Composite Slabs

Failure modes and ultimate resistance

Steel–concrete composite structures



LEARNING GOALS

What makes a slab act compositely?

1 Recognize the failure mode

Connect the observed damage to the force path.

2 Calculate a flexural resistance

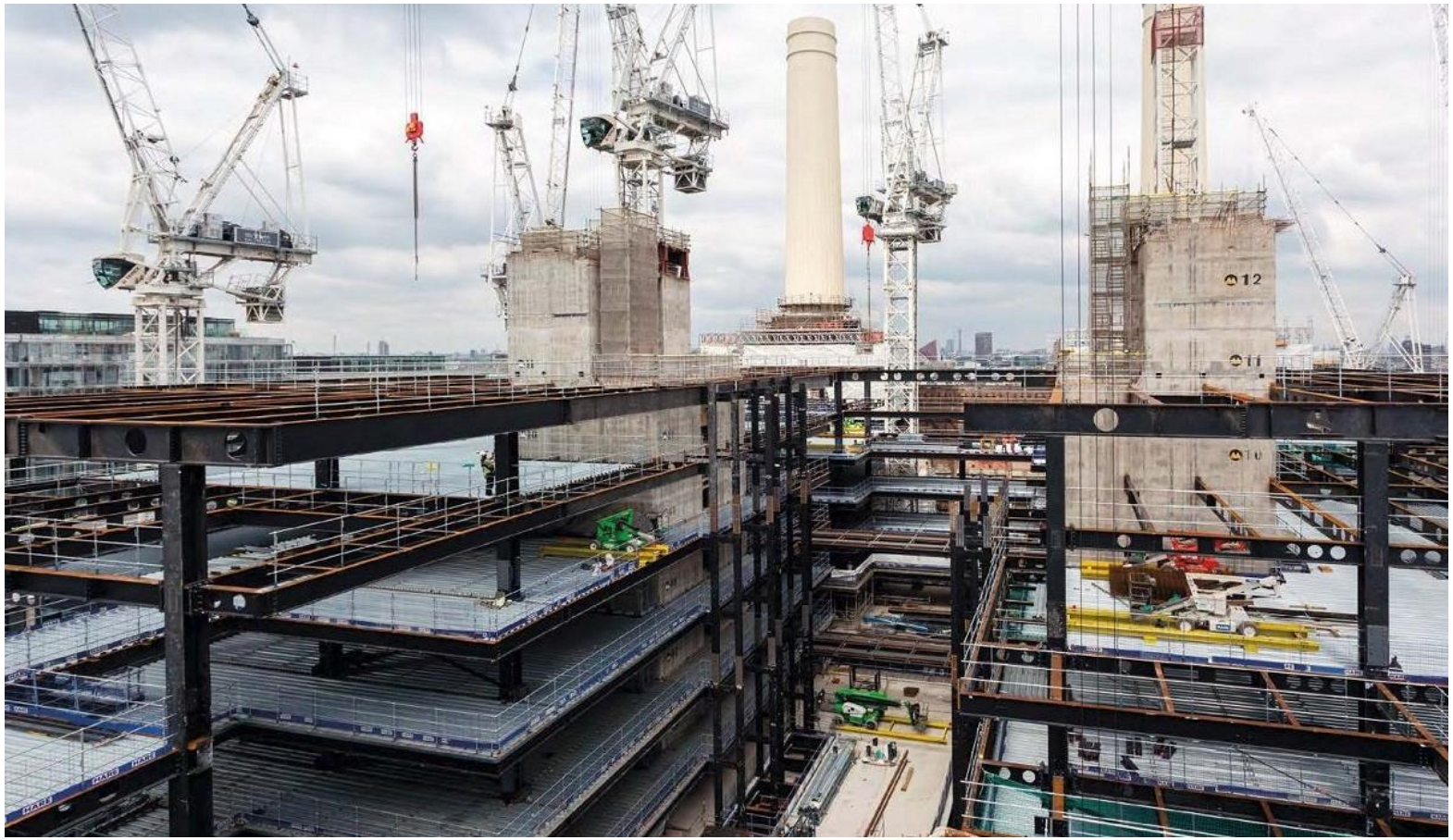
Use equilibrium, a stress block and a lever arm.

