Joint Meeting of the Precast/Prestressed Concrete Institute (PCI) and the SC Department of Transportation (SCDOT)

BRIEF STATUS REPORT

ACCELERATED BRIDGE CONSTRUCTION: PRECAST ALTERNATE FOR FLAT SLAB SPANS

Presented by:

Scott D. Schiff, PhD

Glenn Department of Civil Engineering

Clemson University

November 7, 2013

PART 1: COMPLETED WORK

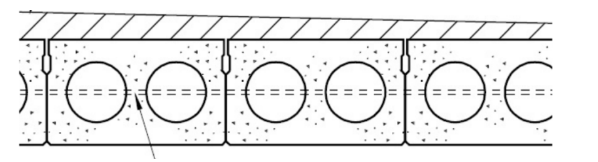
PIs: Nielson, Pang and Schiff

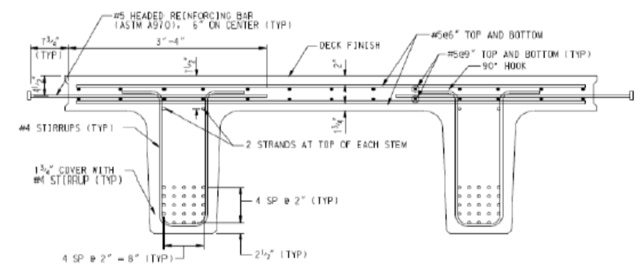
PhD Student: Sheng

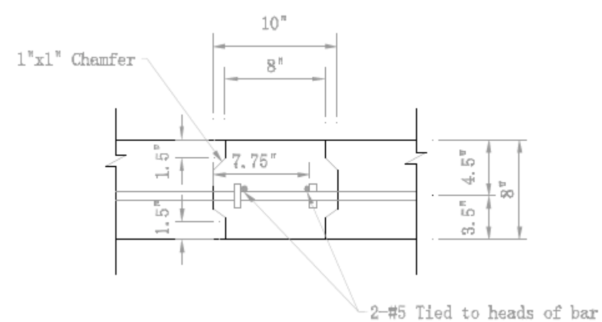
MS Students: Roberts, Deery, Funcik, Flores and Stevenson

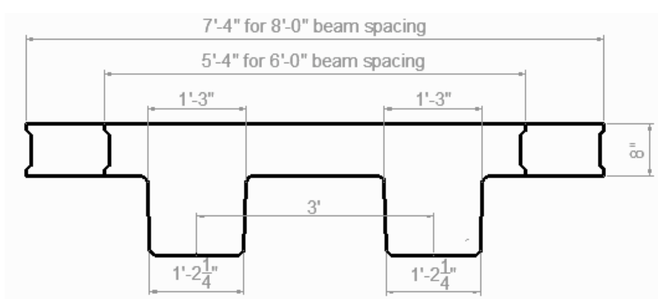
MOTIVATION

- ❑ Cast-in-Place vs Precast Construction
  - Advantages: ABC
  - Issues: Joint performace anddurability
- ❑ NEXT-D vs Hollow Core/Beam
  - Promising (High ADT, robust joint)
  - Gaps in knowledge
- ❑ Modified NEXT-D cross section
  - Shorter span and narrower width

