Structural Evaluation of Slab Rehabilitation by Method of Hydrodemolition (HD) and Latex Modified Concrete (LMC) Overlay

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Motivation

Aging Infrastructure

Approximately 70% of US bridges have concrete decks (FHWA)

Deck ***replacement*** typically on 20-40 year cycle

Deck ***rehabilitation*** often more frequent

Objective

The objective of this work is to provide laboratory-based experimental verification and assessment of the performance of reinforced concrete deck slabs rehabilitated by means of hydrodemolition (HD) followed by the application of a latex modified concrete (LMC) overlay.

The fundamental objective is to ***determine whether the overlay may be considered composite with the residual deck*** and under what conditions composite behaviour may be assumed in load rating of the rehabilitated deck.

PennDOT Pub 15 Section 5.5.5.1 " ***a latex overlay is not considered structurally effective***"

pennsylvania
DEPARTMENT OF TRANSPORTATION

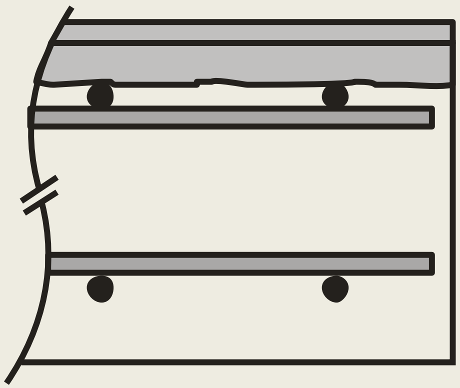
Scope

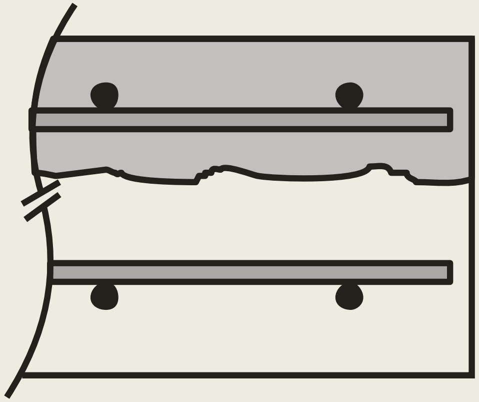
Partial depth repairs only (PennDOT Pub 408 1040):

Type 1: exposing no more than one quarter of bar diameter of top mat of steel

Type 2: repair extends at least ¾" beyond top mat of reinforcing but does not extend through full thickness of deck

using LMC only (Method 2)


Type 1


Type 2

Factors affecting overlay (bond) performance

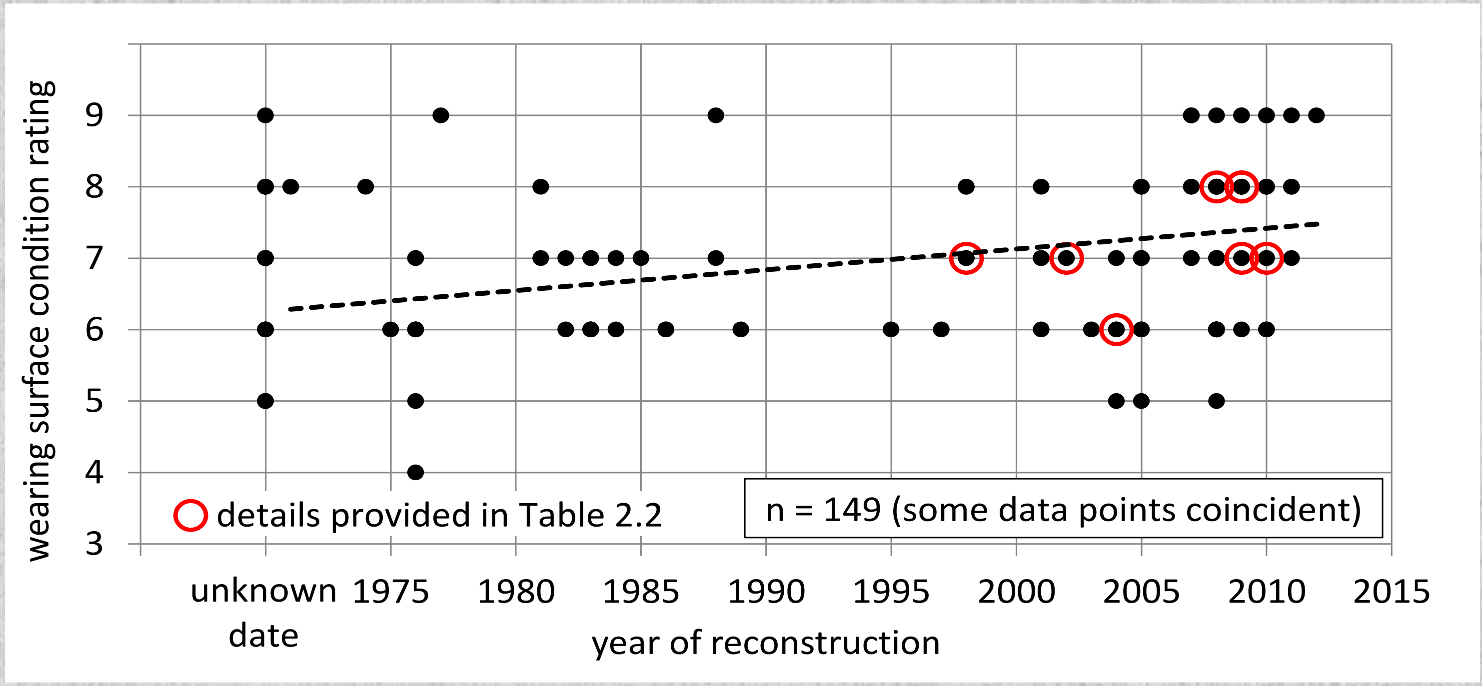
greatest impact	moderate impact	least impact
Laitance/cleanliness	Prewetting	Substrate concrete properties
Microcracks	Overlay concrete properties	Interface roughness
Compaction		Use of bonding agents
Curing		Placement
		Early traffic loading
		Fatigue
		Environment

method of demolition

Silfwerbrand, J. (2009) Bonded Concrete Overlays for Repairing Concrete Structures. *Failure, Distress and Repair of Concrete Structures*, Woodhead Publishing Limited, Oxford UK, 208-243.

Snapshot – PennDOT D11

149 bridges with LMC overlay (8%; 20% by deck area)



9 selected for further study

5 selected for coring

Snapshot – PennDOT D11

Overall, LMC overlays performing very well.

Where problems are observed these appear to be construction process-related; primarily inadequate curing practices.

'depth to sound concrete' was not well reported.

Damage to overlays was isolated and often associated with skew corner

↑hairline cracking of LMC

← damage near acute skew

mortar patch of LMC ↑

← apparent pop-out

Experimental Programme

10 laboratory-cast specimens

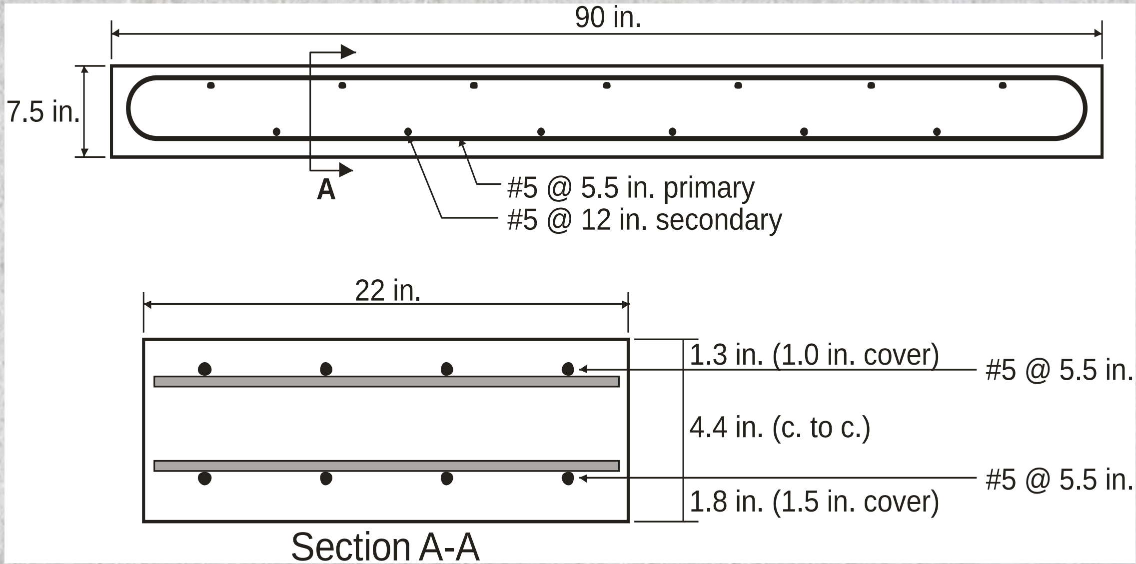
AAA substrate concrete:

