ISU Spring Transportation Seminar Series
April 1, 2016

IMPLEMENTING SEISMICALLY ROBUST ACCELERATED BRIDGE CONSTRUCTION in CALIFORNIA

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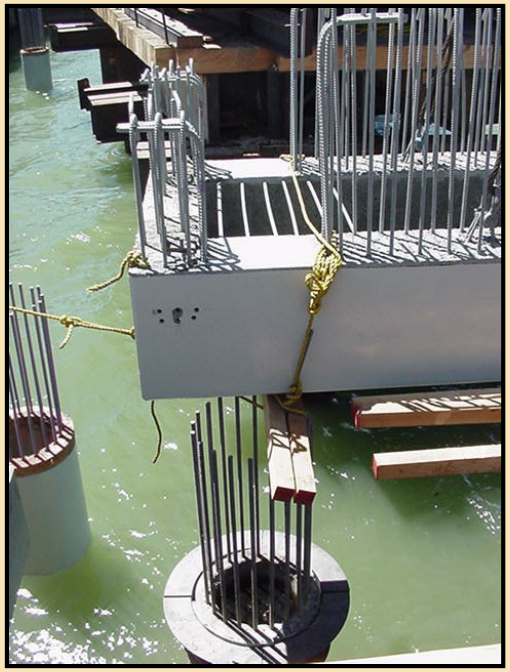
California Department of Transportation

San Mateo-Hayward Bridge Widening (2002)

- Up to 270 feet of structure completed per week
- 5.15 mile long portion of south bay crossing
- PC Hollow Piles
- PC Cap Tubs
- PC Girders
- PC Deck Forms

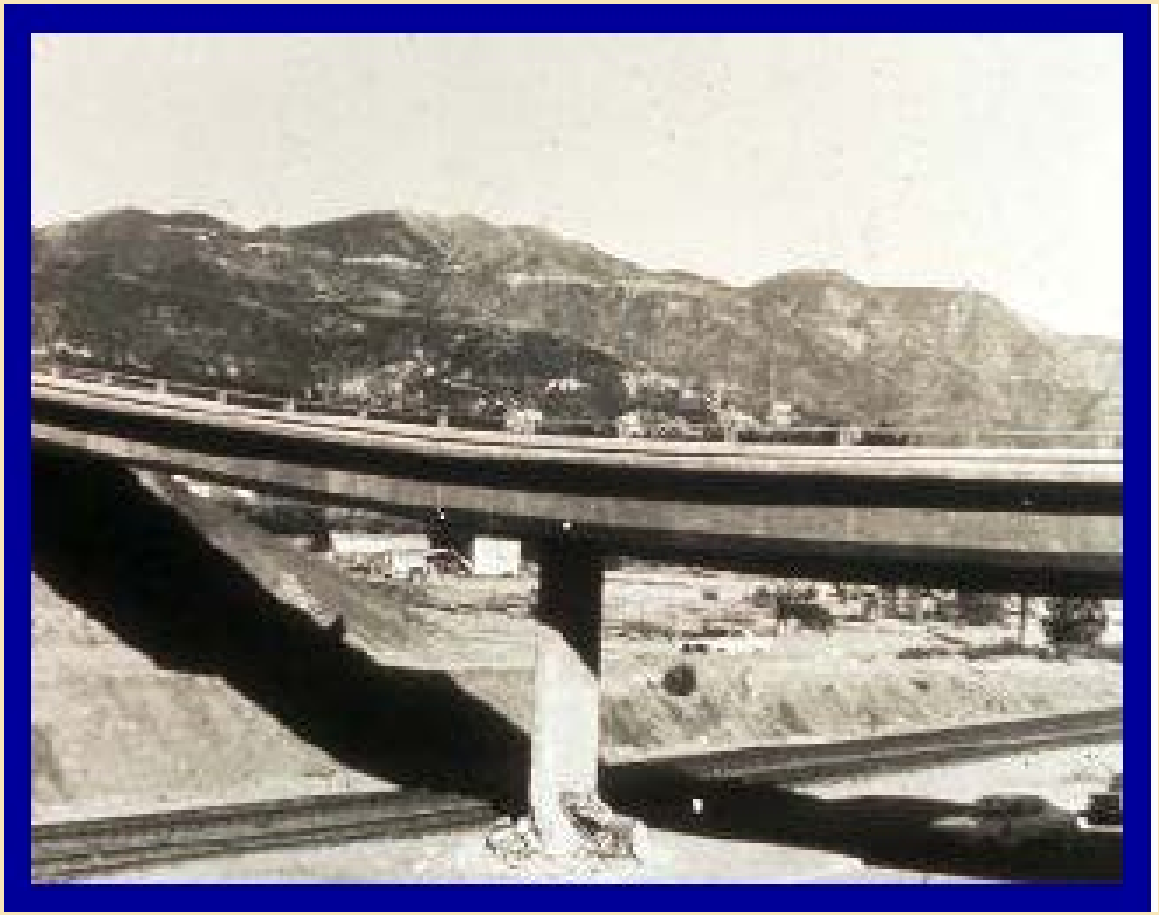


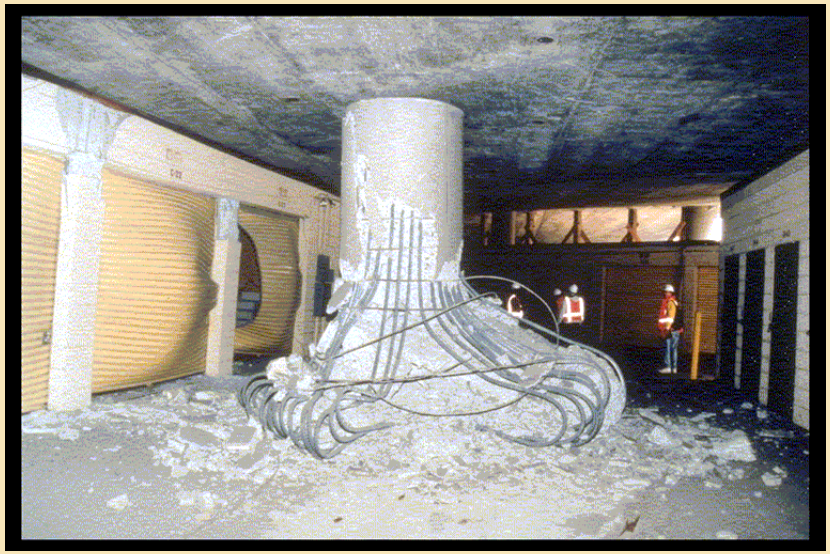
- California Experience:
  - Three major California earthquakes.
  - Influence of earthquakes on Caltrans' Seismic Design Criteria (SDC).

- Concepts of "*Confinement*", "*Continuity*", and "*Balance*" in the SDC.

- Proof of Ductility in California Columns.

1971 San Fernando EQ: Collapse of multiple structures including Route I-5/I-405 Separation Structure resulted in a drastic increase in "Confinement" reinforcement in columns.





Caltrans' pre- 1971 columns, 1994 damage.

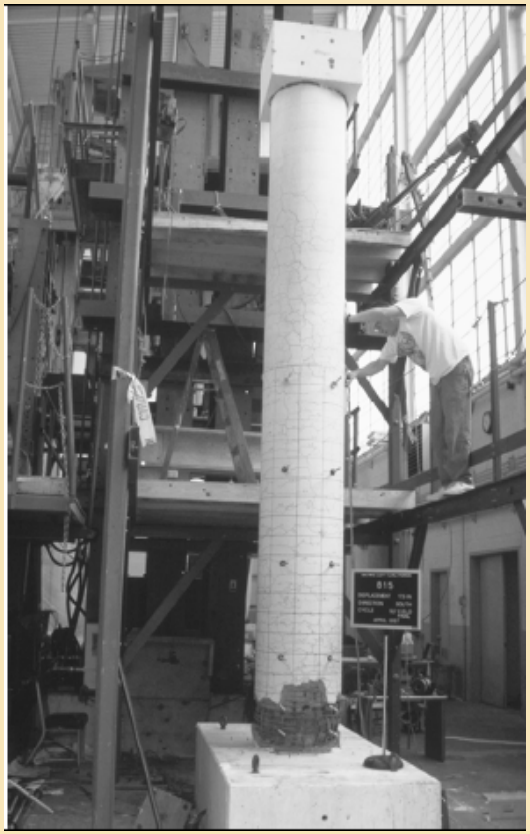
Caltrans' new confined columns

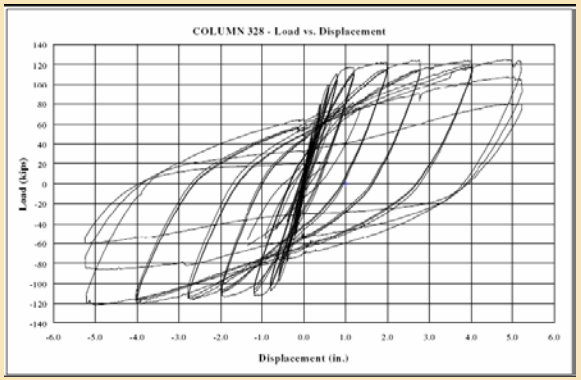
Confinement:

