LECTURE 3

Composite Slabs

Serviceability and complete slab design

Steel–concrete composite structures



Serviceability and a complete design

Explain serviceability

Deflection, cracking and vibration in a composite floor.

Calculate by construction stage

Track stiffness, sustained loads and installation time.

Complete a slab-strip design

Use one code basis and compare the other systems.

Can a slab pass its strength checks and still be unacceptable?

Floor performance after construction



Floor level

Permanent deformation affects levels and finishes.

Occupant comfort

The slab and supporting beams vibrate together.

Strength is one requirement.

Serviceability checks

Question	Response to assess	Acceptance basis
Will the floor remain usable?	Total and incremental deflection	Code and project limits
Will cracking be acceptable?	Crack width and detailing	Exposure and restraint
Will people feel discomfort?	Frequency and acceleration	Floor use and dynamic model

Each limit applies to a defined response, load case and time.

Current standards and project adoption

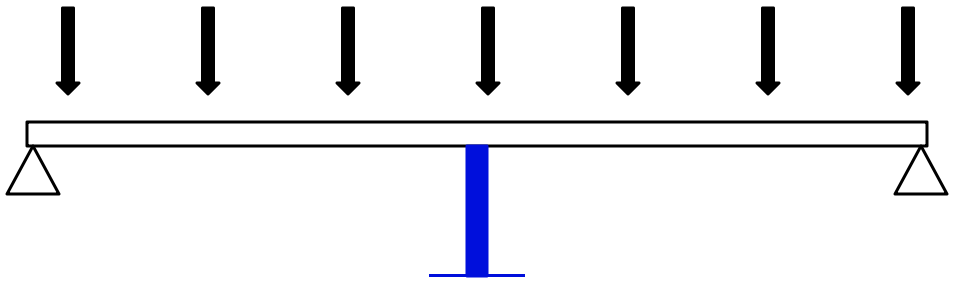
System	Latest relevant publications	Project decision
China	GB 55004-2021 JGJ 138-2016 T/CECS 273-2024	Mandatory general code plus applicable detailed rules
United States	ANSI/SDI SD-2022 + S1 ASCE/SEI 7-22	Check local adoption and product qualification
Europe	EN 1994-1-1:2026 Applicable National Annex	Check national transition and the adopted generation

A newly published standard is not automatically the project basis.

Construction history and deformation

During concreting

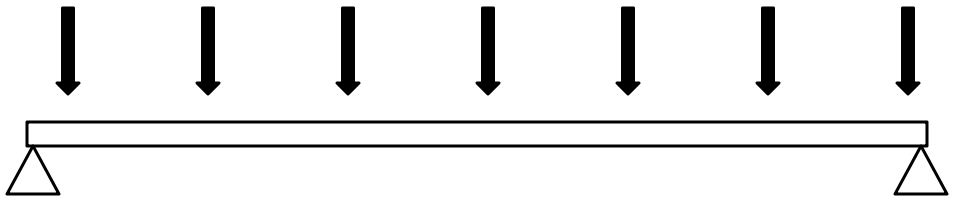
Wet concrete



Deck and temporary props

After prop removal

Transferred dead load



Composite slab over the full span

The load history determines which stiffness carries each increment.

Service load combinations

Standard combination

One variable gravity action

$$w_s = G_k + Q_k$$

Quasi-permanent combination

Sustained share of the variable action

$$w_q = G_k + \psi_q Q_k$$

Separate the construction dead load from loads added after hardening.

