

# *Devil's Slide and South Fork Eel River Bridge Projects*

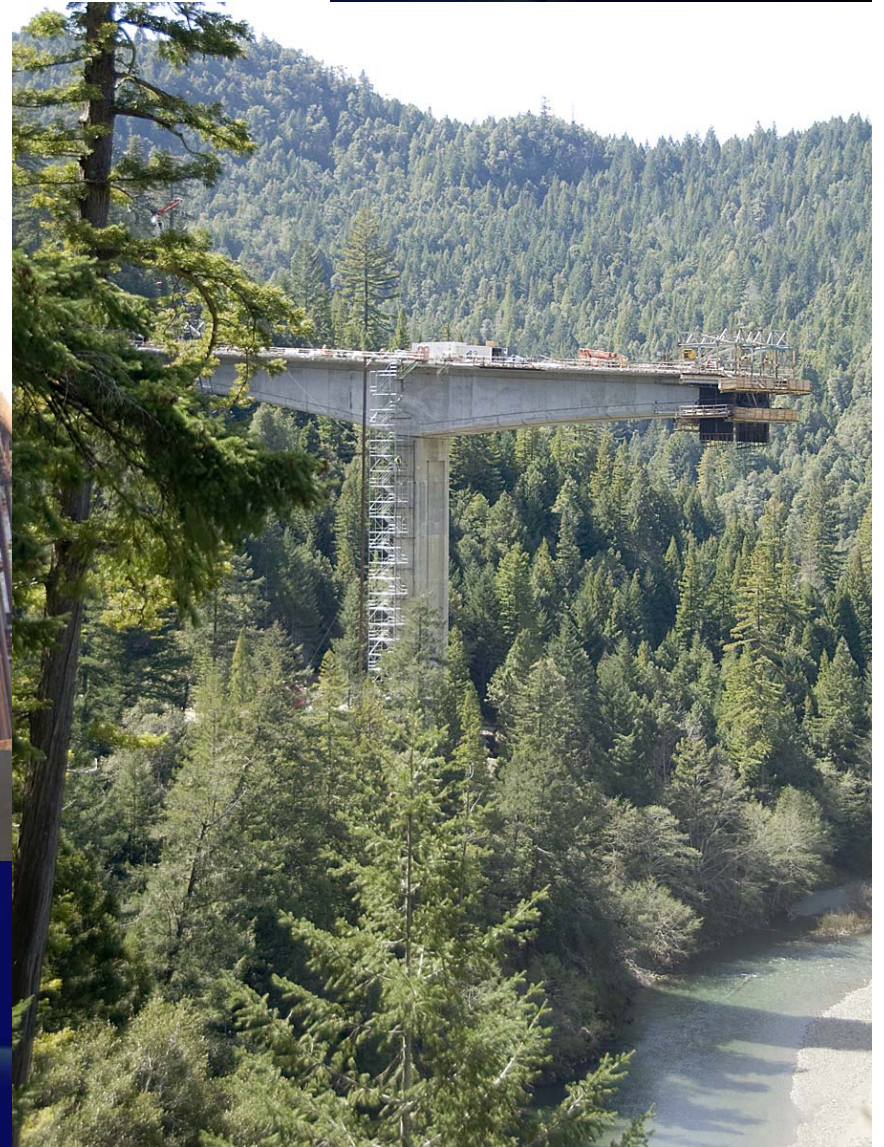


*Kevin Harper*





Devil's Slide



Confusion Hill

CIP Balanced Cantilever Segmental Construction





≈ 200miles

Devil's Slide is located 18 miles South of San Francisco

Both Projects Located in Northern CA

© 2006 Europa Technologies  
Image © 2006 TerraMetrics  
© 2006 Navteq  
Image © 2006 NASA

Google™

Pointer 37°21'17.57" N 111°44'27.59" W

Streaming ||||| 100%

Eye alt - 1678.75 mi

# Devil's Slide



# Confusion Hill Slide



1995

Wong '95



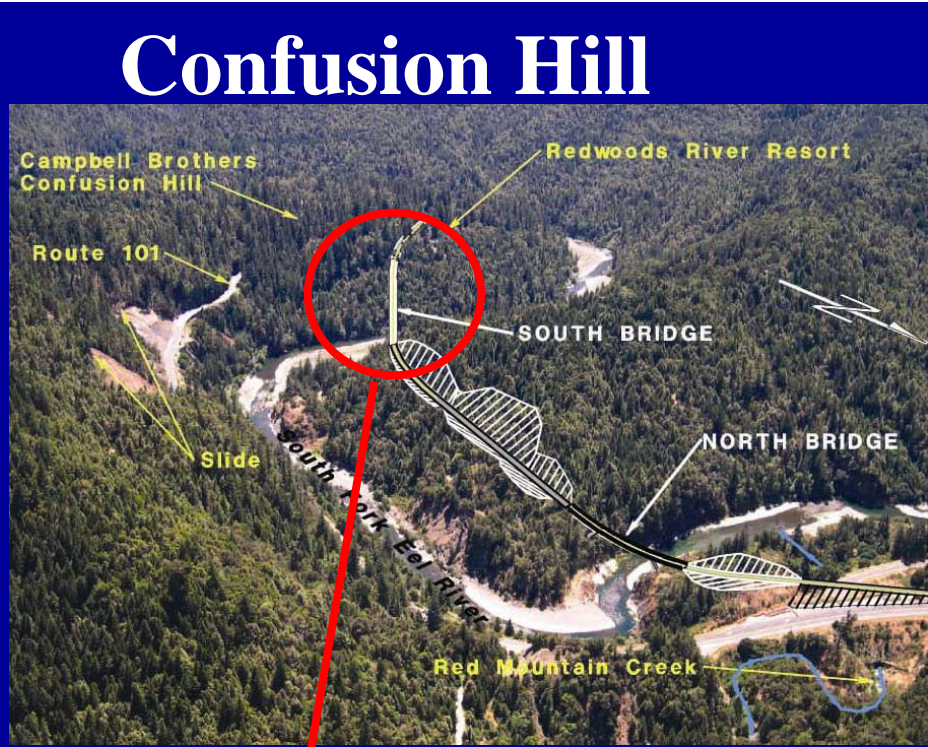
May 2006



Confusion Hill  
Winter of  
2002/03

Emergency Projects  
Bypass Large Landslides  
100% FHWA Emergency Relief Funding





Both Projects Relocate The Highway Away From Slide Prone Areas



# Devil's Slide

Segmental Because of ESA



Main Span Length = 445.4'

# Confusion Hill

Segmental Because of Height



Main Span Length = 570.9'



26.2'

### Cantilever Tendons (Tot. 36 tendons):

Rt Br. Pj = 483 k ea. (11-0.6" strand)

Lt. Br. Pj = 527 k ea. (12-0.6" strand)

### Cantilever Tendons (Tot. 68 tendons):

Pj = 588 k ea. (14-0.6" strand)



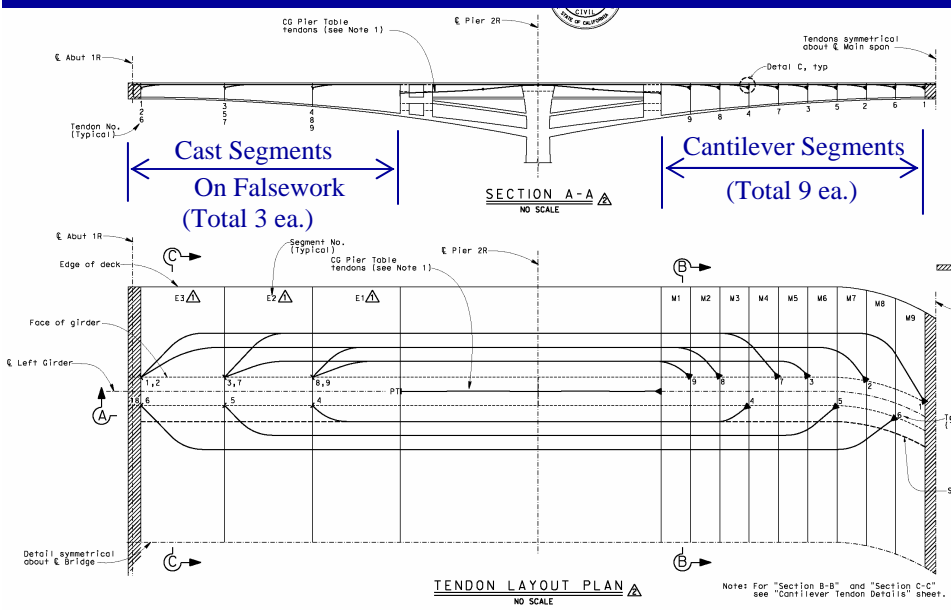
# Devil's Slide Bridges

## Cantilever Tendons (Tot. 36 tendons):

Rt Br. Pj = 483 k ea. (11-0.6" strand)

