IMAGINE THE UNIVERSITY OF UTAH

Evaluation of Grouted Splice Sleeve Connections for Reinforced Precast Concrete Bridge Piers

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TLN Learning Series 2015-2016 1/25/2016

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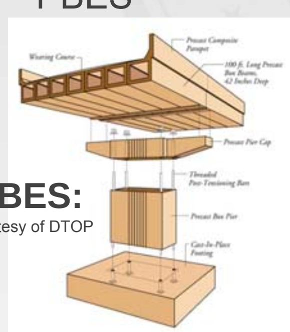
Accelerated Bridge Construction (ABC)

- Innovative techniques, methodologies, and materials
- Reduced construction time and traffic disruption
- Higher level of work-zone safety
- Environmental-friendly procedures
- PBES



PBES:
Courtesy of DTOP

Courtesy of Hanson Structural Precast (Forterra)

Khaleghi et al. (2012)

INTRODUCTION

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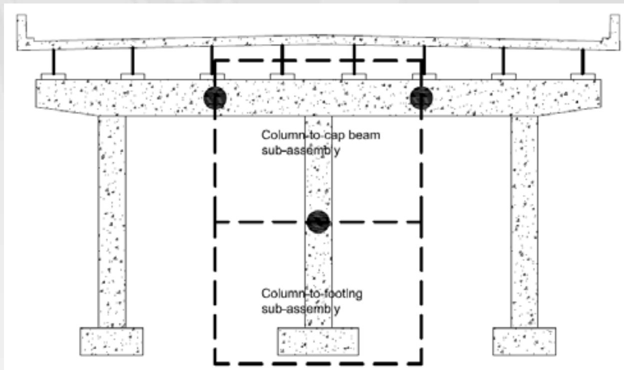
Common Emulative ABC Connections

- Under Study (Especially for high-seismic zones)
- Already Implemented
- Experimental Research:



INTRODUCTION

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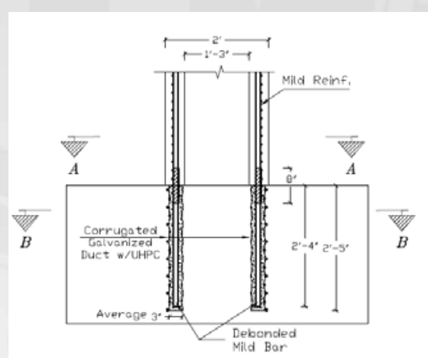
Common Emulative ABC Connections

- Grouted Duct Connections

Column-to-cap beam connection (Matsumoto, 2009)



Column-to-footing connection (Tazarv et al., 2012)

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Common Emulative ABC Connections

- Pocket Connections

Column-to-cap beam connection (NCHRP 698)

INTRODUCTION

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Common Emulative ABC Connections

- Socket Connections (Khaleghi et al., 2012)

Column-to-footing connection

Grouted Duct connection used for cap beam

INTRODUCTION

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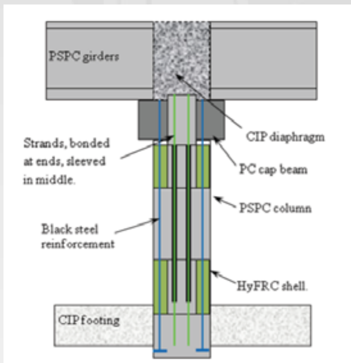
Common Emulative ABC Connections

- Hybrid Connections (Pre-tensioning)



Haraldsson (2013)

Schaefer (2013)

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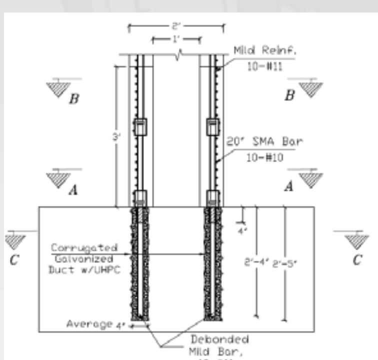
Common Emulative ABC Connections

- Advanced Materials, SMA (Tazarv et al., 2014)



Column-to-footing connection

SMA bars in column end

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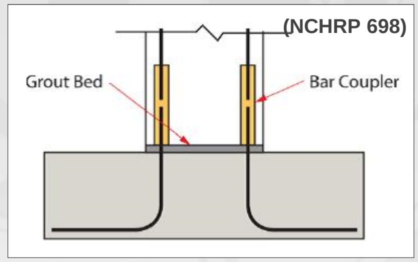
Grouted Splice Sleeve (GSS) Connections

- Alternatively called:
  - Mechanical rebar splices
  - Grout-filled steel sleeves
- Components:
  - Rebar
  - Sleeve
  - Grout
- GSS in Design Codes
  - ACI 550 (Type 1, Type 2)
  - AASHTO (Full mechanical connection)
  - Caltrans (Service and ultimate couplers)



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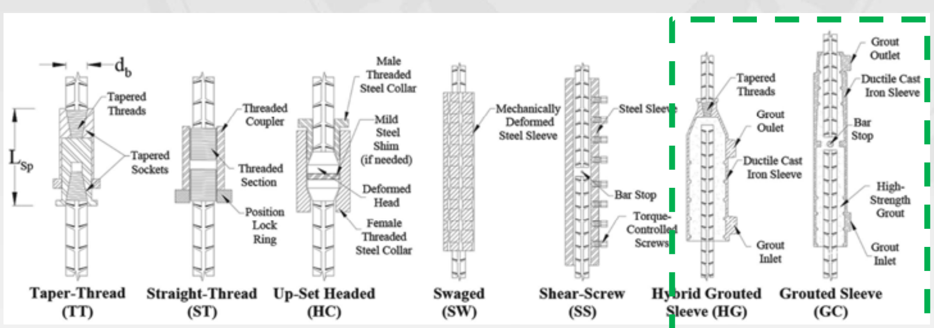
Grouted Splice Sleeve (GSS) Connections

- Used as replacement for welded and lapped splices
- Considerably reduced dowel length
- Grouted splice sleeves are suitable for precasting (good construction tolerance)
- **Not permitted** in plastic hinge zone of bridge piers in seismic regions



Haber et al. (2015)

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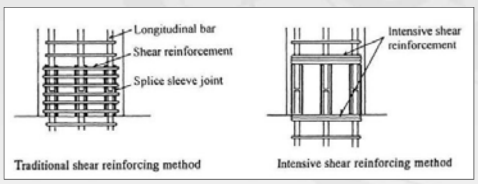
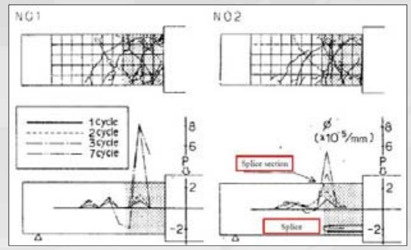
Previous Research

Large scale tests conducted in Japan:

- Limited to strength properties
- Typical of buildings



ISR method (Yoshino et al., 1996)



Matsuzaki et al. (1987)

INTRODUCTION

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Previous Research

- Two half-scale specimens @ UNR (Haber et al. 2013)

GGSS in column end

(1) Footing dowels/No pedestal

(2) Footing dowels/12-in. pedestal

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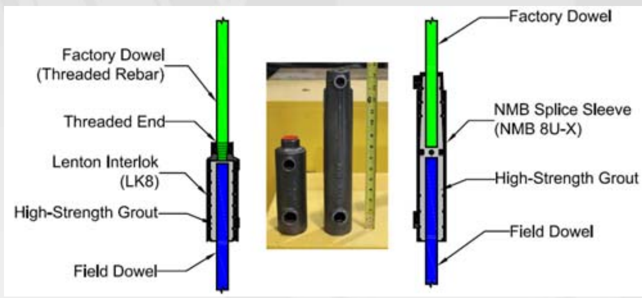
Research Objective

- To evaluate seismic performance of precast bridge piers with GSS inside and outside column plastic hinge



FGSS for column-to-cap beam [Lenton Interlok]

GGSS for column-to-footing [NMB Splice Sleeve]