Caltrans' SDC 4.1.1

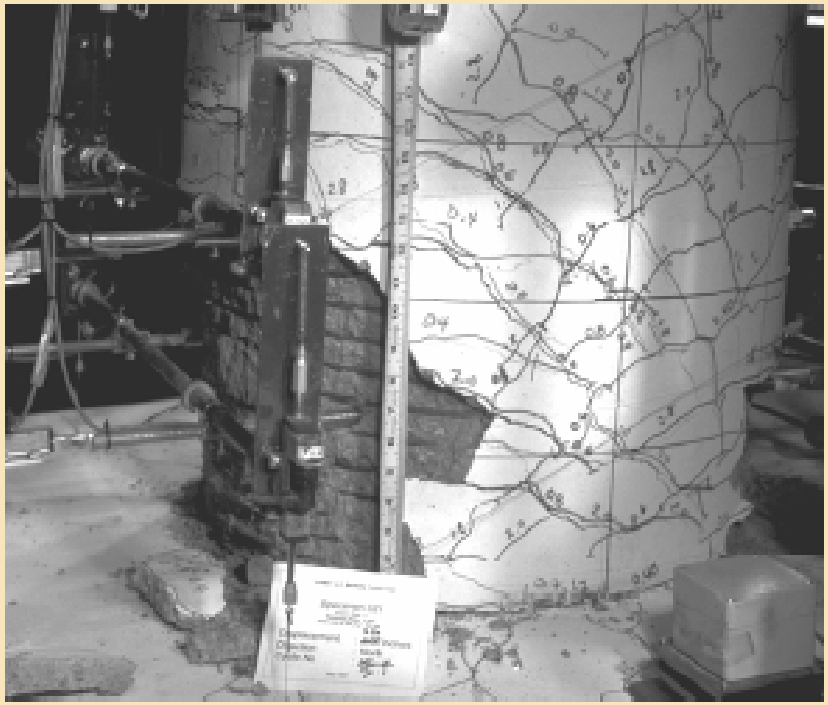
$\Delta_C > \Delta_D$

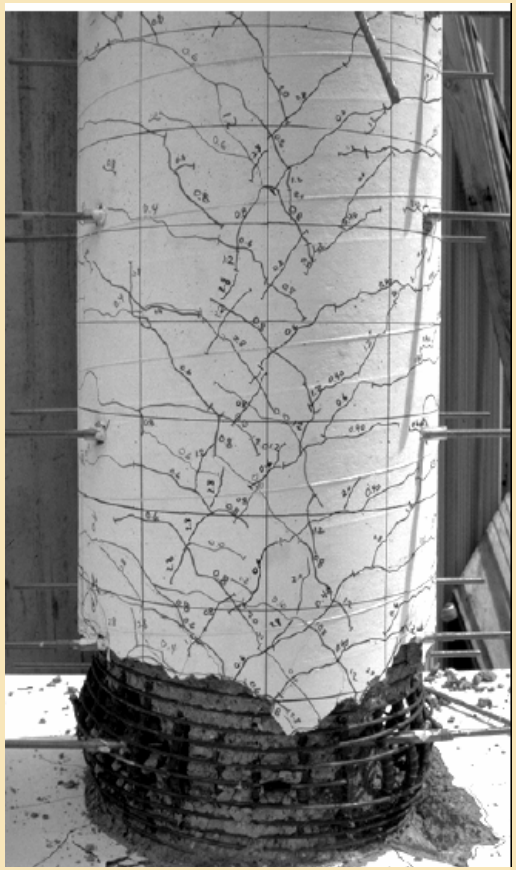
Caltrans' post-1989 Column Testing





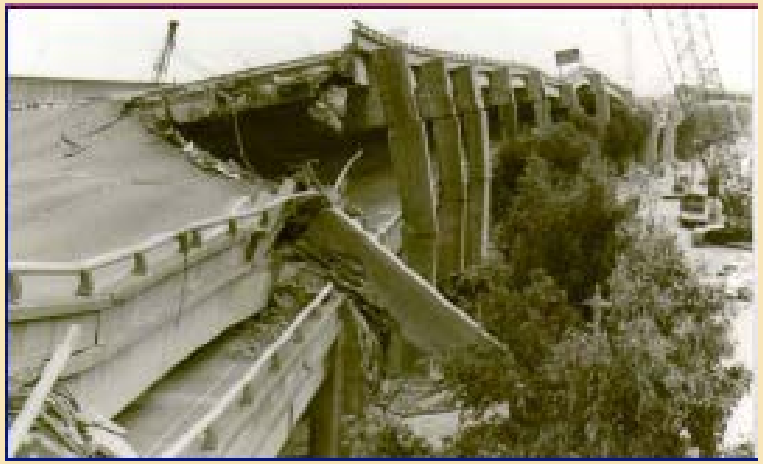
Caltrans’ post-1989 Column Testing





1989 Loma Prieta Earthquake: The San Francisco-Oakland Bay Bridge lost a deck segment due to insufficient hinge seat.

1989 Loma Prieta Earthquake: The Cypress Viaduct collapsed partly due to excessive joints in the structure



Caltrans’ columns and shafts, new construction

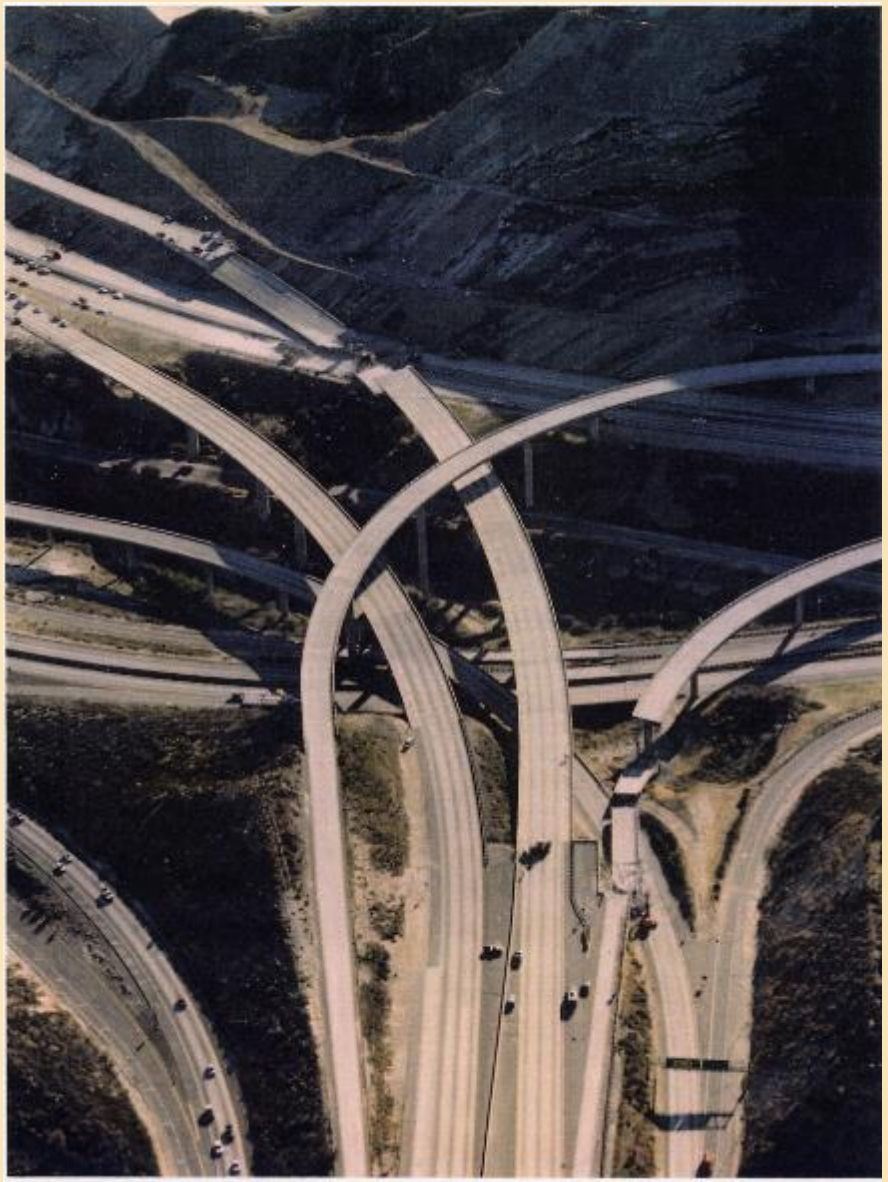
Caltrans' hinge seat, before 1971

Continuity:

- Caltrans' SDC 7.2.5.4 and 7.8.3

  Equation 7.5, *minimum 24"* seat width for in-span hinges and Equation 7.46, *minimum 30" at abutments*.
- Caltrans' Cast-In-Place, post-tensioned box girder bridges have excellent continuity and framing. They meet the SDC requirements.
- Do Pre-Cast bridges meet the continuity requirements?

1994 Northridge Earthquake: I-5/SR-14 collapse, lack of stiffness and mass "*Balance*" from bent to bent.



Route 14/Interstate 5 Interchange
Collapsed Connectors 53-1964F & 53-1960F

1994 Northridge Earthquake: I-5/SR-14 collapse.

Caltrans' Seismic Design Criteria

- *Balance*:

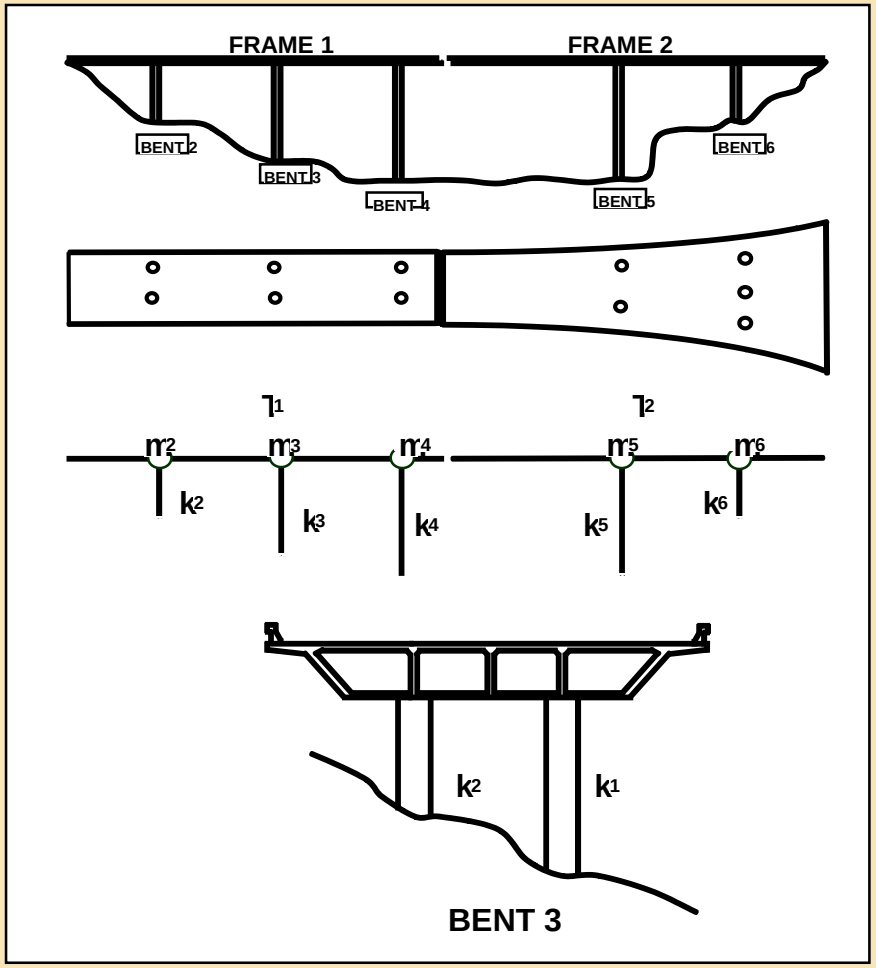
  Caltrans' SDC 7.1.1,

  Any two bents or columns:

$$\frac{k_i^e m_j}{k_j^e m_i} \geq 0.50$$

  Adjacent bents or columns:

$$\frac{k_i^e m_j}{k_j^e m_i} \geq 0.75$$



UCSD 4-foot Diameter Column Test

UCSD 4-foot Diameter Column Test

Videos 3, 5, 10 are shown as examples of performance

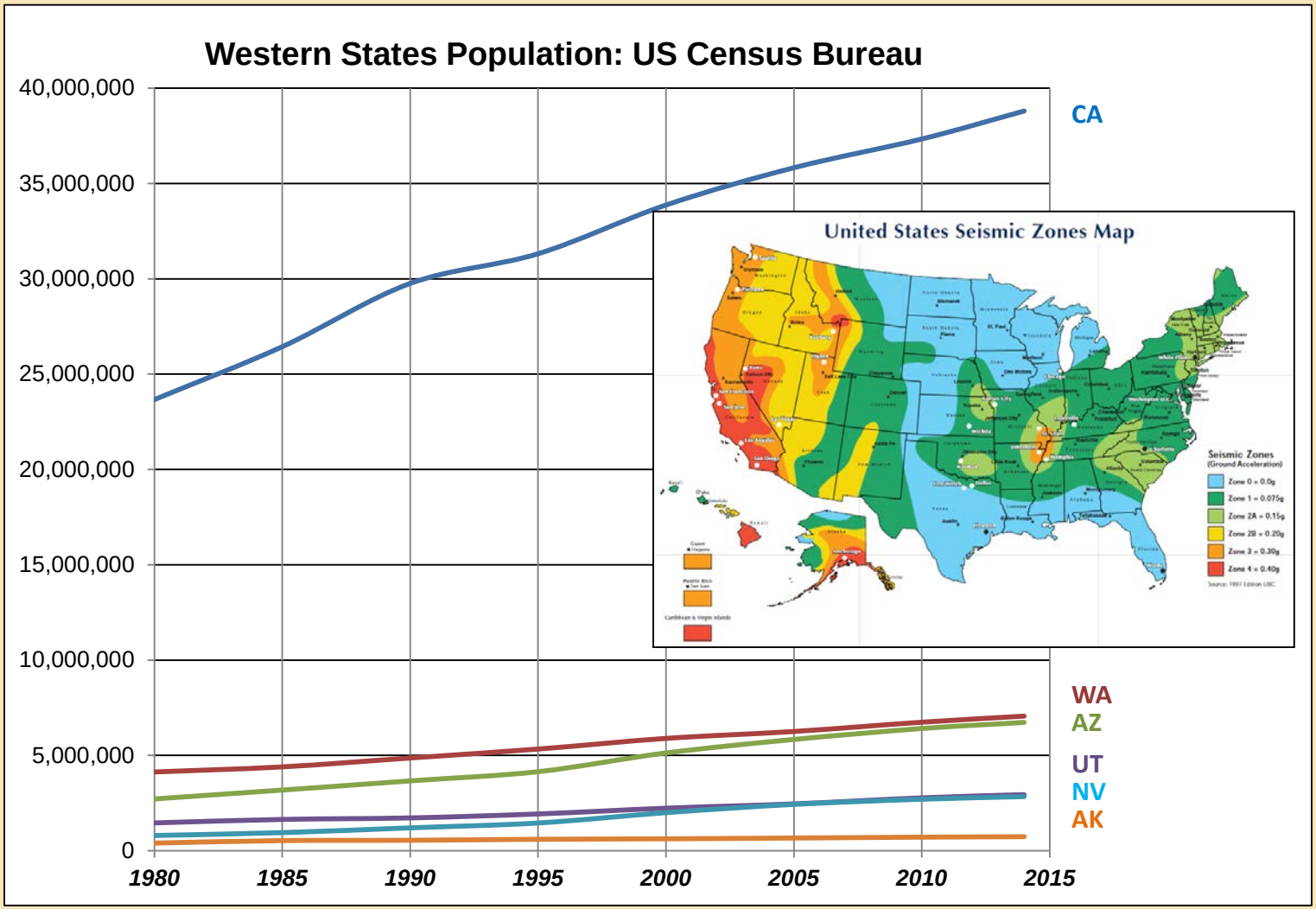
Test ID EQ	Record	Magnitude	Scale	Table PGA	Target Ductility
2	Loma Prieta 1	6.9	1.0	0.409	2
3	Loma Prieta 2	6.9	1.0	0.526	4
5	Kobe-Takatori	6.9	-0.8	-0.533	8
7	Kobe-Takatori	6.9	1.0	0.646	?
8	Kobe-Takatori	6.9	-1.2	-0.829	?
9	Kobe-Takatori	6.9	1.2	0.819	?
10	Kobe-Takatori	6.9	1.2	0.851	?