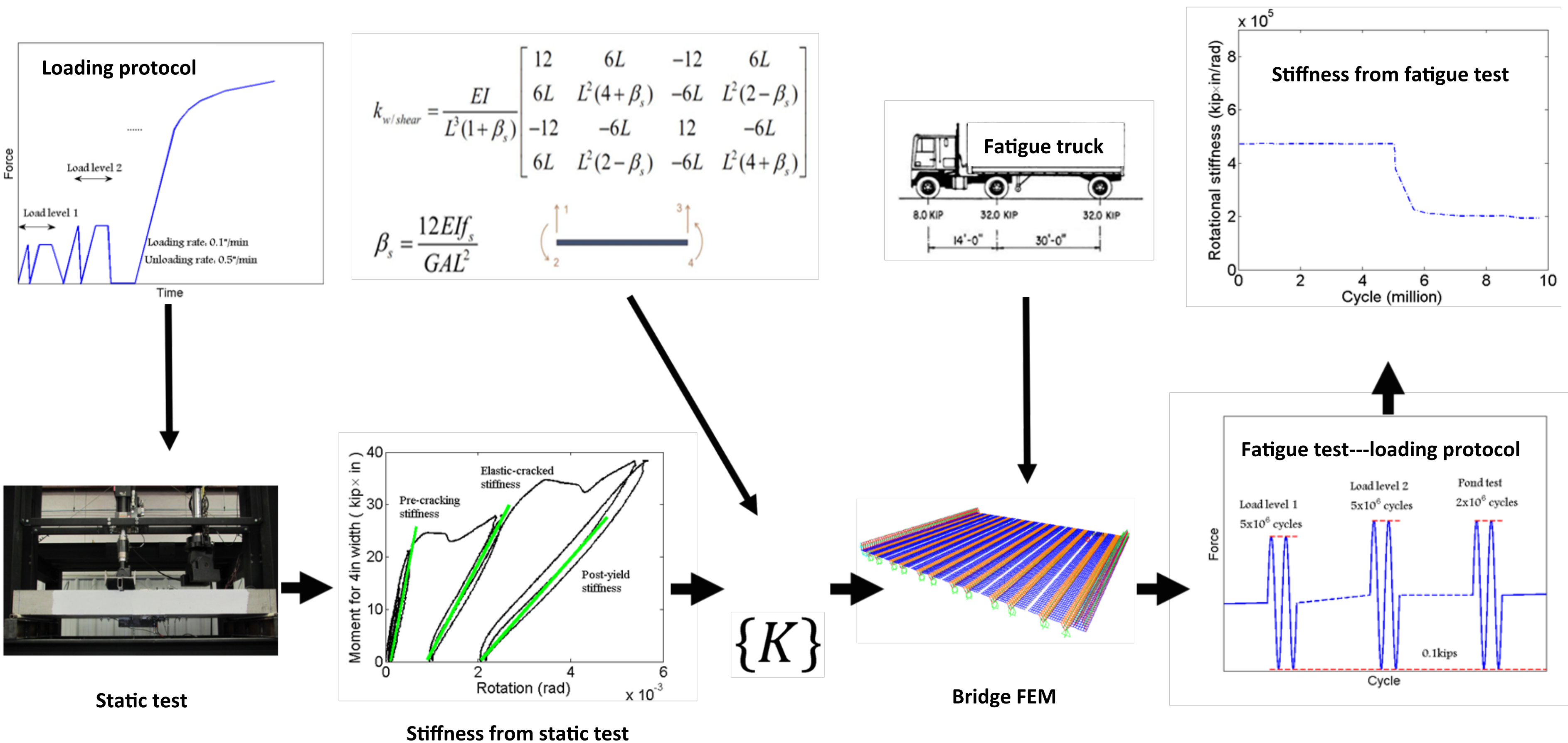








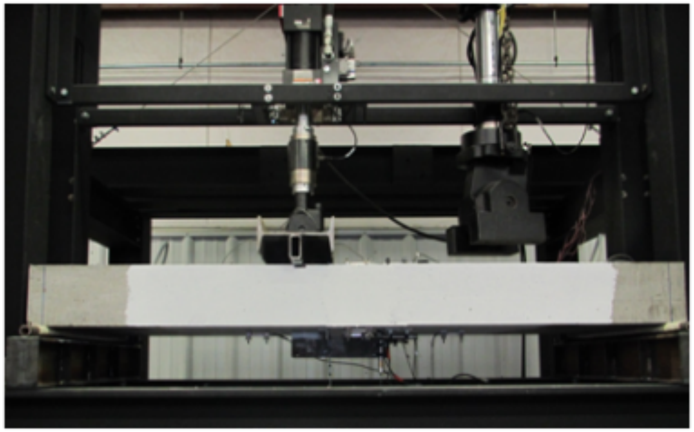
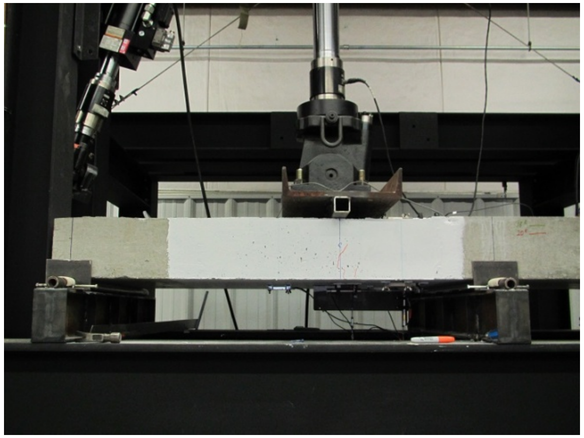
BIG PICTURE



Loading protocol
Force
Time
Load level 1
Load level 2
......
Loading rate: 0.1"/min
Unloading rate: 0.5"/min
$$k_{w/shear} = \frac{EI}{L^3(1+\beta_s)} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & L^2(4+\beta_s) & -6L & L^2(2-\beta_s) \\ -12 & -6L & 12 & -6L \\ 6L & L^2(2-\beta_s) & -6L & L^2(4+\beta_s) \end{bmatrix}$$
$$\beta_s = \frac{12EIf_s}{GAL^2}$$
Fatigue truck
8.0 KIP
32.0 KIP
32.0 KIP
14'-0"
30'-0"
x 10^5
Stiffness from fatigue test
Rotational stiffness (kip×in/rad)
Cycle (million)
Static test
Moment for 4in width (kip× in)
Rotation (rad)
x 10^-3
Pre-cracking stiffness
Elastic-cracked stiffness
Post-yield stiffness
Stiffness from static test
$\{K\}$
Bridge FEM
Fatigue test---loading protocol
Load level 1
5x10^6 cycles
Load level 2
5x10^6 cycles
Fond test
2x10^6 cycles
0.1kips
Force
Cycle