$f_c' = 6500$ psi

reinforcing steel:

$f_y = 67.8$ ksi

$f_u = 107.9$ ksi



Experimental Programme

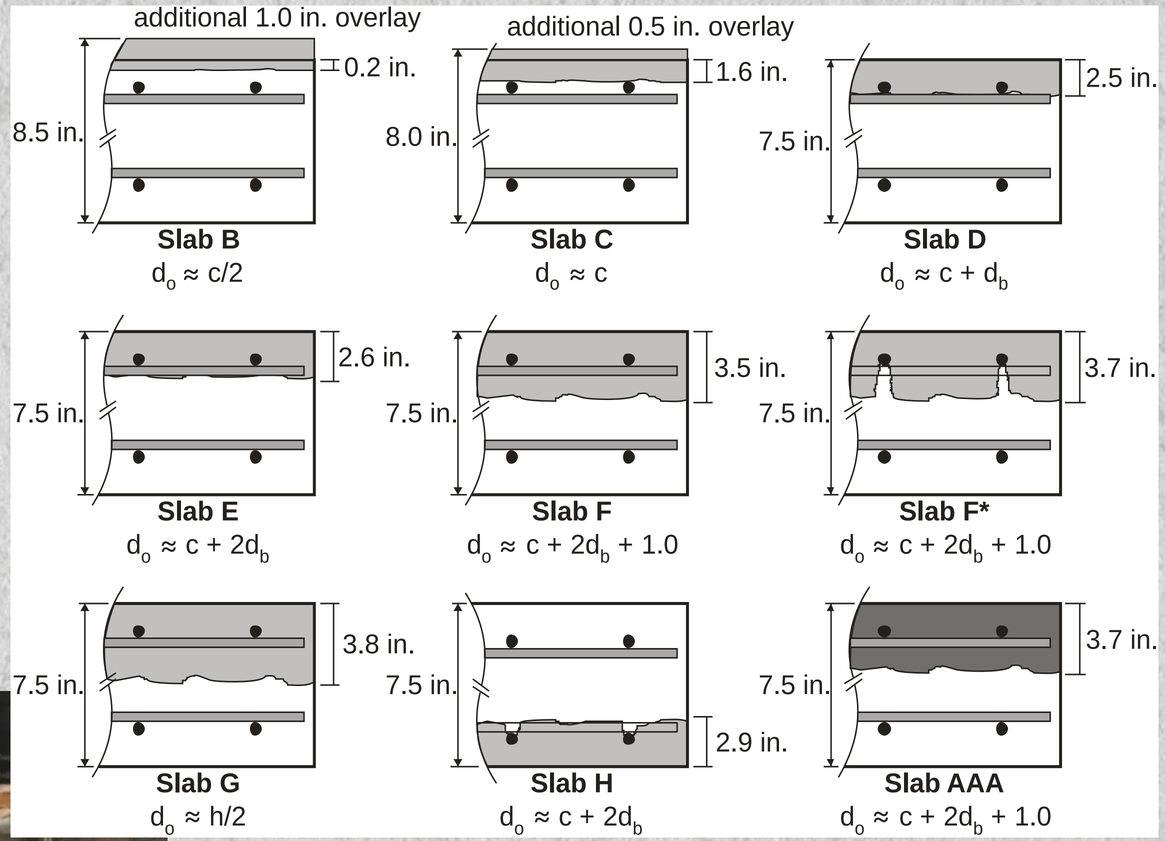
Parameters

HD/LMC depth

'shadows'