3 Check the interface

Identify when longitudinal shear limits the slab.

Think first: can stronger steel alone guarantee a stronger composite slab?

Battersea Power Station, London



New floor construction

Steel beams support metal decking in most new floor areas.

The design question

How does the floor carry load before and after concreting?

Components and load path



Floor load → slab strip → beams → columns

Concrete

Compression zone in sagging bending.

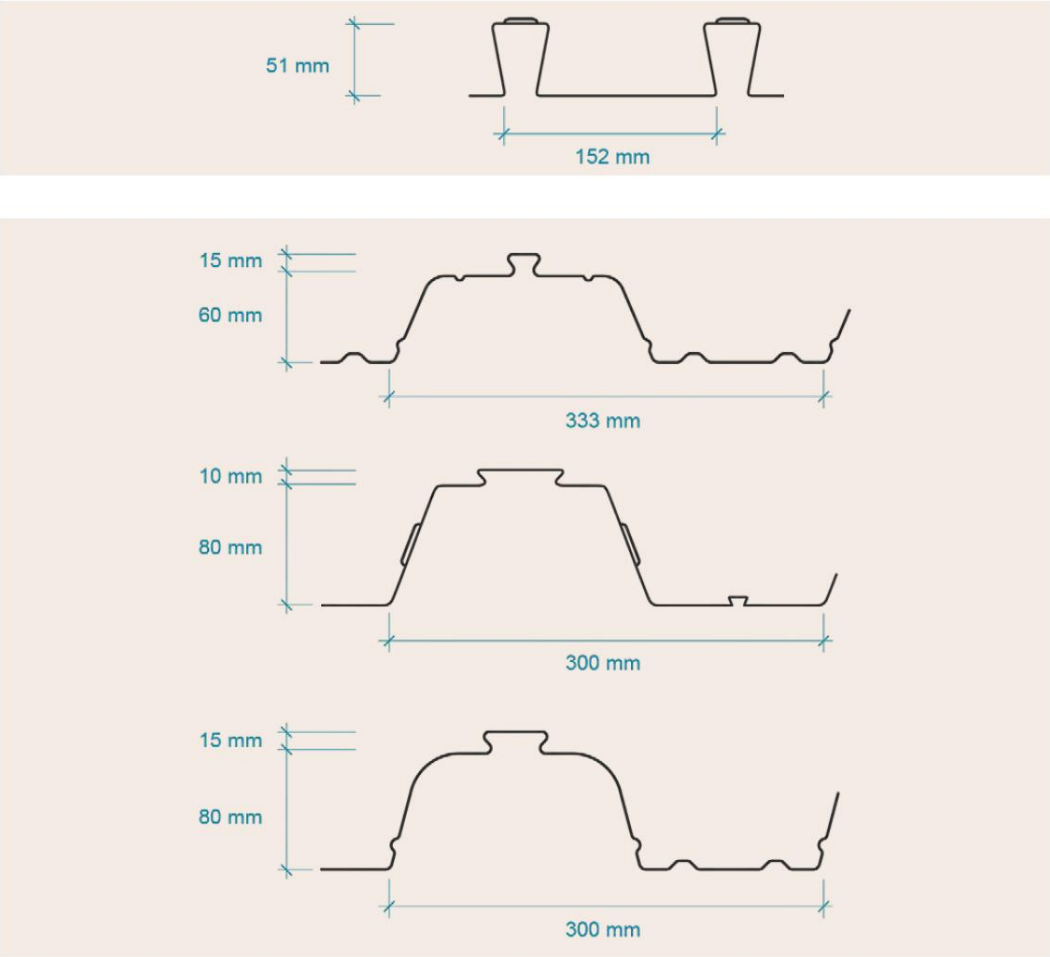
Profiled steel deck

Permanent formwork and tensile reinforcement.

Support beams

Receive the one-way slab reactions.

Deck profiles and mechanical interlock



Close-formed profile

The rib shape helps restrain separation.

Trapezoidal profile

Embossments and tested details provide interlock.

Profile geometry affects stiffness, resistance and bond behavior.

Two interfaces in a composite floor

Deck–concrete interface

Transfers longitudinal force within the slab.