EXPERIMENT

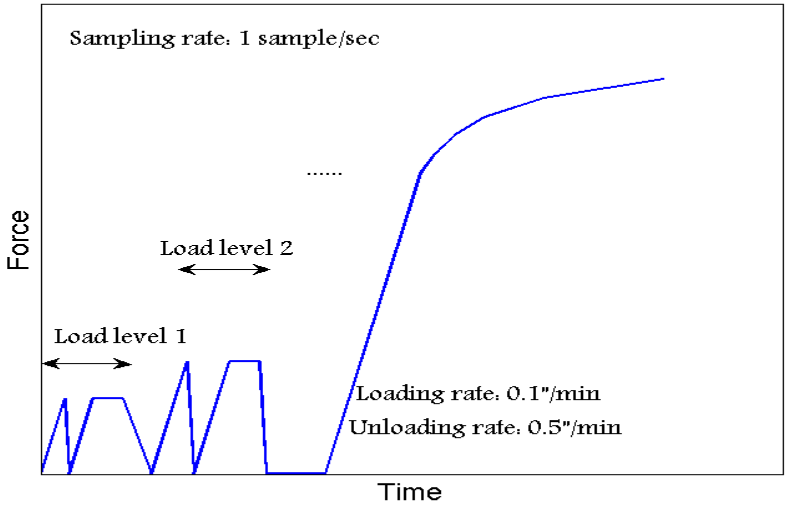
- Focus
  - Initial strength and stiffness from static testing
  - Degradation and durability) from fatigue test
  - Consider two moment/shear demand ratios

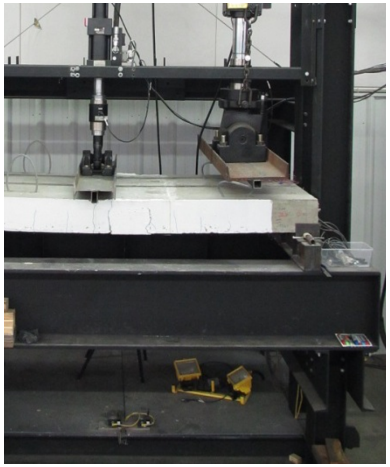



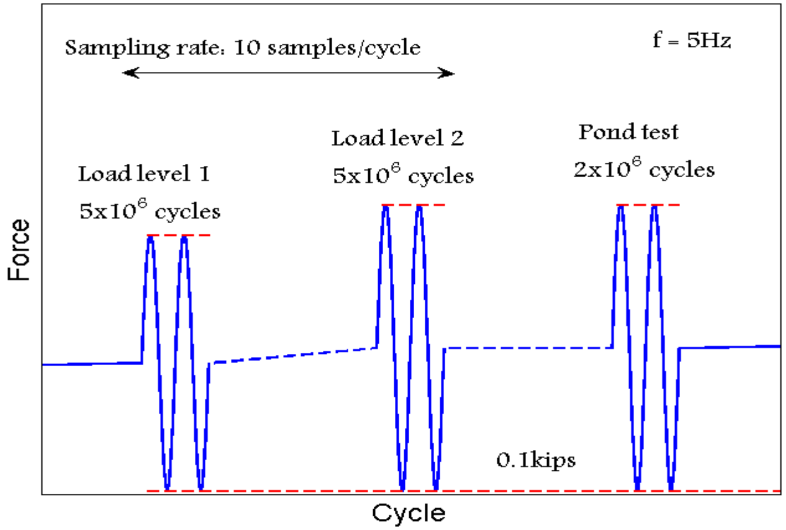
SHEAR KEY MATERIAL

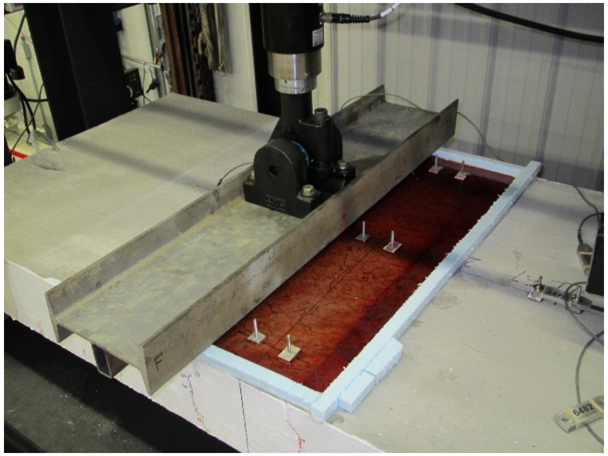
- Traditional concrete grout vs UHPC grout
  - Quikrete + PVA fibers
  - UHPC + steel or PVA fibers