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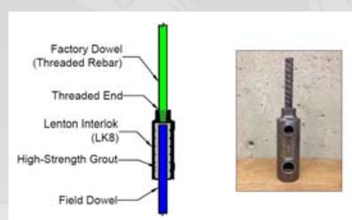
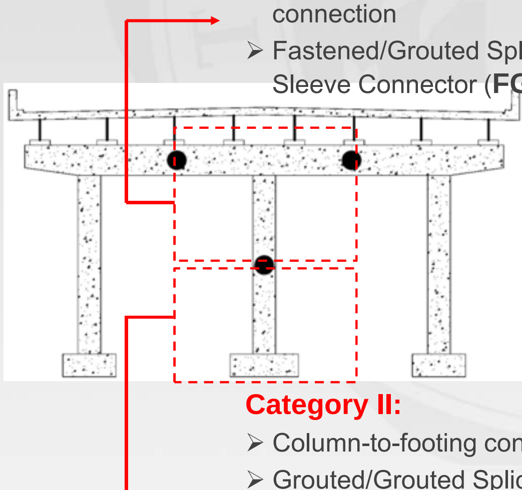
Research Objective

Category I:

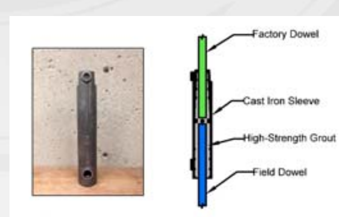
- Column-to-cap beam connection
- Fastened/Grouted Splice Sleeve Connector (**FGSS**)





Category II:

- Column-to-footing connection
- Grouted/Grouted Splice Sleeve Connector (**GGSS**)



INTRODUCTION

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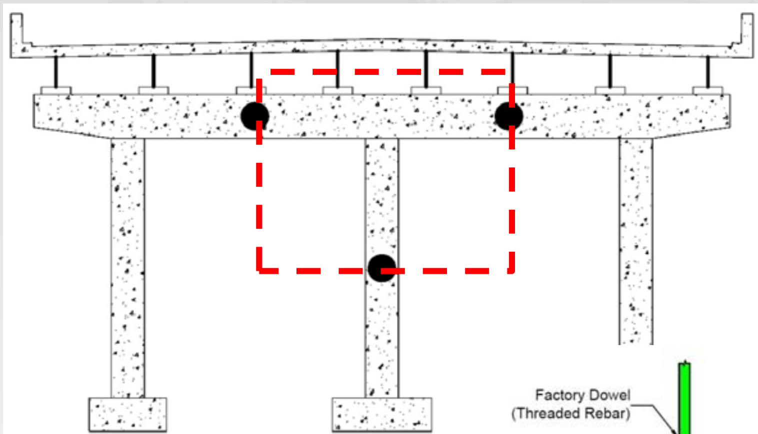

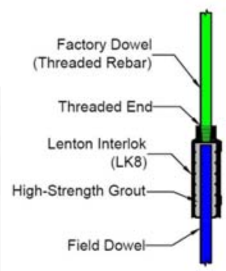

CATEGORY I

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Connector Tests

- Monotonic tensile load
- Pullout failure
- 1.44fy average strength (nominal)
- Type 1 splice (building)
- FMC (bridge)

CATEGORY I

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Connector Tests

Air test identification	Maximum load (kip)	Maximum bar stress (ksi)	Maximum bar stress normalized to f_y	Observed failure mode
Air test-1	69.7	88.2	1.47	Reinforcing bar pullout
Air test-2	71.5	90.5	1.51	Reinforcing bar pullout
Air test-3	66.4	84.1	1.40	Reinforcing bar pullout
Air test-4	68.0	86.1	1.43	Reinforcing bar pullout
Air test-5	64.6	81.8	1.36	Reinforcing bar pullout
Air test-6	69.1	87.5	1.46	Reinforcing bar pullout

CATEGORY I

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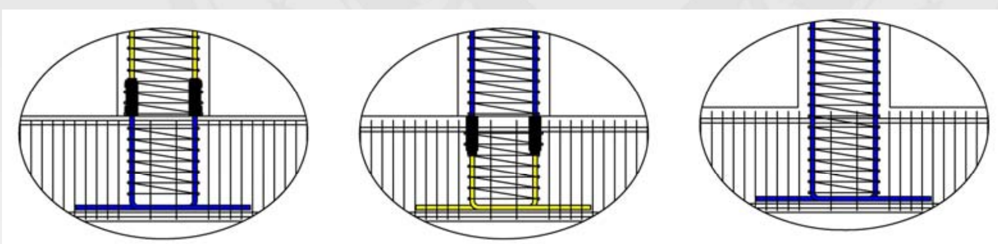
Half-scale Experiment: Test Matrix

No.	Specimen	Connector Location	Details
(a)	FGSS-1	Column	Precast
(b)	FGSS-2	Cap Beam	Precast
(c)	FGSS-CIP	--	Cast in Place



FGSS-1 FGSS-2 FGSS-CIP

CATEGORY I

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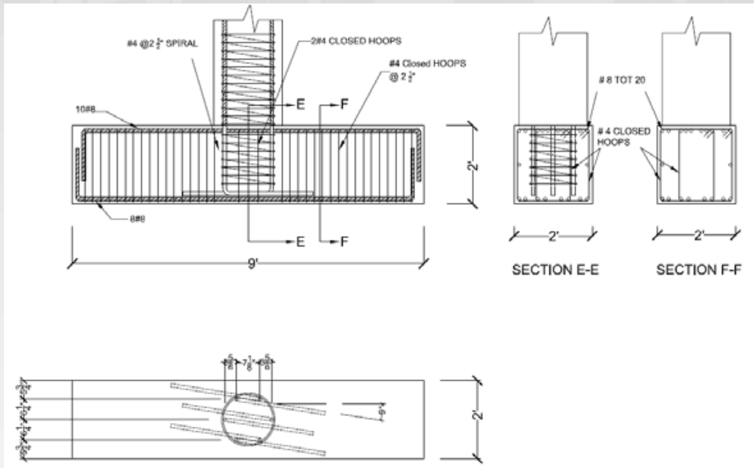
Half-scale Experiment: Design and Construction

- Design according to AASHTO Guide Specifications



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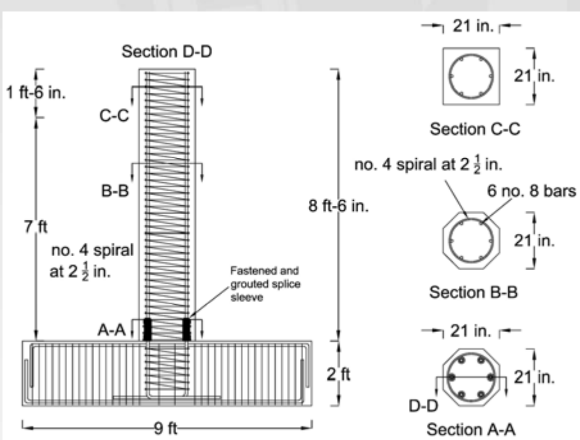
Half-scale Experiment: Design and Construction

- **FGSS-1**



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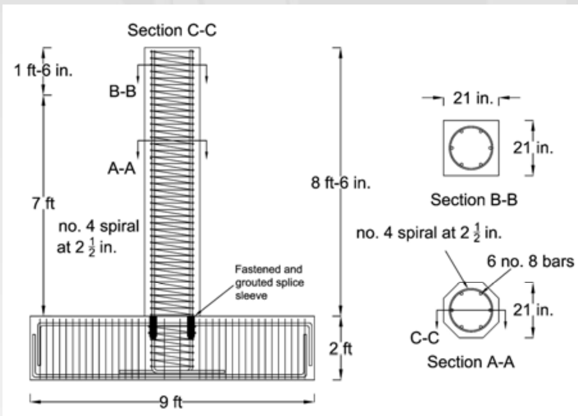
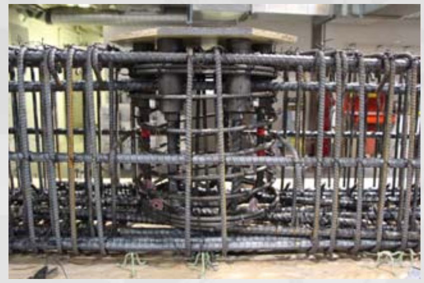
Half-scale Experiment: Design and Construction