Relevant check: slab longitudinal shear.

Beam–slab interface

Transfers force between the beam and slab.

Relevant check: beam shear connection.



One floor, two structural stages

Question	During concreting	After hardening
Load-carrying member	Steel deck, with props if specified	Composite slab
Concrete role	Fresh load on the deck	Compression material
Key concerns	Deck strength, deflection and stability	Flexure, interface shear and local actions

Construction history remains relevant after composite action develops.

Loads during concreting



Loads to include

Deck self-weight
Wet concrete
Workers and equipment

Propped and unpropped construction



Unpropped

The deck carries wet concrete over the construction span.

Propped

Props shorten the construction span. Removal transfers load.

Construction checks across the three systems

Common engineering checks	Code entry points
Bending and shear of the deck	China: JGJ 138, Ch. 13 + T/CECS 273
Support reactions and local effects	USA: ANSI/SDI SD-2022 + S1
Stability and construction deflection	Europe: EN 1994-1-1:2026, 10.5–10.6

Checkpoint: may we use composite flexural resistance during pouring?

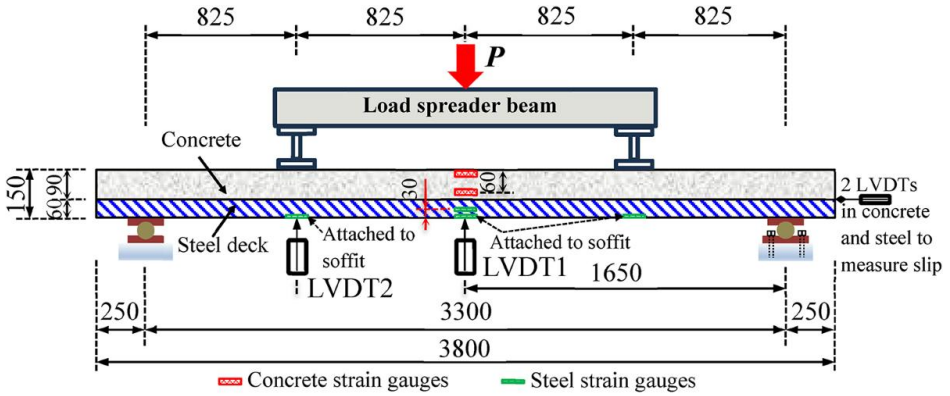
A full-scale slab test

What is measured?

Applied load
Midspan deflection
End slip
Strain and crack development

Why two-point loading?

It provides a bending region and defined shear spans.



(a)



(b)

Four possible ultimate failure modes

Mode	Where to look	Key evidence
Flexure	High-moment region	Yielding, compression damage, curvature
Longitudinal shear	Deck–concrete interface	Relative slip and loss of force transfer
Vertical shear	Across the slab depth	Diagonal cracking or web-related failure
Punching	Around a concentrated action	A local perimeter failure mechanism

Flexural cracking and failure

Sagging bending

The top concrete carries compression.
The deck carries tension.

Ultimate mechanism

Steel yielding and/or concrete compression can limit resistance.

Does a flexural crack identify the final failure mode?



(a) Flexural cracking



(b) Distributed flexural cracking-shear crack



(c) Distributed flexural cracking

Longitudinal shear failure





Visible symptom

Relative movement between the deck and concrete.

Structural consequence

The interface may limit the compressive force and bending resistance.

Why the shear span matters

$$M = VL_s$$

A shorter shear span

Higher shear force for the same bending moment.

A shorter transfer length

Less interface length may be available to develop force.

Geometry changes the competition between failure modes.

An ultimate-limit-state calculation

1 Define the system

Deck profile, span, supports and construction sequence.

2 Calculate the effects

Actions and combinations give bending moments and shear forces.

3 Calculate compatible resistances

Section resistance and interface resistance use one code basis.