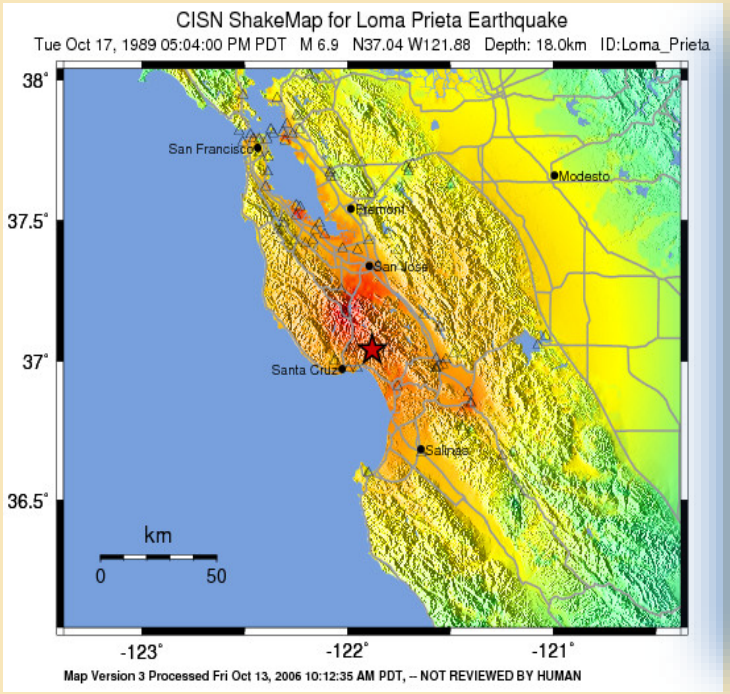
UCSD 4-foot Diameter Column Test

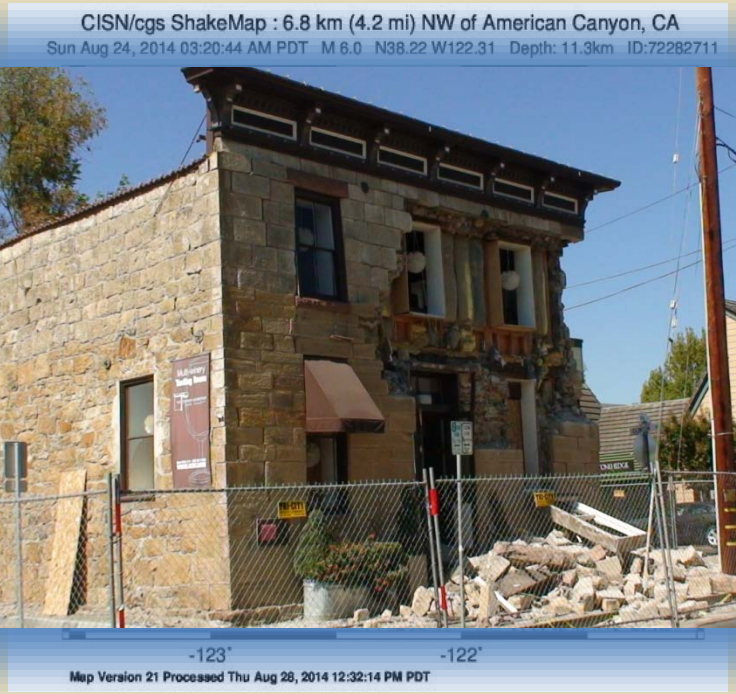
Video 3 at ductility demand of 4
Video 5 at ductility demand of 8
Video 10 at ductility demand beyond 8

Summary of Cast-In-Place (CIP) practice

- Single Column Bents supported on fixed foundation $\mu D \leq 4$
- Multi-Column Bents supported on fixed or pinned footings $\mu D \leq 5$
- Columns designed for ductility values of 4 and 5 are proved to perform to ductility values of 8 to 10 in laboratory testing.
- CIP post-tensioned box girder and properly detailed PC bridges can meet the above seismic requirements.


Western States Population: US Census Bureau
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
1980
1985
1990
1995
2000
2005
2010
2015
CA
WA
AZ
UT
NV
AK
United States Seismic Zones Map
Seismic Zones
(Ground Acceleration)
Zone 0 = 0.0g
Zone 1 = 0.075g
Zone 2A = 0.15g
Zone 2B = 0.20g
Zone 3 = 0.30g
Zone 4 = 0.40g





CISN ShakeMap
Loma Prieta EQ
M6.9
October 1989
63 lives lost
$ 6,000,000,000 damage

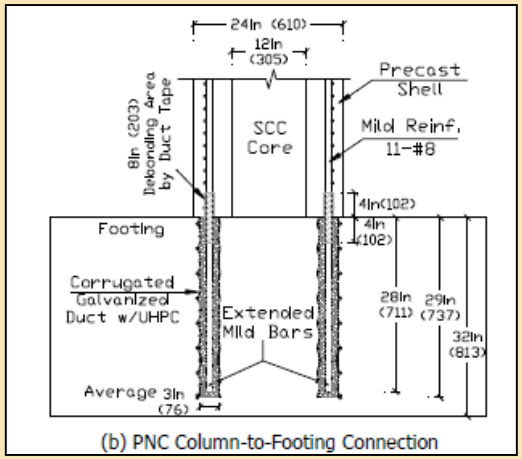
CISN ShakeMap
Napa EQ
M6.0
August 2014
0 lives lost
$ 1,000,000,000 damage (est)

ABC Related Research at Caltrans

	Arena	Researcher	Cost
1	NGB – Column Connections 65A0372-2176	UNR	$ 307,815
2	CFT1– Footing Connections 59A0641-1972	UW	$ 384,503
3	CFT1– Footing Connections 59A0446-2417	UW	$ 399,539
4	Girder Continuity1 59A0615-2001	ISU	$ 609,000
5	Girder Continuity2 65A0411-2265	ISU	$ 462,000
6	Column Pins 65A0423-2281	UNR	$ 279,539
7*	PC Full Depth Deck Panels 59A0519-2544	UNR	$ 264,575
8*	Structure Isolation for OSB TO 1	SCSoin	$ 357,000
9*	Continuity Analysis TO 3-59A0791	SCSoin	$ 240,000
10*	ABC System Bridges 2757	UNR	$ 770,295
*Denotes ongoing Contracts			$4,074,266