Lt. Br. Pj = 527 k ea. (12-0.6" strand)

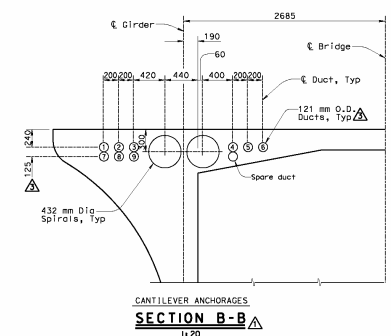
## Balanced Cantilever Method (Contract Plans)



## Cantilever Tendons (Tot. 18 tendons):

Rt Br. Pj = 966 k ea. (22-0.6" strand)

Lt. Br. Pj = 1054 k ea. (24-0.6" strand)



## Contractor Method (Falsework in Back spans)

## Project Costs

	Devil's Slide	Confusion Hill
• Structures:	<b>\$ 33.1 million</b> (+7% Eng Est)	<b>\$ 49.4 million</b> (\$36.7 mill for Seg. Br) -3%
• Roadway:	<b>\$ 2.6 million</b>	<b>\$ 16.3 million</b>
• Total:	<b>\$ 35.7 million</b>	<b>\$ 65.7 million</b>
Begin Const.	<b>April 2006</b>	<b>June 2006</b>
Complete Const.	<b>Fall 2008</b>	<b>Fall 2009</b>



	<b>Devil's Slide Br.</b>	<b>SF Eel River Br.</b>
Span Lengths:	Lt: 281'- <del>445'</del> -251' Rt: 230'-445'-225'	348'- <del>571'</del> -436'
End Span Ratio :	Lt: 0.63L - L - 0.56L Rt: 0.52L - L - 0.50L	0.61L - L - 0.76L
Max Structure Depth:	30'-2" (D/S = 0.068)	31'-6" (D/S = 0.055)
Min Structure Depth:	8'-10" (D/S = 0.020)	11'-6" (D/S = 0.020)
Max Seg. Wt:	163 tons	200 tons
No. of Segments:	48 (72 design)	68



	<b>Devil's Slide Br.</b>	<b>SF Eel River Br.</b>
Tot Br. Length:	<b>Lt: 977 feet Rt: 900 feet</b>	<b>1355 feet</b>
Bridge Width:	<b>29 feet (ea.)</b>	<b>42.8 feet</b>
Max Bridge Ht:	<b>125 feet</b>	<b>265 feet</b>
Pier Clear Ht:	<b>56 feet</b>	<b>168 feet</b>
Contractor Bridge Price:	<b>\$ 33,067,000 (\$ 607/sqft) And 500 Working Days  (total \$ for both bridges)</b>	<b>\$ 36,718,500  (\$ 633/sqft)</b>



	<b>Devil's Slide Br</b>	<b>SF Eel River Br.</b>
Contractor:	<b>Disney Construction, Inc.</b>	<b>MCM Construction, Inc.</b>
Contractor's Segmental Engineer:	<b>NRV (Nutt, Redfield, &amp; Valentine)</b>	<b>Finley Engineering Group, Inc.</b>
Post-Tensioning Subcontractor:	<b>Schwager Davis, Inc.</b>	<b>Schwager Davis, Inc.</b>
Form Travelers:	<b>Schwager Davis, Inc.</b>	<b>AVAR</b>

**Both Contractors Did Not Have Previous Segmental Experience**



# South Fork Eel River Bridge



Landslide and Project are named after the neighboring Confusion Hill Mystery Spot

CONFUSION HILL

 SOUTH BRIDGE  
01- MEN-101  
PREPARED BY DES. BRIDGE ARCHITECTURE & AESTHETICS

 Caltrans

 Caltrans



Abut 4

Pier 3

Temporary Trestle and start of North Bridge Falsework





North Bridge Falsework approximately 140' tall  
(Temporary trestle in background)



**Spans: 175.8'-229.3'-175.8'**

**Cost: \$8,969,000 (\$361/sqft)**



Photograph taken July 2003



Relocate 1.5 miles of US-101 away from landslide – requires 2 bridges

South Fork Eel River is a federally designated “Wild & Scenic River” Under jurisdiction of the National Parks System

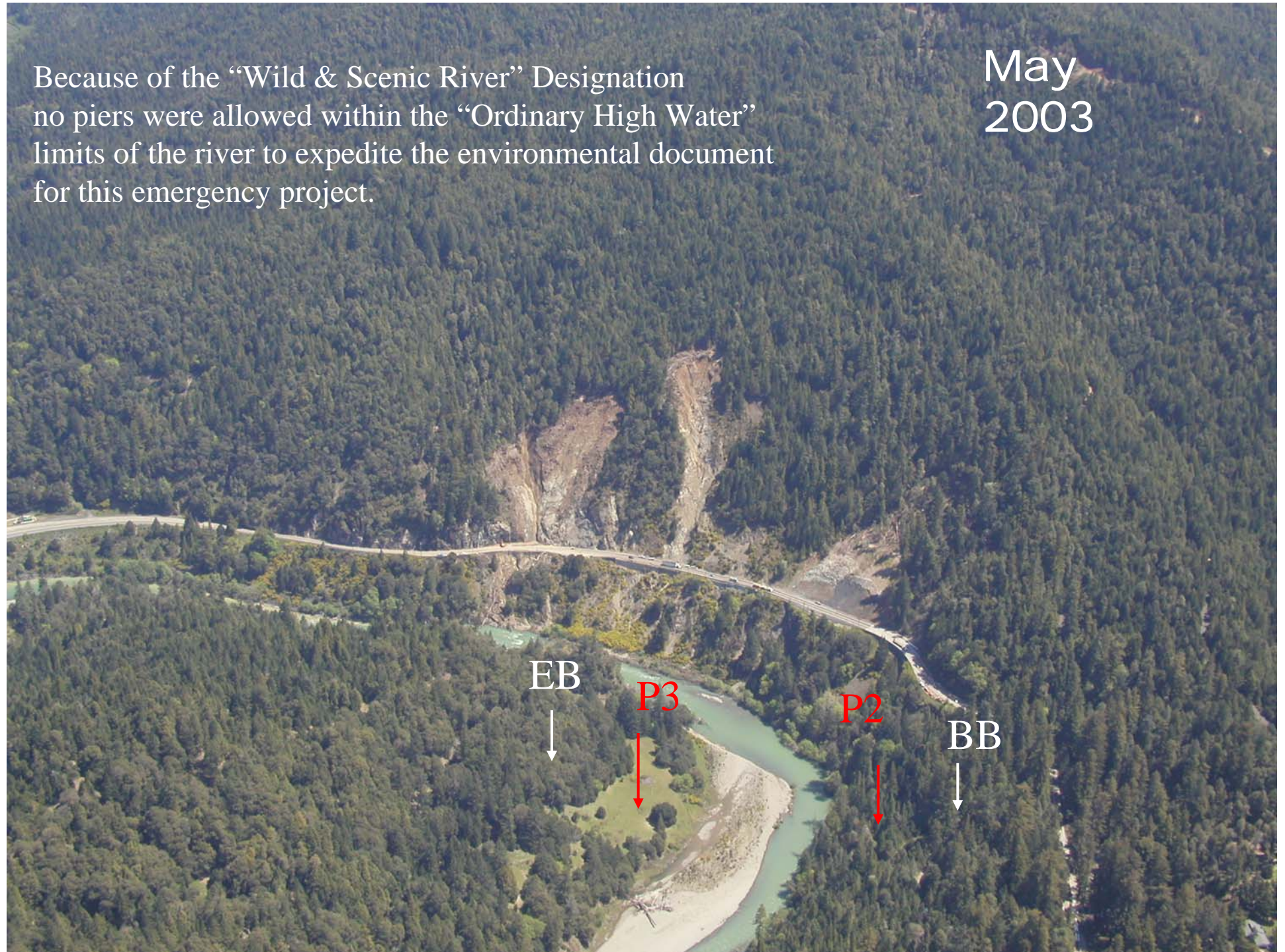
3-D Photo Rendering of Project





Because of the “Wild & Scenic River” Designation no piers were allowed within the “Ordinary High Water” limits of the river to expedite the environmental document for this emergency project.