4 Identify the governing check

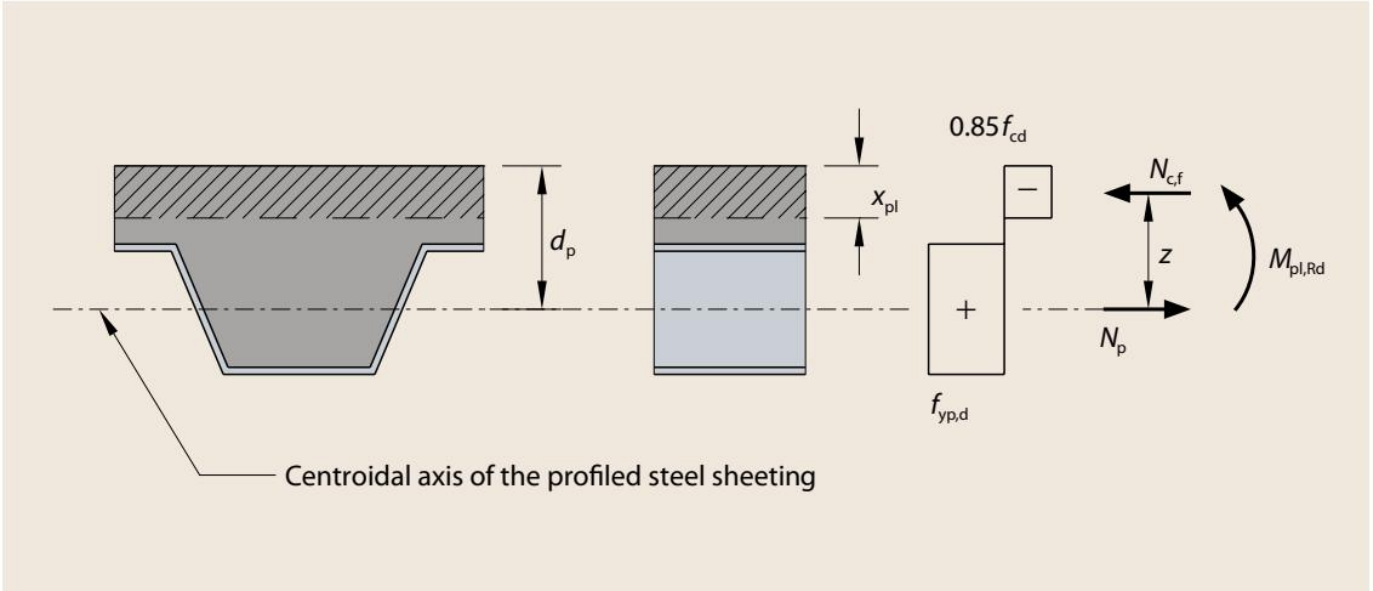
All relevant ultimate limit states must satisfy their criteria.

Safety formats across the three systems

System	Typical format	What must stay together
China	$S_d \le R_d$	Load combinations, material design values and code model
USA (LRFD)	$U \le \phi R_n$	SDI model, nominal resistance and resistance factor
Europe	$E_d \le R_d$	EN model, partial factors and National Annex

A factor from one system cannot repair an incompatible model from another.

Positive bending with full shear connection



Compression balances tension

$$N_{c,f} = N_p$$

Assumptions: full connection, suitable ductility, neutral axis above the deck.