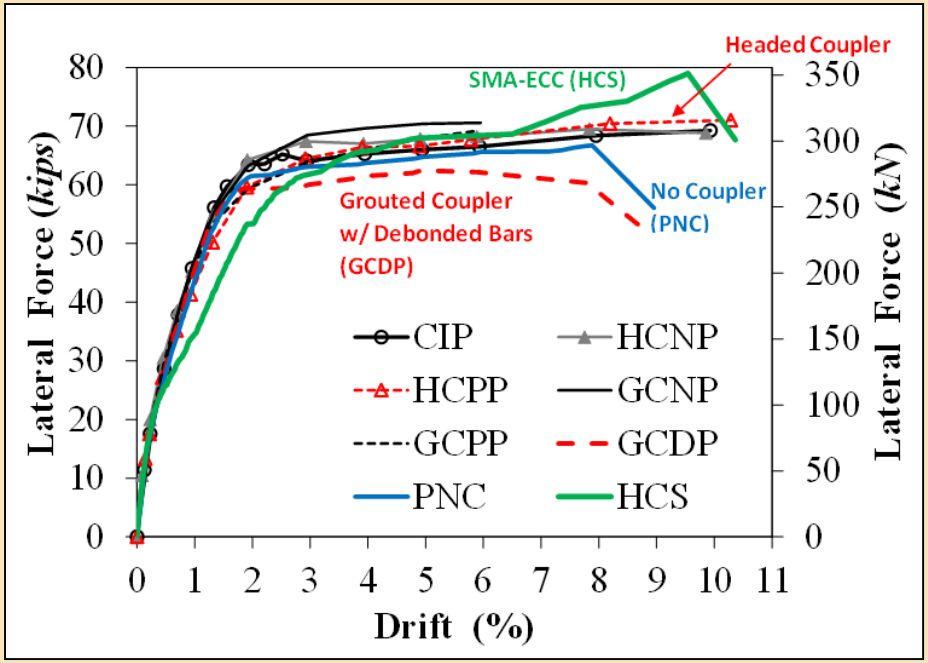
ABC Column Connection Research

PC Column with partially debonded bars plunged into UHPC filled voids

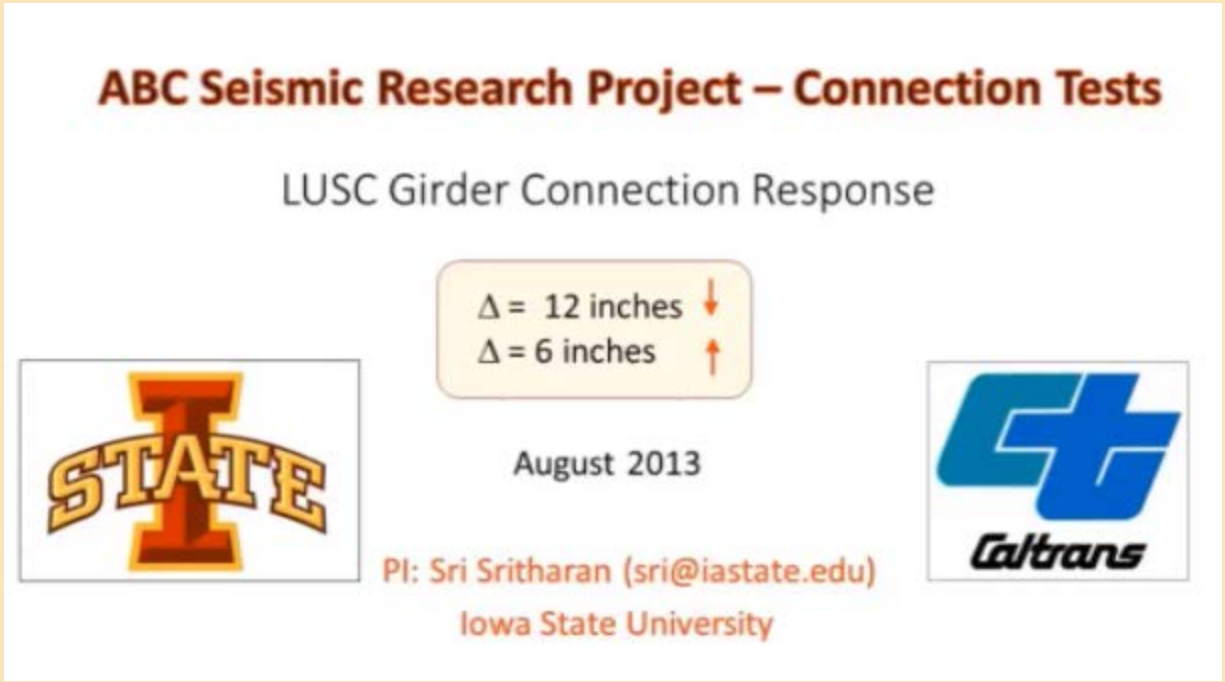


(b) PNC Column-to-Footing Connection

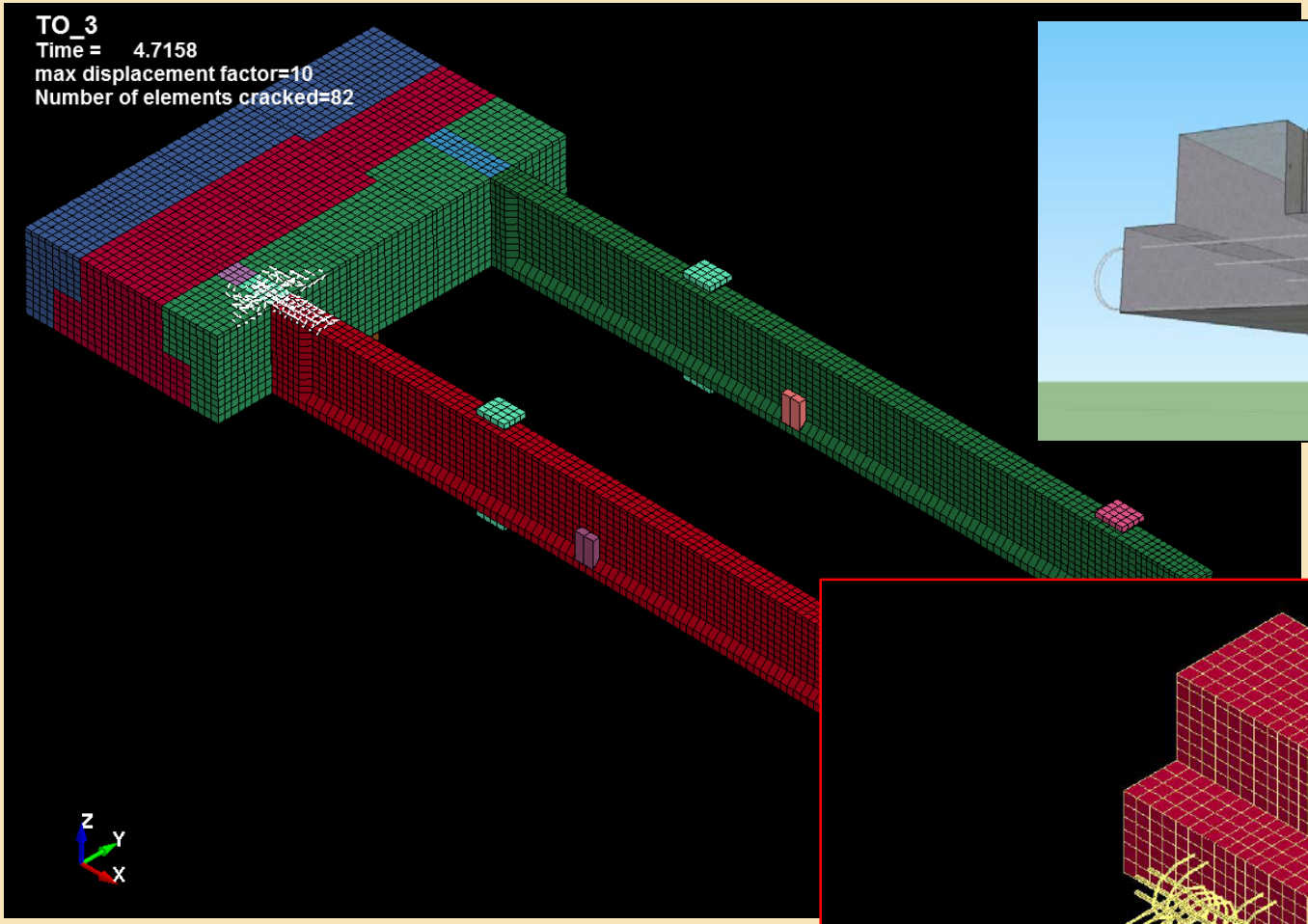
Testing at University of Nevada, Reno

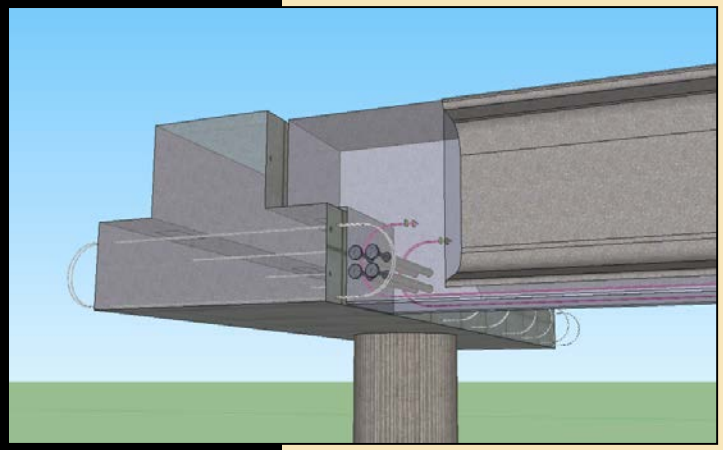


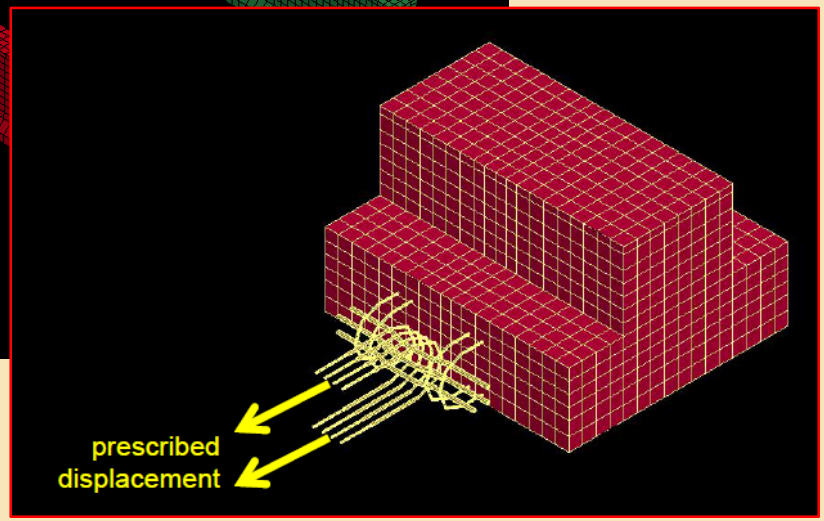
PC Girder Continuity through Bent Caps



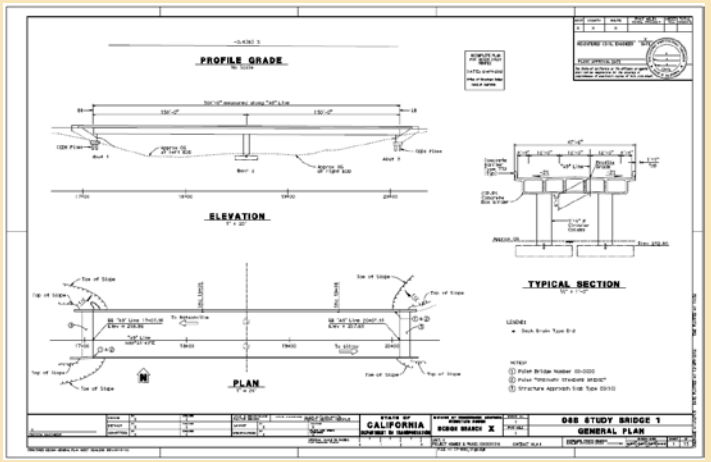