- **FGSS-2**





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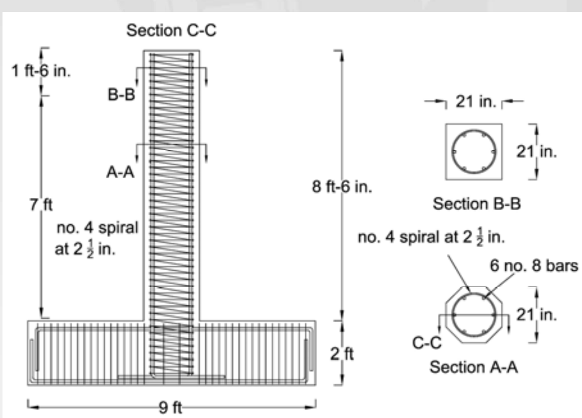
Half-scale Experiment: Design and Construction

- **FGSS-CIP**



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Half-scale Experiment: Design and Construction

- Grouting Operation

CATEGORY I

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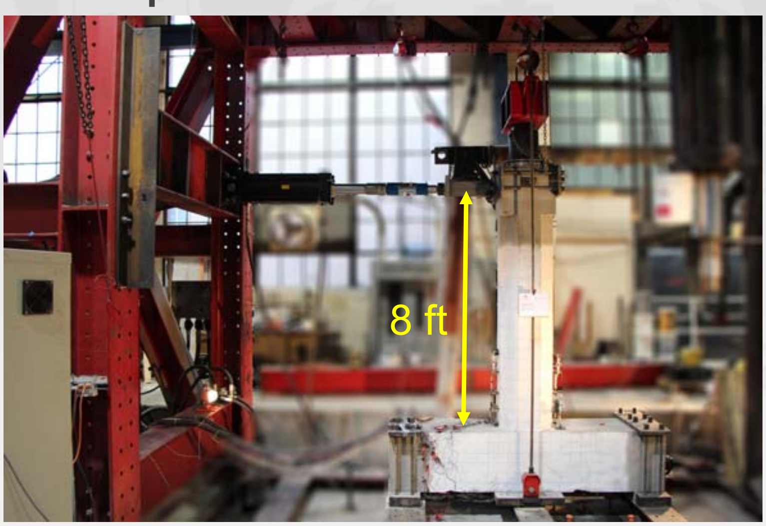
Half-scale Experiment: Test Procedure and Instrumentation

- Test Setup



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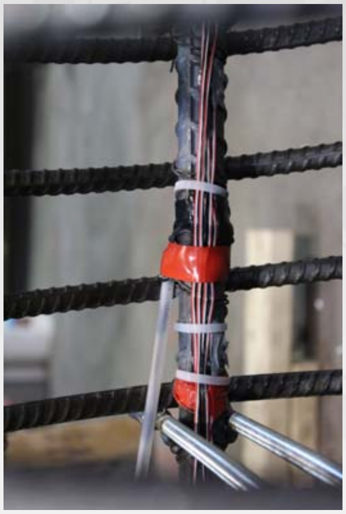
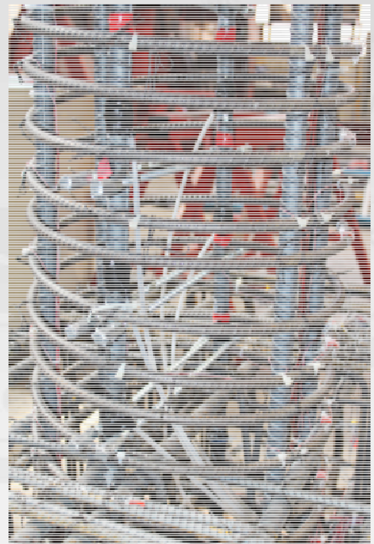
Half-scale Experiment: Test Procedure and Instrumentation

- Strain Gauges





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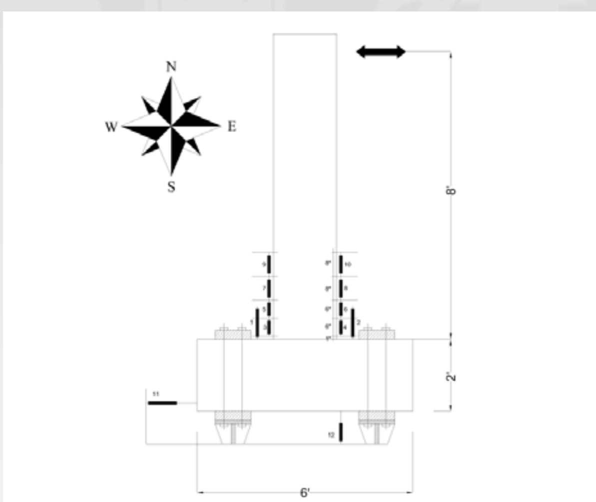
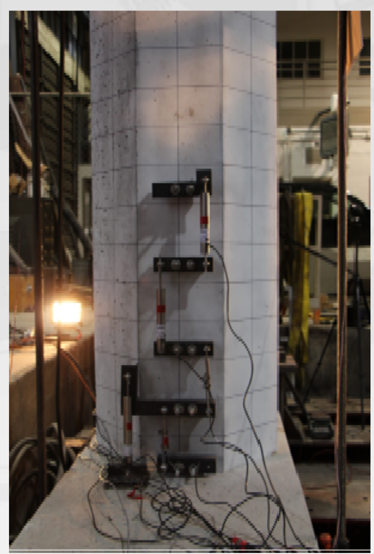
Half-scale Experiment: Test Procedure and Instrumentation

- LVDTs





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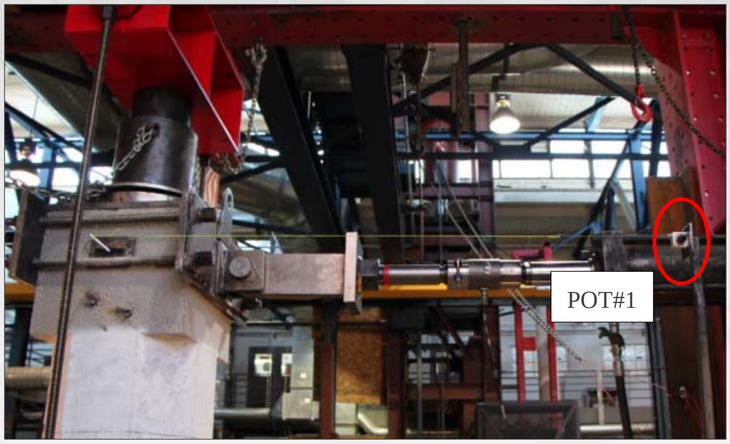
Half-scale Experiment: Test Procedure and Instrumentation

- **String Potentiometers**



CATEGORY I

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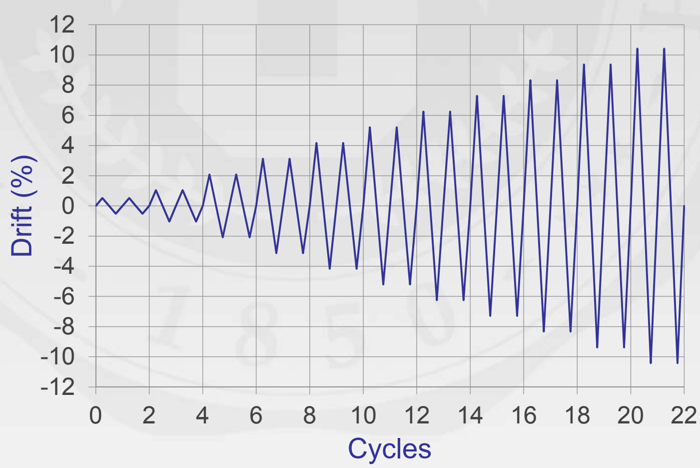
Half-scale Experiment: Test Procedure and Instrumentation