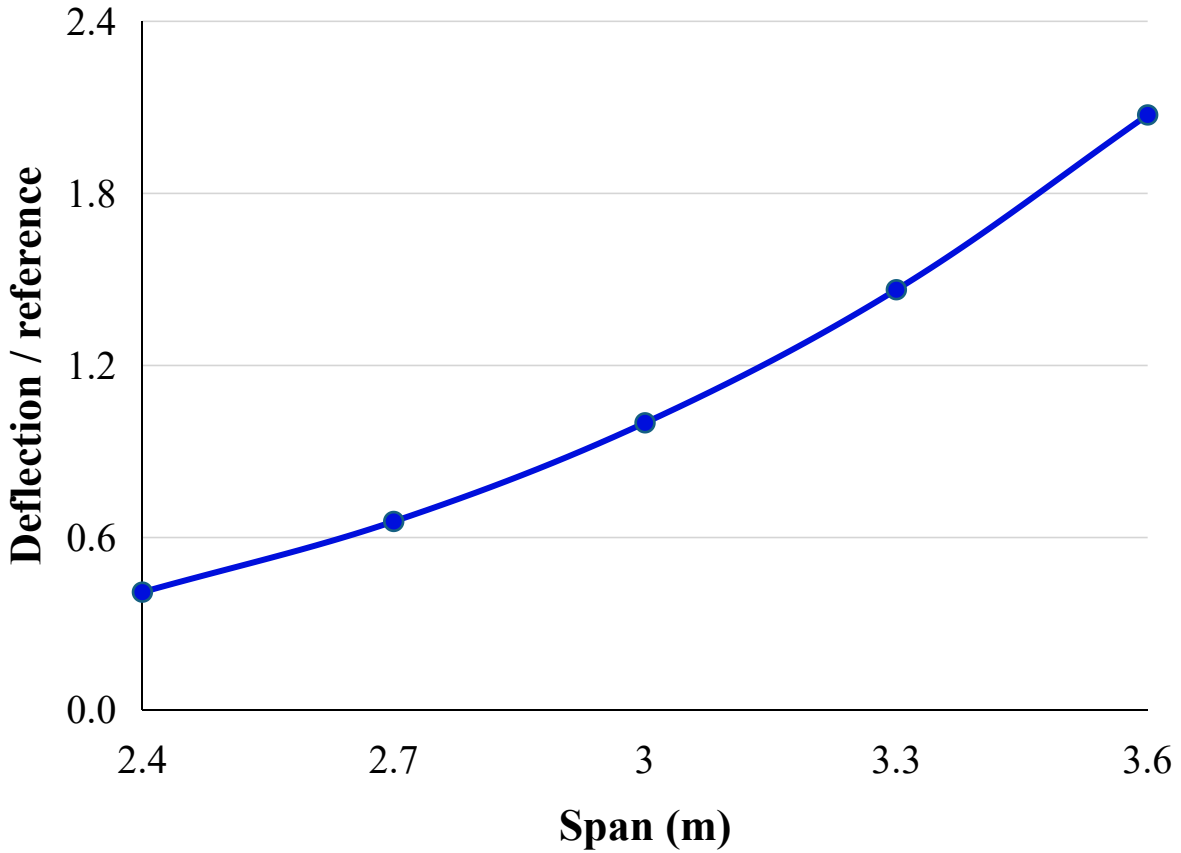
Use service combinations with the appropriate short- and long-term stiffness.

Deflection of a simply supported strip

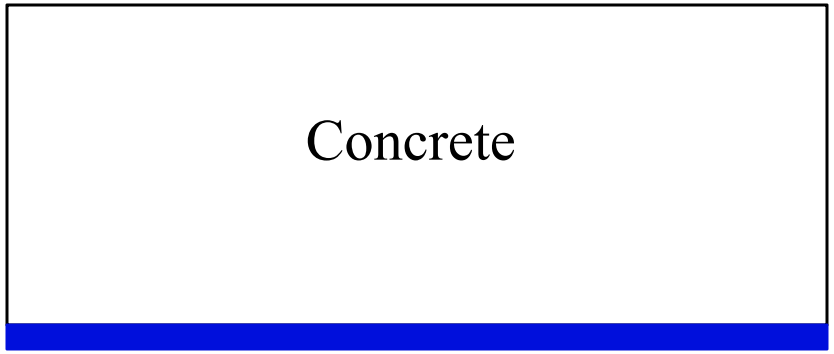
$$\delta = \frac{5wL^4}{384B}$$

$$B = EI$$

Span has a fourth-power effect when load and rigidity are fixed.