PC Girder Continuity through Bent Caps

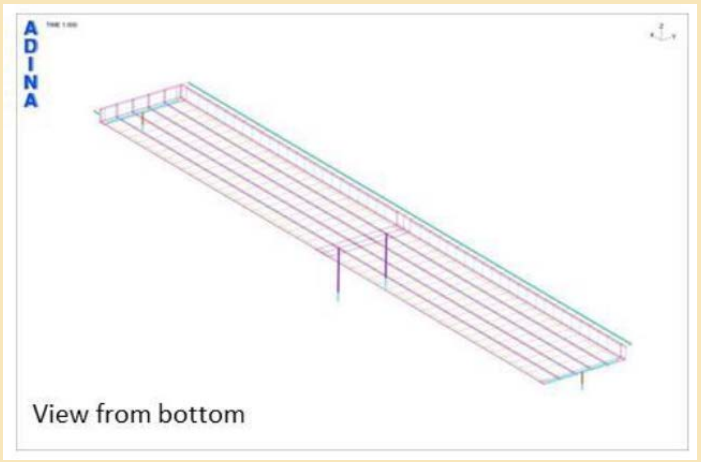


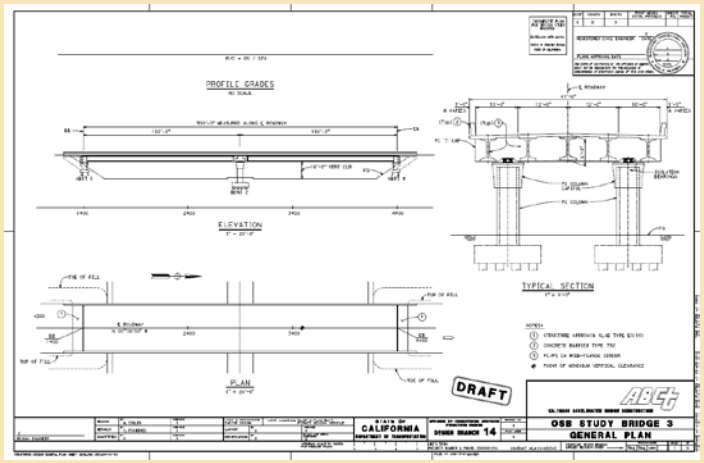


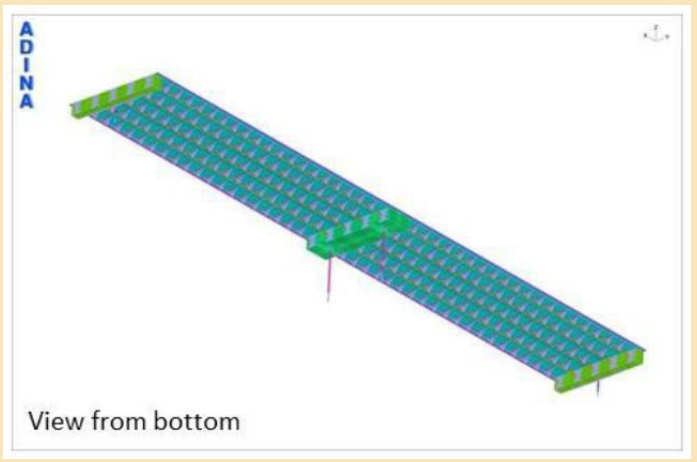


ISOLATED ABC BRIDGE LIFE CYCLE COST ANALYSIS

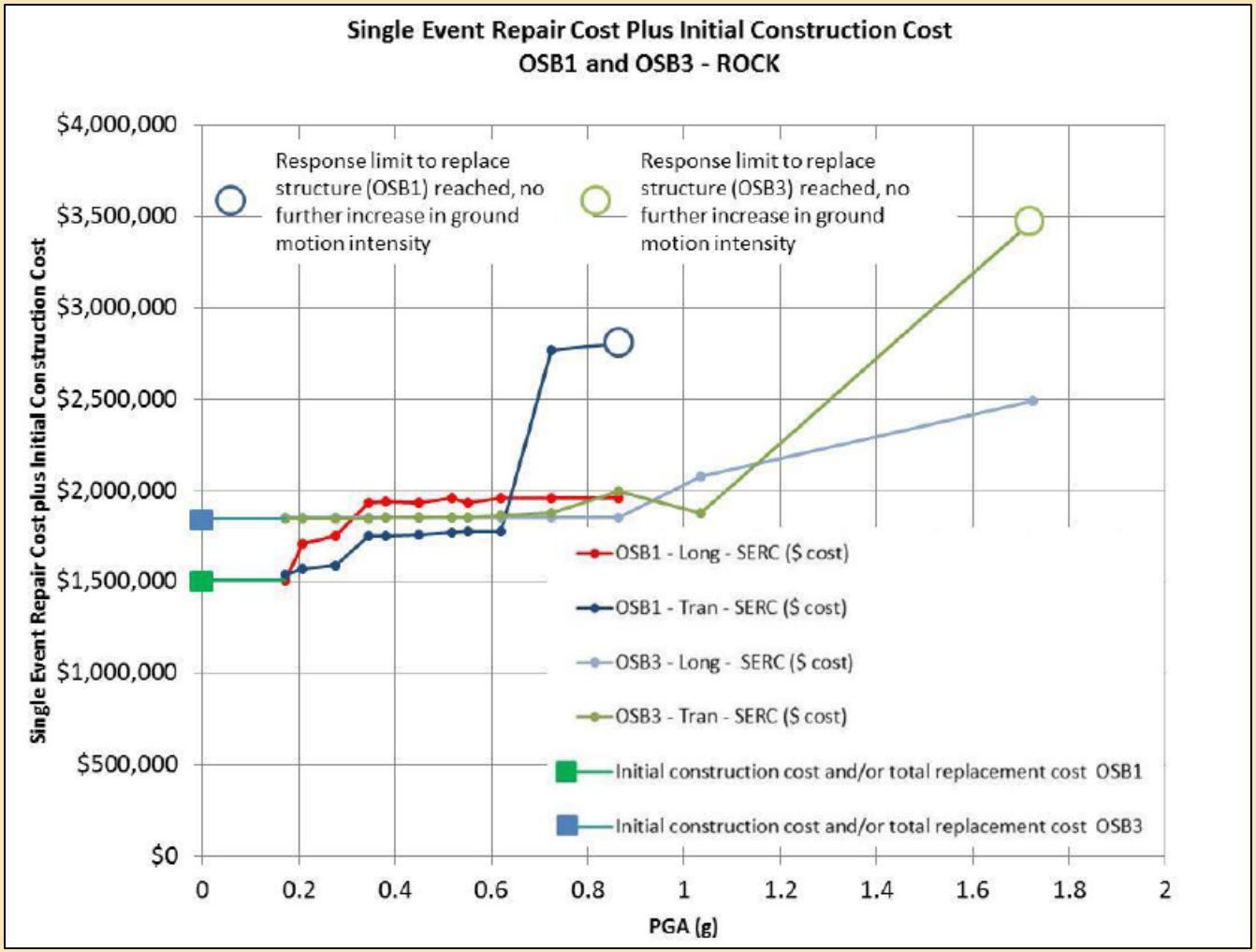




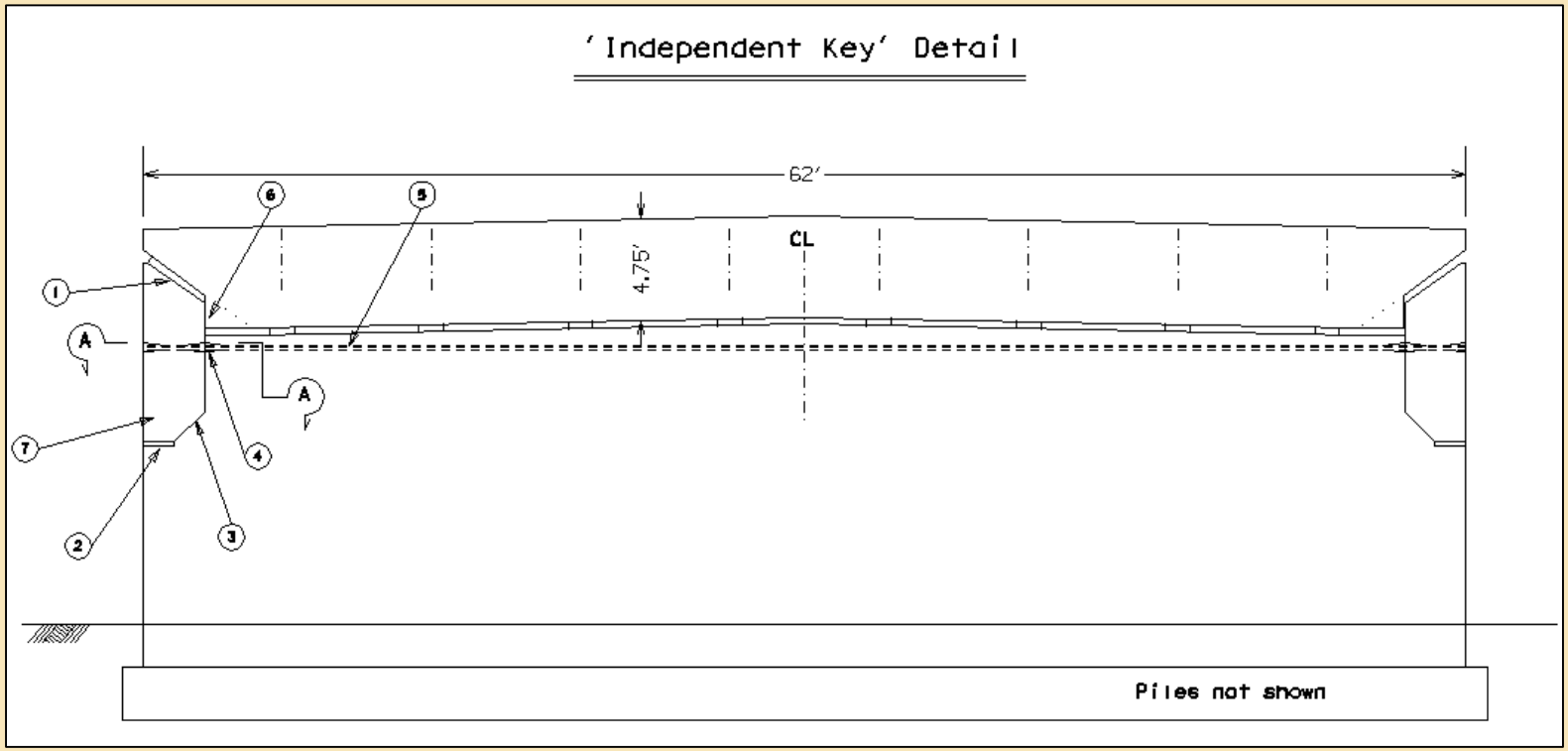




ISOLATED ABC BRIDGE LIFE CYCLE COST ANALYSIS

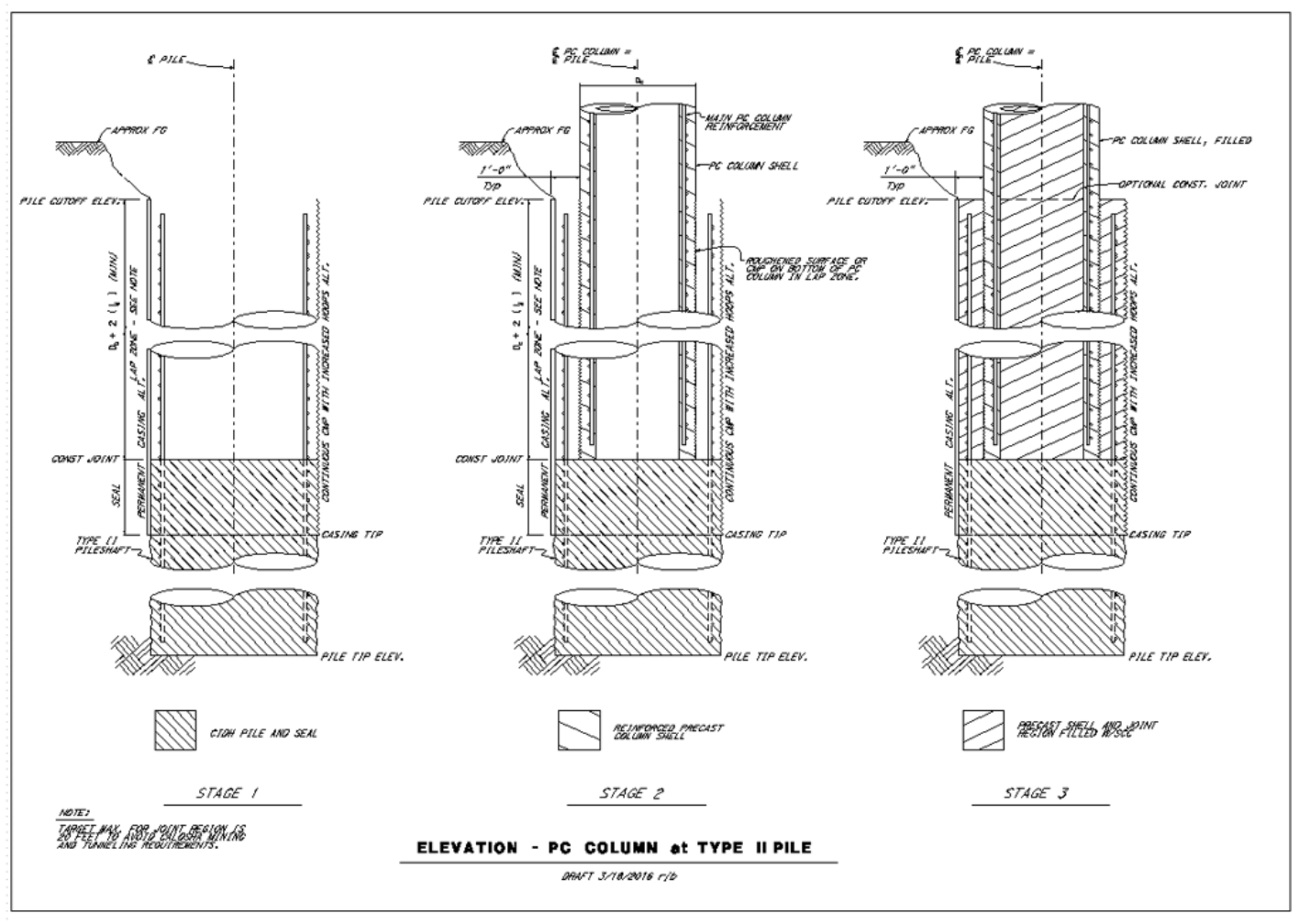


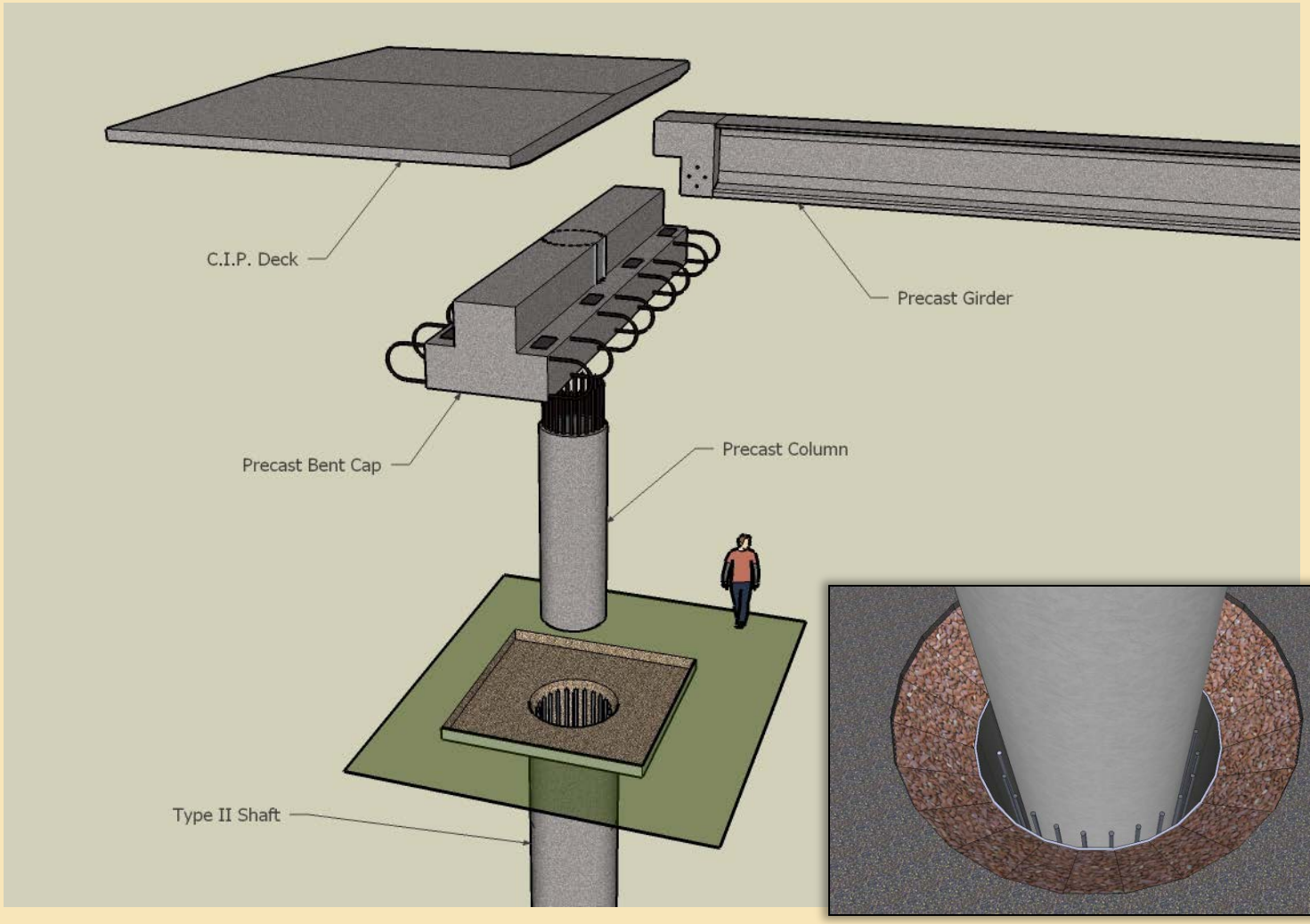
PC Shear Key Concept (2013)