- **Loading Protocol**

- ❑ ACI 374 instructions followed
- ❑ Displacement-controlled history
- ❑ Two cycles per drift ratio
- ❑ First cycle $\Delta y/2$ (predicted)
- ❑ Multiples of Δy for higher excursions
- ❑ 1.2 & 4.0 in/min displacement rate



CATEGORY I

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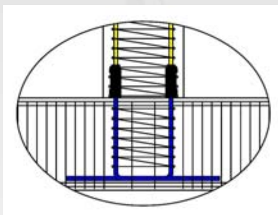
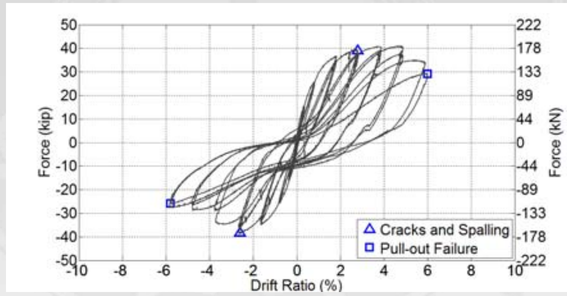
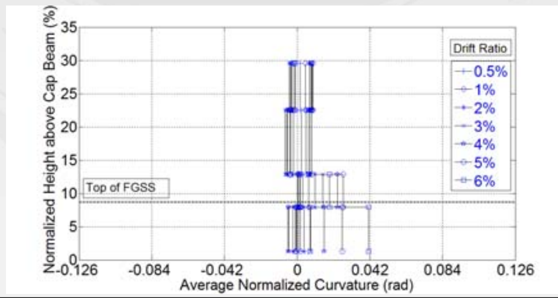
Test Results: Hysteretic Response/FGSS-1







CATEGORY I

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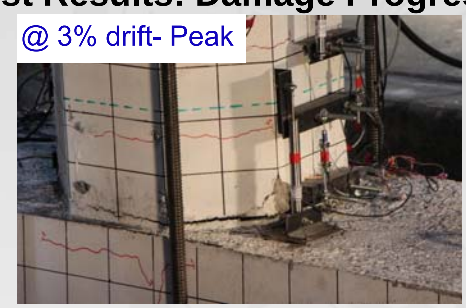
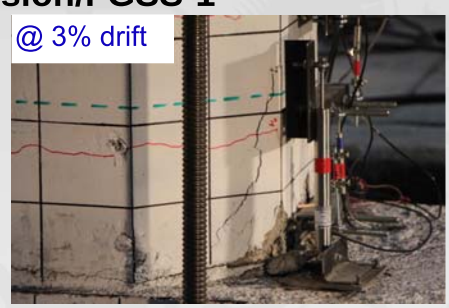
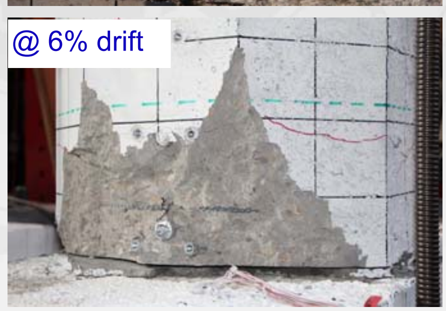
Test Results: Damage Progression/FGSS-1







CATEGORY I

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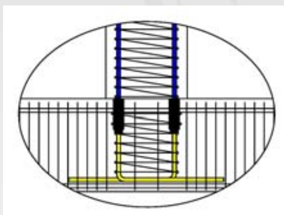
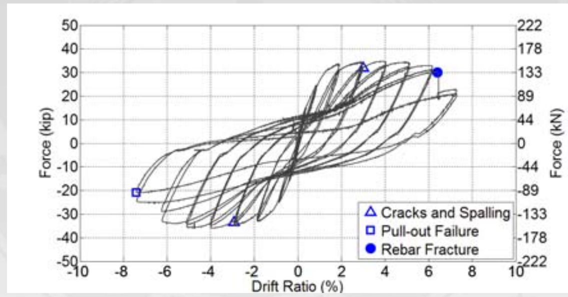
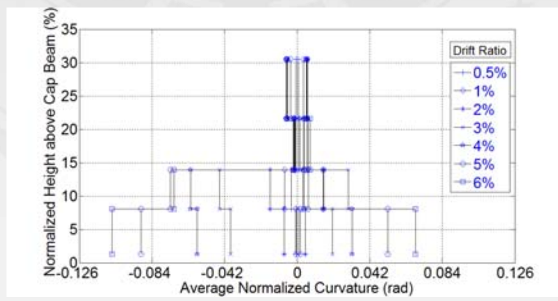
Test Results: Hysteretic Response/FGSS-2







CATEGORY I

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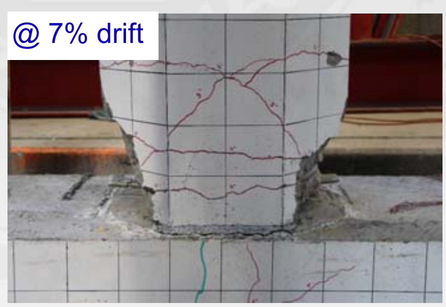
Test Results: Damage Progression/FGSS-2



CATEGORY I

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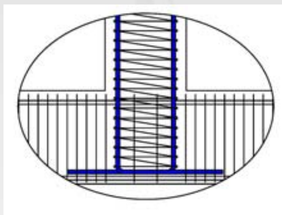
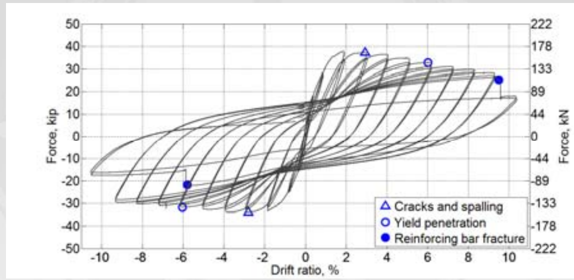
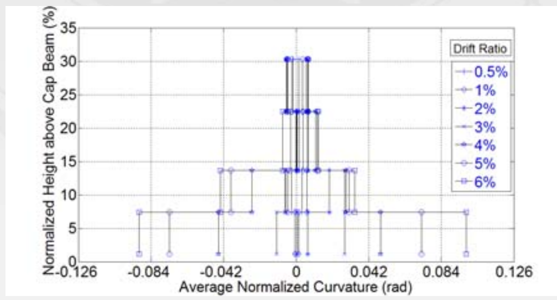
Test Results: Hysteretic Response/FGSS-CIP







CATEGORY I

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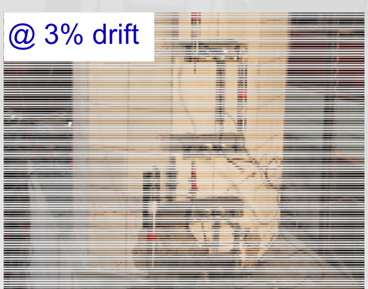
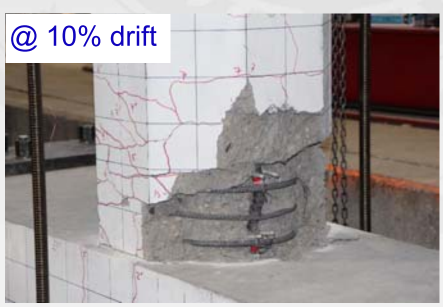
Test Results: Damage Progression/FGSS-CIP





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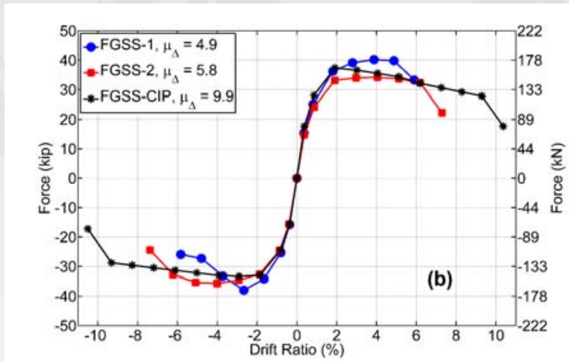
Test Results: Displacement Capacity