The transformed section



Elastic modular ratio

Transform steel into equivalent concrete area.

$$\alpha_{\mathrm{E}} = \frac{E_{\mathrm{a}}}{E_{\mathrm{c}}}$$

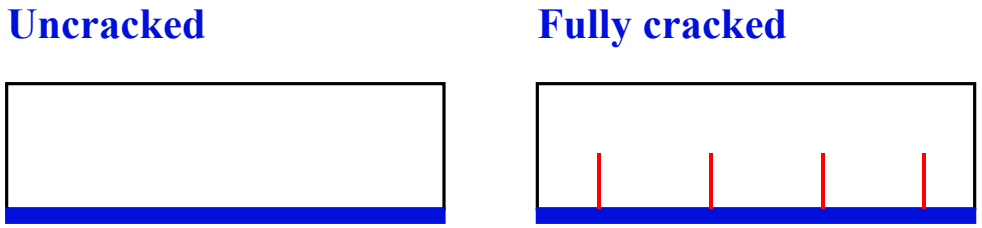
$$A_{\mathrm{eq}} = \alpha_{\mathrm{E}} A_{\mathrm{a}}$$

The elastic neutral axis differs from the plastic neutral axis.

Cracked and uncracked stiffness

The code adopts an effective stiffness between uncracked and fully cracked idealizations.

Why use an average?



Concrete between cracks still carries tension.
The 1/2 weighting is an empirical equivalent, not a cracked-length ratio.

$$B_s = E_c \frac{I_{u,s} + I_{c,s}}{2}$$

Positive bending with $x \le h_c$; tensile concrete is omitted.

Cracked section calculation

$$\frac{bx^2}{2} = nA_a(h_0 - x)$$

$$I_{c,s} = \frac{bx^3}{3} + n\left[I_p + A_a(h_0 - x)^2\right]$$

b: width; x: neutral-axis depth
h_0: depth to the deck centroid; $n = E_a/E_c$
A_a: deck area; I_p: deck centroidal inertia

Long-term stiffness

Sustained stress causes concrete creep. The steel remains approximately elastic.

Short term

$$n = \frac{E_a}{E_c}$$

Use the initial concrete modulus and the short-term neutral axis.

$$B_l = \frac{E_c}{2}\frac{I_{u,l} + I_{c,l}}{2}$$

Long term

$$E_{c,eff} = \frac{E_c}{2}, \qquad n_l = \frac{E_a}{E_{c,eff}} = 2n$$

Steel becomes relatively stiffer. Recalculate the neutral axis and both section inertias.

$$\frac{B_l}{B_s} = 0.778 \quad \text{(example)}$$

The concrete softens; the steel contribution is retained.

Time-dependent deflection

China	United States	Europe
Recalculate the transformed section for long-term effects.	Add time-dependent deflection of sustained loads.	Use the adopted EC4 method and National Annex.
Long-term section rigidity	SD-2022 F10.2.1 5 years or more: factor 2.0	Keep code generation and material models consistent.

$$\delta_{\text{final,sust}} = (1+\lambda)\delta_{\text{i,sust}}$$

The SDI factor is an additional deflection, not the total multiplier.

How shrinkage adds slab deflection

Differential free strain



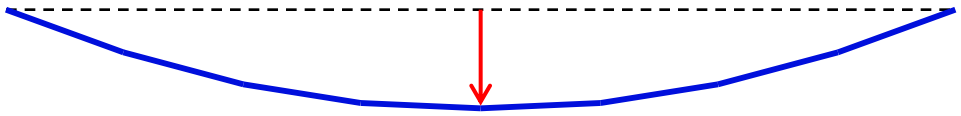
Bonded steel deck

Concrete tends to shorten.
The deck restrains its free shrinkage.