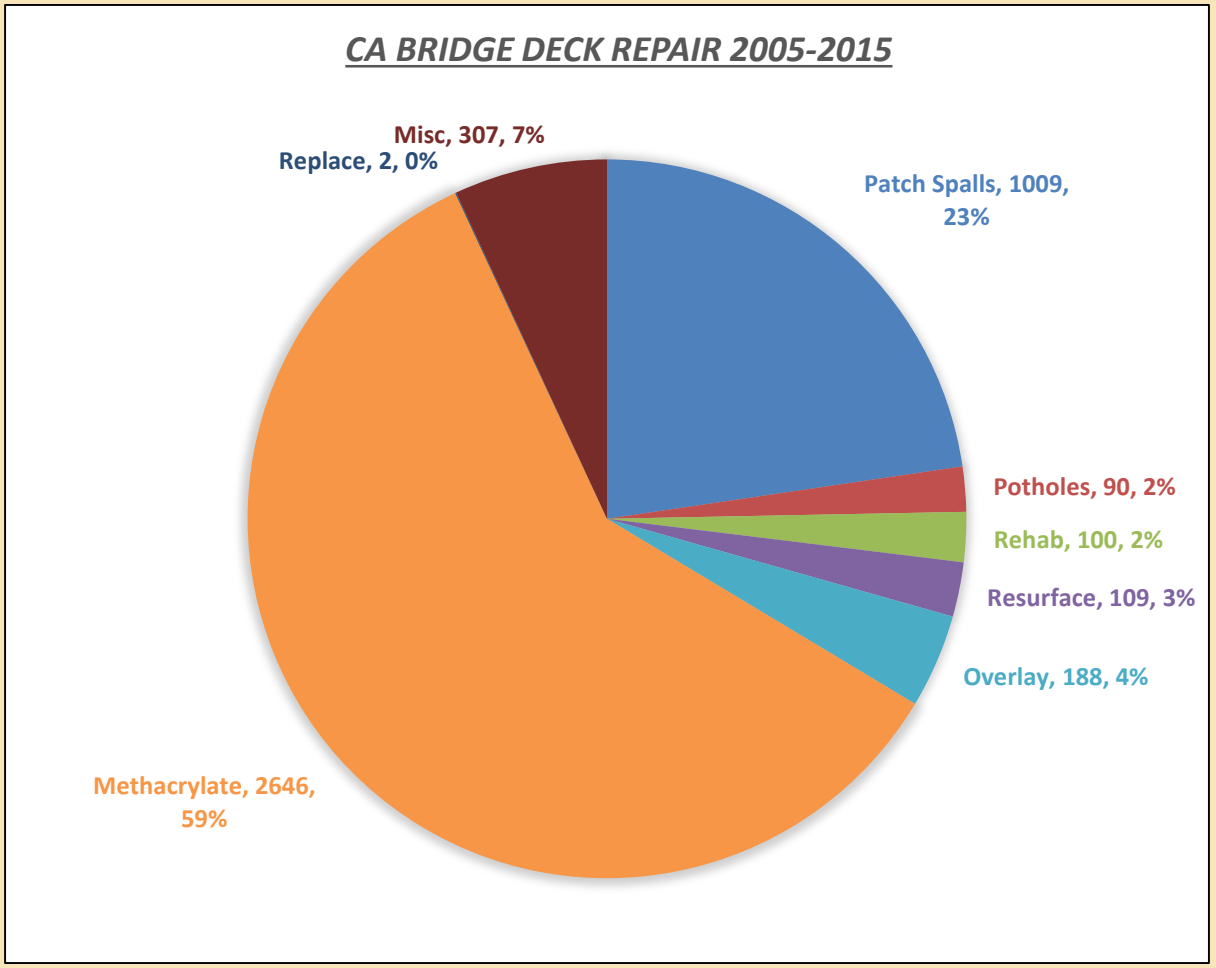


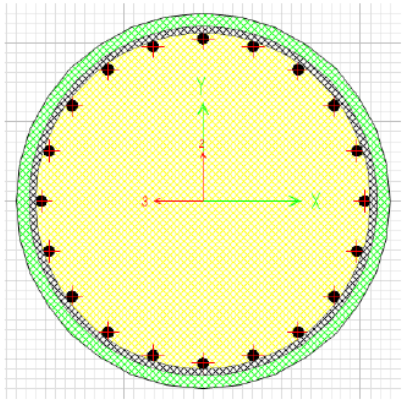

CALTRANS-UCSD
Shear Key Test
Specimen 11
Test 5
June 24, 2015

Proposed Type II shaft with PC Column




C.I.P. Deck
Precast Girder
Precast Bent Cap
Precast Column
Type II Shaft


CA BRIDGE DECK REPAIR 2005-2015
Misc, 307, 7%
Replace, 2, 0%
Patch Spalls, 1009, 23%
Potholes, 90, 2%
Rehab, 100, 2%
Resurface, 109, 3%
Overlay, 188, 4%
Methacrylate, 2646, 59%



$f'_{ce} = 5000\ psi$

$w_{conc} = 143.96\ {}^{lb}/_{ft^3}$

$f_{ye} = 68\ ksi, f_{ue} = 95\ ksi$

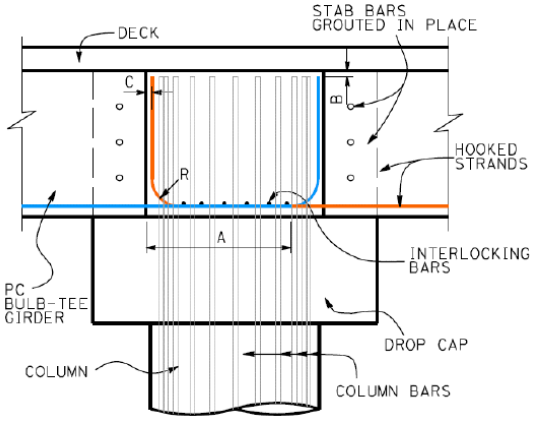
Column Diameter = 4.75 feet

Longitudinal bar: 20 - #14

Hoops: #8 @ 6”

$E_c = 33 \times w_{conc}^{1.5} \times \sqrt{f'_{ce}} = 4030.5\ ksi$

Seven wire uncoated prestressing strand (ASTM A416/A416M, size 0.6") is used for this example bridge.



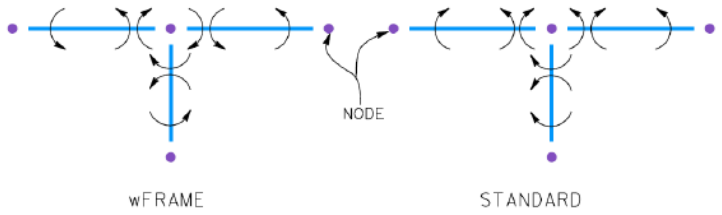
A = minimum 8 inches

B = 1 inch

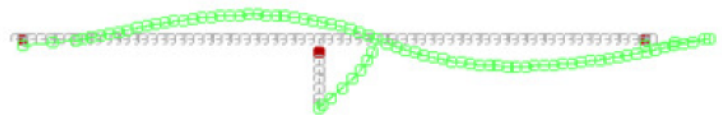
C = 2 inches

R = 15 X Strand Diameter = 9 inches

Positive Sign convention

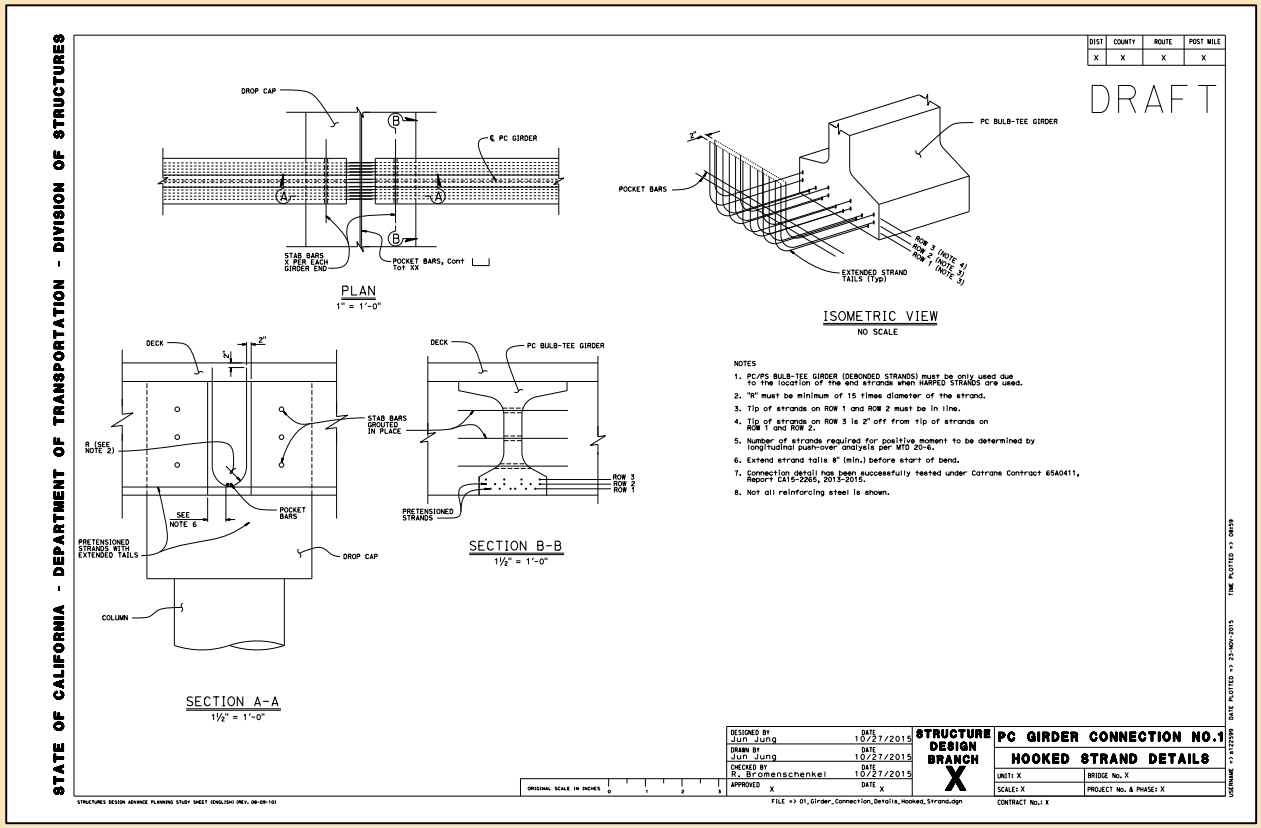


Right push



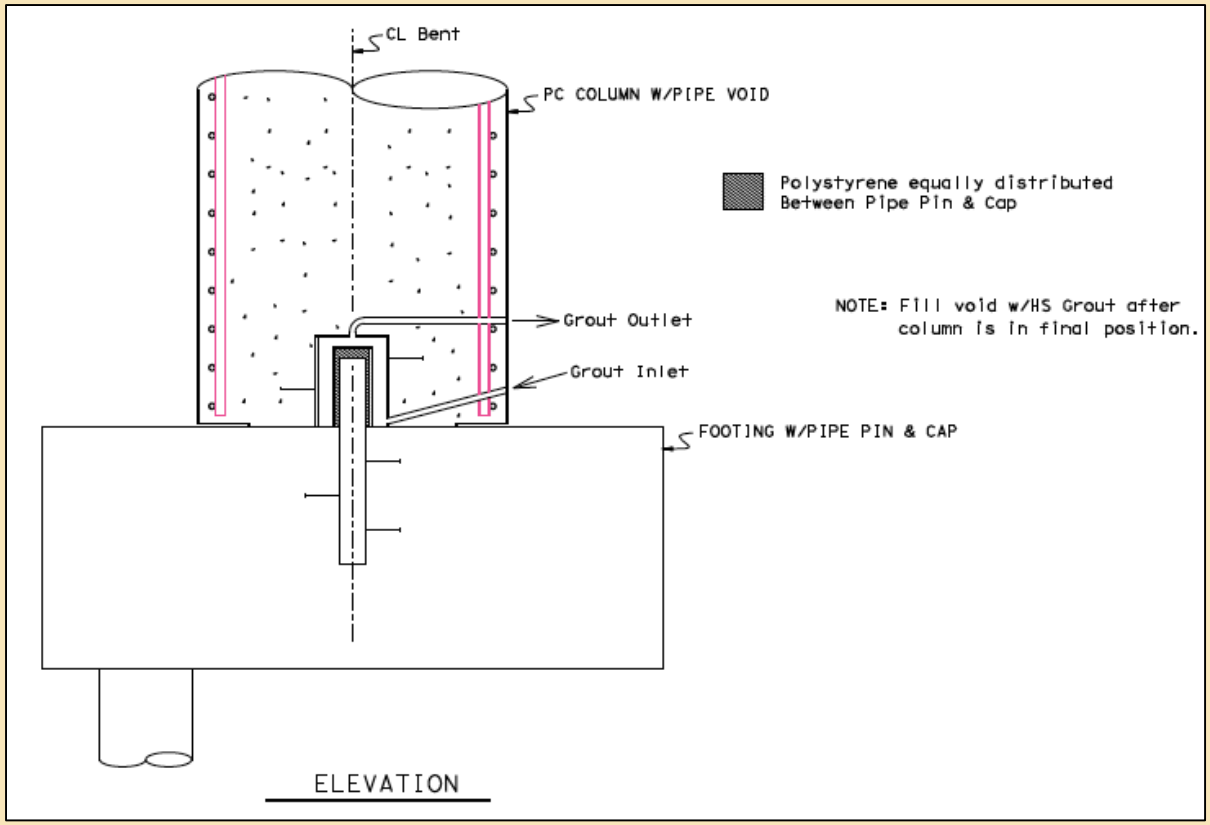
Caltrans positive moment connections for joining PC girders to bent caps are based on proof testing done at Iowa State University.

Six details are being developed to provide designers with options at different ABC (and non-ABC) sites.