Specimen	Last Drift	F_y	Δ_y	Δ_u	K_{eff}	μ_Δ
	Ratio (%)	(kip)	(in.)	(in.)	(kip/in)	
FGSS-1	6	35.35	1.08	5.32	32.70	4.9
FGSS-2	7	33.29	1.11	6.50	29.92	5.8
FGSS-CIP	10	32.33	0.90	8.95	35.84	9.9



CATEGORY I

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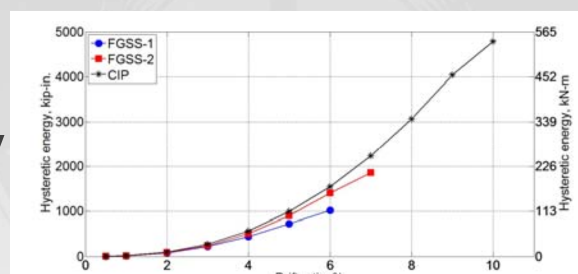
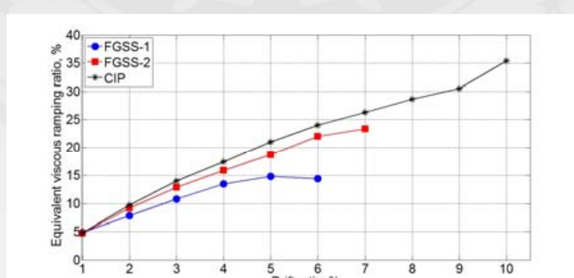
Test Results: Energy Dissipation Capacity

- **Cumulative Energy**



- **Equivalent Viscous Damping**



CATEGORY I

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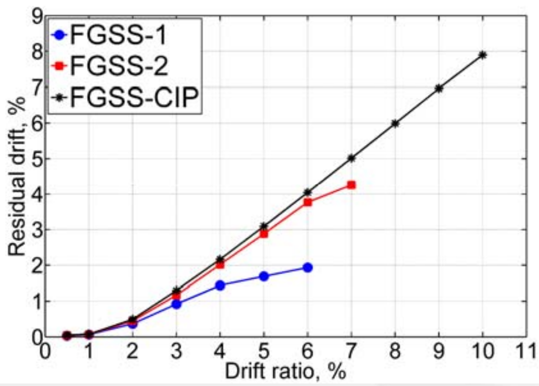
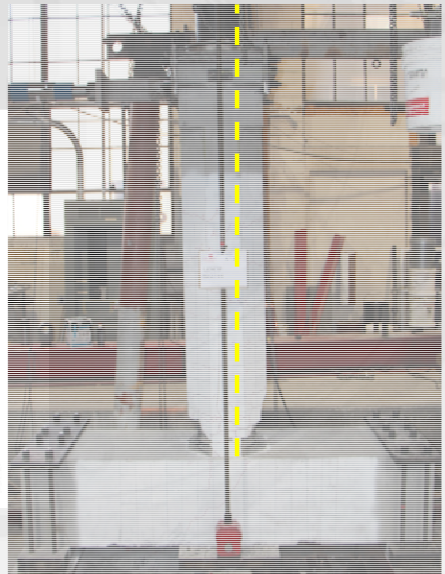
Test Results: Residual Drift





CATEGORY I

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Test Results: Conclusions

- Desirable performance (ductile), rebar fracture, μ_{Δ} equal to 9.9 for FGSS-CIP.
- FGSS-CIP had very good hysteretic performance, energy dissipation capacity, and well-distributed flexural cracks.
- Localized damage for FGSS-1. Smaller spalled region with respect to FGSS-CIP.
- Similar damage states for FGSS-2 and FGSS-CIP, with no FGSS in the column base.
- Rebar fracture for FGSS-CIP and premature rebar fracture for one FGSS-2 bar due to higher values of concentrated strains at interface. Excessive bond-slip led to pull-out failure of FGSS-1 and FGSS-2's east rebar.

CATEGORY I

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Test Results: Conclusions, cont'd

- A more ductile response achieved by incorporating FGSS inside cap beam. One bar fractured and , μ_{Δ} increased from 4.9 to 5.8.
- Different distribution of inelasticity for FGSS-1, as FGSS connectors were in the column base. Similar inelasticity distribution for FGSS-2 and FGSS-CIP.
- Strain gauge data showed both field and factory dowel yielded for FGSS-1. The factory dowel of FGSS-2 did not yield at all.
- Displacement ductility for all specimens exceeded minimum component ductility of 3 per Caltrans SDC. μ_{Δ} of 5.8 (FGSS-2) was greater than maximum ductility demand of 5.0 per AASHTO Guide Specifications for single-column bents.

CATEGORY I

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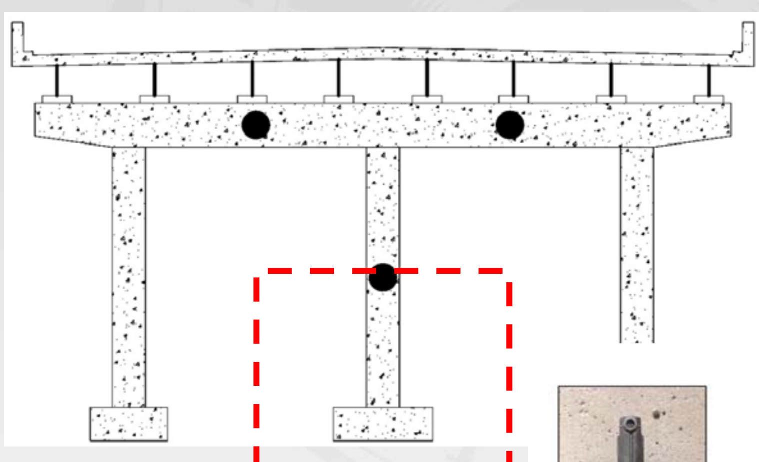

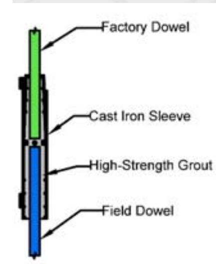

Column-to-footing connections with Grouted/Grouted Splice Sleeve Connector (**GGSS**)

CATEGORY II

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Connector Tests

- o Monotonic tensile load
- o Bar Fracture
- o 1.69fy average strength (nominal)
- o Type 2 splice (building)
- o FMC (bridge)

CATEGORY II

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Connector Tests

Connector test identifier	Maximum load (kip)	Maximum bar stress (ksi)	Maximum bar stress normalized to f_y	Failure mode
Connector test-1	81.2	102.8	1.71	Bar fracture
Connector test-2	80.7	102.2	1.70	Bar fracture
Connector test-3	80.1	101.4	1.69	Bar fracture
Connector test-4	79.9	101.1	1.69	Bar fracture
Connector test-5	80.0	101.3	1.69	Bar fracture
Connector test-6	77.3	97.8	1.63	Bar fracture

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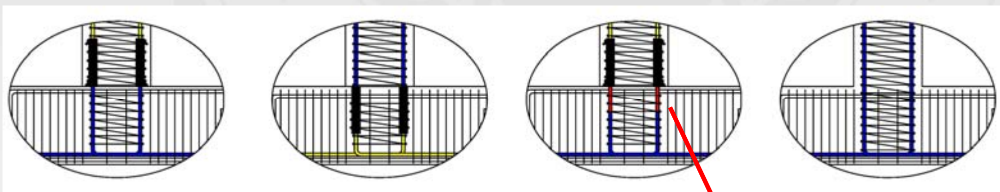
Half-scale Experiment: Test Matrix

No.	Specimen	Connector Location	Details
(a)	GGSS-1	Column	Precast
(b)	GGSS-2	Footing	Precast
(c)	GGSS-3	Column	Precast with debonded bars in footing
(d)	GGSS-CIP	--	Cast in Place