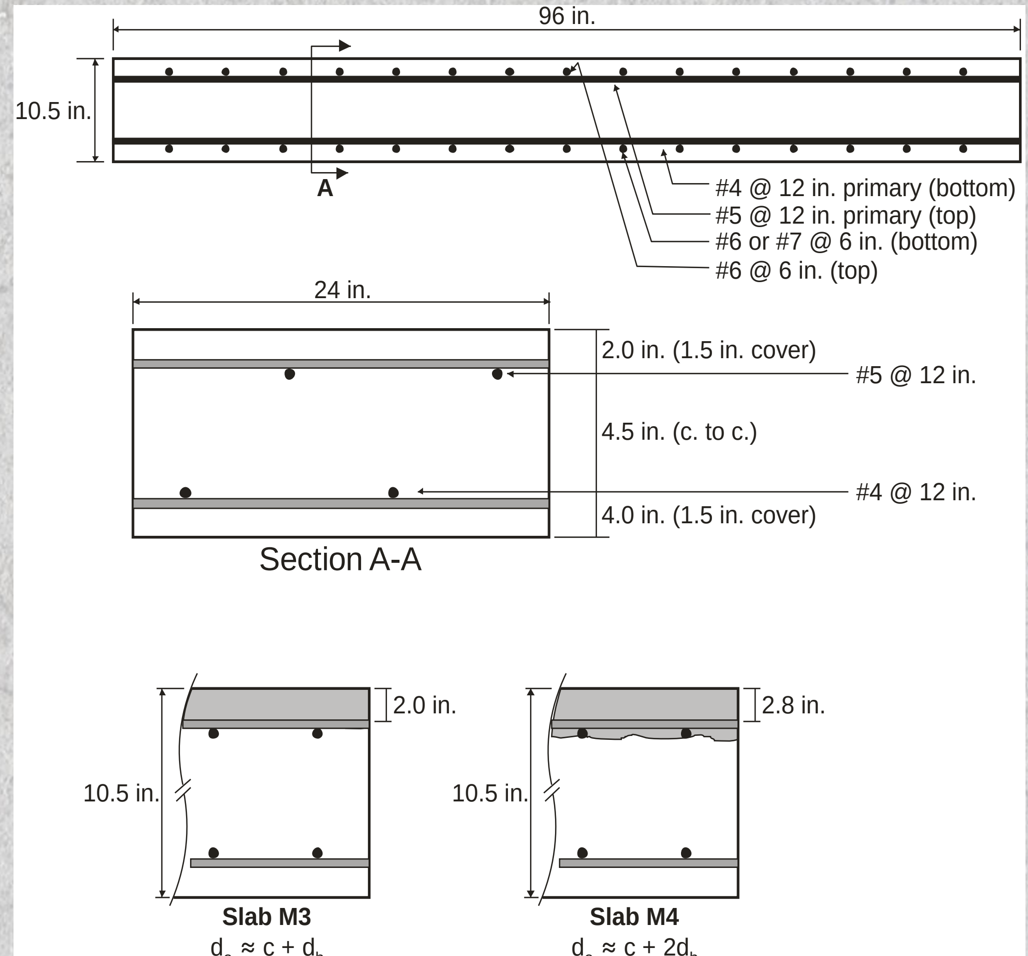
positive and negative flexure

AAA concrete



Experimental Programme

4 – 44 year-old decommissioned slabs



f_c' = 5015 psi substrate concrete

f_y = 43 ksi reinforcing steel

Hydrodemolition

Commercial HD contractor

Excellent control of depth

Lab specimens: 63 days old

Latex-Modified Concrete

Commercial LMC contractor

LMC mix prequalified under *FHWA RD-78-35*

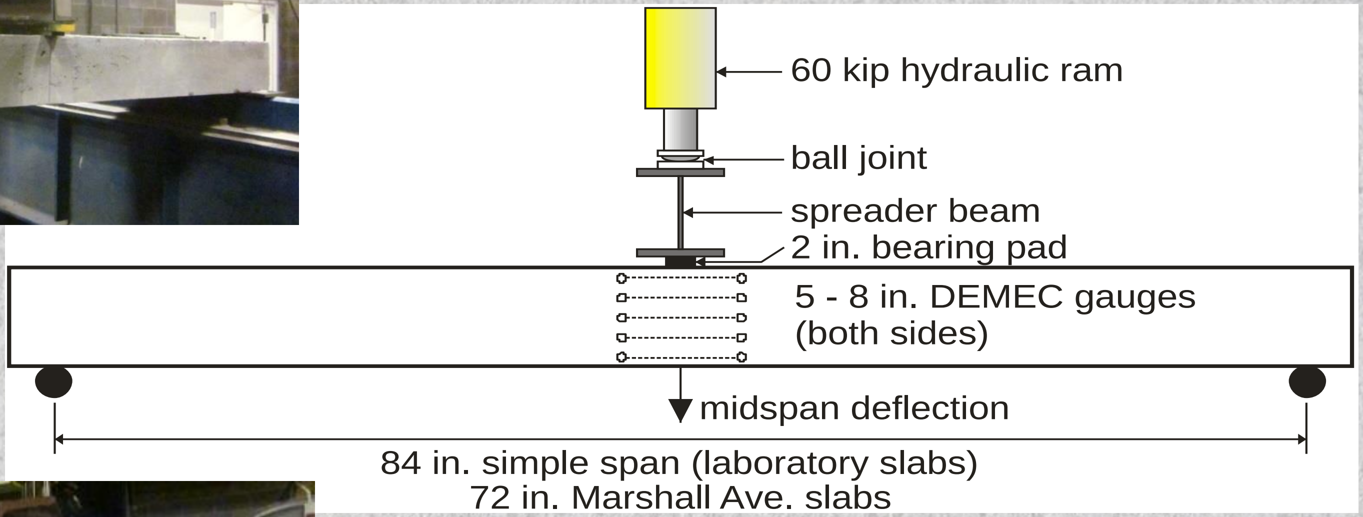
$f_c' = 6560$ psi

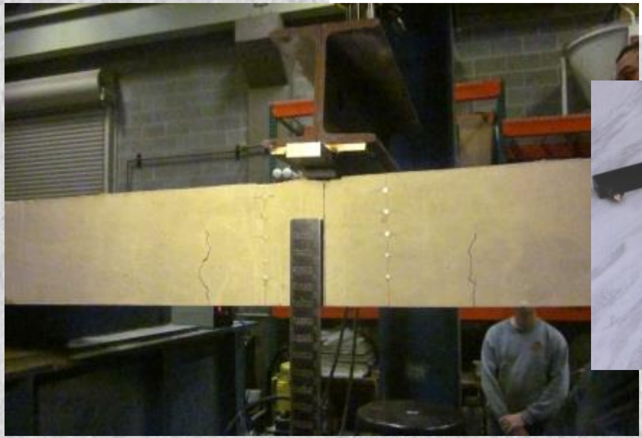
Saturated interface at placement

Seven days moist curing

Test Set-up and Instrumentation

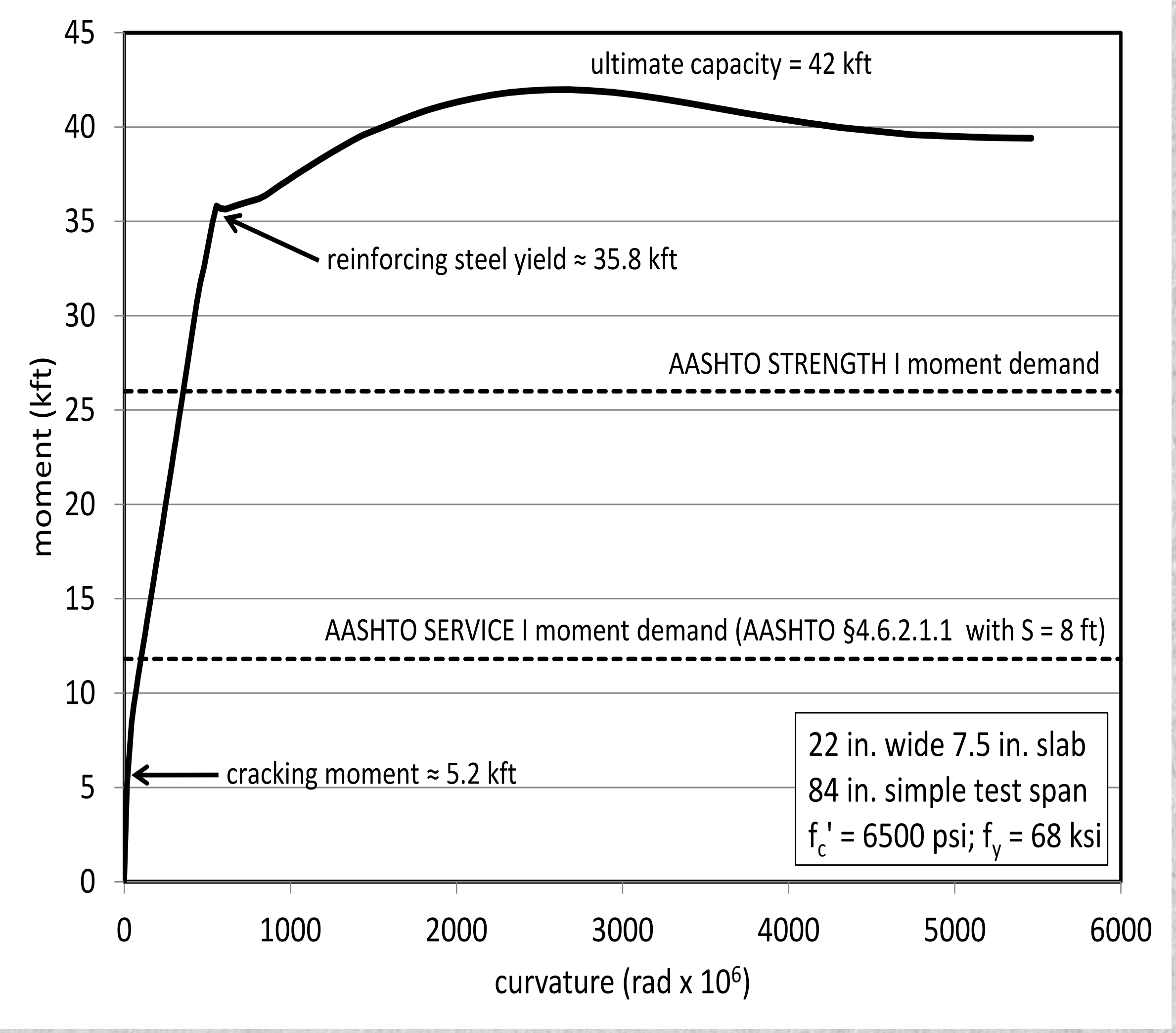
Midpoint flexure (selected to match fatigue testing)





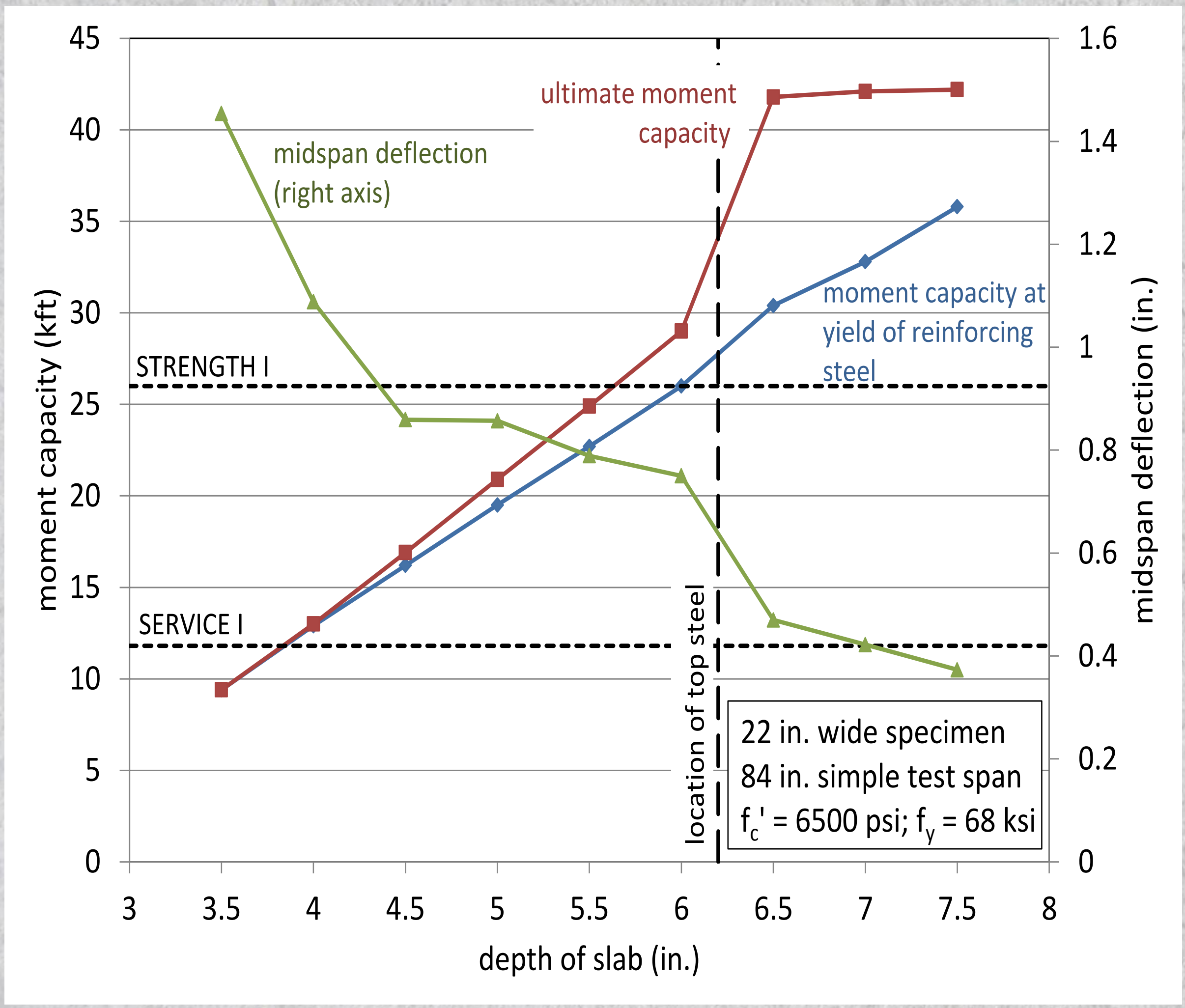
concrete strains using DEMEC points (both faces)