PC Girder Continuity
Hwy 50, El Dorado Hills, CA (2013)

Strand tails lapped and hooked, then tied into place for longitudinal continuity

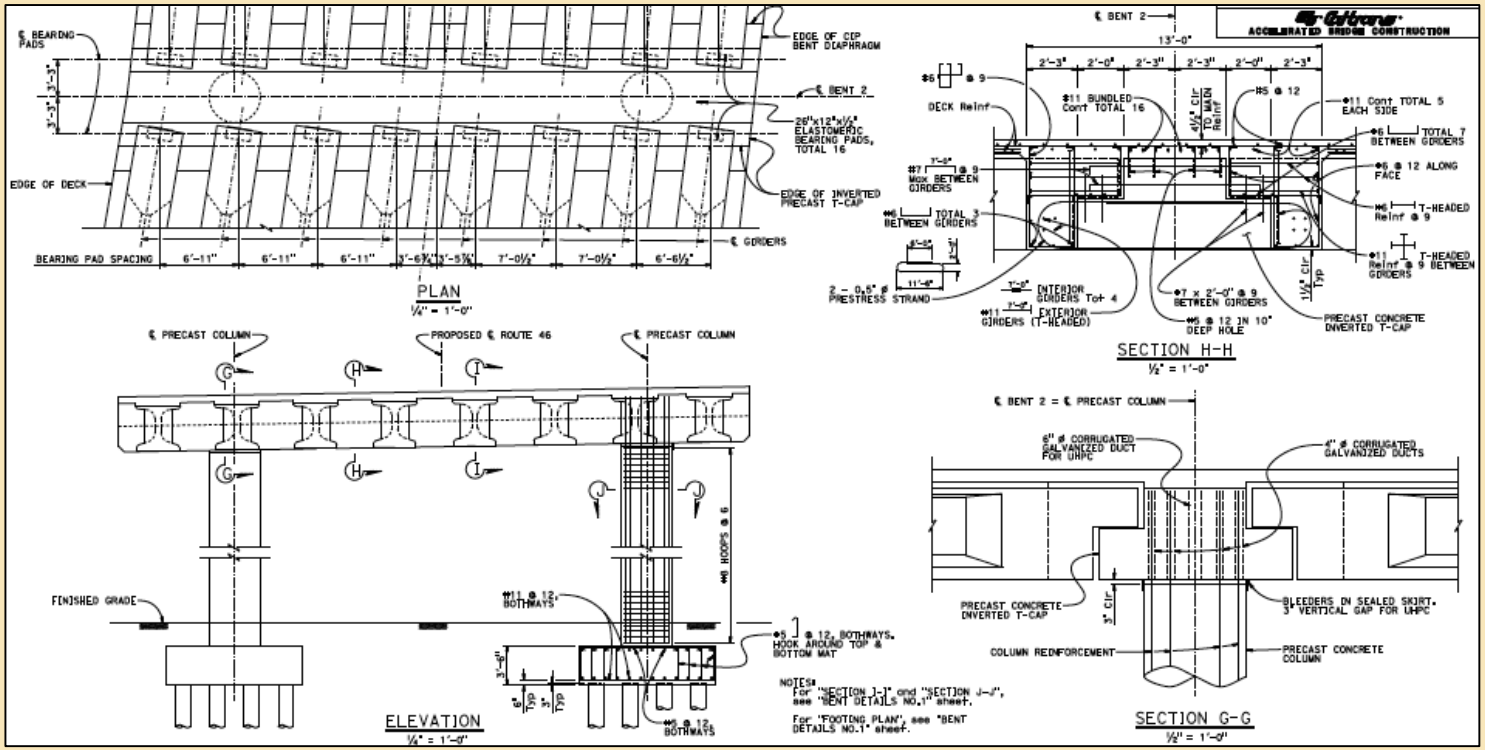


PC Column with adjustable Pipe Pin base

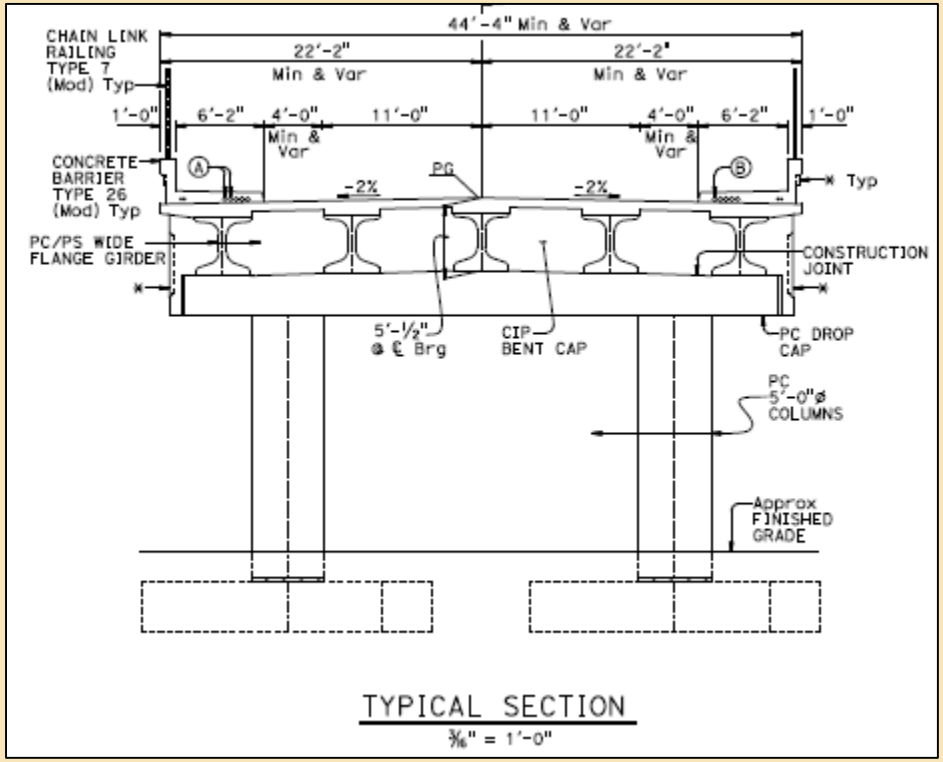
PC multi-column bents using pinned bases can offer construction fit-up tolerance challenges.

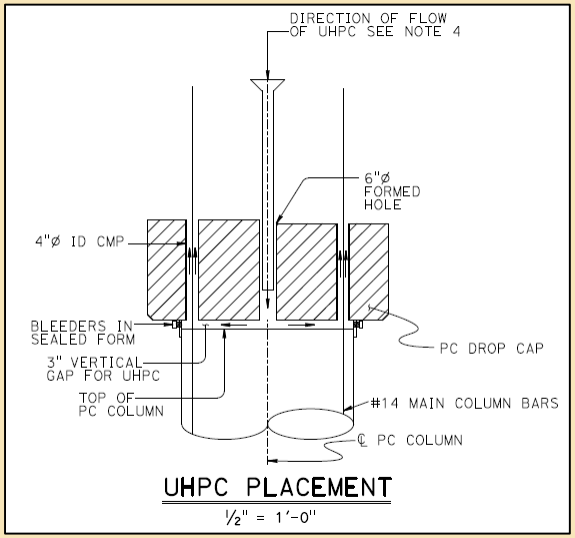
This detail allows the PC column to be spun or shifted to better align with top of column bars being inserted into a PC cap.

Excerpt from two-span Caltrans ABC pilot project featuring PC columns, inverted T bent cap, and PC girders. Looped strand girder continuity detail used.



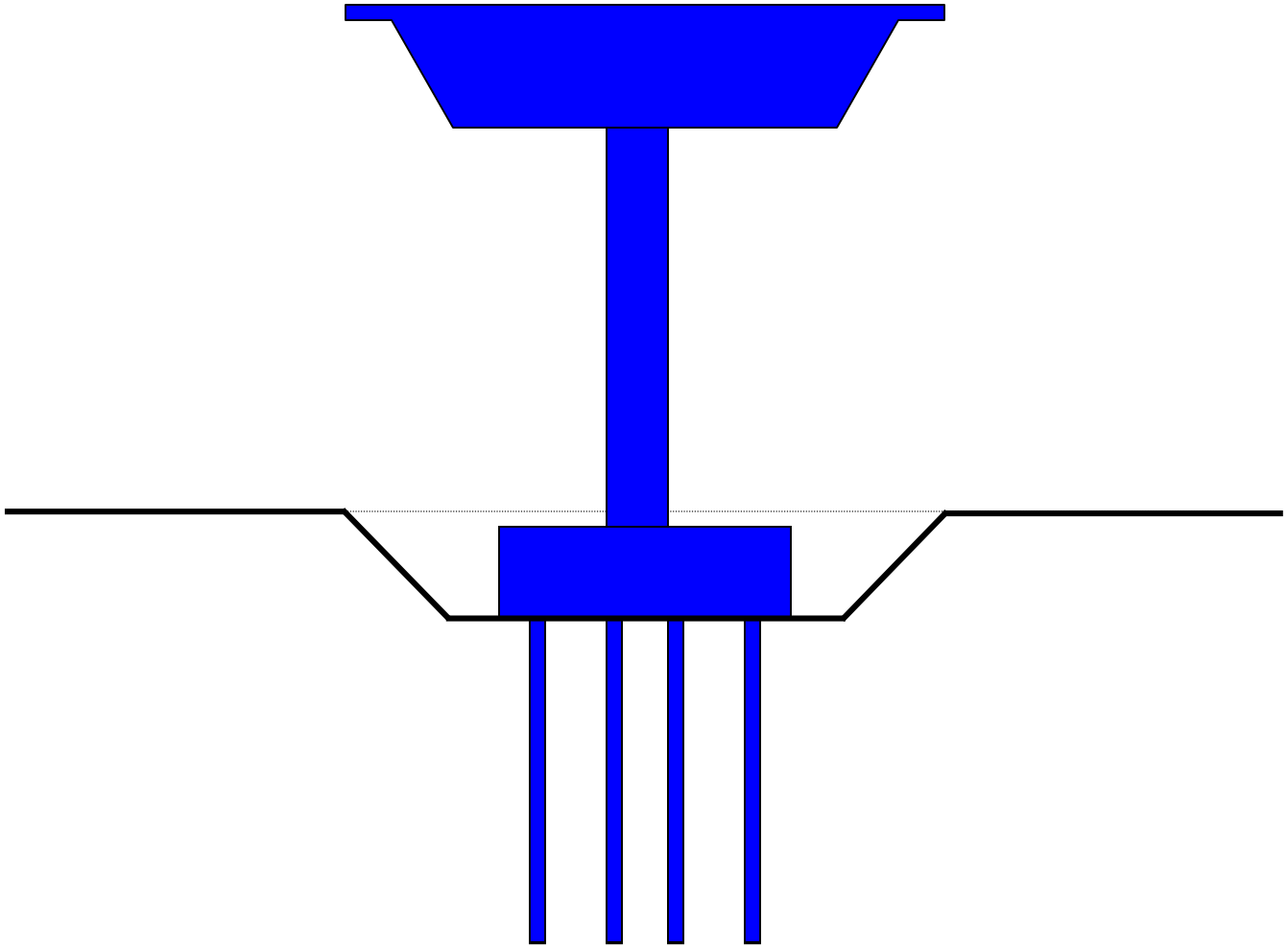
Excerpt from second two-span Caltrans ABC pilot project featuring PC columns, drop-bent cap, and PC girders. Hooked strand girder continuity detail used.