May  
2003





Existing US-101



CONFUSION HILL

SOUTH BRIDGE  
01-MEX-101



S. Br Pier 2 - 10/16/06



5' CIDH Piles (11 each per ftg)  
2190 ton Compression Capacity  
(Service State)



\* Stepped Hollow Piers with deep fluting. \* Heavily confined corner elements for good ductility



Hollow Pier allows deep architectural fluting & makes it easy to provide 7' high maintenance Access opening thru Pier Cap.



#36 reinf in walls

Majority of Pier main reinf (#18)  
Concentrated in four well confined  
Circular corner elements  
(# 10 hoop dia = 5.6')



3.6'x3.6'  
Utility Opening

3.6'x7.0' Maintenance  
Opening



# Pier 2 Table w/ travelers



October 2007







## Pier 3 Construction

Pier Height is  
200 ft from top  
Of deck to top of  
ftg

Piers were  
Constructed in  
8 lifts  
(16' to 24' lifts)

2 more 24' lifts  
remain until pier  
reaches soffit  
Of bridge



4-30-08

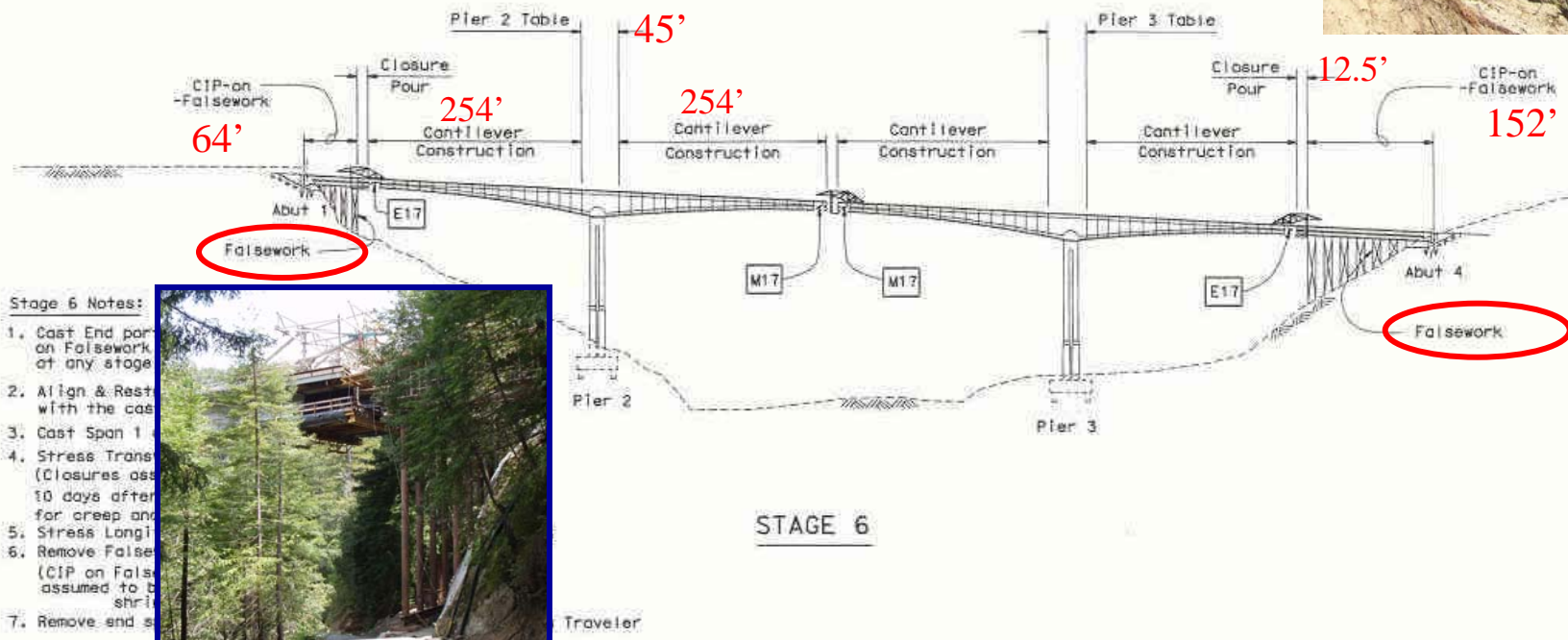
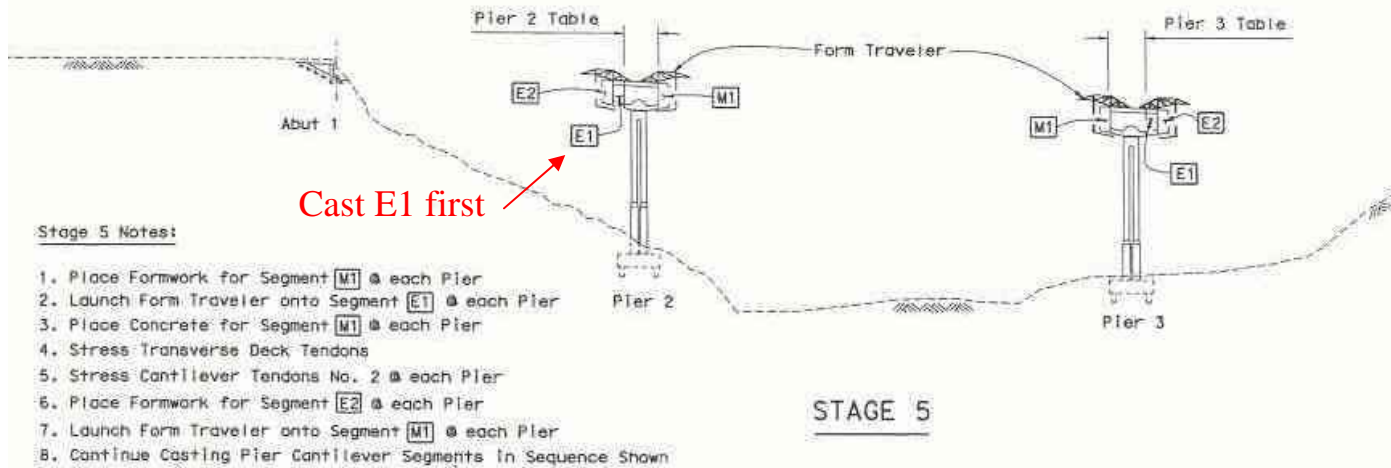


Pier 3 Table Construction  
On Falsework (170' tall Posts)

Pier Table length = 45'  
(18.7' + 26.2') ecc. = 7.5'



