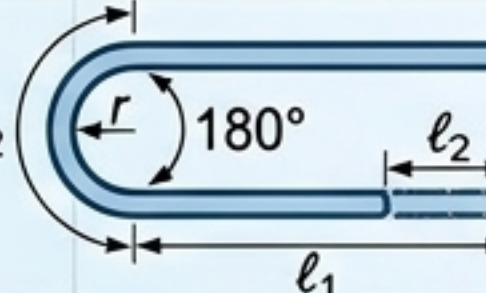


BAEL Minimum Bend Radius Matrix

1	Smooth Bars	Anchor hooks: $r \geq 3\emptyset$ (Due to brittleness/ cracking risk)	Frames/Stirrups: $r \geq 2\emptyset$
2	HA Bars	Anchor hooks: $r \geq 2\emptyset$ (Improved ductility)	Frames/Stirrups: $r \geq 2\emptyset$

Example: For HA bar $\emptyset = 12$ mm,
required hook radius $r \geq 24$ mm.

The Hook Efficiency Matrix (Table 3.2)

	$l_s = 1.87l_1 + l_2 + 2.19r$	Minimal Anchoring / Limited Stopping Effect
	$l_s = 2.31l_1 + l_2 + 3.28r$	Size/Strength Optimization
	$l_s = 2.57l_1 + l_2 + 3.92r$	Recommended Standard (Best Balance)
	$l_s = 3.51l_1 + l_2 + 6.28r$	Maximum Anchoring (Mechanical Locking Effect)

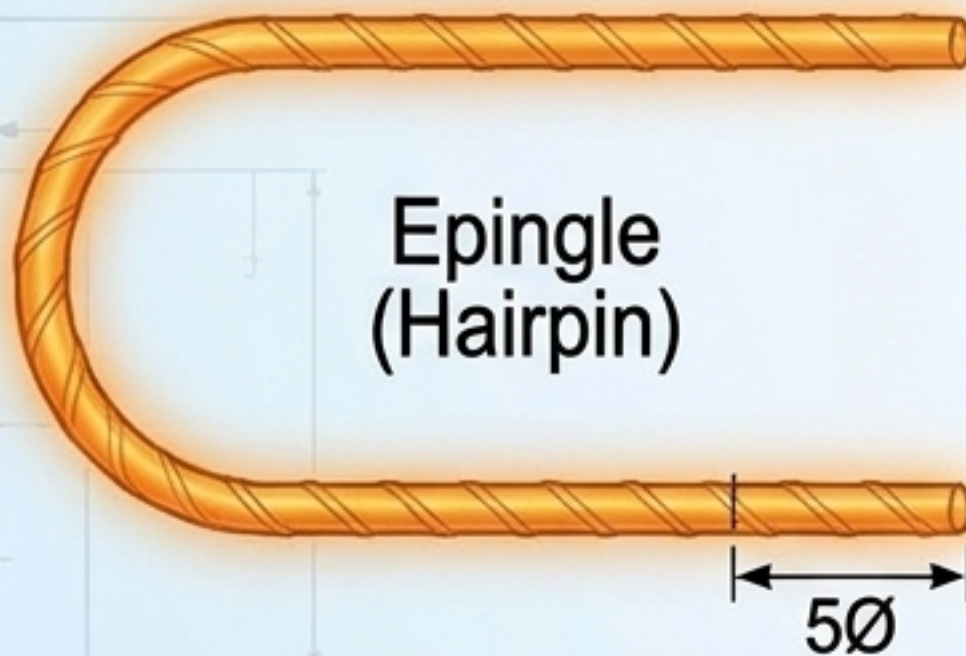
Efficiency Note: A 135° bracket calculation typically yields a ~30% reduction in required embedment length compared to a straight anchorage.