Predictions and 'Target' Behaviour

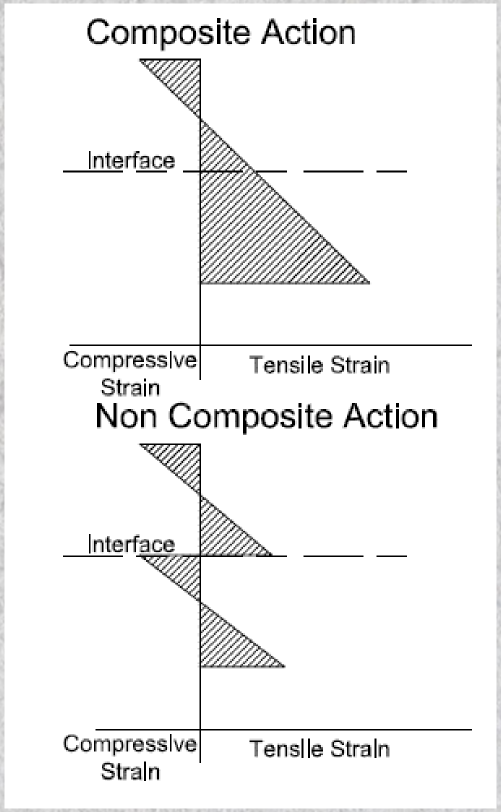


Slab behaviour

Predictions and 'Target' Behaviour

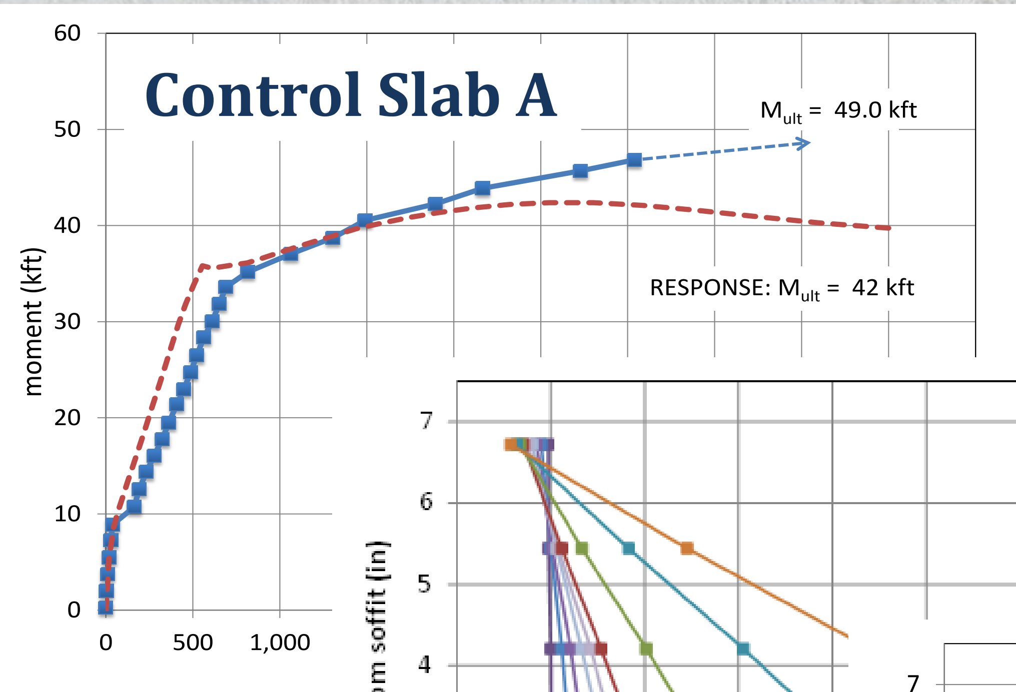


HD/LMC slab behaviour

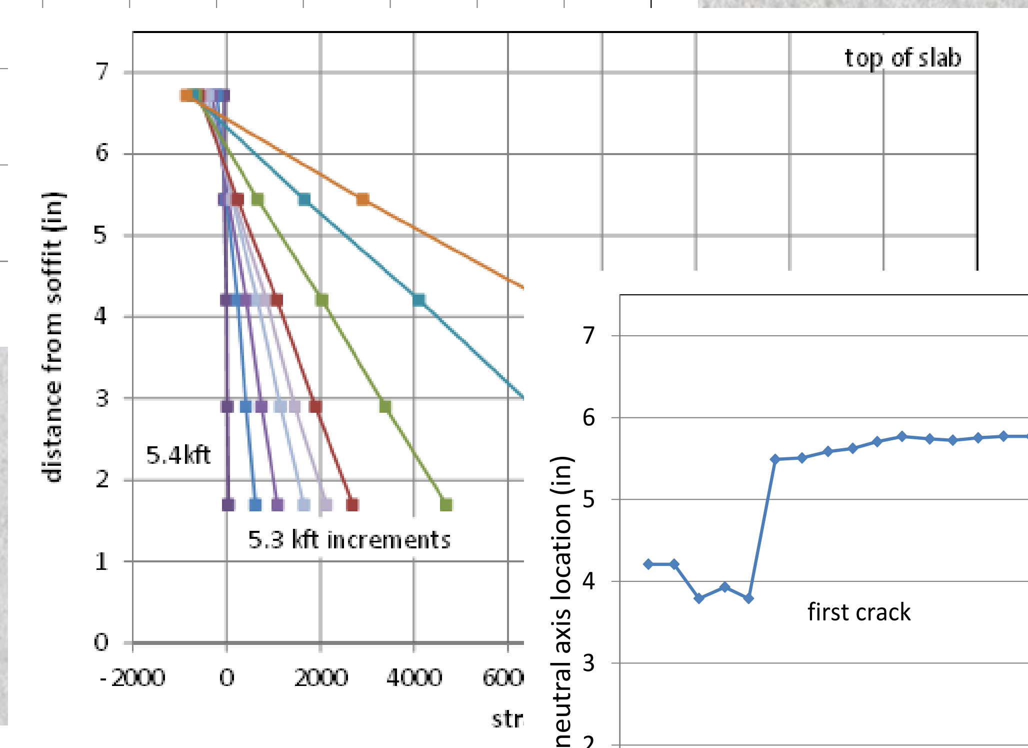


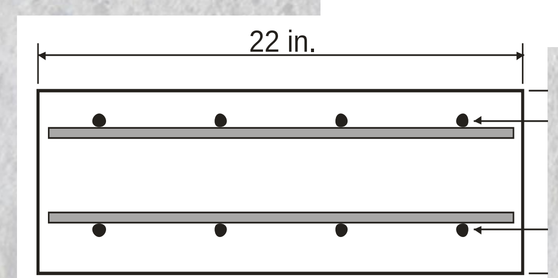
Test Results

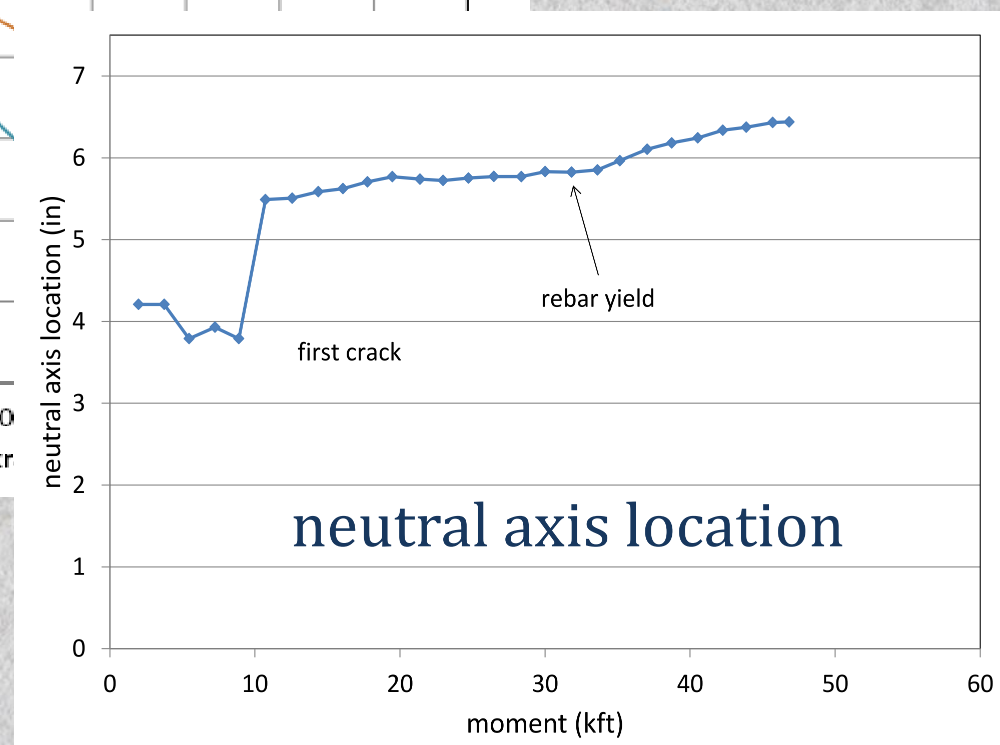
moment-curvature



strain gradients

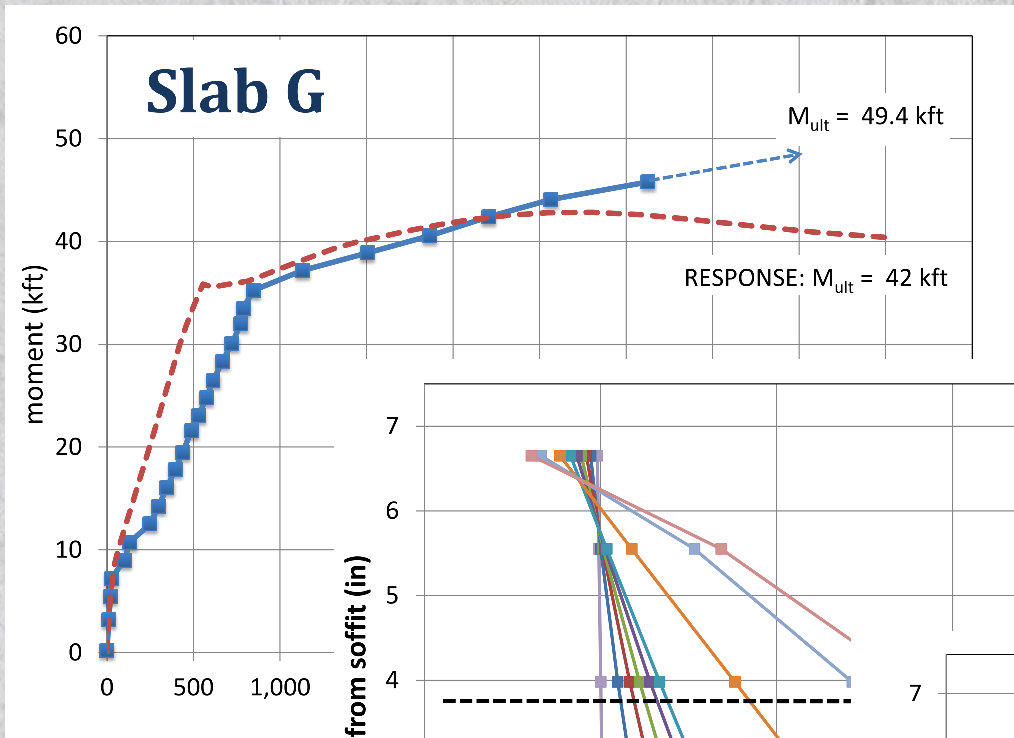




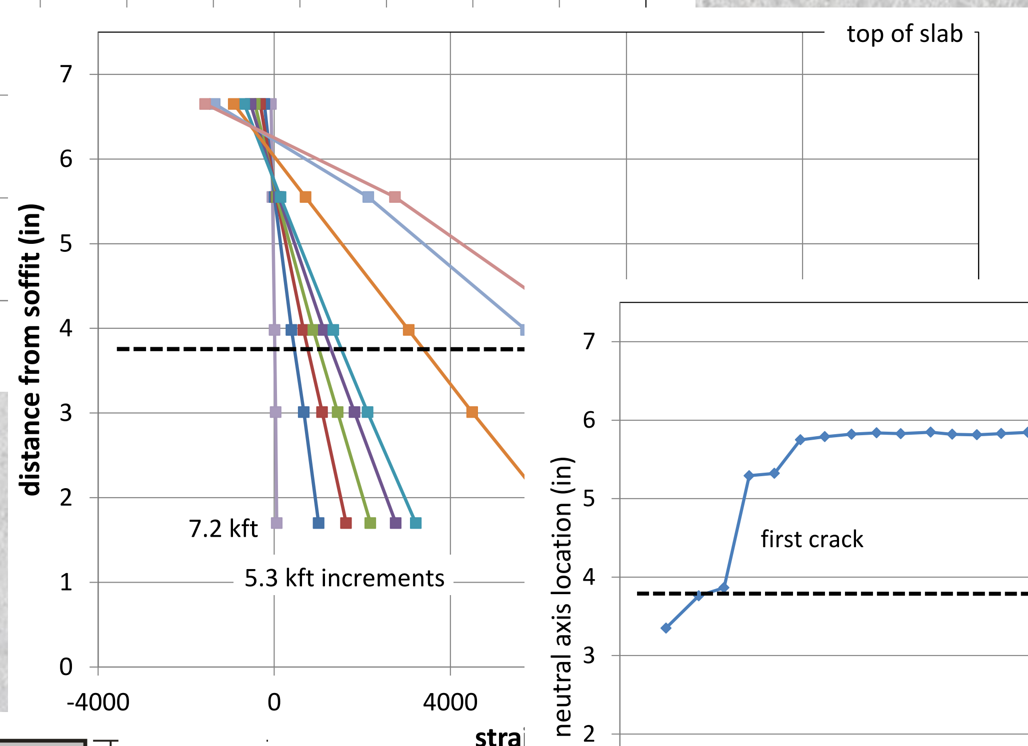


neutral axis location

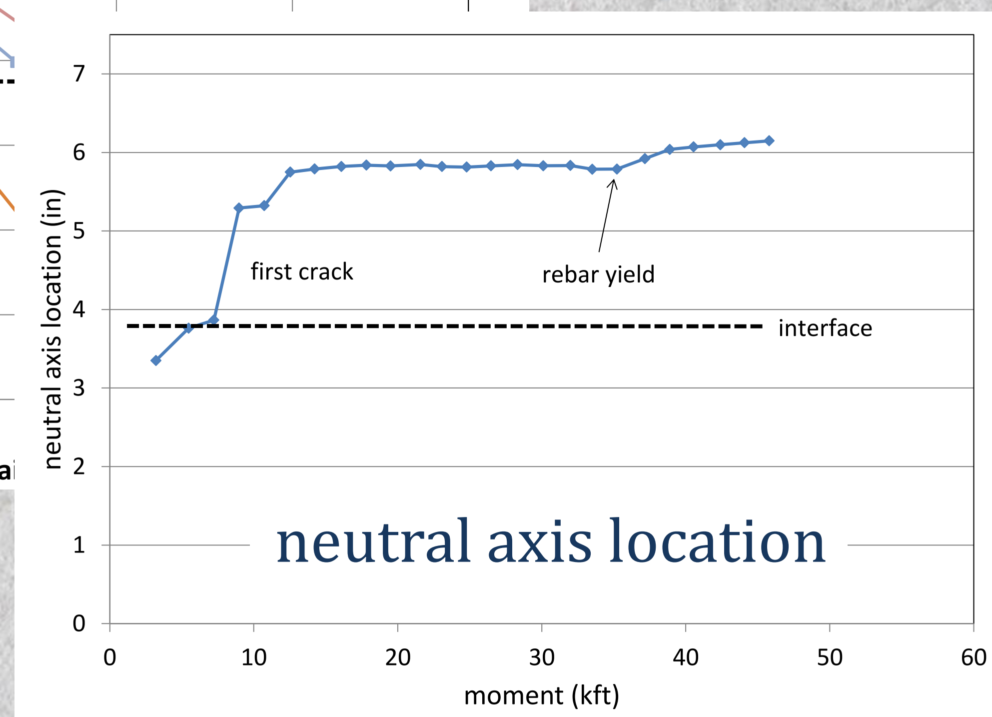