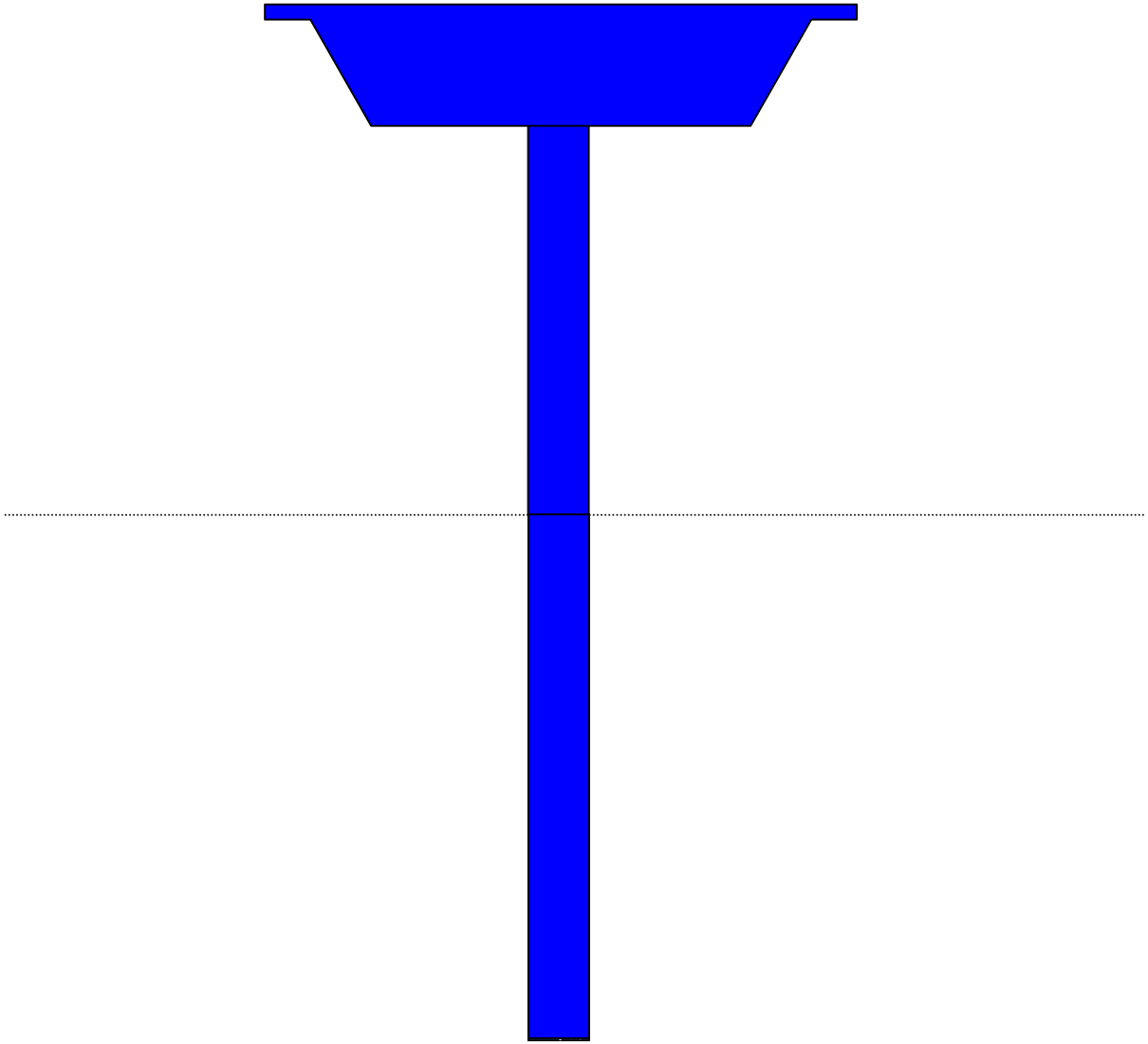


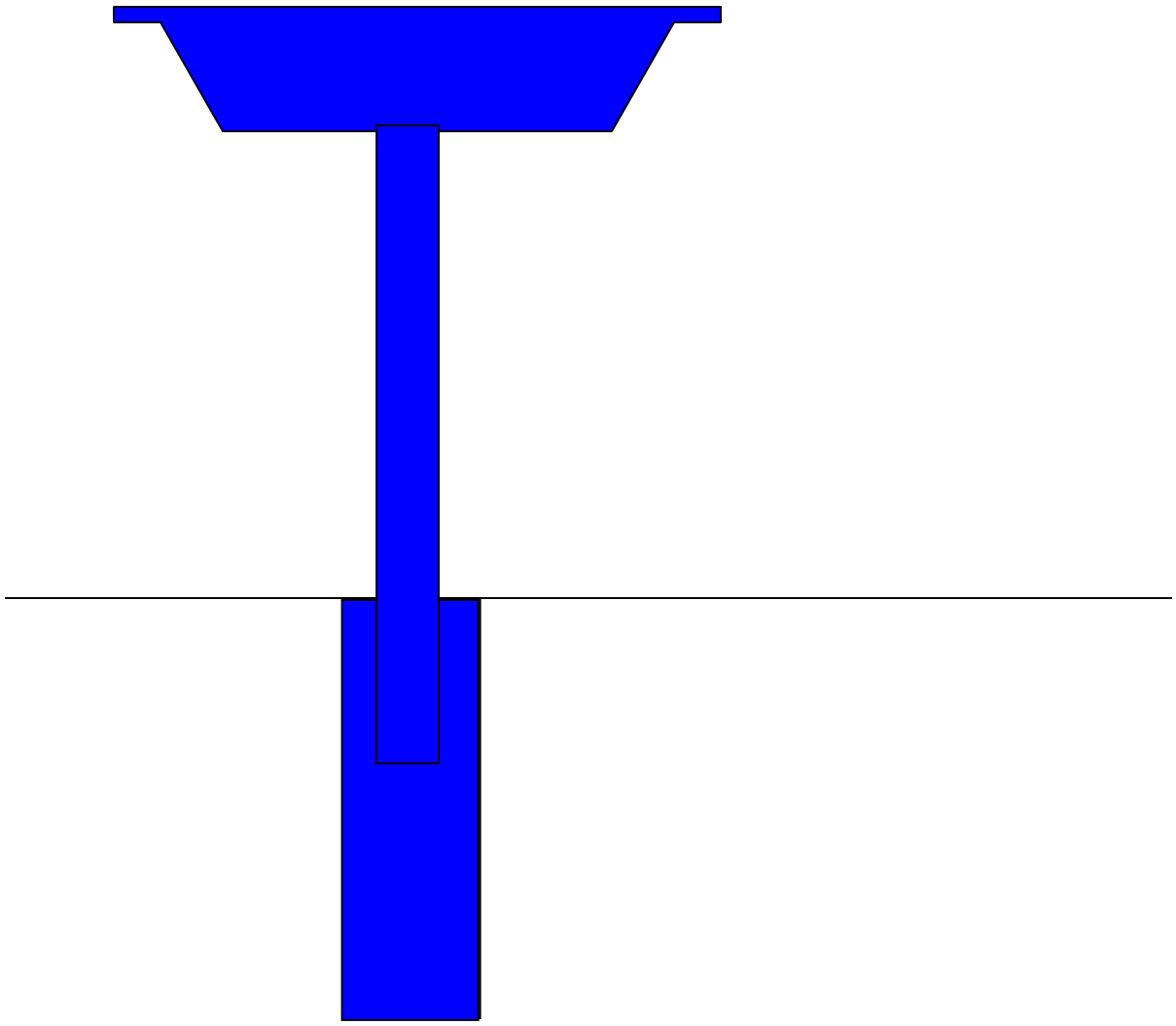


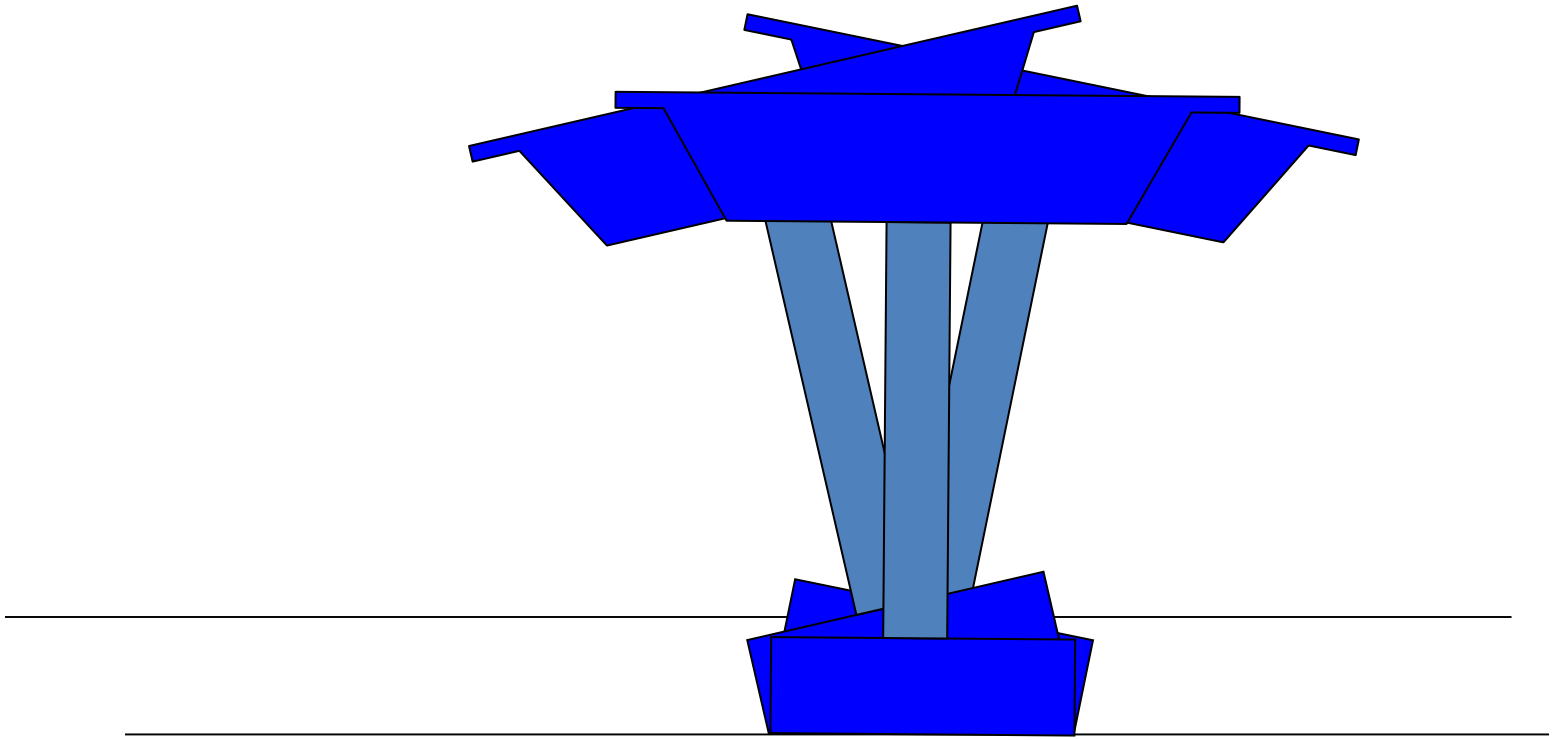
Comments?

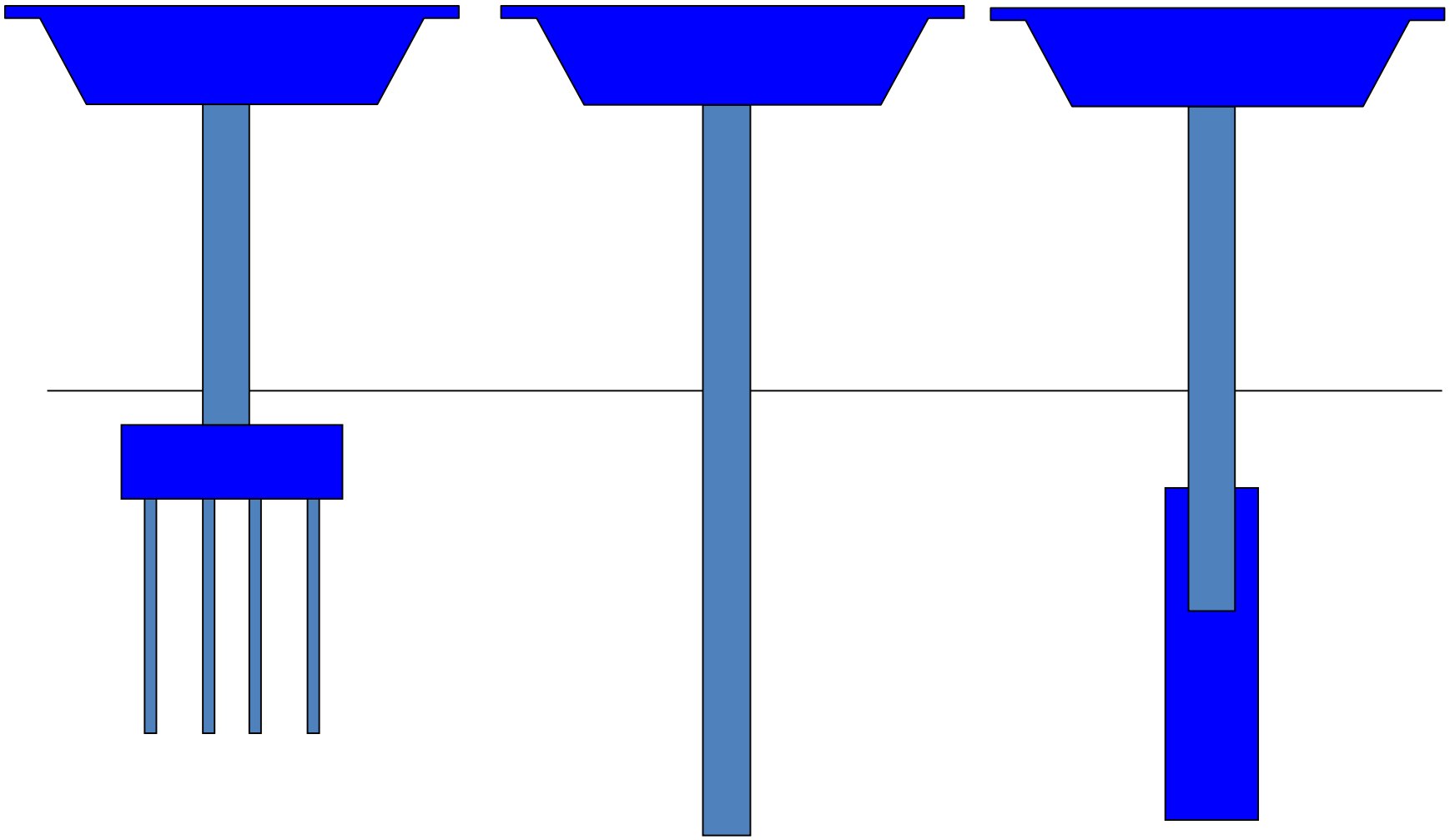
Questions?











6’-diameter column/shaft test at UCLA

6’-diameter column/shaft test at UCLA