RUTGERS Infrastructure Monitoring & Evaluation (RIME) Group

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Flexural Behavior of Prestressed Concrete Slabs with Varying Strand Configurations and Span-to-Depth Ratios

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01 BACKGROUND

In an unbonded post-tensioned member the tendon slips freely inside its duct, so it is never strained together with the concrete section it passes through. The tendon stress at ultimate, f_pU, is set by the elongation of the whole member between anchorages rather than by compatibility at any one cross section, which makes the stress gain Δf_pU a global, deformation-driven quantity.

With no section-level compatibility to rely on, codes predict Δf_pU using empirical expressions fitted largely to beam tests. ACI 318 separates slab from beam behavior at a single discrete cutoff of $L/d_p = 35$. How Δf_pU develops across slab slenderness, whether one discrete cutoff represents that behavior, and whether FRP systems follow the same trend remain open questions for the long-span floor systems now being built.

Objectives

1. Measure Δf_pU across a continuous slenderness range, L/d_pU = 18.7 to 40, spanning the ACI 318 cutoff at 35.
2. Compare steel and CFRP tendons against mild-steel and GFRP passive reinforcement at constant slenderness.
3. Evaluate capacity and tendon stress against ACI 318, AASHTO LRFD, ACI 440.4R and MDBA.
4. Build a FEM of the unbonded system calibrated to the measured response.

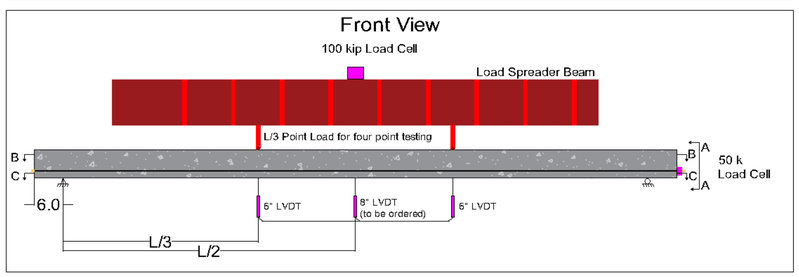
02 TEST PROGRAM

Nine one-way slabs were tested in two phases. Both share the same cross section, tendon depth, anchorage detail and four-point loading arrangement, so the two sets form one continuous series.

Phase	Primary variable	Slabs	L/d_pU	Status
I	Span-to-depth ratio	5	18.7 to 34.7	Complete
II	Tendon / passive type	4	40.0	2 of 4 tested

Specimens and Materials

Parameter	Phase I	Phase II
Cross section, b × h	15 × 6 in.	15 × 6 in.
Clear span, L	7 to 13 ft	15 ft
Tendon depth, d_pU	4.5 in.	4.5 in.
L/d_pU	18.7 to 34.7	40.0
Tendons, 2 per slab	3/8 in. strand	Steel 1/2 in. or CFRP 0.425 in.
Effective prestress, f_{se}	155 to 178 ksi	162 ksi steel, 221.6 ksi CFRP
Concrete f'c / Ec	8 to 10 ksi	8.5 ksi / 5,255 ksi
Passive reinforcement	4 #3 mild steel	4 #3 mild steel or #3 GFRP
FRP properties	—	GFRP 123.3 ksi, CFRP 369.4 ksi



03 PHASE I: SLENDERNESS

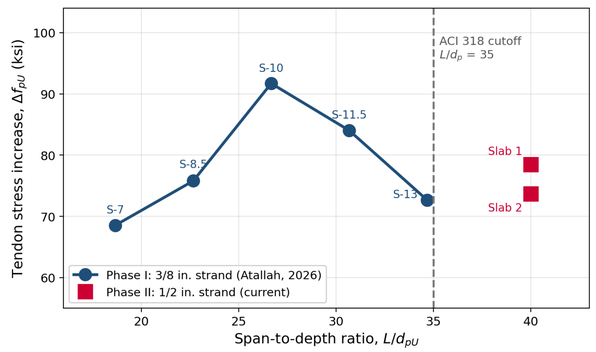
Five slabs identical except in clear span were proportioned to reach approximately the same nominal moment, so differences in response are attributable to slenderness alone. Each was post-tensioned with two unbonded 3/8 in. low-relaxation strands and loaded to failure.

Slab	L/d_pU	F_u (kip)	M_u (kip-in)	f_pU,exp (ksi)	Δf_pU (ksi)
S-7	18.67	24.22	339.2	238.1	68.6
S-8.5	22.67	19.66	334.3	245.5	75.8
S-10	26.67	17.83	356.6	251.6	91.7
S-11.5	30.67	14.91	343.1	245.3	84.0
S-13	34.67	12.76	331.9	241.5	72.7

Cracking and Failure Modes

Slab	Failure mode	Location	$\bar{w}^f$ (in)	$\bar{s}$ (in)	Cracks
S-7	Flexure + crushing	L/2	0.0141	2.46	11
S-8.5	Flexure–shear	L/3	0.0158	3.79	10
S-10	Flexure–shear	Near L/3	0.0181	3.20	12
S-11.5	Flexure + crushing	L/2	0.0188	3.75	13
S-13	Flexure + crushing	Near L/3	0.0211	3.20	15

Crack width at failure grows steadily with slenderness, from 0.0141 in. at L/d_pU = 18.7 to 0.0211 in. at 34.7, and spacing widens from 2.46 in. to roughly 3.2 to 3.8 in. The response shifts from a distributed multi-crack pattern toward a localized hinge, with top-fiber crushing growing more severe as the span lengthens.