Uniform free shrinkage of an unrestrained homogeneous strip causes shortening only.

Compatibility creates curvature

Restraint stresses act at different depths. Their eccentric action creates curvature, which changes the slab deflection.



Given constant curvature, simply supported

$$\delta_{sh} = \frac{\kappa_{sh} L^2}{8}$$

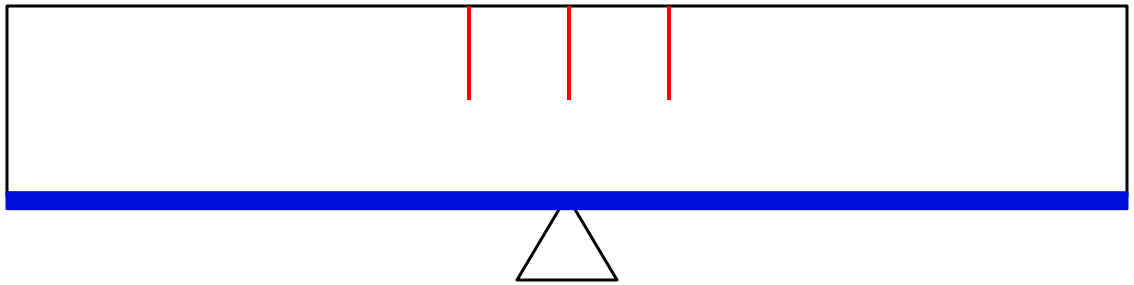
Shrinkage can add deflection without additional gravity load.

Service-stage deflection criteria

Criterion	What must be defined?
China: general slab limit below 7 m	Span/200, with the required load combinations A stricter project requirement may govern.
USA: SD-2022 commentary	Span/360 is a common live-load recommendation. F10 does not impose one universal numerical limit.
Finish-sensitive project criterion	Deflection occurring after installation State the time datum and acceptable increment.

Total deflection and finish-sensitive deflection are different quantities.

Crack control



Top reinforcement over a support

China: dry indoor exposure

Maximum force-induced crack width

$$w_{max} \leq 0.30 \text{ mm}$$

Other conditions: 0.20 mm

A mesh area check alone is not a calculated crack-width check.

Floor vibration

$$f_1 = \frac{\pi}{2L^2}\sqrt{\frac{EI}{\mu}}$$

A slab-strip frequency

An idealized beam model, not a floor-system acceptance test.

Office floor: Chinese criterion

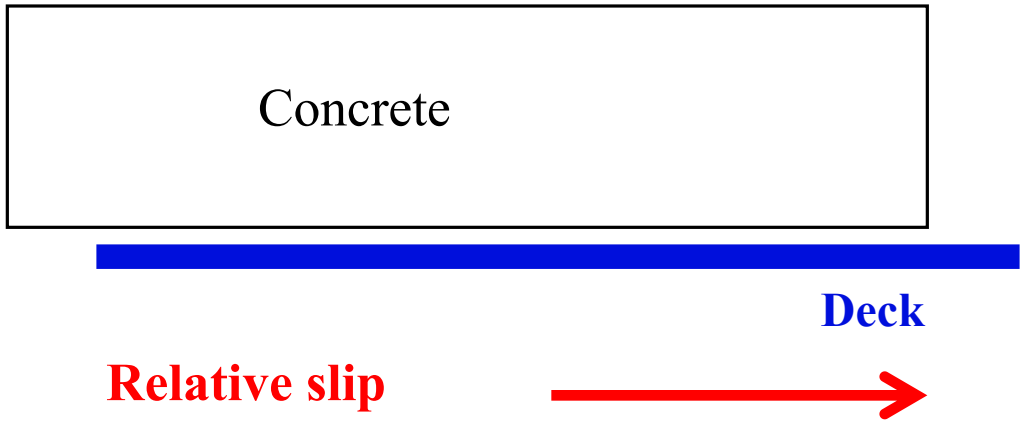
Evaluate the floor-system peak response.

$$\frac{a_p}{g} \le 0.005$$

Use the actual floor mode, modal mass and damping.