Test Results



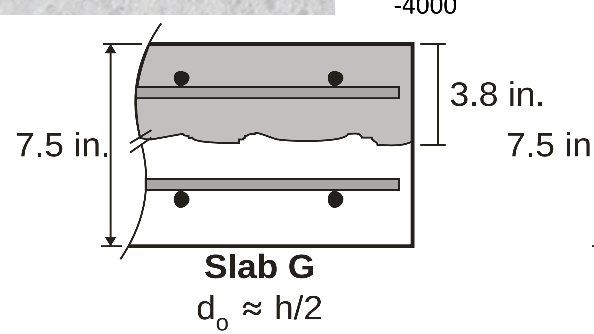
moment-curvature



strain gradients



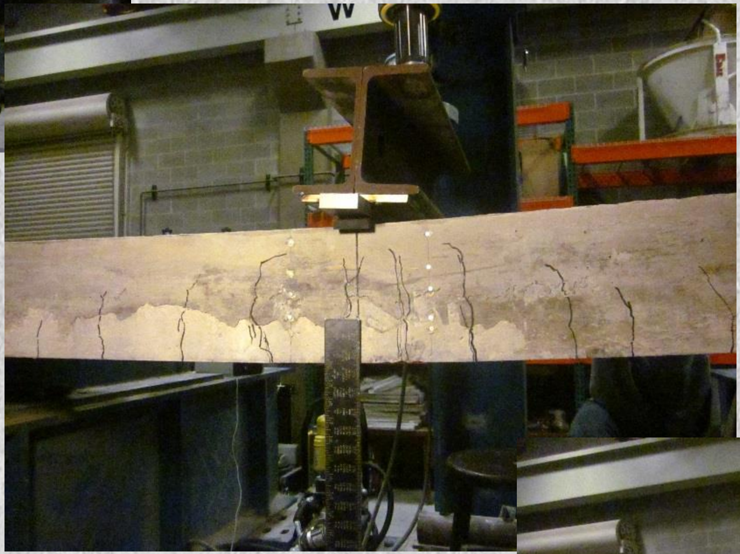
neutral axis location



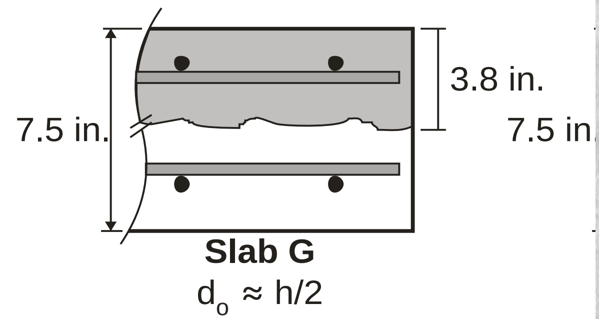
Test Results

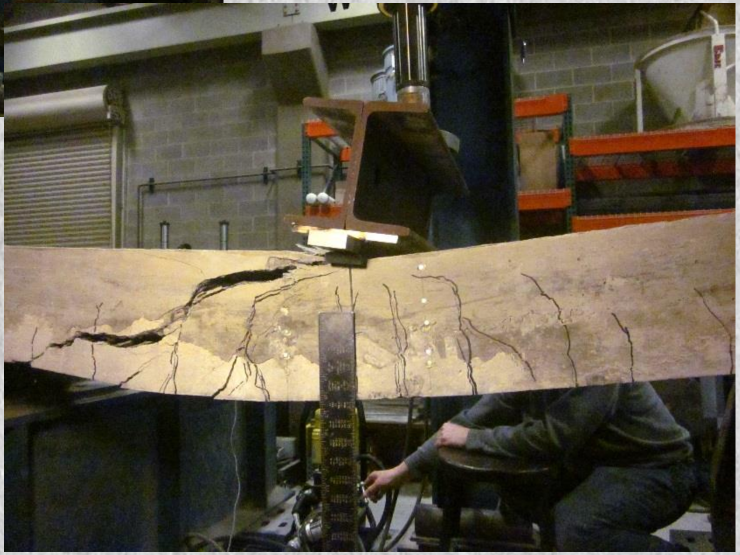
Yield of Reinforcement

Final DEMEC Reading



Slab G



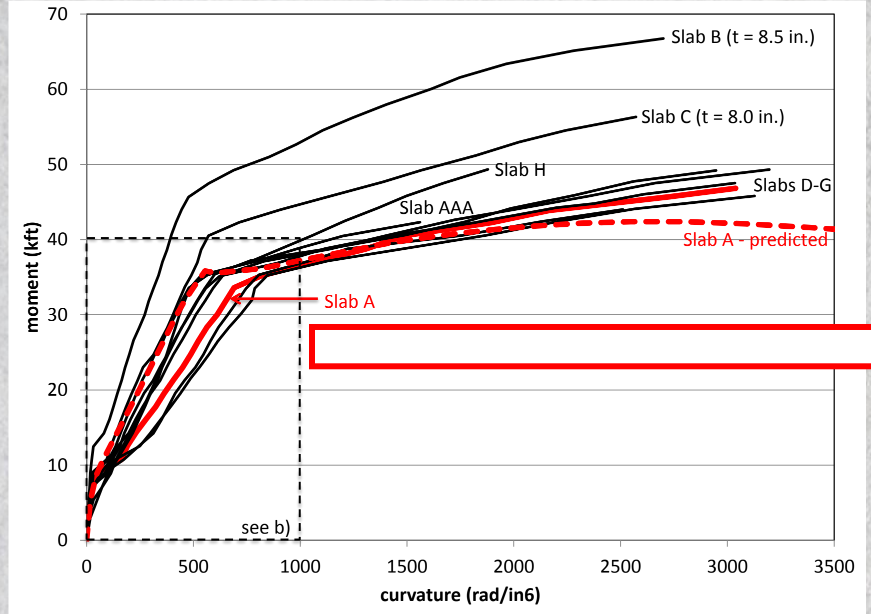


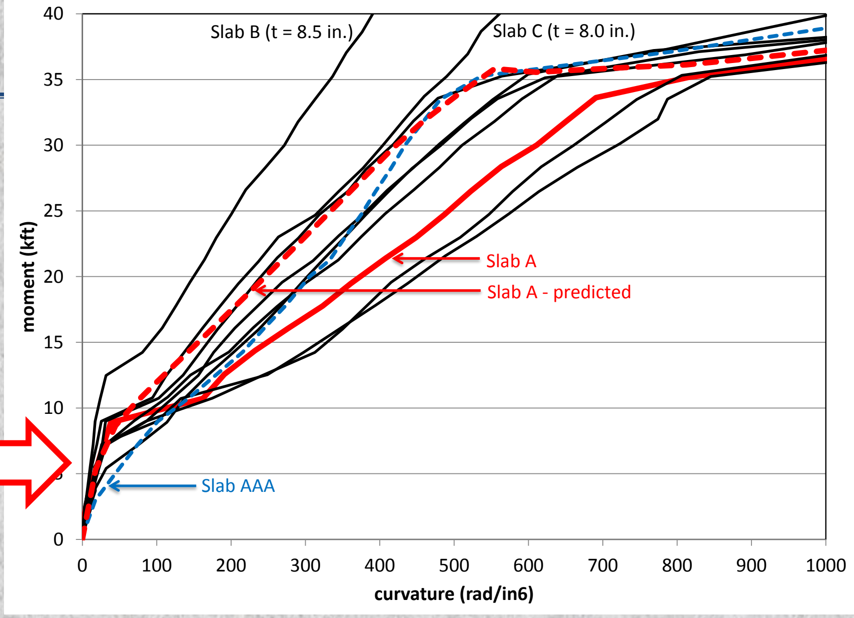
Failure

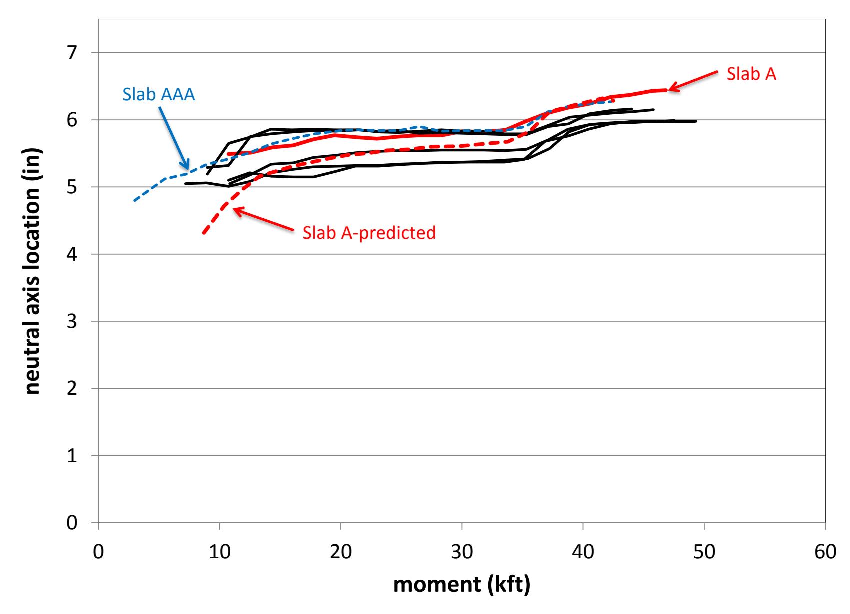
Test Results

	A		B	C	D	E	F	F*	G	H	AAA