Δf_pU against slenderness across both phases. The stress gain is not monotonic: it peaks near $L/d_pU \approx 27$, then declines toward the ACI 318 cutoff at 35.

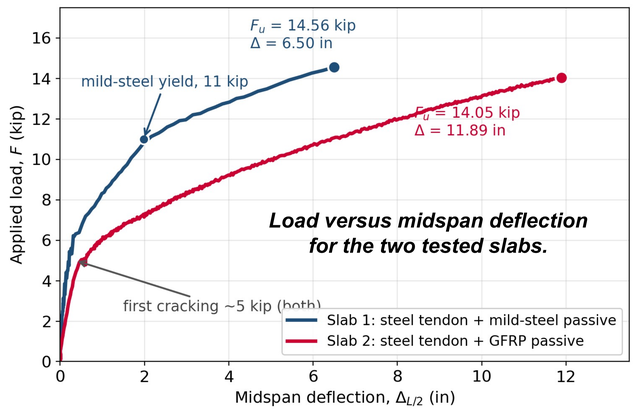
Slab	f_pU,exp (ksi)	ACI 318 (ksi)	Under-predict	AASHTO (ksi)	Under-predict
S-7	238.1	215.0	9.7%	203.6	14.5%
S-8.5	245.5	217.3	11.5%	198.8	19.0%
S-10	251.6	208.2	17.3%	185.2	26.4%
S-11.5	245.3	211.2	13.9%	183.9	25.0%
S-13	241.5	219.3	9.2%	188.6	21.9%

Both codes are conservative throughout and least accurate in the intermediate band around S-10 and S-11.5, where the measured stress gain peaks. That is the same interval in which the governing mechanism appears to change, suggesting the single discrete cutoff in ACI 318 does not capture the transition it is meant to represent.

04 PHASE II: STRAND TYPE

Four slabs at L/d_pU = 40, past the ACI cutoff and past the Phase I range, pair steel and CFRP tendons with mild-steel and GFRP passive reinforcement. A load cell at each anchorage reads tendon force directly, so Δf_pU is measured rather than inferred.

Slab	Tendon	Passive	φM_n (kip-in)	Pred. Δf_pU (ksi)	Status
1	Steel	Mild steel	371.8	76.0	Tested
2	Steel	GFRP	339.5	63.8	Tested
3	CFRP	Mild steel	308.1	80.2	Pending
4	CFRP	GFRP	402.5	64.5	Pending

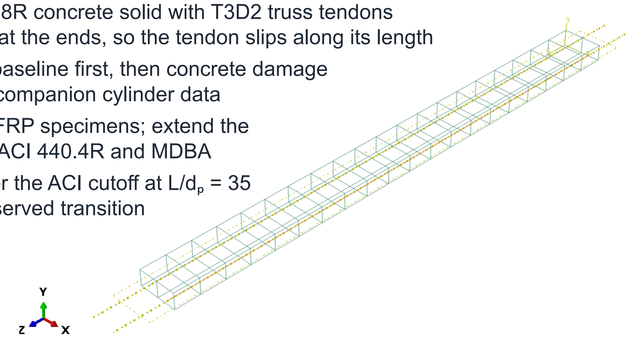


	F_u (kip)	Δ_u at L/2 (in)	M_u (kip-in)	M_u / φM_n	Δf_pU meas. (ksi)	Predicted (ksi)
Slab 1	14.56	6.50	436.7	1.17	78.7	76.0
Slab 2	14.05	11.89	421.4	1.24	73.6	63.8

Both slabs cracked near 5 kip and carried load well past prediction. Replacing mild steel with GFRP removes the yield plateau: Slab 2 stays nearly linear after cracking and reaches almost twice the deflection of Slab 1 at a comparable peak load. At failure the GFRP strain was 3,902 με, only 28% of rupture, so the compression zone governed the peak, not the reinforcement.

05 MODEL AND NEXT STEPS

- ABAQUS: C3D8R concrete solid with T3D2 truss tendons anchored only at the ends, so the tendon slips along its length
- Linear-elastic baseline first, then concrete damage plasticity from companion cylinder data
- Test the two CFRP specimens; extend the comparison to ACI 440.4R and MDBA
- Assess whether the ACI cutoff at L/d_p = 35 reflects the observed transition



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