Transverse Reinforcement Anchorage

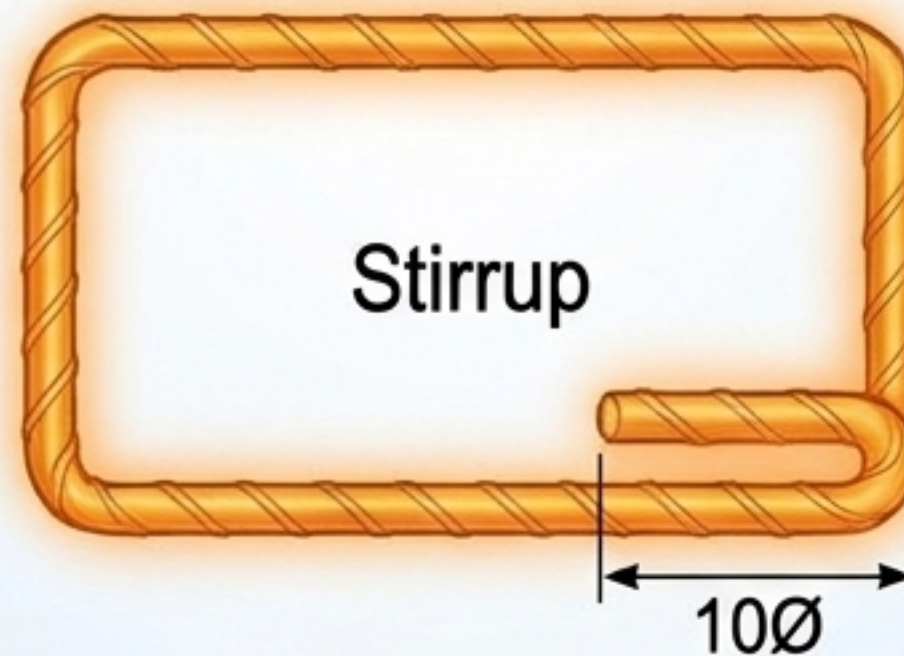
Stirrups, Ties, and Hairpins (BAEL A.6.1)

BAEL Rules Dashboard

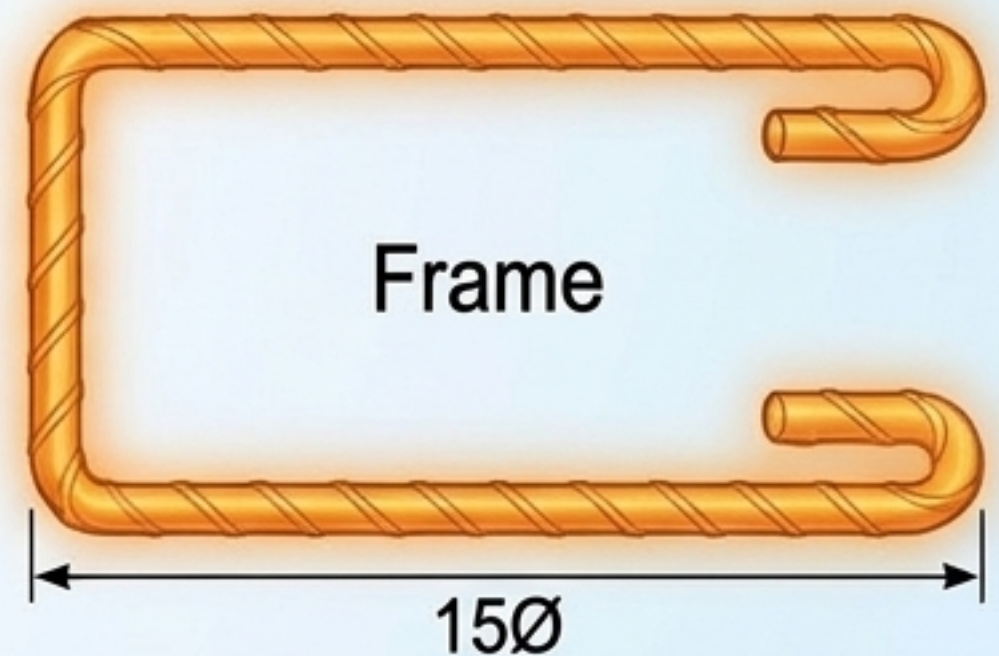
- 🔧 Bend Radius Constraint: $r \geq 2\emptyset$
- 📐 Deviation Limit: Anchorage plane cannot deviate $> \pi/8$ (22.5°) from main reinforcement plane.