	pred	exp									
HD depth (in)	none		1.2	2.1	2.5	2.6	3.5	3.7	3.8	2.9	3.7
first crack (kipft)	5.2	8.89	12.47	5.42	9.01	8.97	7.19	8.97	8.97	10.74	-
rebar yield (kipft)	35.8	31.8	47.5	40.5	35.3	35.3	35.1	35.2	35.4	35.3	35.3
normalised by A	**-**	**-**	**1.16**	**1.12**	**1.11**	**1.11**	**1.10**	**1.11**	**1.11**	**-**	**1.11**
curvature at yield (rad/in)	600	651	572	571	640	806	622	845	600	565	537
ultimate capacity (kipft)	42.0	49.0	68.9	59.7	52.9	51.3	51.0	49.4	54.5	51.2	44.1
normalised by A	**-**	**-**	**1.09**	**1.07**	**1.08**	**1.05**	**1.04**	**1.01**	**1.11**	**-**	**0.90**

Comparison of Tests







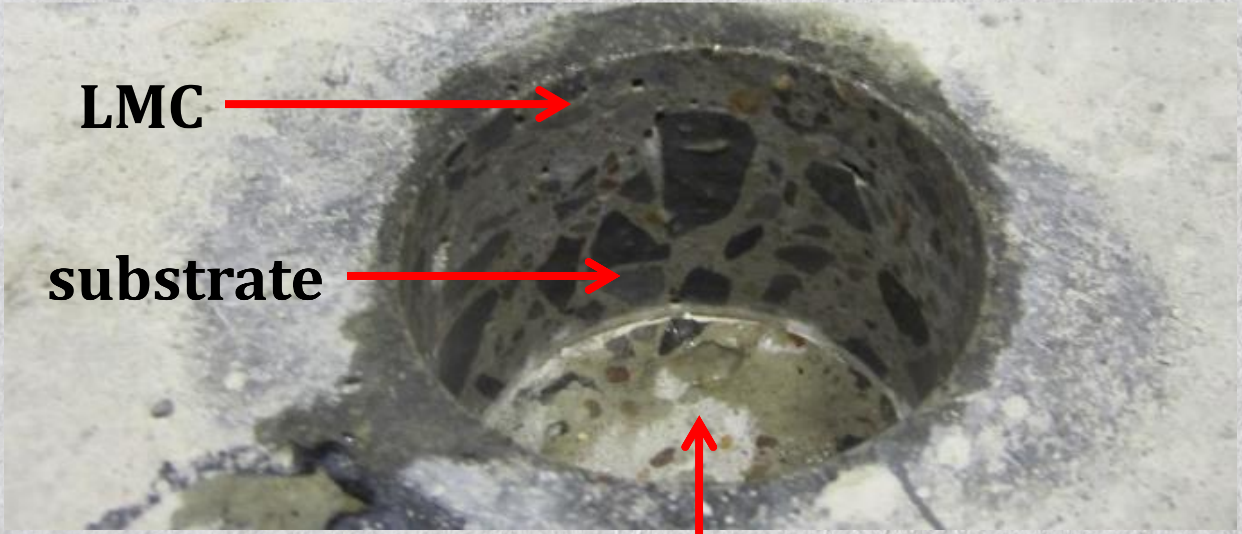
Presence of LMC overlay had little effect on cracking, stiffness, yield, ultimate capacity, or overall flexural behaviour.

Pull-off Tests (ASTM C1583)

Investigate integrity of interface bond

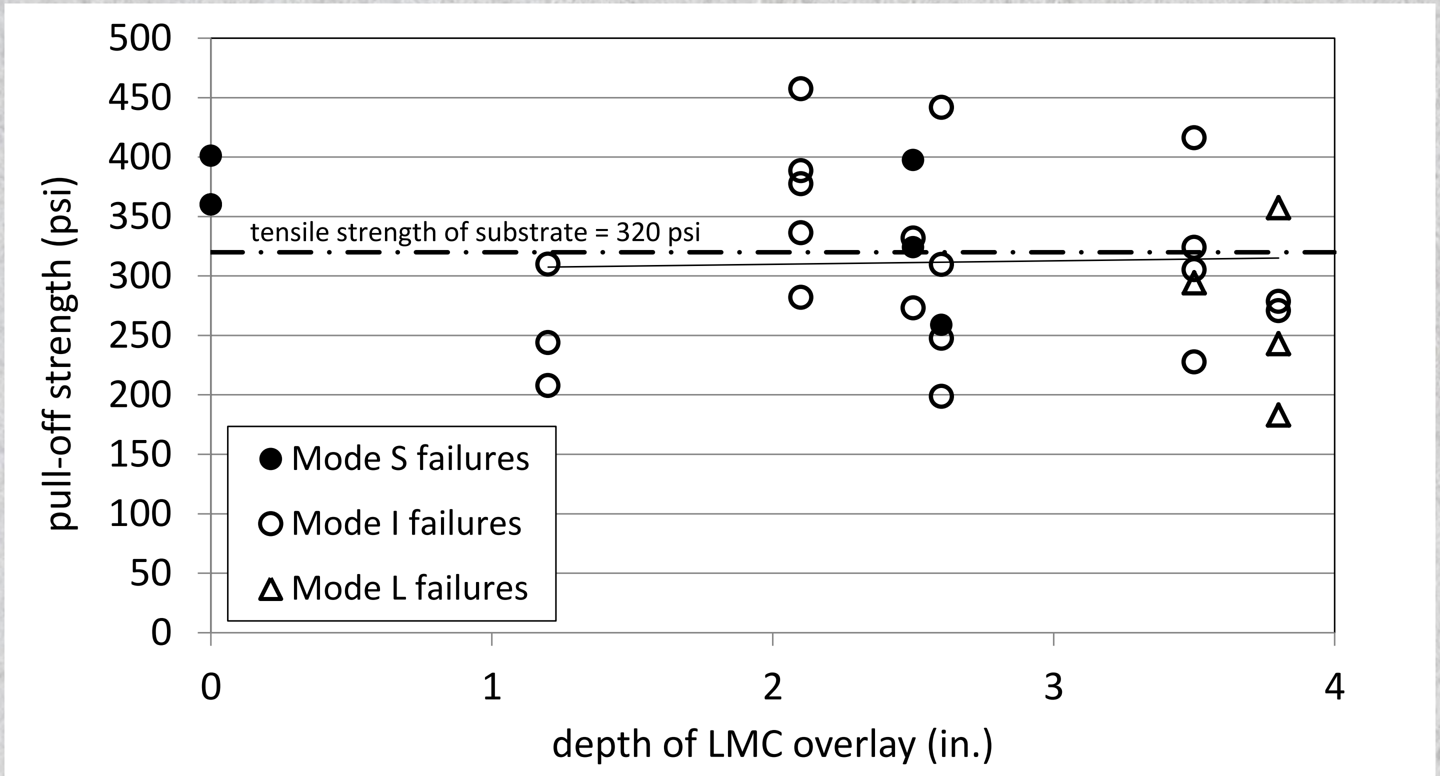
Common QC/QA procedure

92 – 2 in. cores and pull-off tests



tension failure in substrate

Pull-off Tests (ASTM C1583)