SPECIMEN TESTING



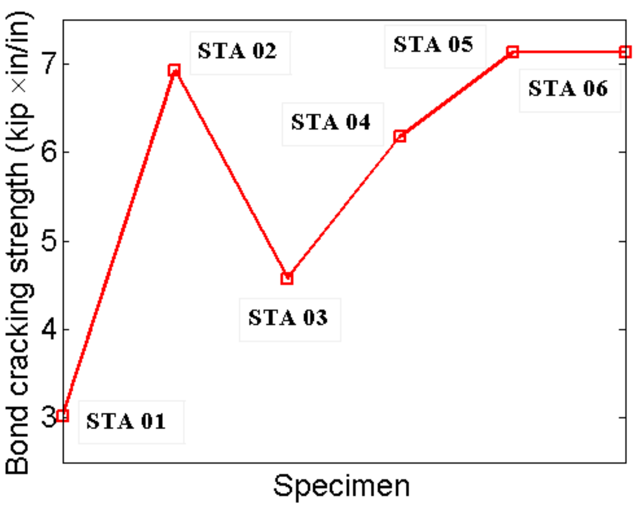






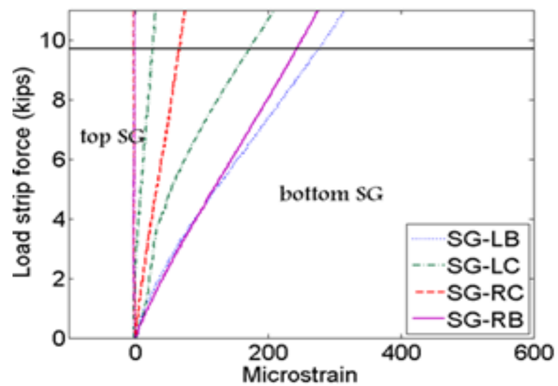
INITIAL BOND TESTING

- Static test: bond cracking strength
- Cylinder test

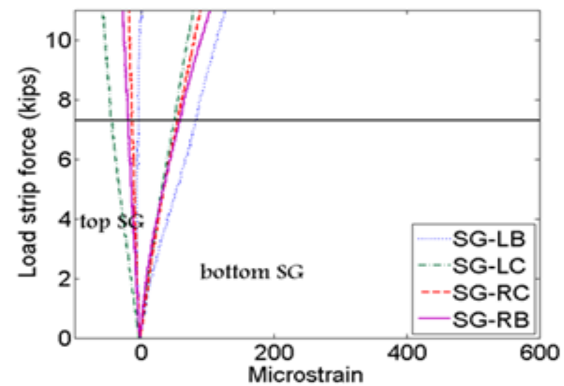


LONG-TERM BOND TESTING

- Fatigue test
  - No seepage
  - Rebar strain



(a) FAT-02



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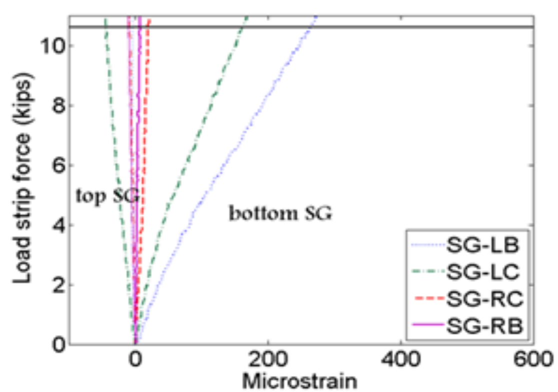

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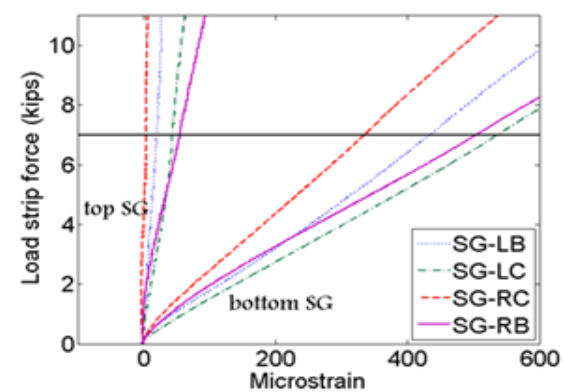
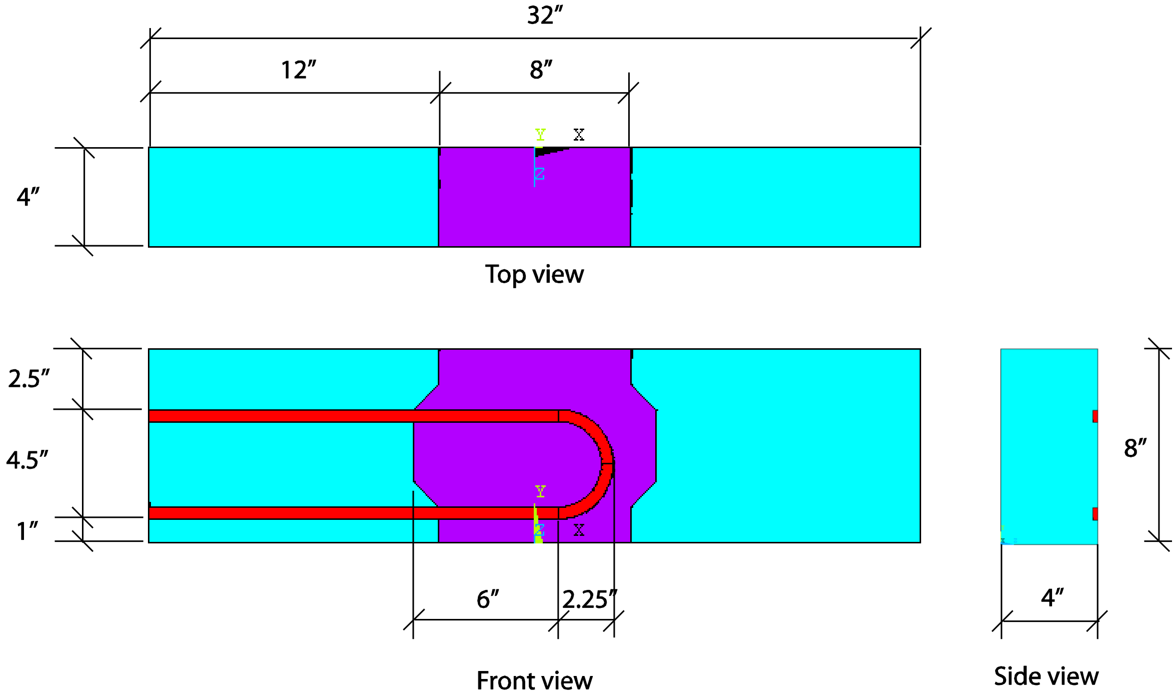