180° (Full bend)
→ Return $\geq 5\emptyset$

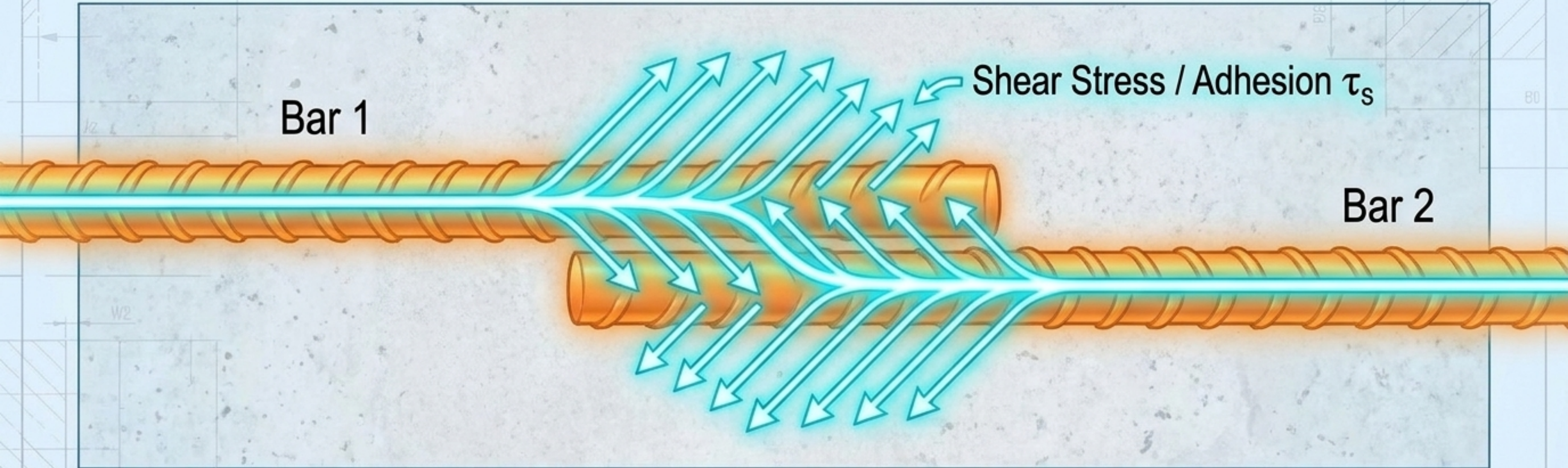


135° (Standard)