GGSS-1 GGSS-2 GGSS-3 GGSS-CIP

Debonded

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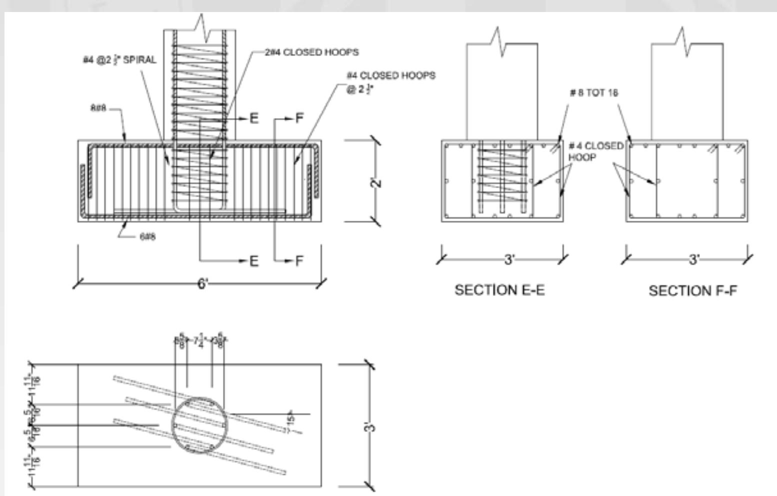
Half-scale Experiment: Design and Construction

- Design according to AASHTO Guide Specifications



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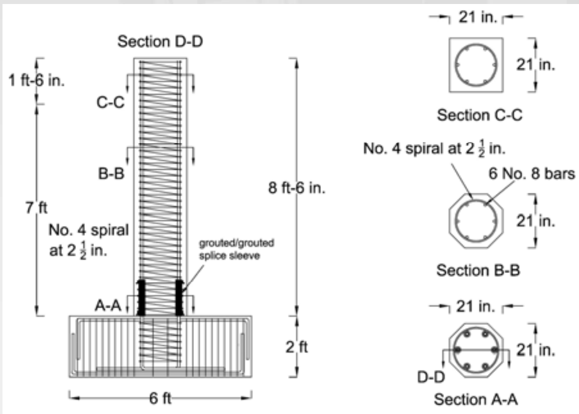
Half-scale Experiment: Design and Construction

- GGSS-1



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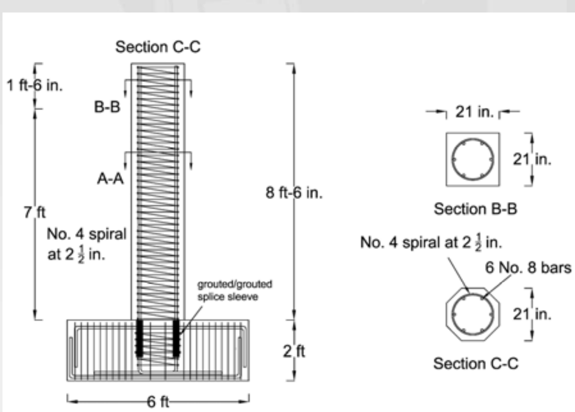
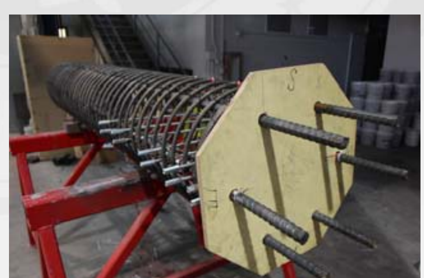
Half-scale Experiment: Design and Construction

- GGSS-2





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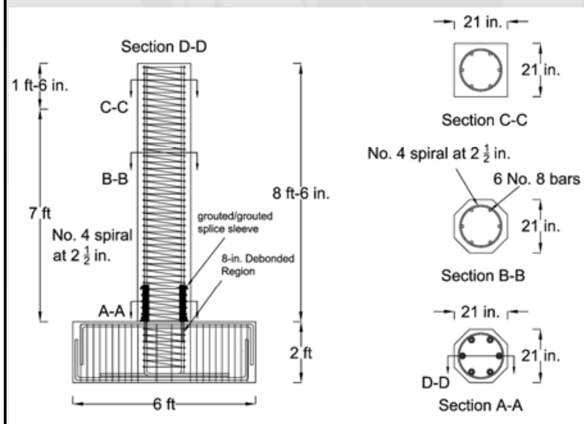
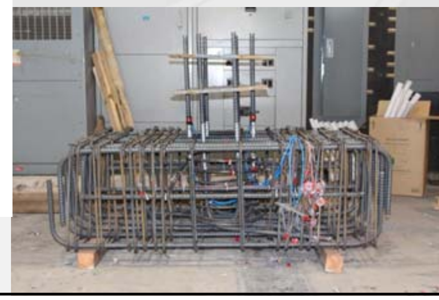
Half-scale Experiment: Design and Construction

- GGSS-3





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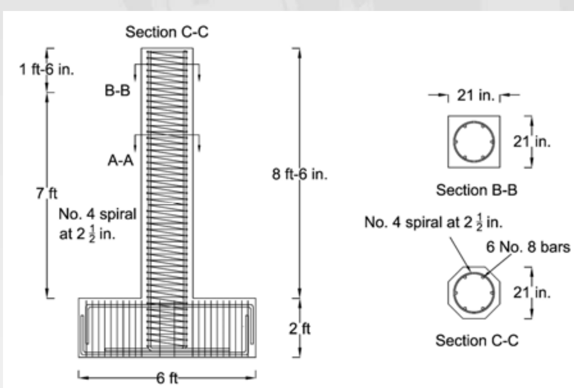
Half-scale Experiment: Design and Construction

- GGSS-CIP



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Half-scale Experiment: Design and Construction

- Grouting Operation

CATEGORY II

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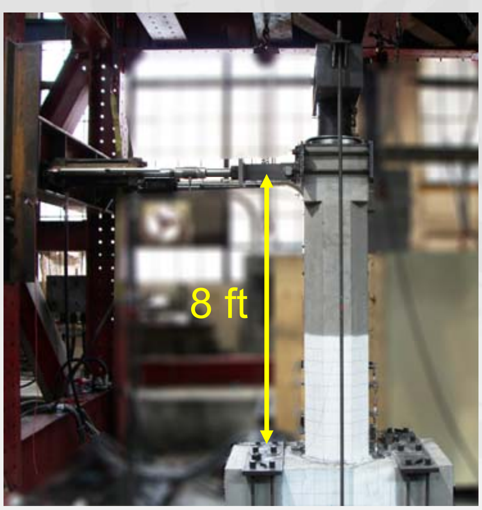
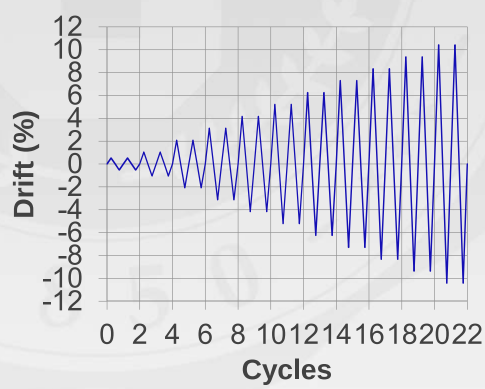
Half-scale Experiment: Test Procedure and Instrumentation

- Test configuration and instrumentation similar to CATEGORY I





CATEGORY II

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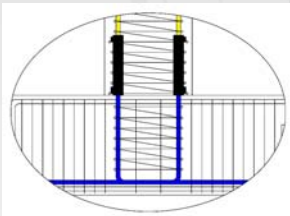
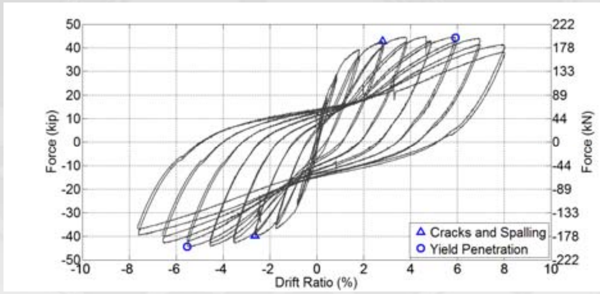
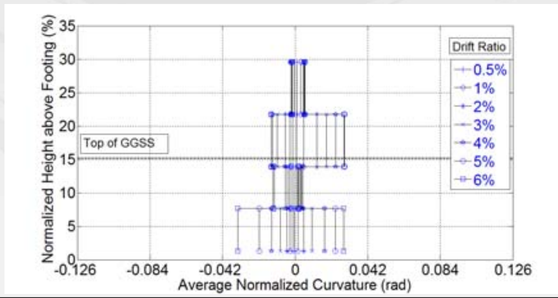
Test Results: Hysteretic Response/GGSS-1