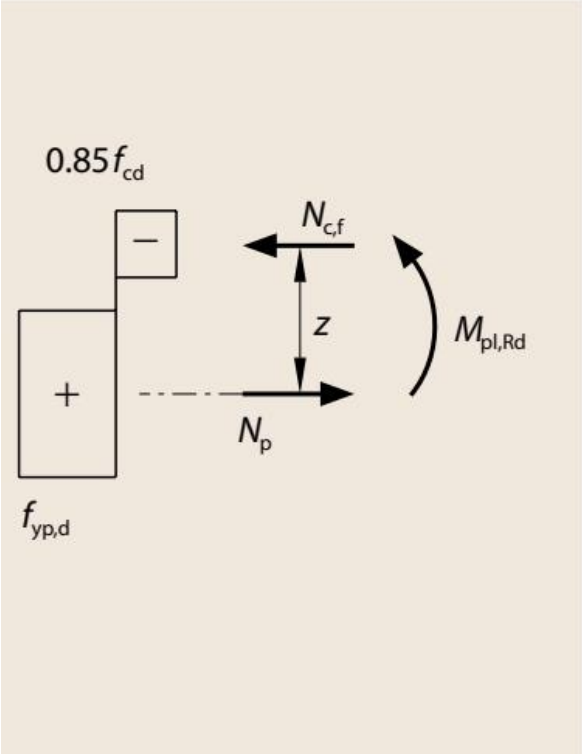
Force equilibrium and the lever arm

$$N_{c,f} = N_p = A_{pe} f_{yp,d}$$

$$x_{pl} = \frac{N_{c,f}}{0.85 f_{cd} b}$$

$$z = d_p - \frac{x_{pl}}{2}$$

$$M_{pl,Rd} = N_{c,f} z$$



Definitions

b	Strip width
x_{pl}	Compression-block depth
d_p	Depth to deck centroid
h_c	Concrete above the ribs