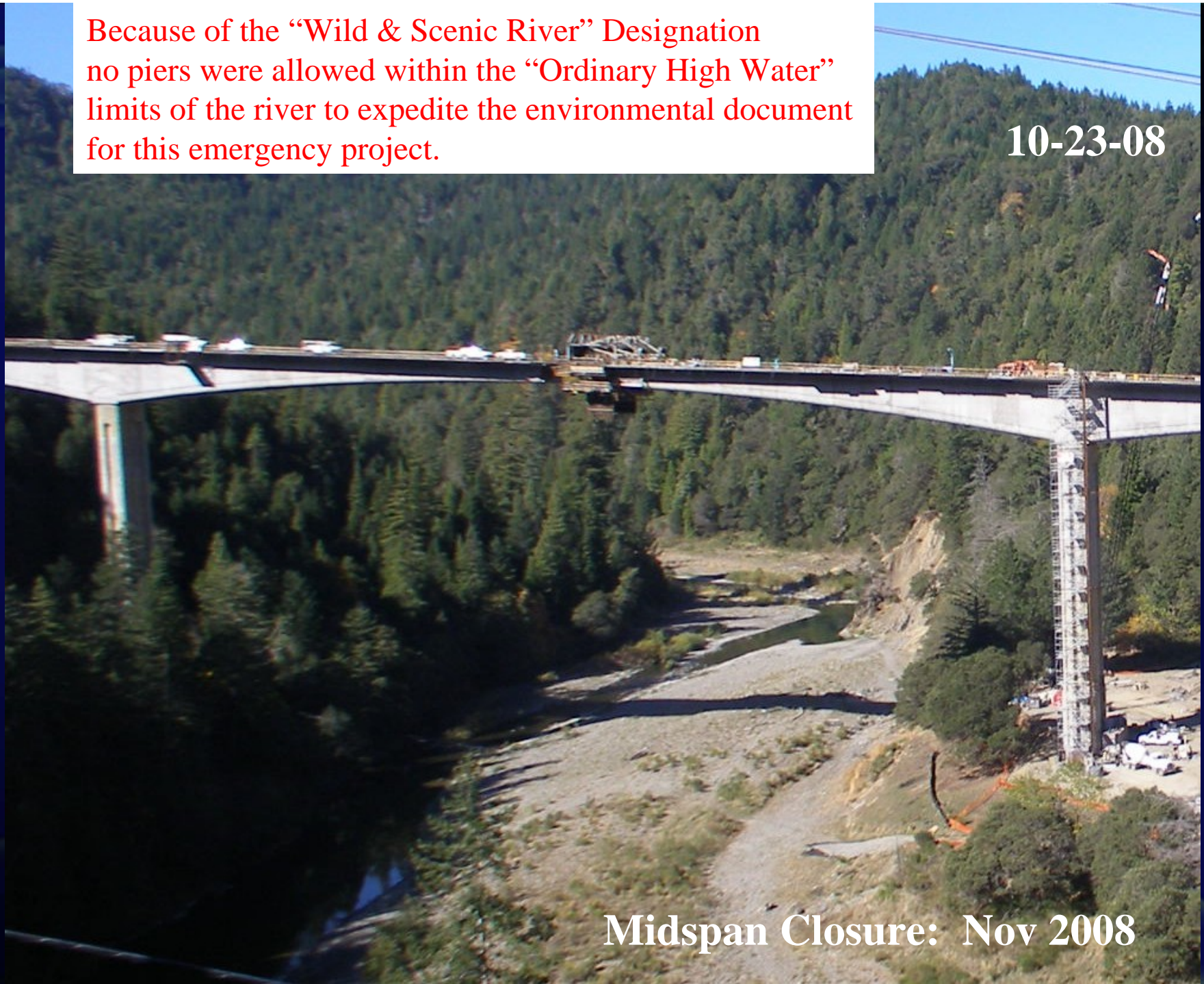
# South Fork Eel River Bridge



Because of the “Wild & Scenic River” Designation no piers were allowed within the “Ordinary High Water” limits of the river to expedite the environmental document for this emergency project.

10-23-08

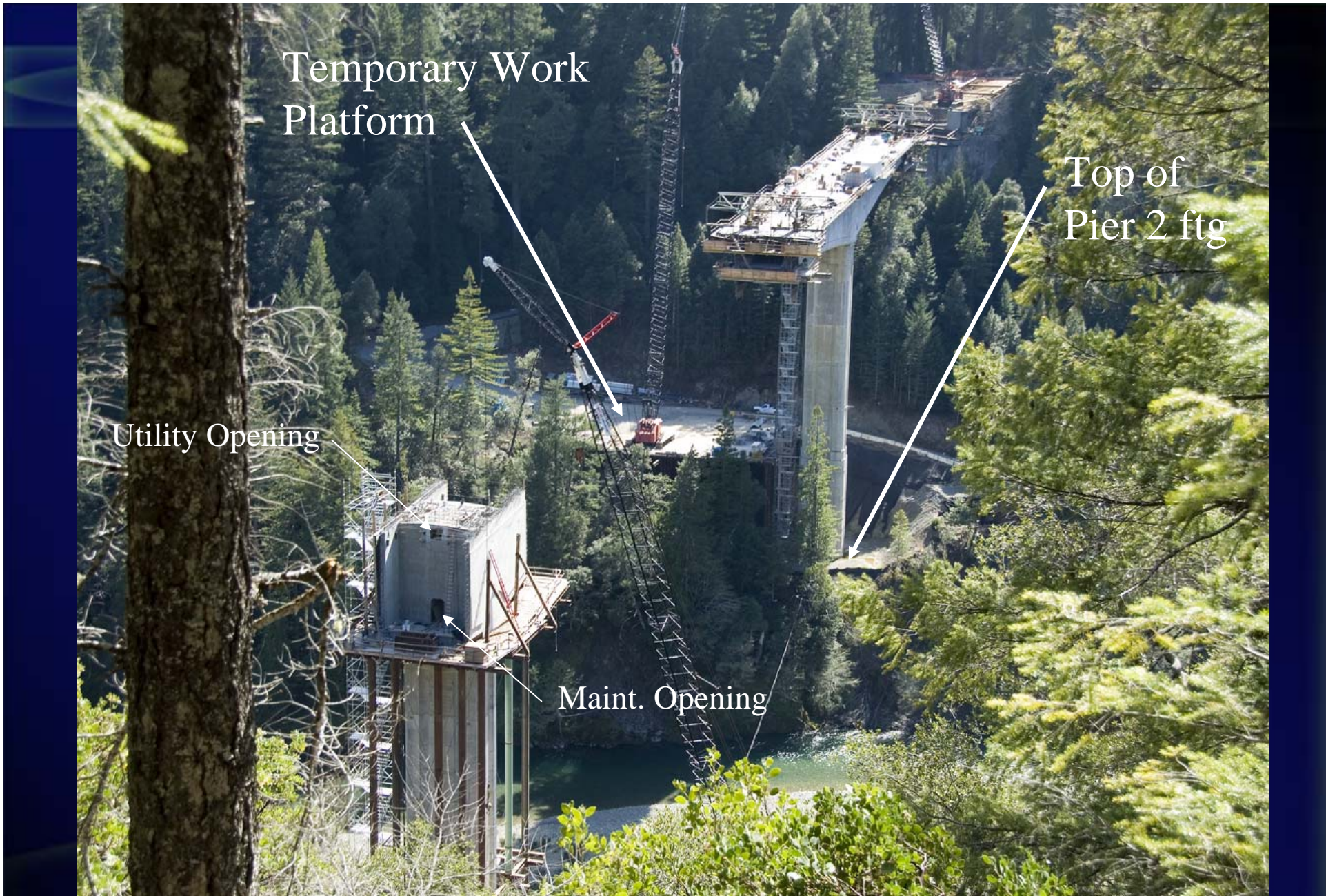
Midspan Closure: Nov 2008





Girder Aesthetics:  $3\frac{1}{2}$ " build outs on girder & soffit  
2' Radius at bottom of girder, OH = 9.5'





South Bridge Cantilever Construction

April-2008





Pier 2 Cantilever construction above redwood trees





## Segment Production:

One Segment Pair per Week ( E & M segments)

E-segments stressed and traveler launched on 3<sup>rd</sup> day (concrete pour every Friday)

M-segments stressed and traveler launched 1 day after concrete pour (concrete pour every Wed.)



# Devil's Slide Bridges



# Devil's Slide Bridges

18 miles south of San Francisco

Approx Slide limits



Bridges

The Devil's Slide has been a frequent cause of closure since Rte 1 was constructed  
In 1930's



South Portal



March 2008

Cantilever  
Construction  
Complete on  
Lt. Bridge  
(southbound)