CATEGORY II

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Test Results: Damage Progression/GGSS-1

@ 3% drift

@ 6% drift

@ 8% drift

@ 8% drift- rebar fracture

CATEGORY II

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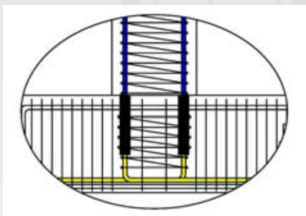
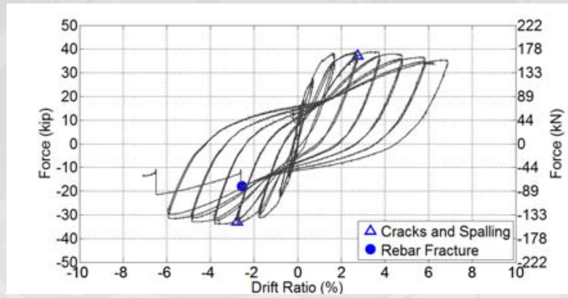
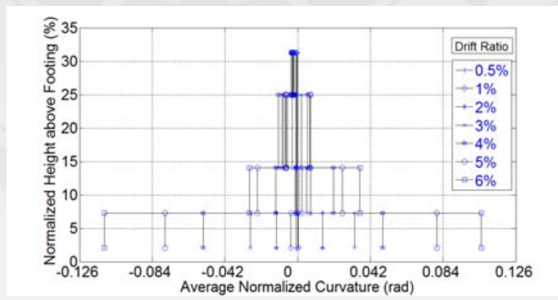
Test Results: Hysteretic Response/GGSS-2







CATEGORY II

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Test Results: Damage Progression/GGSS-2

CATEGORY II

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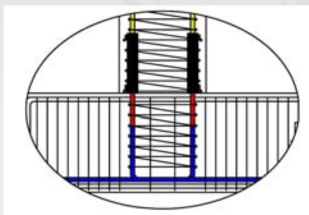
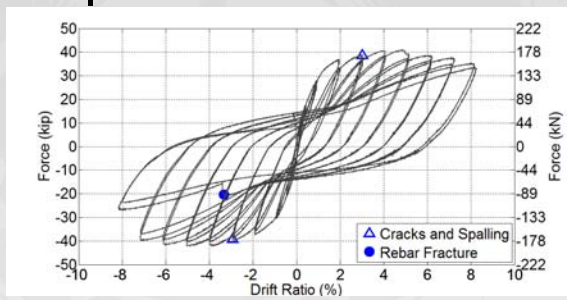
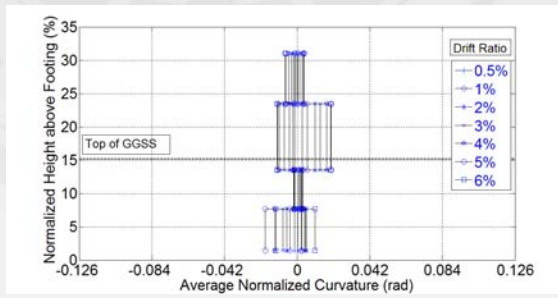
Test Results: Hysteretic Response/GGSS-3







CATEGORY II

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Test Results: Damage Progression/GGSS-3

@ 3% drift

@ 8% drift

@ 8% drift- rebar fracture

CATEGORY II

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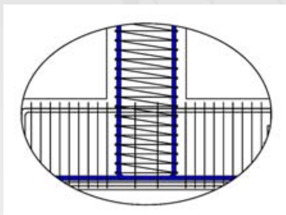
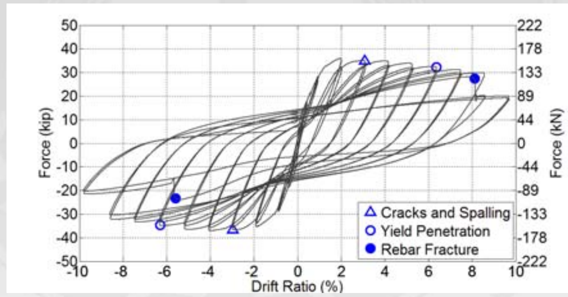
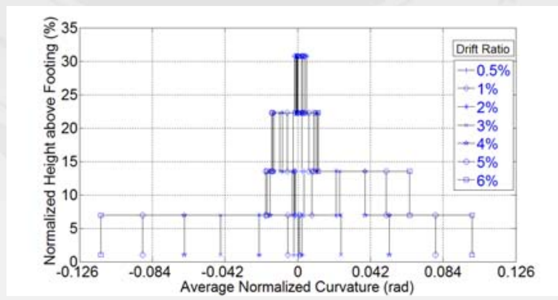
Test Results: Hysteretic Response/GGSS-CIP







CATEGORY II

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Test Results: Damage Progression/GGSS-CIP

CATEGORY II

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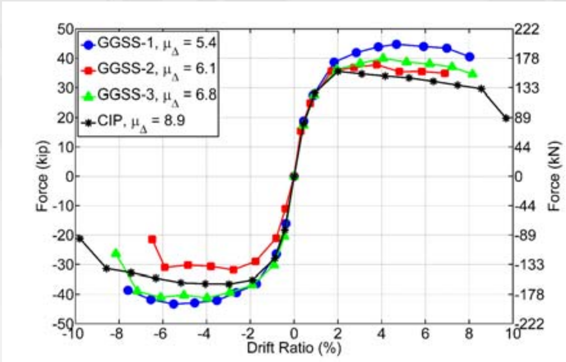
Test Results: Displacement Capacity

Specimen	Last Drift Ratio (%)	F_y (kip)	Δ_y (in.)	Δ_u (in.)	K_{eff} (kip/in)	μ_Δ
GGSS-1	8	41.8	1.34	7.32	31.2	5.4
GGSS-2	7	32.6	1.05	6.42	31.0	6.1
GGSS-3	8	38.2	1.11	7.58	34.4	6.8
GGSS-CIP	9	33.6	0.95	8.45	35.4	8.9



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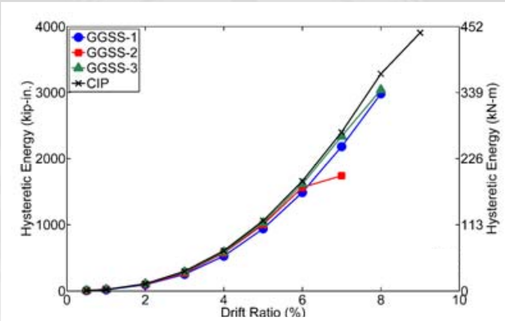
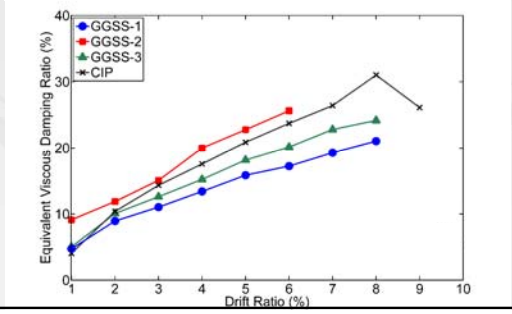
Test Results: Energy Dissipation Capacity