Validity check

$$x_{pl} \leq h_c$$

Worked example: full-connection bending

Assumed inputs, 1.00 meter strip

$b = 1000 \text{ mm}$

$h = 130 \text{ mm}, \quad h_c = 70 \text{ mm}$

$d_p = 100 \text{ mm}$

$A_{pe} = 1200 \text{ mm}^2$

$f_{yp,d} = 320 \text{ MPa}$

$f_{cd} = 20 \text{ MPa}$

$0.85 f_{cd} = 17 \text{ MPa}$

$$N_{c,f} = 384000 \text{ N} = 384 \text{ kN}$$

$$x_{pl} = \frac{384000}{0.85 \times 20 \times 1000}$$

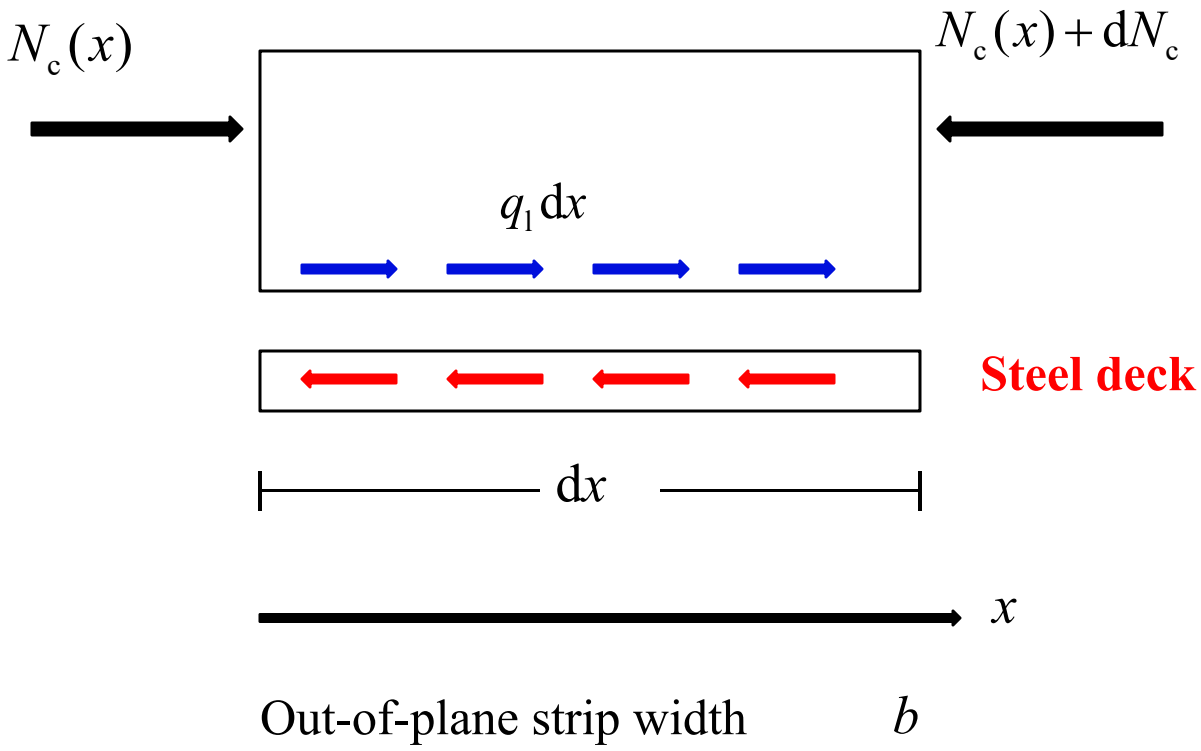
$$= 22.6 \text{ mm} < 70 \text{ mm}$$

$$z = 100 - \frac{22.6}{2} = 88.7 \text{ mm}$$

$$M_{pl,Rd} = 34.1 \text{ kN} \cdot \text{m/m}$$

The interface develops the concrete force

Concrete free body



Longitudinal equilibrium

$$N_c + q_1\,dx - (N_c + dN_c) = 0$$

$$q_1 = \frac{dN_c}{dx}$$

$$\tau = \frac{q_1}{b}$$

Interface shear transfers the change in concrete compression.

How the interface transfers force

Mechanical interlock

Embossments and re-entrant ribs restrain relative movement.

Friction and support effects

Their contribution depends on the model and test procedure.

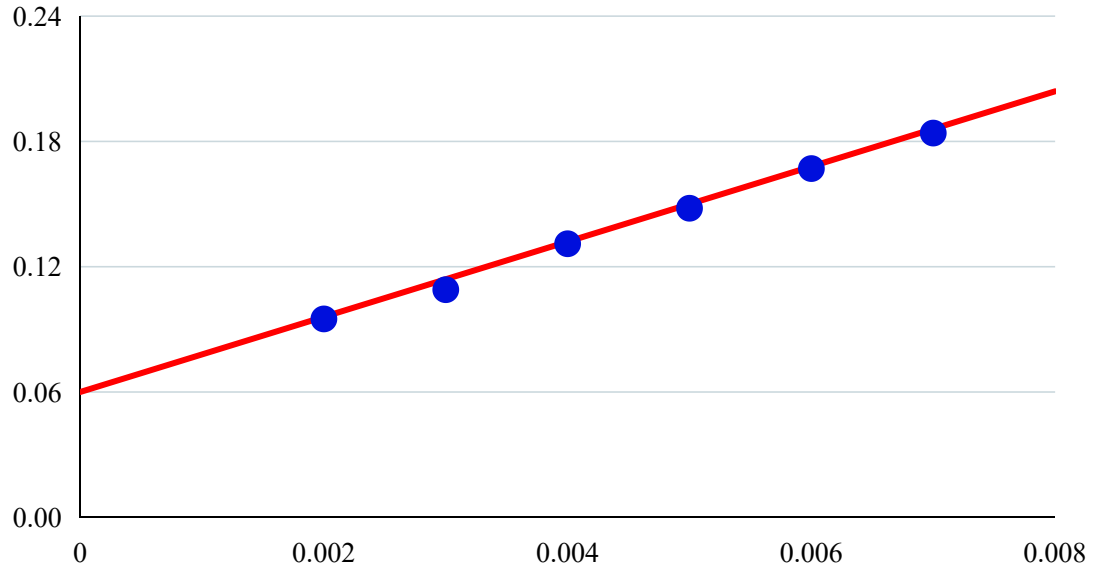
End anchorage

A verified detail may increase the force that can develop.

Design evidence must match the actual profile, materials and detailing.

m-k method: from tests to shear-bond resistance

Test calibration



$$X = \frac{A_p}{bL_s} \qquad Y = \frac{V_t}{bd_p}$$

$$Y = mX + k$$

Schematic data

Design shear-bond resistance

$$V_{l,Rd} = \frac{bd_p}{\gamma_{Vs}}\left(\frac{mA_p}{bL_s} + k\right)$$

$$V_{Ed} \le V_{l,Rd}$$

The resistance is a vertical shear force limited by longitudinal shear failure.

***m* and *k* - Use code-evaluated coefficients.**

End anchorage and force transfer



A verified end detail

May provide additional transfer when the code model permits it.

A complete load path

Check the connector, deck and concrete around the anchorage.