concrete age > 132 days

LMC age > 52 days

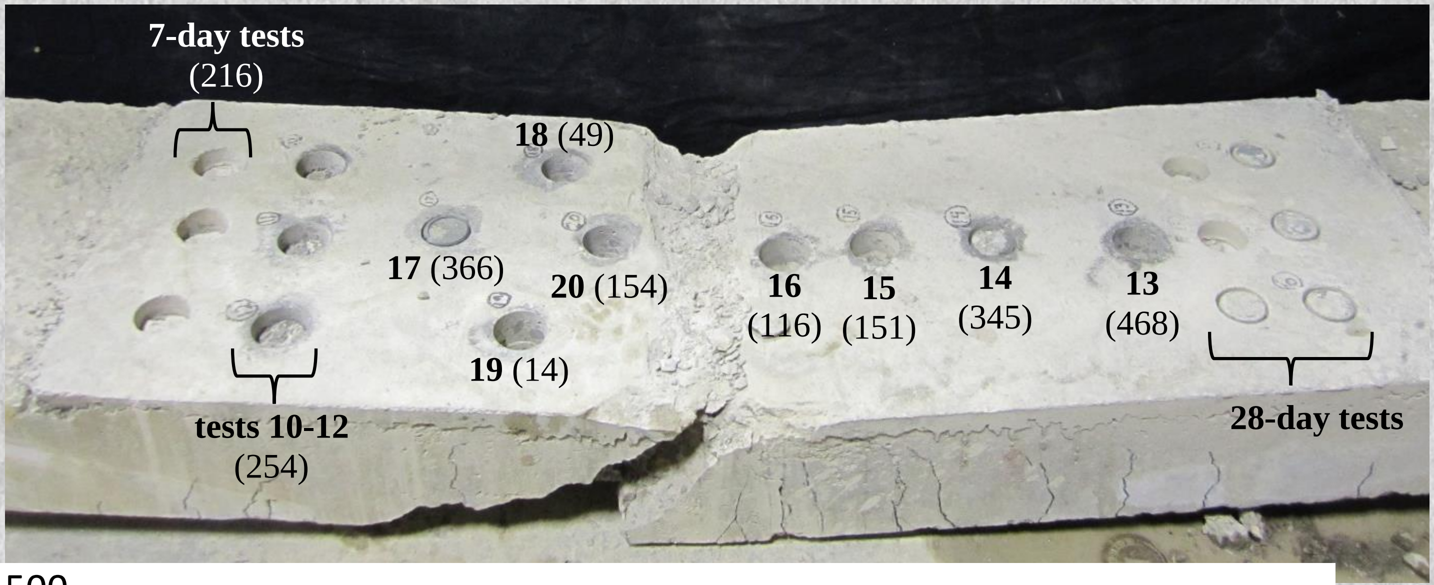
Assumed concrete tensile capacity = $4\sqrt{f_c'}$ = 320 psi

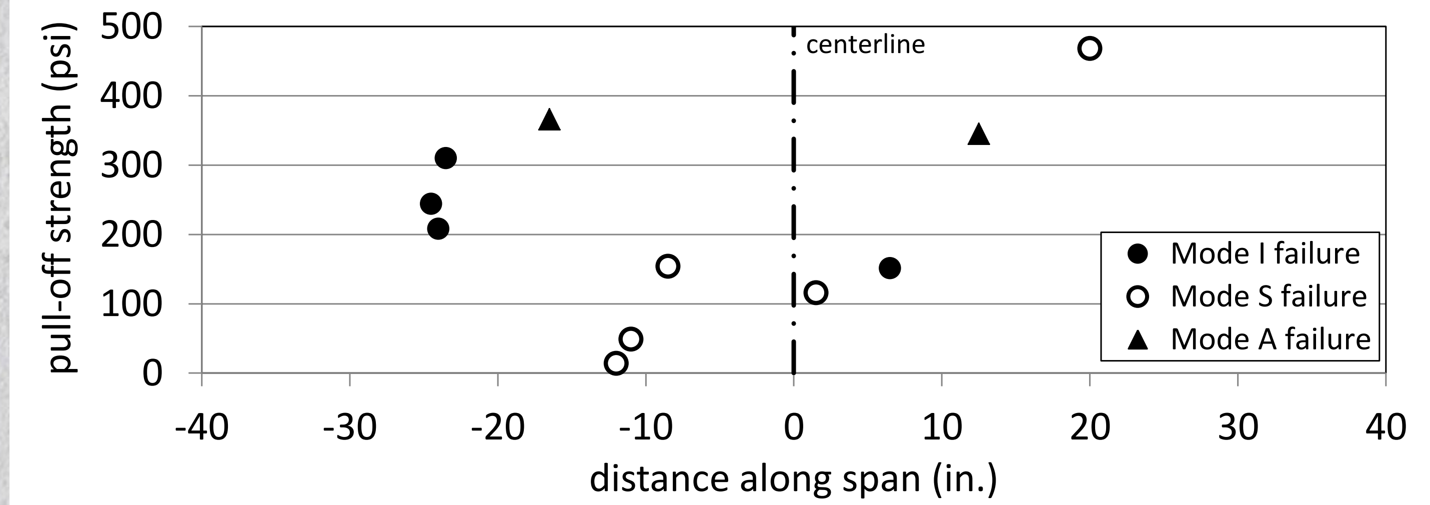
Observed concrete tensile capacity = $4.6\sqrt{f_c'}$ = 373 psi

All interface capacities exceeded 200 psi

Pull-off Tests (ASTM C1583)

Post failure tests of overlay (Slab B; HD depth = 1.2 in.)





Field testing

Cores and pull-off tests were conducted at five bridges.

Core locations were selected based on observable cracking and potential delaminations identified using chain-dragging and GPR

	I	II	III	IV	V
age of LMC (years)	11	5	15	4	9
depth of LMC (in.)	2.6	2.6	2.4	4.0	3.3
surface amplitude (in.)	0.9	0.6	0.5	0.9	0.4
pull-off strength (psi)	285	348	202	-	284

Interesting finding:

Chlorides were found in some cores.

Distribution of chloride suggested contamination of LMC from underlying substrate.

Putting it all together

Composite behaviour of LMC should be expected; at the ultimate slab capacity, interface shear is only 91 psi.

Direct tension pull-off tests all exceeded 200 psi.

Minimum acceptable values of pull-off tests to ensure sound interface bond:

200 psi (ACI 440)

175 psi (ICRI)

200 psi (Basham 2004)

100 psi (Wenzlick 2002)

Interface shear capacity is known to be 2 (Silfwerbrand 2009) to almost 3 times (Gillum et al. 2001) greater than the direct tension capacity.

Conclusions – Composite Behaviour of LMC

The primary objective of this study was to assess the validity of *PennDOT Publication 15 Section 5.5.5.1*, specifically that "a latex overlay is not considered structurally effective", in terms of the structural response of the bridge superstructure.

Experimental evidence from this study clearly demonstrates that the LMC overlay exceeding 1.25 in. in thickness ***is structurally effective*** in terms of load carrying capacity.

The LMC-repaired slabs acted as monolithic slabs in all cases and the capacity was uniform regardless of LMC depth.

The capacity of the LMC-repaired slabs tested in positive flexure exceeded their predicted ultimate capacities and the capacity of the unrepaired control slab in all cases.

Conclusions – Pull-off testing for QC/QA

Provided the pull-off strength exceeds 200 psi, the interface shear capacity will be adequate and the overlay will behave in a fully composite manner with the substrate concrete.

For pull-off capacities less than 200 psi, the mode of failure is telling. If the failure remains in the substrate (Mode S), the interface is stronger than the substrate and the shear capacity is at least that of the residual substrate concrete. In such a case, composite behaviour of the overlay is likely.

Pull-off tests indicating an interface failure (Mode I) are cause for further investigation.

Pull-off tests less than 100 psi, regardless of failure mode should not be accepted.

Recommendations to PennDOT

Revision of *Pub. 15* Section 5.5.5.1 to permit LMC overlays greater than 1.25 in. to be considered structurally effective.

Revisions to *Pub. 408* Section 1040.3 to permit and encourage use of hydrodemolition.

Revisions to *Pub. 408* Section 1042.3 to prescribe pull-off testing per ASTM C1583 for acceptance testing of LMC overlays.

Recommended acceptance criteria.

Summary of best construction practices for LMC overlays.

Commentary and clarification to ASTM C1583 specifically for LMC applications.

Partners

Pennsylvania Department of Transportation

Rampart Hydro Services (HD)

Trumbull Corporation (LMC)

SIVA Corrosion Services (field cores)

Watkins Haggart Structural Engineering Laboratory

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