(d) FAT-01(redo)

SHEAR KEY FEM

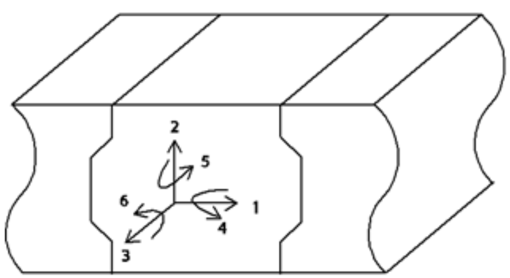
- U-bar configuration
- Elements

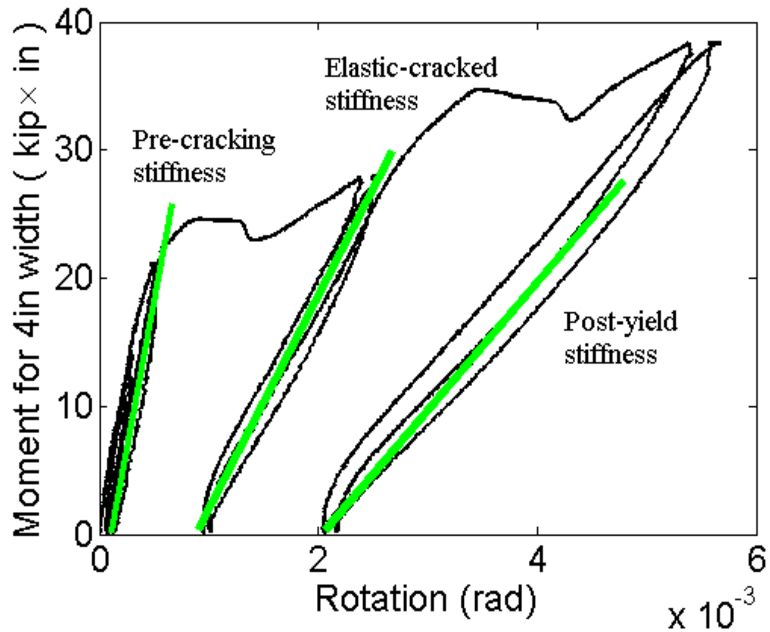


SHEAR KEY FEM CALIBRATION

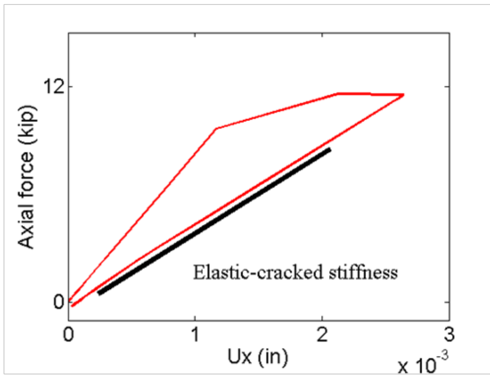
- Static test => model calibration => bridge FEM