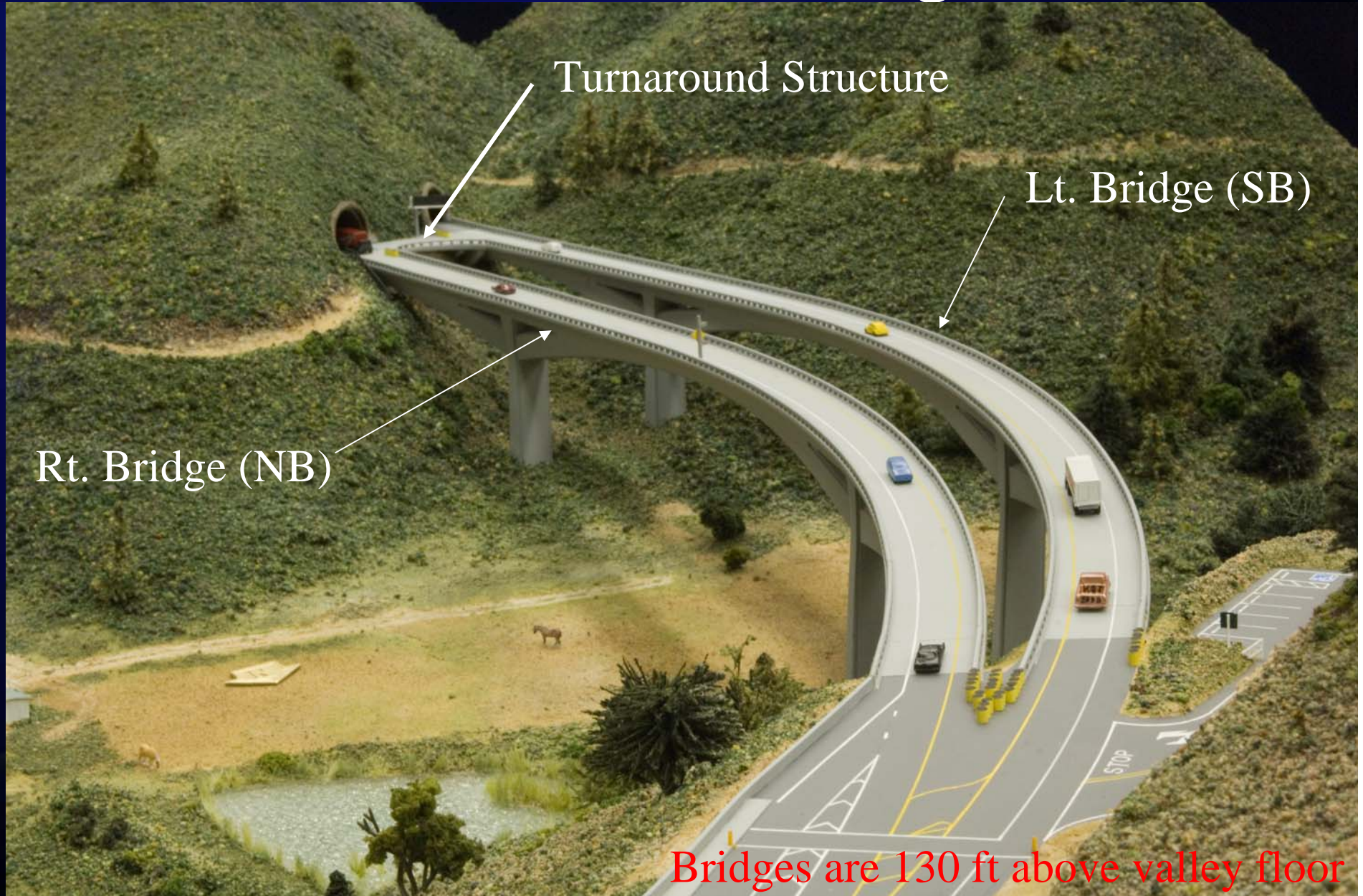
# Devil's Slide Bridges

Turnaround Structure

Lt. Bridge (SB)

Rt. Bridge (NB)

Bridges are 130 ft above valley floor



# Devil's Slide Bridges

**Bridge Aesthetics were very critical and public input dictated that they become an integral part of the bridge design.**

**A standard monolithic structure was not considered adequate mitigation at the site.**



Pacific  
Ocean



BB

North Portal

EB

ESA  
Coastal  
Wetlands

Pond

Not even foot traffic was allowed within the ESA limits  
March 2008



Ballast

# Devil's Slide Bridges

Note: For "General Sequence Notes" see [redacted] DIST COUNTY ROUTE KILOMETER POST SHEET TOTAL  
TOTAL PROJECT SHEETS 190

**STAGE 5**

**Stage 5 Notes:**

1. Place concrete for Segment E2
2. Stress transverse deck tendons in Segment E2
3. Move form traveler into position for Segment M2
4. Place formwork for Segment M2
5. Place concrete for Segment M2
6. Stress transverse deck tendons for Segment M2
7. Stress cantilever tendons for Segment M2, falsework at E1 may be released
8. Repeat steps 3 thru 7 for Segment M3
9. Apply hold down force HD2=900kN as shown, HD1 to be removed
10. Repeat steps 3 thru 7 for Segment M4

**STAGE 6**

**Stage 6 Notes:**

1. Place concrete for Segment E3
2. Stress transverse deck tendons in Segment E3
3. Move form traveler into position for Segment M3
4. Place formwork for Segment M3
5. Place concrete for Segment M3
6. Stress transverse deck tendons for Segment M3
7. Stress cantilever tendons for Segment M3, falsework at E2 may be released
8. Repeat steps 3 thru 7 for Segment M4
9. Apply hold down force HD3=900kN as shown, HD2 to be removed
10. Repeat steps 3 thru 7 for Segment M5

**STAGE 7**

**Stage 7 Notes:**

1. Remove one of the form travelers from Span 2. Transfer 1/2 of weight of remaining traveler to opposite cantilever.
2. Align the span 2 cantilever tips and restrain to prevent rotation or movement of one cantilever relative to the other.
3. Cast closure in Span 2 (Closure assumed to be completed according to contractor's proposed schedule for creep and shrinkage calculations)
4. Stress transverse deck tendons in Span 2 closure
5. Stress 1/3 of longitudinal span tendons (Longest tendons) in Span 2 within one day of casting closure
6. Stress remaining longitudinal span tendons in Span 2
7. Remove form traveler in Span 2
8. Grout all cantilever tendons and all transverse tendons

**STAGE 8 - LEFT BRIDGE**

10. Grout unused spare Span Tendon Ducts

**STAGE 8 - RIGHT BRIDGE**

**Stage 8R Notes:**

1. Remove falsework and HD3 forces from Spans 1 and 3
2. Cast Abutment 1 & 4 Diaphragm segments supported on falsework
3. Stress transverse deck tendons in diaphragm segments
4. Stress longitudinal span tendons, grout span tendons in Span 1 & 3
5. Remove remaining falsework.
6. Cast ballast block in Span 3 (ballast block assumed to be completed 7 days after stressing longitudinal span tendons)
7. Construct concrete barriers and install utilities (Assumed to be 14 days after ballast block has been cast)
8. Grout unused spare Span Tendon Ducts.

CONTRACT CHANGE ORDER NO. \_\_\_\_\_  
SHEET \_\_\_\_\_ OF \_\_\_\_\_

ALL DIMENSIONS ARE IN METERS UNLESS OTHERWISE SHOWN

DESIGN	R. V. Nutt	CHECKED	R. N. Valentine
DETAILS	R. E. Uhlmann	CHECKED	R. N. Valentine
QUANTITIES		CHECKED	