Interface slip increases deflection

Interface behavior determines whether transformed-section stiffness is applicable.



Full interaction

Bond transfers longitudinal shear.
Steel and concrete share compatible strains.

Partial interaction

Slip reduces composite action.
The same load produces more deflection.

Check both bond resistance and service stiffness.

Example: the stated configuration permits the given full-interaction stiffness.

DISCUSSION

Checkpoint before the design example

Statement A

A higher ultimate resistance guarantees a smaller service deflection.

Statement B

The Chinese long-term rigidity is always half the short-term rigidity.

Statement C

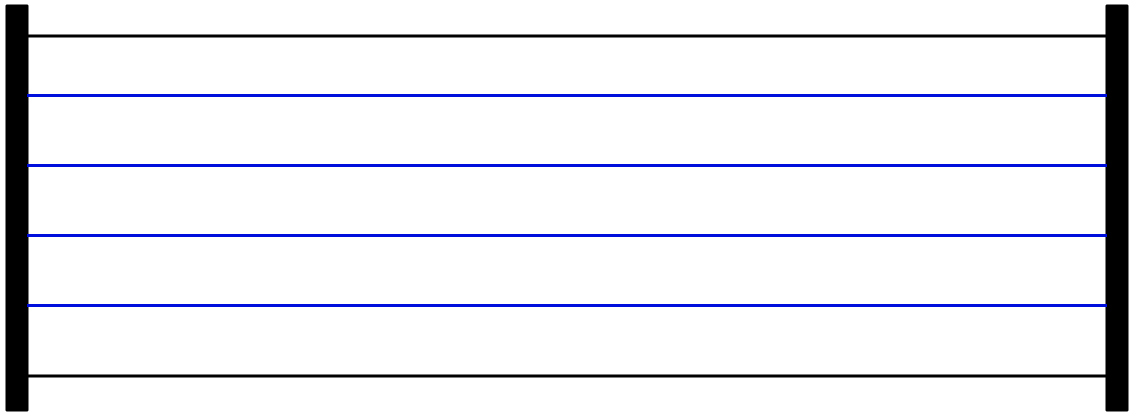
A satisfactory slab-strip frequency proves that the whole floor is comfortable.

Which statement is valid? Explain the missing condition.

A 3 m office slab strip

Plan of the design strip

1 m strip width



3 m between supports

Geometry

Total depth: 130 mm
Concrete above ribs: 70 mm
Depth to deck centroid: 100 mm

Construction

One temporary support at midspan.

Assumed teaching dataset for a defined gravity-load case.

Materials and design evidence

Input	Value for this example
Concrete C30	Design compression: 14.3 MPa Design tension: 1.43 MPa, modulus: 30 GPa
Profiled steel S350	Design strength: 290 MPa, modulus: 190 GPa
Deck section per metre width	Area: 1200 mm^2, effective inertia: 0.70 × 10^6 mm^4
Given design capacities	Deck bending: ±3.00 kN·m/m Longitudinal shear-bond: 18.0 kN/m
Qualified service model	Section stiffness and interface behavior valid for the stated configuration

Use the material strengths and product evidence of the selected code basis.