	1	2	3	4	5	6
1	K11	0	0	0	0	0
2		K22	0	0	0	K26
3			K33	0	K35	0
4				K44	0	0
5					K55	0
6		(Sym.)				K66

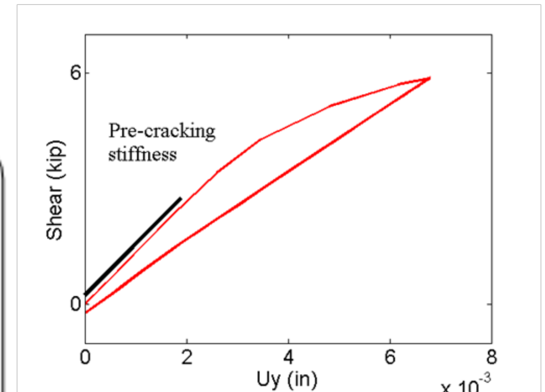




STIFFNESS MATRIX



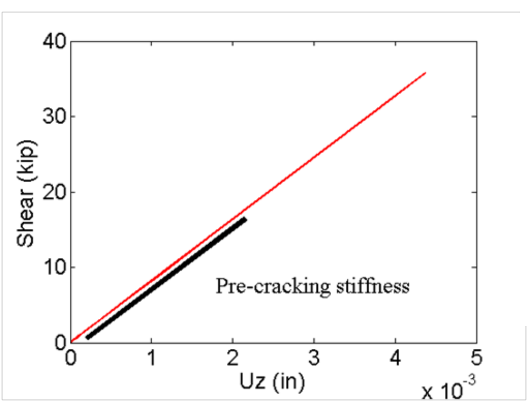
	1	2	3	4	5	6
1	4376	0	0	0	0	0
2		1340	0	0	0	1478
3			8171	0	--	0
4				--	0	0
5					--	0
6		(Sym.)				15960

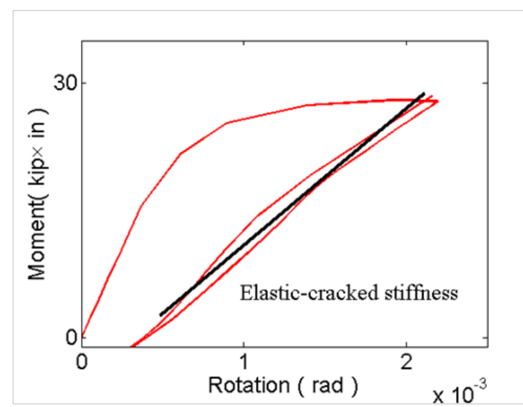


	U1	U2	U3	R1	R2	R3
U1	=A*E/L	0	0	0	0	0
U2	0	=12*X_3	0	0	0	=6*L*X_3
U3	0	0	=12*X_2	0	=6*L*X_2	0
R1	0	0	0	=J*G/L	0	0
R2	0	0	=6*L*X2	0	=L^2*(4+β_s)*X_2	0
R3	0	=6*L*X3	0	0	0	=L^2*(4+β_s)*X_3

$X_3=$ 167.50 $X_3=EI_3/(L^3*(1+\beta_s))$

$X_2=$ 1021.38 $X_2=EI_2/(L^3*(1+\beta_s))$





BRIDGE DESIGN

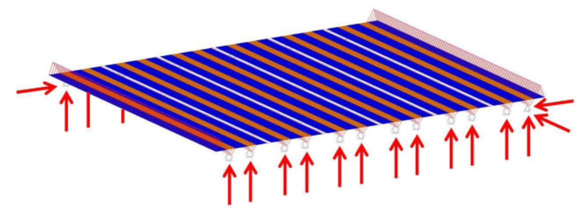
- Target:
  - Cross section: NEXT-D6 and NEXT-D8
  - Span lengths: 22, 30 and 40 feet
  - Parapet and overhang design
  - Beam design
  - Deck design
  - Provide guidelines for NEXT-D bridge design

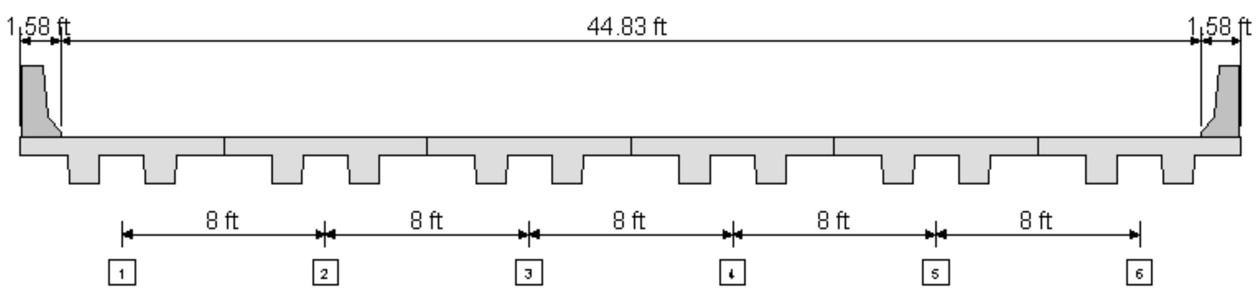
PARAPET/OVERHANG DESIGN

- Use the current rebar configuration as requested by SCDOT
  - Overdesign of the middle zone of parapet wall
  - Overdesign of the middle zone of overhang
  - Uniform rebar configuration