STATE OF CALIFORNIA  
DEPARTMENT OF TRANSPORTATION

DIVISION OF STRUCTURES  
STRUCTURE DESIGN 1

BRIDGE NO. 35-0331R/L  
KILOMETER POST 63.87

DEVIL'S SLIDE BRIDGE  
CONSTRUCTION SEQUENCE DETAILS NO.2

CU 04  
EA 1123K1

FILE NO. PROJECT

DATE PLOTTED: 01-10-11

SCALE: 1:100

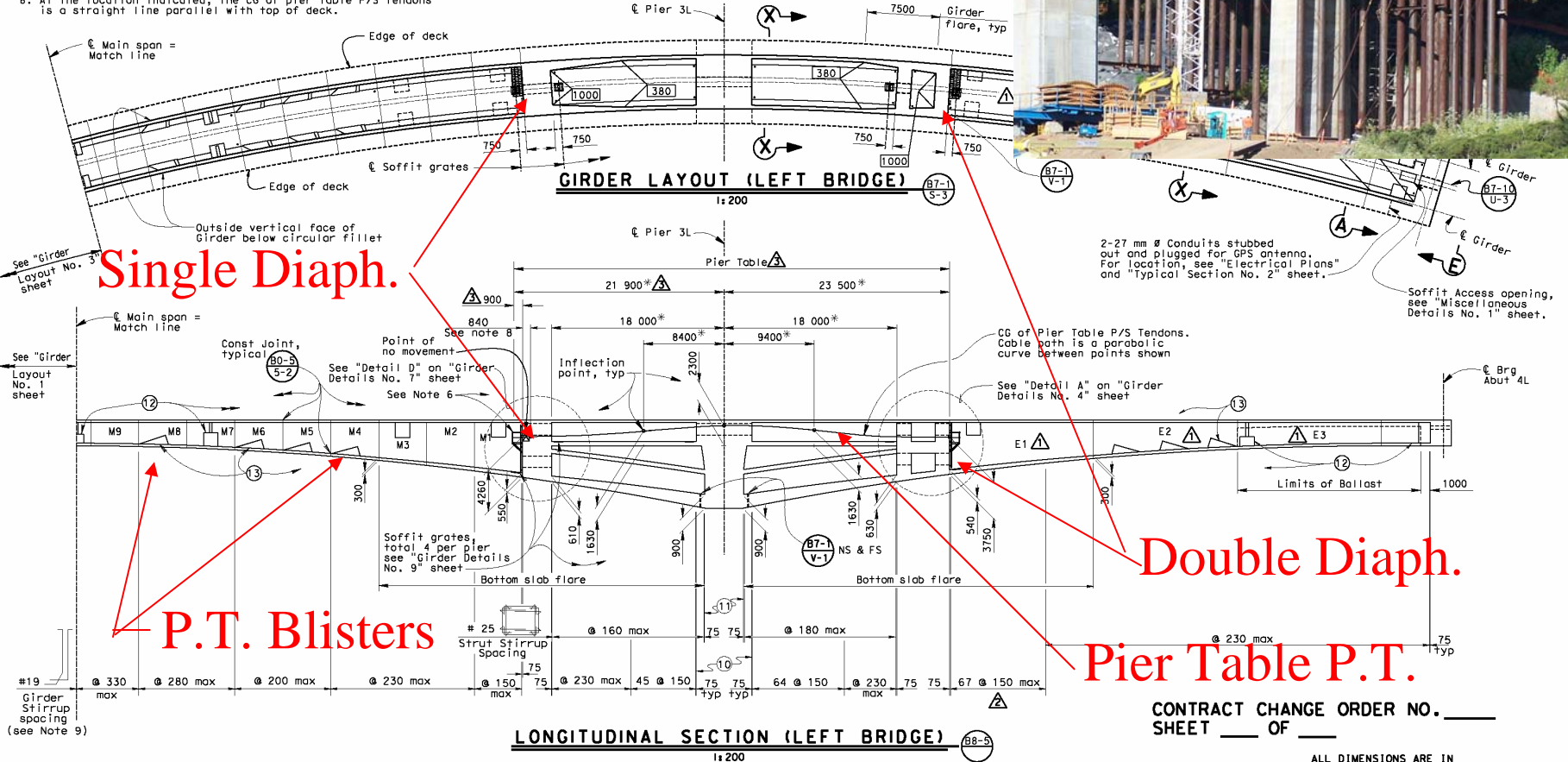
SHEET 108 OF 153



- NOTES:**
- Concrete Ballast shall be cast after stressing of all Span Tendons. See "Construction Sequence" sheets.
  - For additional prestressing, see "Cantilever Tendon Layout" & "Span Tendon Layout" sheets.
  - For "Prestressing Notes", see "Prestressing Notes" sheet.
  - For "View E-E", see "Girder Details No. 2" sheet.
  - For "Section A-A", see "Girder Layout No. 4" sheet.
  - See "Maintenance Landing & Ladder Details No. 1" sheet.
  - For "Part Section X-X", see "Girder Details No. 9" sheet.
  - At the location indicated, the CG of pier table P/S tendons is a straight line parallel with top of deck.

- For limits of girder stirrups within each segment, see "Transverse Reinforcement Detail" on "Typical Section No. 3" sheet.
  - Face of Upper Pier Cap.
  - Face of Strut Pier Cap.
  - Future post tensioning deviator/anchor block, see "Future Post Tensioning Layout" sheets.
  - Span tendon anchorage, see "Span Tendon Layout" sheets.
- \* Dimension measured along  $\phi$  Bridge

9-20-06	PIER TABLE EXT
9-11-06	CHANGED STIRRUP
9-11-06	SEGMENT CHANGE
MARK	DATE
DES	RE



CONTRACT CHANGE ORDER NO. \_\_\_\_\_  
SHEET \_\_\_\_\_ OF \_\_\_\_\_

DESIGN	BY	CHECKED	STATE OF CALIFORNIA	DIVISION OF STRUCTURES	BRIDGE NO.	DEVIL'S SLIDE BRIDGE
DETAILS	BY	CHECKED	DEPARTMENT OF TRANSPORTATION	STRUCTURE DESIGN 1	35-0331R/L	GIRDER LAYOUT NO.2
QUANTITIES	BY	CHECKED			63.87	

STRUCTURES DESIGN DETAIL SHEET (METRIC) (REV.12-1-03)

ORIGINAL SCALE IN MILLIMETERS FOR REDUCED PLANS

CL 04  
EA 1123K1

REVISION DATES (MILEPOST/STAGE ONLY)

DATE PRINTED: 03/04/06

SHEET 48 OF 153

# Foundation work

- 9 Piles per footing
- 5' CIDH piles
- Average depth 40-46'



5' CIDH Piles  
1770 & 2020 ton  
Compression Capacity  
(Service State)



# Footings



- Footing dimensions –39' x 48' x 15'
- Cooling system added due to mass concrete
- Minimum dimension of member exceeding 2m
- Maximum temp 160 F
- Maximum temp differential within member

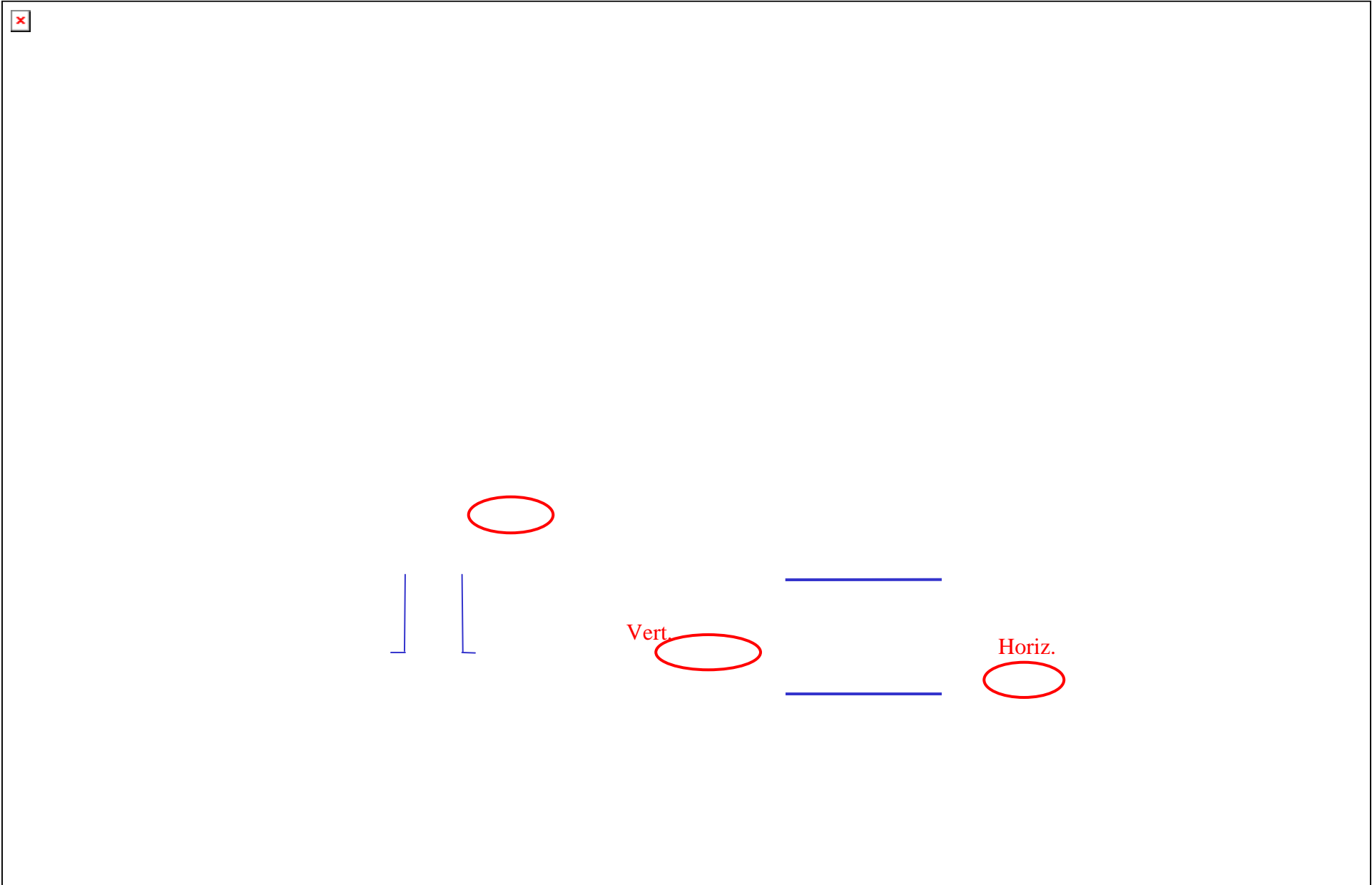




# PIERS

- Max pier height 85'
- Tapered column average
  - 17' x 17' – 17' x 12.5'
- Poured in two segments
- Column Guying