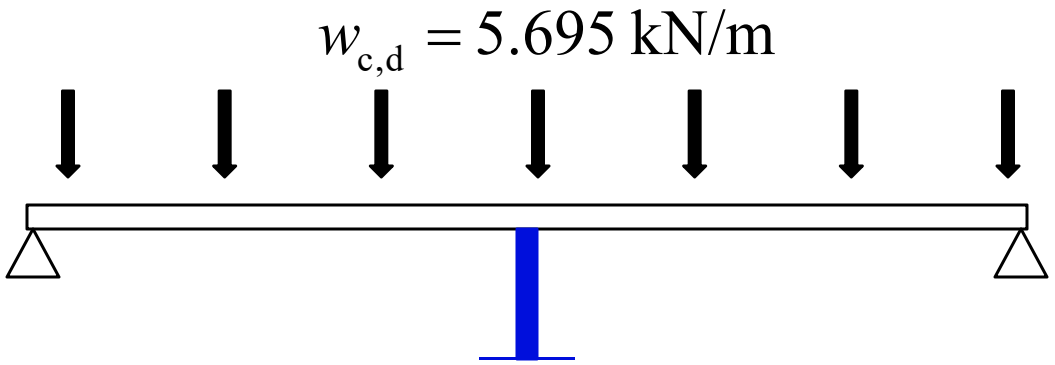
Loads and construction sequence

Action	Area load	When it acts
Construction dead load	2.65 kPa	Deck, wet concrete and related permanent load
Added permanent load	1.50 kPa	Finishes, fixed partitions and services
Office live load	3.00 kPa	Use stage, quasi-permanent factor 0.40
Construction live load	1.50 kPa	Removed before final service conditions

$$w_d = 1.3(2.65 + 1.50) + 1.5(3.00) = 9.895 \text{ kN/m}$$

One metre of slab width converts the area load to the strip line load.

Construction strength with a central prop



Two construction spans of 1.5 m

Positive bending and uplift:
one-span loading envelope

Check	Demand	Given capacity
Negative moment	1.60	3.00
Positive moment	1.23	3.00
Prop-line reaction	10.68	12.00
One-side shear	5.34	10.00
End uplift restraint	0.534	1.00

Moments: kN·m/m Forces: kN/m

Verify both full-span and staged-pour loading.

Construction deflection

$$B_c = E_a I_p = 0.133 \times 10^{12} \text{ Nmm}^2$$

All construction load

Conservative simply supported subspan model

$$\delta_{c,total} = 2.06 \text{ mm} < 8.33 \text{ mm}$$

Permanent load only

Exposed underside criterion

$$\delta_{c,G0} = 1.31 \text{ mm} < 3.75 \text{ mm}$$

Carry the permanent construction deformation into the service history.

Composite flexural resistance

$$N_c = A_a f_a = 348\ \text{kN}$$

Chinese material design strengths

$$x_{pl} = \frac{348000}{1000 \times 14.3} = 24.34\ \text{mm}$$

$$x_{pl} < h_c$$

$$M_{Rd} = N_c \left(h_0 - \frac{x_{pl}}{2} \right) = 30.57\ \text{kN} \cdot \text{m/m}$$

$$M_{Ed} = 11.13\ \text{kN} \cdot \text{m/m} < M_{Rd}$$

Check the interface next.

Shear and support resistance

$$V_{\text{Ed}} = \left[1.3(\gamma G_0 + G_1) + 1.5Q\right]\frac{L}{2} = 12.90\ \text{kN/m}$$

$$R_{\text{support}} = w_{\text{d}} L / 2 = 14.84\ \text{kN/m}$$

Check	Demand (kN/m)	Resistance (kN/m)	Utilization
Longitudinal shear-bond	12.90	18.00 (given)	0.717
Vertical shear	12.90	40.04	0.322
Permanent support bearing	14.84	25.00 (given)	0.594

$$V_{\text{v,Rd}} = 0.7 f_{\text{t}} b_{\text{min}} h_0 = 40.04\ \text{kN/m}$$

Bond governs the stated shear checks.

Short- and long-term section rigidity

Section property	Short term	Long term
Modular ratio	6.333	12.667
Uncracked inertia (10^6 mm^4)	61.982	90.213
Cracked inertia (10^6 mm^4)	50.498	84.695
Average inertia (10^6 mm^4)	56.240	87.454

$$B_s = 1.687 \times 10^{12} \text{ Nmm}^2 \qquad B_l = 1.312 \times 10^{12} \text{ Nmm}^2$$

Recalculate the section when the modular ratio changes.