BEAM ANALYSIS AND DESIGN

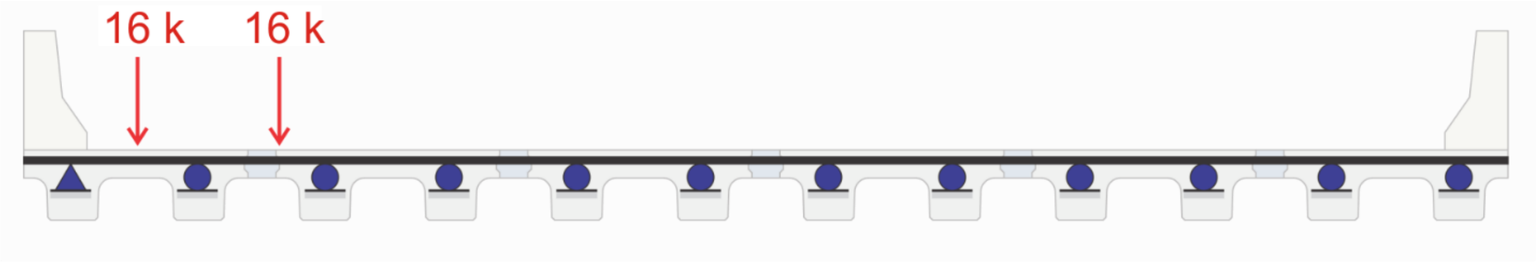
- Stem spacing < 4ft, therefore refined method needed
- Load distribution factors
- AASHTO LDFs are recommended
- Beam design: CONSPAN
  - Prestressing strand design and vertical reinforcement design
  - Exterior beam should not to be weaker than interior beam (LRFD Article 2.5.2.7)



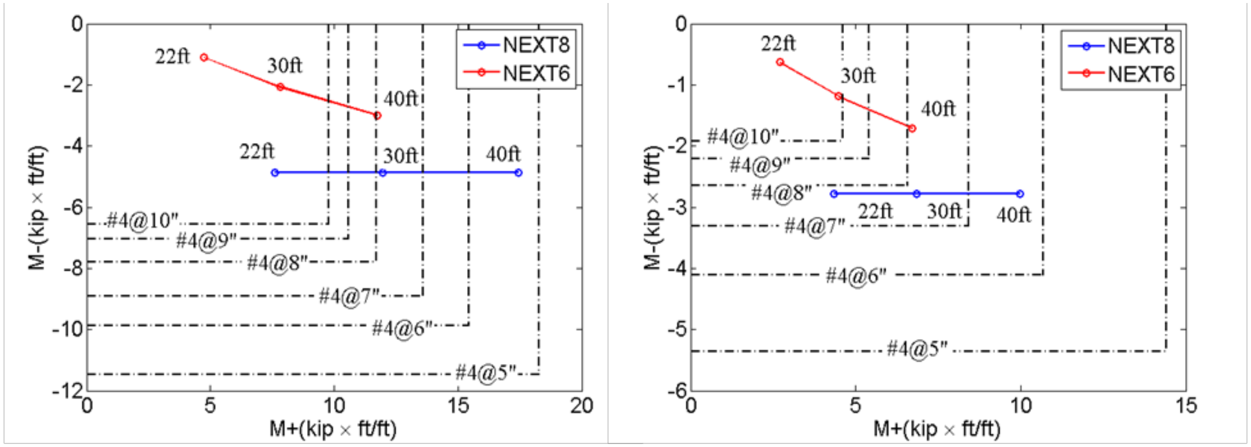


DECK ANALYSIS

- 3-D FEM method
  - Cannot reflect the change of deck span like NEXT-D7
  - Detail modeling is time-consuming
- AASHTO method (commonly used)
  - Does not reflect alternating deck spacing or span length change
- Formulas need to be developed
  - Relate AASHTO FEM with 3-D FEM demands



DECK DESIGN



NEXT 8 --- Final design capacity VS demand

Span length (ft)	Rebar config.	Strength I				Service I			
		M+ (kip*ft/ft)		M- (kip*ft/ft)		M+ (kip*ft/ft)		M- (kip*ft/ft)	
		Demand	Capacity	Demand	Capacity	Demand	Capacity	Demand	Capacity
22	#4@7”	7.61	13.59	-4.87	-8.90	4.35	8.42	-2.78	-3.32
30	#4@7”	11.98	13.59	-4.87	-8.90	6.85	8.42	-2.78	-3.32
40	#4@5”	17.44	18.29	-4.87	-11.47	9.96	14.41	-2.78	-5.36

NEXT 6 --- Final design capacity VS demand

Span length (ft)	Rebar config.	Strength I				Service I			
		M+ (kip*ft/ft)		M- (kip*ft/ft)		M+ (kip*ft/ft)		M- (kip*ft/ft)	
		Demand	Capacity	Demand	Capacity	Demand	Capacity	Demand	Capacity
22	#4@10”	4.72	9.79	-1.10	-6.55	2.70	4.61	-0.63	-1.92
30	#4@10”	7.84	9.79	-2.07	-6.55	4.48	4.61	-1.18	-1.92
40	#4@7”	11.74	13.59	-2.99	-8.90	6.71	8.42	-1.71	-3.32

PAPERS IN PROGRESS

- Paper 1: Static test and model calibration
  - Sensitivity of stiffness to selected parameters

- Paper 2: Long-term performance
  - Bond performance
  - Stiffness degradation
  - Conservativeness of fatigue loads
  - Sensitivity study of fatigue demands