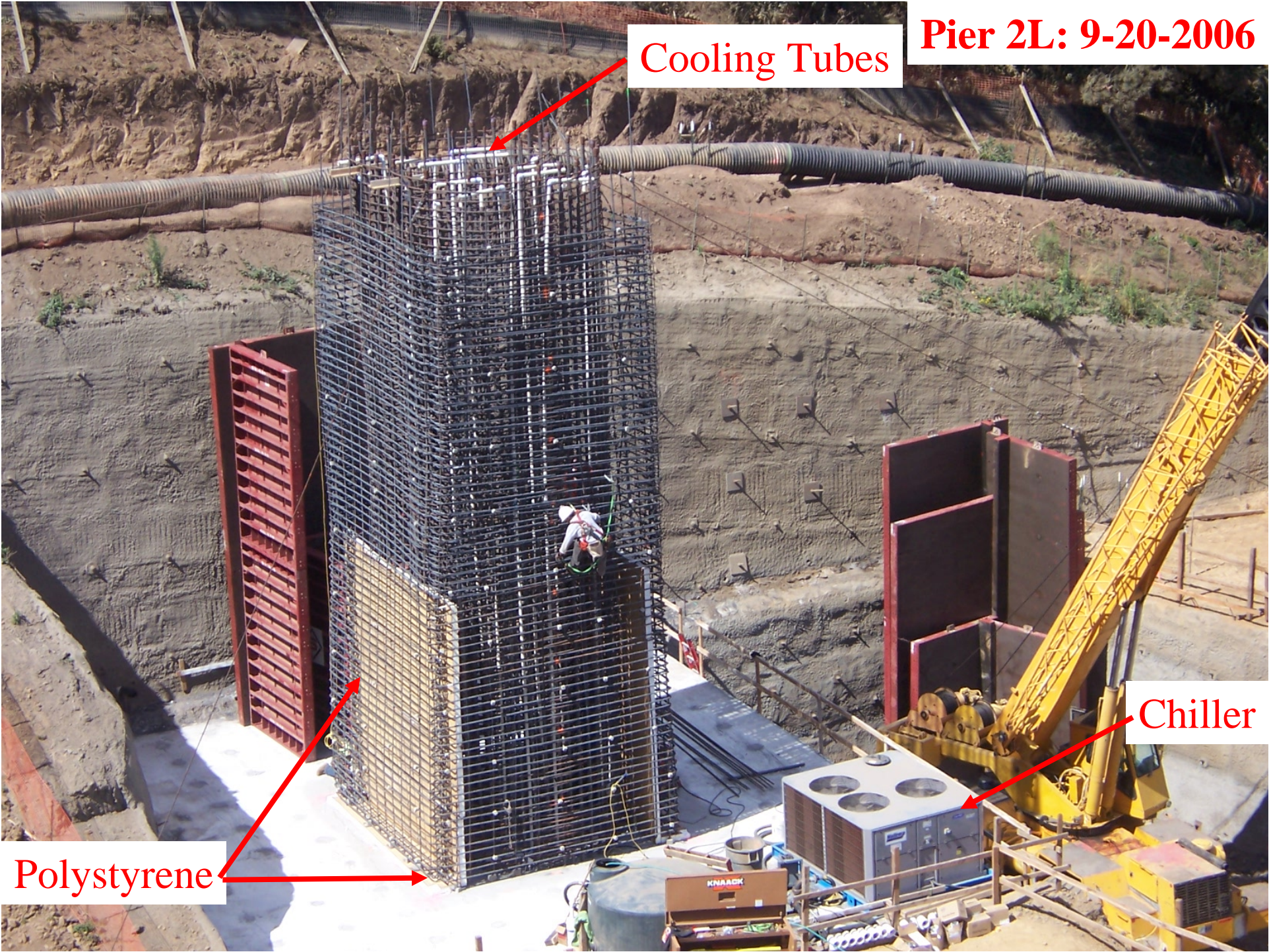


**Pier 2L: 9-20-2006**

**Cooling Tubes**

**Chiller**

**Polystyrene**



# Devil's Slide Bridges

## Seismicity – cont.

	w/o Vert. Polystyrene	With Vert. Polystyrene
<b>Lp</b>	<b>50''</b>	<b>64''</b>
<b>Local</b>	$\mu_C = \frac{\Delta_C}{\Delta_Y} = \frac{5.6''+3.0''}{3.0''} = \mathbf{2.9} < 3.0 \text{ NG}$	$\mu_C = \frac{\Delta_C}{\Delta_Y} = \frac{7.2''+3.0''}{3.0''} = \mathbf{3.4} > 3.0 \text{ ok}$
<b>Global</b>	$\mu_D = \frac{\Delta_D}{\Delta_Y} = \frac{11.7''}{5.7''} = \mathbf{2.0} < 4.0 \text{ ok}$	$\mu_D = \frac{\Delta_D}{\Delta_Y} = \frac{11.7''}{5.7''} = \mathbf{2.0} < 4.0 \text{ ok}$
<b>Displ. D/C</b>	$\frac{\Delta_D}{\Delta_C} = \frac{11.7''}{16.9''} = \mathbf{0.7} < 1.0 \text{ ok}$	$\frac{\Delta_D}{\Delta_C} = \frac{11.7''}{19.1''} = \mathbf{0.6} < 1.0 \text{ ok}$

(Displ. Capacity SFERB = 68'')



\*Architectural details at abutments are intended to give the impression that the bridges continue

on into the hill sides. - Ret Walls mimic bridge girders.

\* This detail does not allow for exterior shear keys in a high seismic region.







TS 20 x 18 x 5/8



Shear Key Slot

W/ Bar 4" x 16" x 5'-0' & 2" spacer bars grouted inside

ABUTMENT SHEAR KEY — Non fusing (Abut sprd. ftg)