→ Return $\geq 10\emptyset$



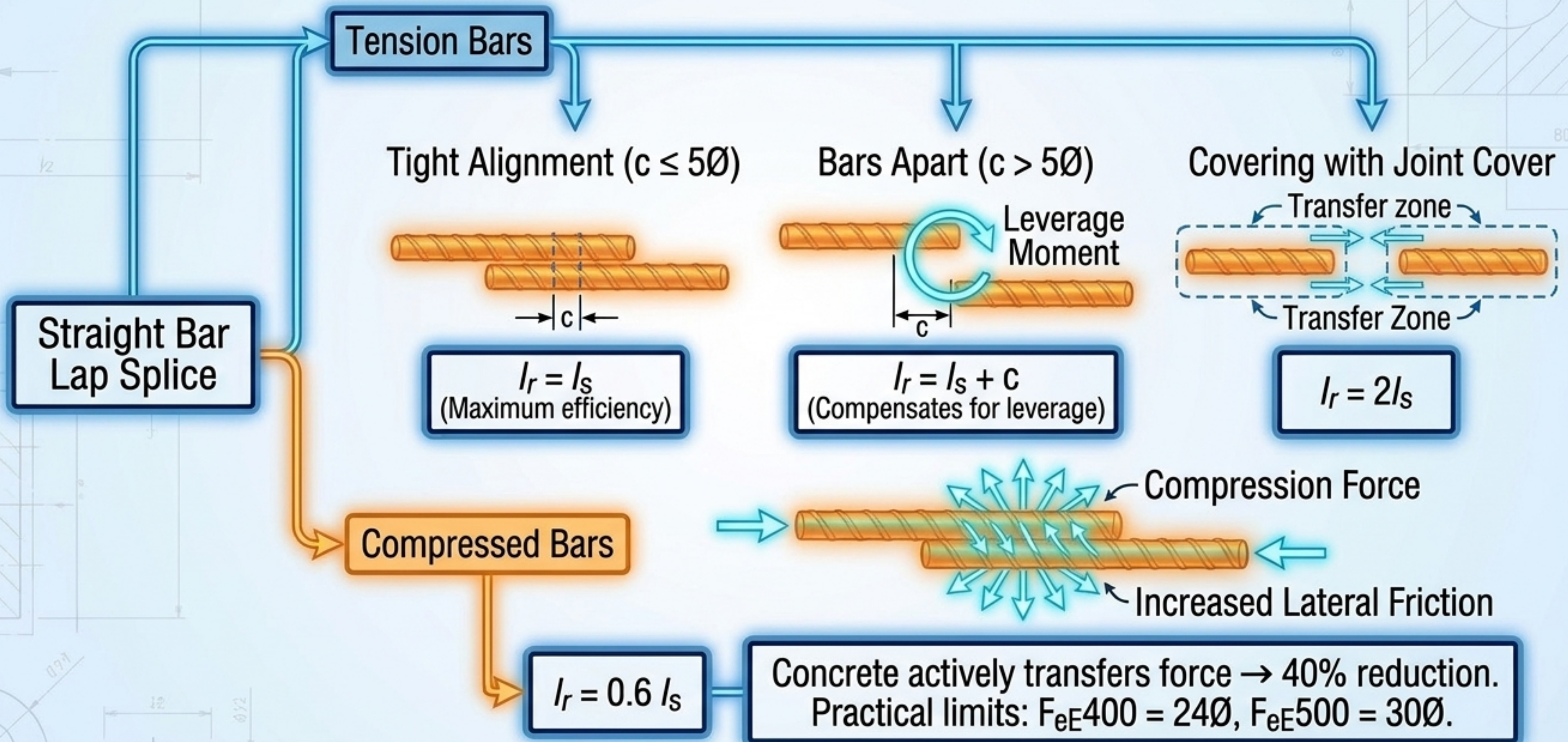
90° (Right angle)
→ Return $\geq 15\emptyset$