Vertical shear acts across the slab depth

$$V_{\mathrm{Ed}} \leq V_{\mathrm{Rd}}$$

Vertical shear

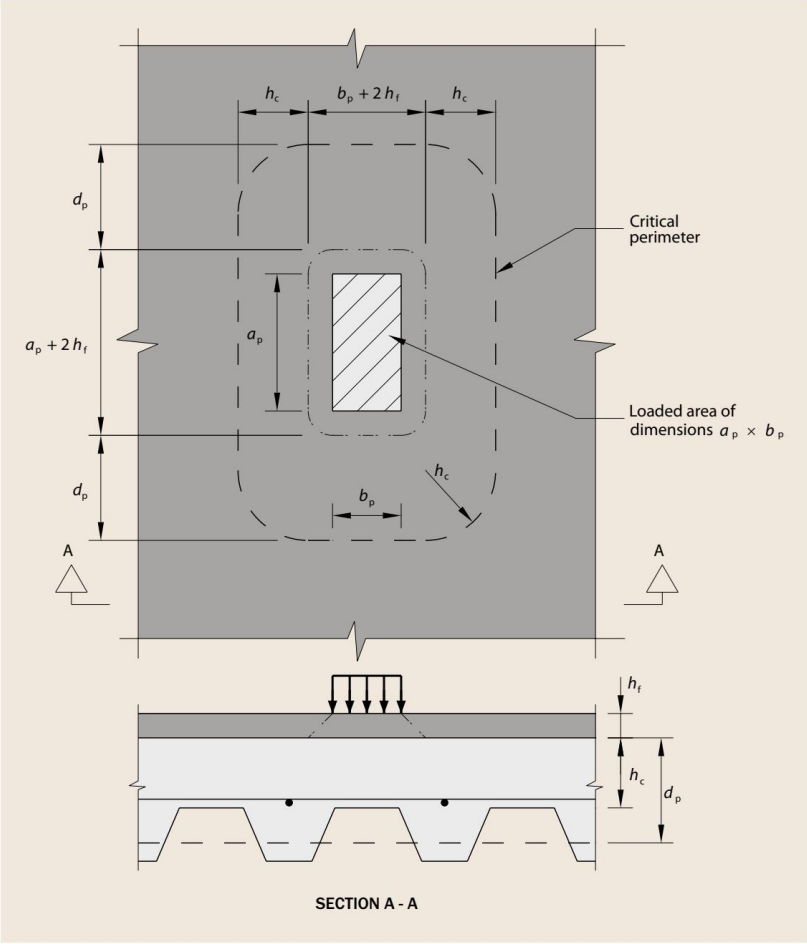
A force across the slab section.
Check near supports and concentrated actions.

Longitudinal shear

A force along the interface.
Check the transfer of concrete compression.

The two checks use different resisting mechanisms.

Punching around a concentrated action



A local failure mechanism

A concentrated load can cause failure around a critical perimeter.

Information required

Loaded area and load level
Effective concrete geometry
Nearby edges and openings

A complete set of ULS checks

Stage / action	Required verification
Construction	Deck bending, shear, support/local effects and stability
Composite slab bending	Sagging and hogging regions, with compatible connection
Interface force transfer	Longitudinal shear and any verified end anchorage
Local and transverse actions	Vertical shear, punching and load distribution

Class exercise: is the slab adequate?

Given, 1 m slab strip

Simply supported span	$L = 3.0\ \text{m}$
Design floor load	$q_{\text{d}} = 24\ \text{kN/m}^2$
Full-connection resistance	$M_{\text{pl,Rd}} = 34.1\ \text{kN} \cdot \text{m/m}$

Connection information

Required for full connection	$N_{\text{c,f}} = 384\ \text{kN}$
Available transfer force	$N_{\text{tr}} = 180\ \text{kN}$

1 Find the design moment. 2 State what is verified. 3 Identify the missing check.

What controls composite slab resistance?

The structural stage matters

The deck and the hardened composite slab carry load differently.

Flexural resistance needs equilibrium

The compression block and steel tension form the resisting couple.

The interface can govern

Available force transfer limits the sectional resistance.

Exit question: when might a thicker deck give only a small increase in resistance?

Standards used in this lecture

China

JGJ 138-2016, Chapter 13 and Appendix A
T/CECS 273-2024, Technical Specification for Composite Slabs

United States

ANSI/SDI SD-2022 with Supplement 1 (2026)
ANSI/SDI T-CD-2022, Test Standard for Composite Steel Deck-Slabs

Europe

EN 1994-1-1:2026, Chapter 10, with the applicable National Annex