- Cumulative Energy



- Equivalent Viscous Damping



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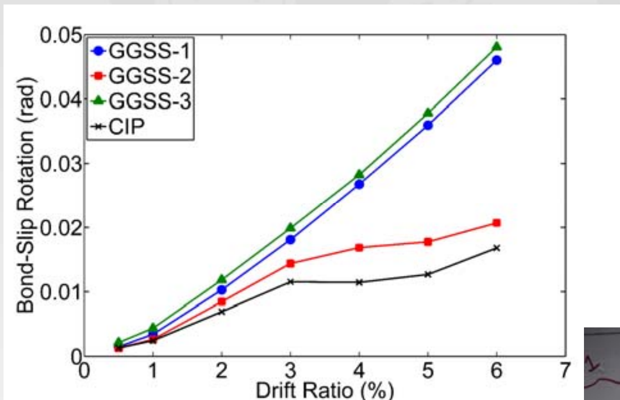
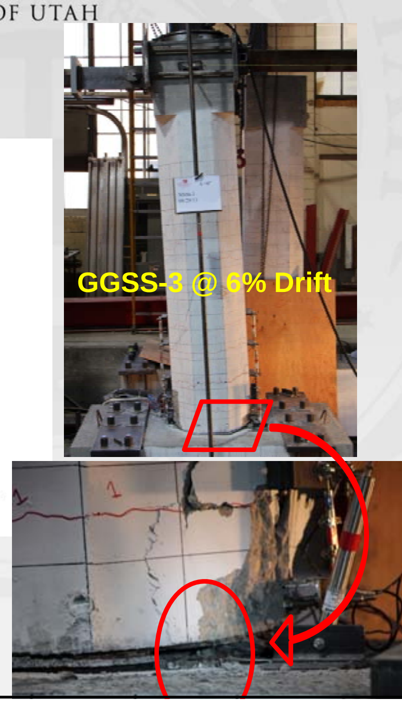
Test Results: Bond-Slip Rotation





CATEGORY II

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Test Results: Conclusions

- Desirable performance (ductile), rebar fracture, μ_Δ equal to 8.9 for GGSS-CIP.
- GGSS-CIP had very good hysteretic performance, energy dissipation capacity, and well-distributed flexural cracks.
- Localized damage for GGSS-1 and GGSS-3. Smaller spalled region with respect to GGSS-CIP.
- Similar damage states for GGSS-2 and GGSS-CIP, with no GGSS in the column base.
- Rebar fracture for GGSS-CIP and premature rebar fracture for all precast specimens due to higher values of concentrated strains at interface.

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Test Results: Conclusions, cont'd

- ❖ A more ductile response achieved by incorporating GGSS inside footing. Displacement ductility capacity increased from 5.4 to 6.1.
- ❖ The most ductile response was achieved for GGSS-3 with connectors in column base + debonding in footing. Compare displacement ductility of 6.8 vs. 6.1.
- ❖ Different distribution of inelasticity for GGSS-1 and GGSS-3, as GGSS connectors were in the column base. Similar inelasticity distribution for GGSS-2 and GGSS-CIP.
- ❖ Strain gauge data showed both field and factory dowel yielded for GGSS-1 and GGSS-3. The factory dowel of GGSS-2 did not yield at all.
- ❖ Displacement ductility for all specimens exceeded minimum component ductility of 3 per Caltrans SDC and maximum ductility demand of 5 per AASHTO-Seismic for single-column bents.

CATEGORY II

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❑ For flexural-dominant precast components connected by Grouted Splice Sleeve connectors:

- ❖ Well-confined connector zone is advantageous. Transverse reinforcement shall be used to secure the GSS connectors.
- ❖ Spiral splice length equal to two extra turns was found satisfactory.
- ❖ FGSS was found promising for moderate-seismic zones, if the limitation on displacement ductility is accounted for.
- ❖ Enhanced ductility capacity may be achieved when FGSS is inside the cap beam. This alternative is more cumbersome.
- ❖ GGSS was found promising for high-seismic zones, if the limitation on displacement ductility is accounted for.
- ❖ More ductile performance is achievable when GGSS is in the column base and a debonded rebar zone in top of the footing is implemented.

RECOMMENDATIONS

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❑ Recommended design approach for precast flexural columns:

❖ Design procedure based on AASHTO Guide Specifications and Caltrans SDC using a predefined length of plastic hinge.

$\mu_c = \frac{\Delta_c}{\Delta_{ycol}}$ $\Delta_c = \Delta_{ycol} + \Delta_p$

$\Delta_{ycol} = \frac{L^3}{3}\varphi_y$ $\Delta_p = (\varphi_u - \varphi_y)L_p(L - \frac{L_P}{2})$

❖ Reduced displacement capacity of bridge columns with Grouted Splice Sleeves, as observed in the experiments, can be represented by a reduced length of plastic hinge.

❖ Research is ongoing to determine reduced plastic hinge length for precast bridge columns.

RECOMMENDATIONS

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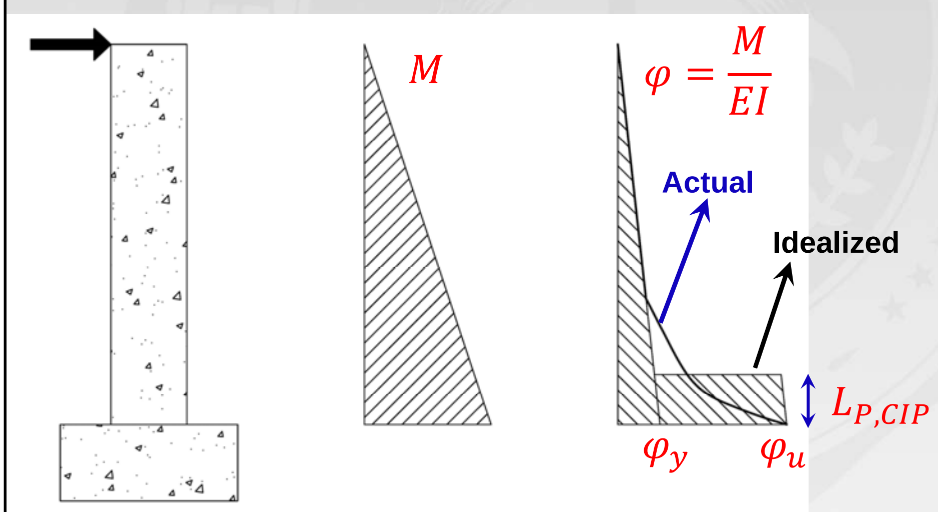
Curvature Distribution Schematic for CIP



RECOMMENDATIONS

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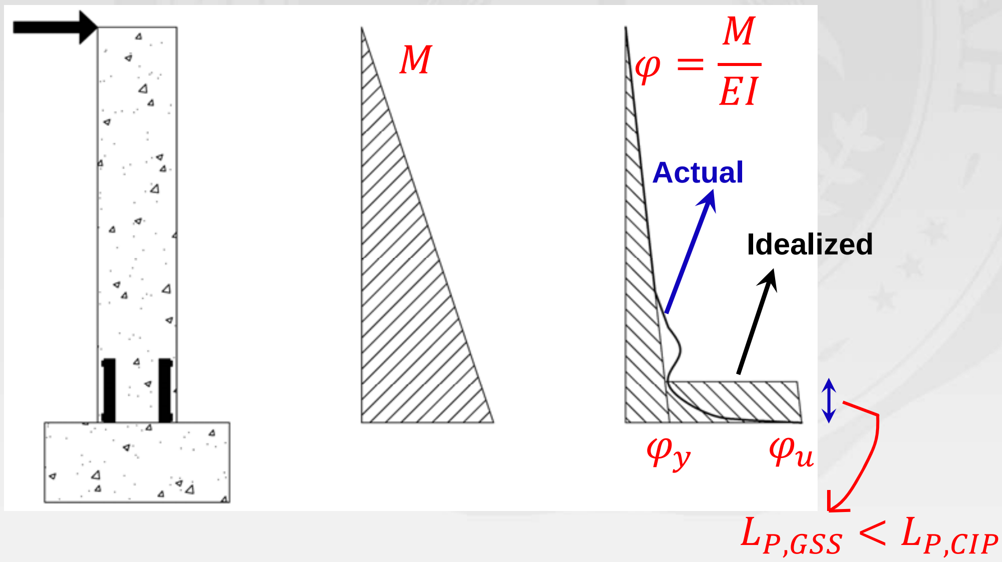
Curvature Distribution Schematic for Precast with GSS



RECOMMENDATIONS

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  - Joel Parks
  - Dylan Brown
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  - Mark Bryant
- Utah Department of Transportation
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- NMB Splice Sleeve
- Erico

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