Staged service deflection

$$\gamma = 0.625, \qquad \delta_{c,G0} = 1.31\ \text{mm}$$

Standard combination, immediate composite response

$$\delta_s = \delta_{c,G0} + C_s(\gamma G_0 + G_1 + Q) = 5.16\ \text{mm}$$

Quasi-permanent combination, long-term response

$$\delta_q = \delta_{c,G0} + C_l(\gamma G_0 + G_1 + \psi_q Q) = 4.82\ \text{mm}$$

The two results contain different fractions of live load.

Peak deflection on a long-term background

Contribution	Deflection
Quasi-permanent long-term background	4.816 mm
Additional transient live load	1.125 mm
Residual shrinkage, given analysis input	1.500 mm
Final peak for the stated history	7.441 mm

$$\delta_{\text{peak}} = \delta_{\text{q}} + C_{\text{s}}(1-\psi_{\text{q}})Q + \delta_{\text{sh,res}}$$

Project limit: 12.00 mm. The total deflection is acceptable.

Deflection after finishes are installed

Installation datum

$$\delta_{\text{install}} = 3.29 \text{ mm}$$

Later peak

$$\delta_{\text{peak}} = 7.44 \text{ mm}$$

$$\delta_{\text{after}} = 7.44 - 3.29 = 4.15 \text{ mm}$$

$$\delta_{\text{after}} < \frac{L}{500} = 6.00 \text{ mm}$$

Project finish criterion

Reinforcement and crack assessment

Top mesh: 8 mm bars at 150 mm



$$A_s = 335\ \text{mm}^2/\text{m} > 130\ \text{mm}^2/\text{m}$$

Bar spacing: 150 mm. Limit: 200 mm.

Given restraint analysis

Maximum crack width for the stated load, exposure and restraint.

$$w_{max} = 0.18\ \text{mm} < 0.30\ \text{mm}$$

Detailing and crack-width evidence are separate checks.

Office-floor vibration assessment

Given floor-system input	Value
First natural frequency	6.0 Hz
Modal damping ratio	3.0%
Effective modal weight	400 kN

$$\frac{a_p}{g} = \frac{0.29\exp(-0.35\times 6.0)}{0.03\times 400} = 0.00296$$

Low-frequency walking-response model

Predicted peak: 0.296%g. Office limit: 0.500%g.

CLASS DISCUSSION

Changes that alter the design decision

Change	Recalculated response	Limit or capacity
Remove the temporary prop	Construction deflection: 32.91 mm Deck moment: 6.41 kN·m/m	16.67 mm 3.00 kN·m/m
Increase live load to 5.50 kPa	Use-stage moment: 15.35 kN·m/m Staged composite shear: 18.53 kN/m	30.57 kN·m/m Bond: 18.00 kN/m
Reduce floor damping to 1.5%	Peak acceleration: 0.592%g	Office criterion: 0.500%g

Identify the governing check and propose a relevant change.

Design decision for the stated case

Verification	Demand	Limit / resistance
Construction deflection	2.06 mm total, 1.31 mm permanent	8.33 mm, 3.75 mm
Composite bending	11.13 kN·m/m	30.57 kN·m/m
Longitudinal shear-bond	12.90 kN/m	18.00 kN/m
Total / after-finish deflection	7.44 mm / 4.15 mm	12.00 mm / 6.00 mm
Cracks, given restraint analysis	0.18 mm	0.30 mm
Walking vibration, given floor mode	0.296%g	0.500%g

Adopt the specified slab, mesh and central construction prop.

Serviceability completes the design

Keep the load history

Use the stiffness that exists when each load is applied.

Define the acceptance measure

Total deflection, incremental movement, cracks and comfort need distinct checks.

Keep the design basis consistent

Code rules and product qualification belong to the same stated design route.

Exit question: what changes if the finishes are installed earlier?