The Illusion of the Continuous Bar

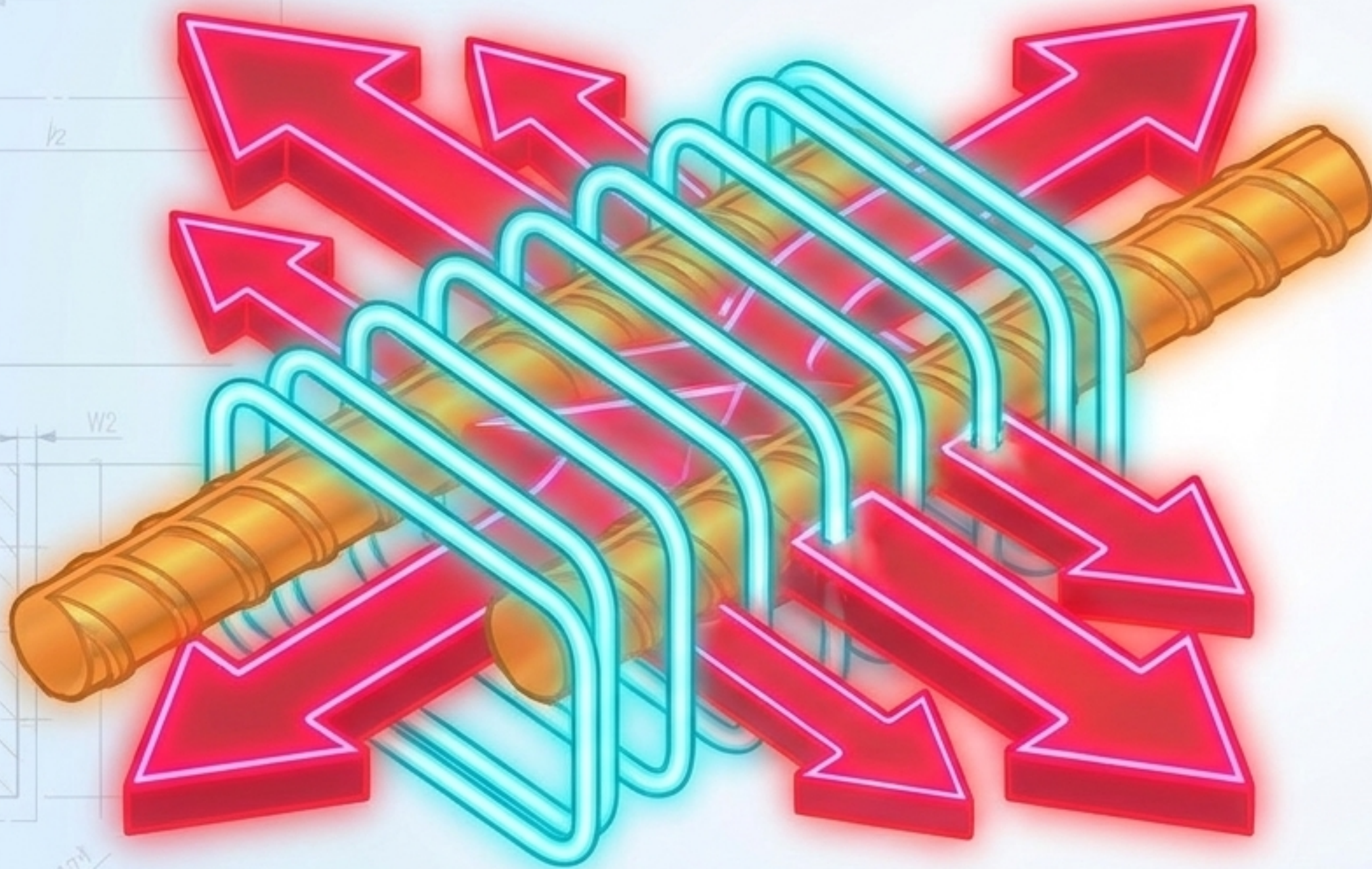


A reinforced concrete structure is rarely a single continuous piece of steel. It is a chain. Without the micro-adhesion principles (τ_s) acting as the 'glue' inside the concrete matrix, macroscopic lap splices are physically impossible. The concrete *is* the splice.

Lap Splices: Straight Bars Decision Matrix



Splice Confinement & Transverse Protection



Design Rule Box

Lap splices generate massive transverse tensile stresses that can explosively split the surrounding concrete.

$$\sum A_t \geq \sum A_s$$

Execution Note:
Choose smaller diameter seam reinforcements to ensure tightly distributed confinement throughout the entire seam.

Optimizing Splices: Normal Hooks (Table 3.5)

Hook Geometry Baseline



Radius: $r \geq 3\emptyset$ (Smooth) / $2\emptyset$ (HA) | Right Return: $\geq 5\emptyset$ | Angle: $\theta = 180^\circ$



Smooth Circles

High-Adhesion (HA) Steels (FeE400/500)

Tight Alignment ($c \leq 5\emptyset$)



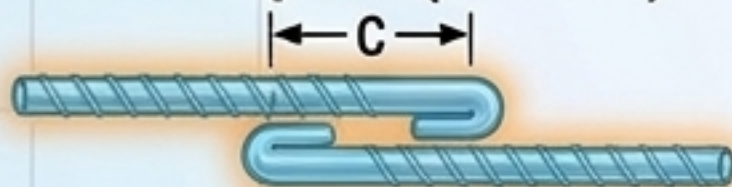
$$c \leq 5\emptyset \rightarrow l_r = 0.6 l_s$$

(Practical: $30\emptyset$)

$$c \leq 5\emptyset \rightarrow l_r = 0.4 l_s$$

(Practical: $16\emptyset$ for 400 / $20\emptyset$ for 500)

Bars Apart ($c > 5\emptyset$)



$$c > 5\emptyset \rightarrow l_r = 0.6 l_s + c$$

$$c > 5\emptyset \rightarrow l_r = 0.4 l_s + c$$

Physical Explanation: Why the massive reduction?

The normal hook creates a hard mechanical support point in the concrete, drastically decreasing reliance on linear friction (-40% compared to straight bars). HA bars drop this a further 33% due to their superior ribbed adhesion.