- Paper 3: Bridge design
  - Load distribution factor determination
  - Transverse demand determination
  - Design guidelines

SCDOT
South Carolina Department of Transportation

CLEMSON
GLENN DEPARTMENT OF CIVIL ENGINEERING

U.S. Department of Transportation
Federal Highway Administration

SUMMARY REPORT

Report No. FHWA–SC–13-04
October 2013

South Carolina Department of Transportation
955 Park Street
P. O. Box 191
Columbia, SC 29202

Precast Alternative for Flat Slab Bridges

Cast-in-place (CIP) flat slab systems have been widely used in the State of South Carolina for short span bridges with spans of 20 to 40 feet in length. These CIP flat slab bridges have a good record of performance in terms of durability and have no restrictions on ADTT (average daily truck traffic). However, on-site construction of CIP bridges often requires a lengthy and costly disruption of traffic. As an alternative to CIP flat slab bridges, the South Carolina Department of Transportation (SCDOT) uses adjacent precast hollow-core slabs or box beams to construct bridges on low volume secondary roads. These sections are used on spans ranging from twenty to seventy feet in length and are relatively quick to install. They are also cost competitive with other systems. However, there are some in-service performance issues that are of concern to the SCDOT such as longitudinal reflective cracks forming in the asphalt overlay above the joints between adjacent sections. Transverse cracks also develop at the abutments and bents where little or no continuity is provided between adjacent simple spans. Reflective cracks are problematic as they allow water to seep through the wearing surface and expose the structural members to water and possible deicing chemicals. The water, especially in freeze-thaw conditions and the chemicals accelerate the rate of deterioration of the concrete and corrosion of embedded steel. The longitudinal cracks between the adjacent precast members also signify the possible breakdown of the desired load transfer provided by the shear key. Since precast concrete slabs/beams are typically designed to take only a fraction of the wheel line load, an overloading of a single precast element is possible without the expected load sharing.

Since the existing precast hollow-core system has limitations, the SCDOT commissioned this study to provide a recommendation for an alternative to existing flat slab and box beam precast concrete bridges but with similar expected performance to cast-in-place bridges. This recommendation should:

- eliminate or minimize longitudinal reflective cracking,
- have a shorter erection time than the CIP flat slab system, and
- have no restriction on ADTT and suitable for use on the National Highway System.

There were two distinct phases in this research. In Phase 1, a thorough online survey and telephone interviews were conducted to investigate the pros and cons of existing short-span bridge systems used by other state departments of transportation. In addition, a mini-workshop was conducted to solicit feedback from contractors and precast element fabricators in the Southeast region (Georgia, South Carolina, and North Carolina). A promising precast bridge system known as the NEXT-D (Northeast Extreme Tee) beam was identified as a potential system to replace the current precast hollow-core systems used by the SCDOT. The NEXT-D section is a double-tee beam with a thick flange that does not require a structural overlay to create continuity but instead uses full-depth closure pours along the longitudinal edges of the precast sections. In Phase 2, an analytical study and an experimental program were carried out to adapt the standard NEXT-D system for use on shorter span bridges by reducing the overall depth of the section and number of prestressing strands and also verify the service and strength performance of the critical shear key (closure pour).

(Continued on back)

PART 2:
ON-GOING WORK

PIs: Rangaraju and Schiff

Post-Doc: Venkata

PhD Student: Li

MS Student: Cousins and Johnson

EXPERIMENTAL WORK

- Modified Quikrete
  - Improved workability
  - Improved bond strength
- Generic UHPC (maybe just a HPC or VHPC)
  - Strength and Stiffness
  - Bond to precast and rebar
  - Workability and Durability
  - Shrinkage
- Rebar Development
  - Lollypop (rebar/confined cylinder)
  - Lollypop (rebar/unconfined cylinder)
  - Design guidelines
- Shear Key Testing
  - U-bar in generic UHPC (static)
  - Straight bars in generic UHPC (static)
  - Generic UHPC (fatigue)

PART 3: FUTURE WORK

PIs: Schiff, Cousins (Virginia Tech), Rangaraju and …

PhD Students: Li and …

MS Students: Cousins, Johnson and …

EXPERIMENTAL WORK

- IBRD (4 simple spans: 40’-70’-70’-40’)
  - Approach spans
    - Modified NEXT-D based of recommendations of completed work
    - Hollow Core or Solid Slab with improved shear key and UHPC grout
  - Main spans
    - Hollow Box with typical key and UHPC grout
    - Hollow Box with …
  - Monitored casting of precast pieces and on-site construction
  - Bridge testing at opening and after 6, 12 and 18 months of traffic
- Refined improvements to generic UHPC
- Additional testing of longitudinal joints
- Testing on continuity joints between spans
- Influence of construction and/or adjacent traffic loads on performance of shear keys and continuity joints
  - Work with Tommy Cousins at Virginia Tech to gain support for an FHWA pooled fund study to address short development lengths in UHPC

COMMENTS OR QUESTIONS

Scott D. Schiff
scott.schiff@ces.clemson.edu
864.656.0456