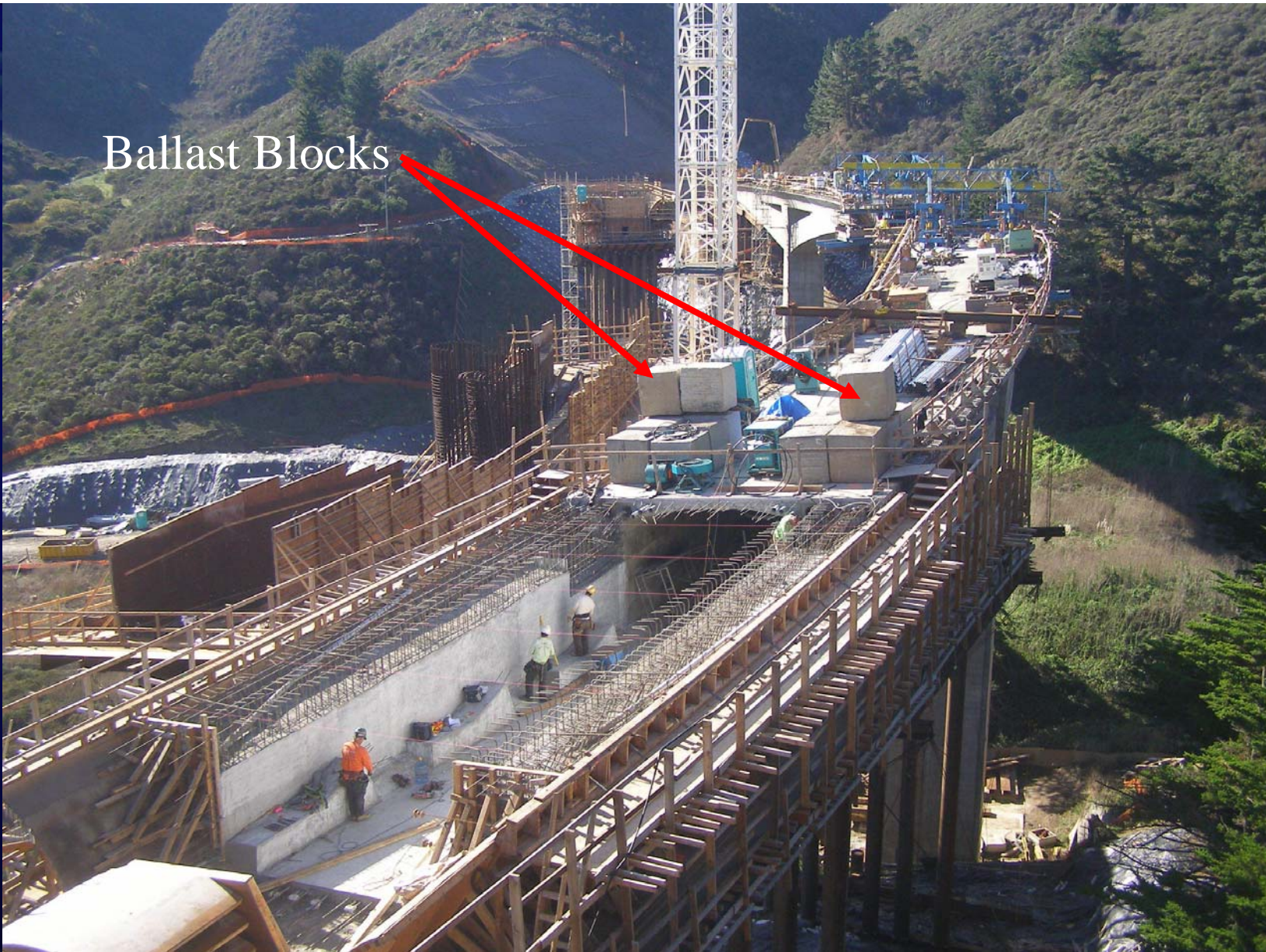
- Back-span length  
23.5m (77.1')
- Mid-span length  
21.9m (71.8')
- Balanced cantilever  
construction



**Pier Table Falsework**



Ballast Blocks



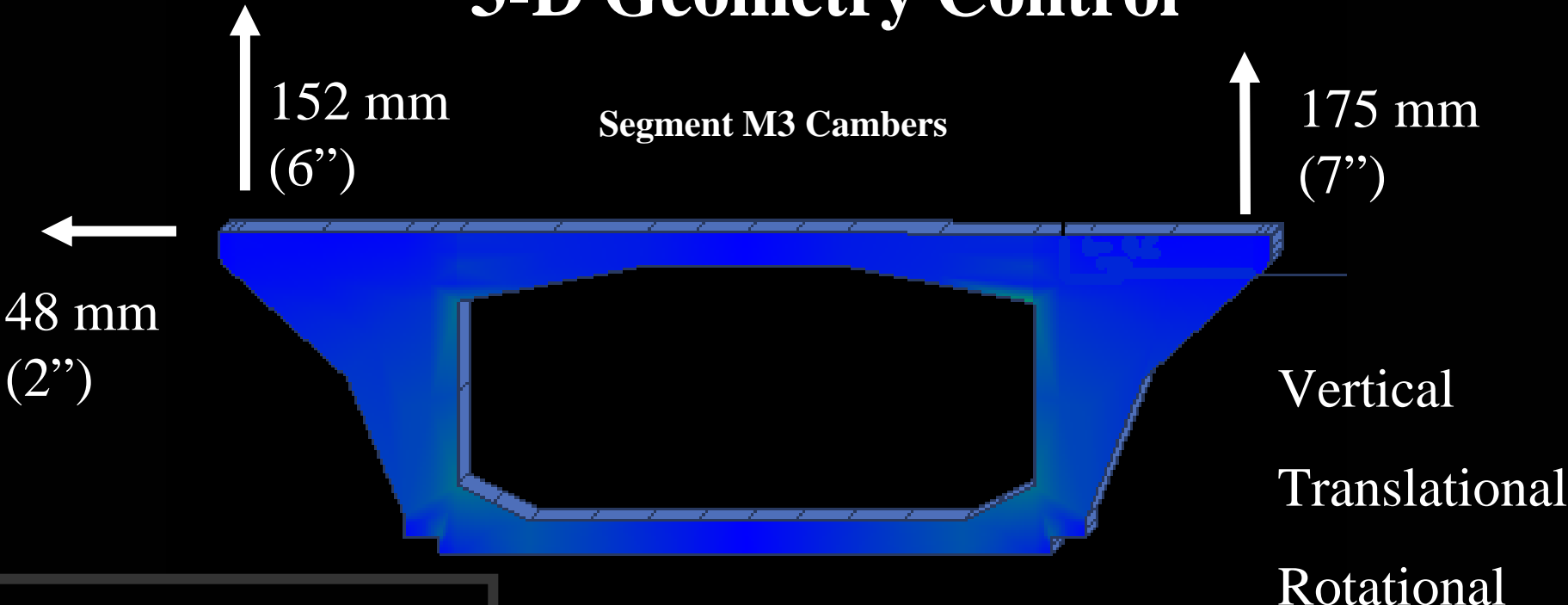
Segment E2 construction on falsework.  
Ballast Blocks at end of segment E1



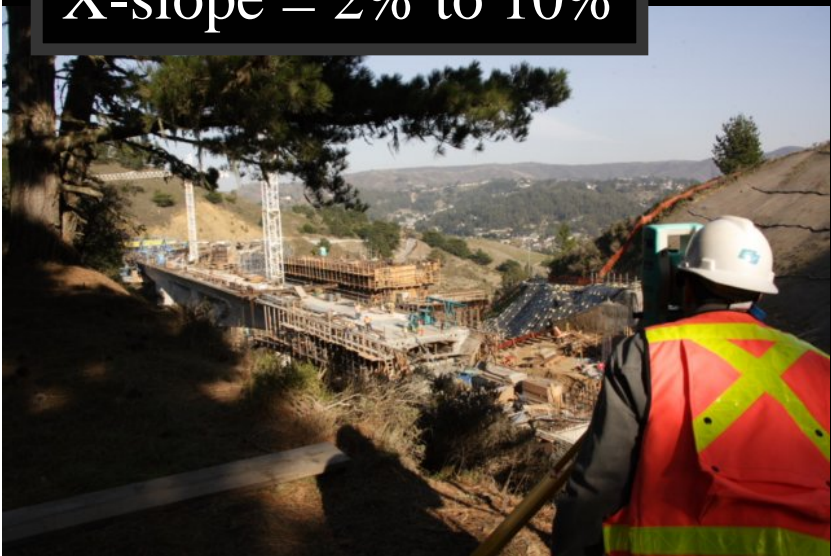


Form Traveler

# 3-D Geometry Control



Radius = 860'  
X-slope = 2% to 10%



**Early 2008**



**Pier 2L Cantilever complete, Pier 3L cantilever near completion**

**Cantilever Alignment prior to closure pour was within  
20 mm of theoretical target position**



# Closure Pour

Cast late afternoon on  
February 6, 2008

Stress 1 set of span tendons out  
Of 6 sets on next morning when  
Concrete strength = 2000 psi

Stress remaining span tendons  
On 2<sup>nd</sup> day after concrete  
Strength has reached 3500 psi



5/9/08



Average Segment Production (traveler segments)

Left Bridge: 12 days

Right Bridge: 7 days (Pour on Friday stress on Monday)

Ave. Concrete age at time of stressing: 2 – 3 days



# Thermal Control Analysis Required for Superstructure Segments

Maximum allowable concrete peak temperature during curing shall not exceed **160 F**

A minimum of 3 concrete internal temperature sensors required per segment

## Maximum Measured Temperatures During Construction

(Temperatures without special procedures or measures)

Devil's Slide Bridges: 142 F

South Fork Eel River Bridge: 135 F



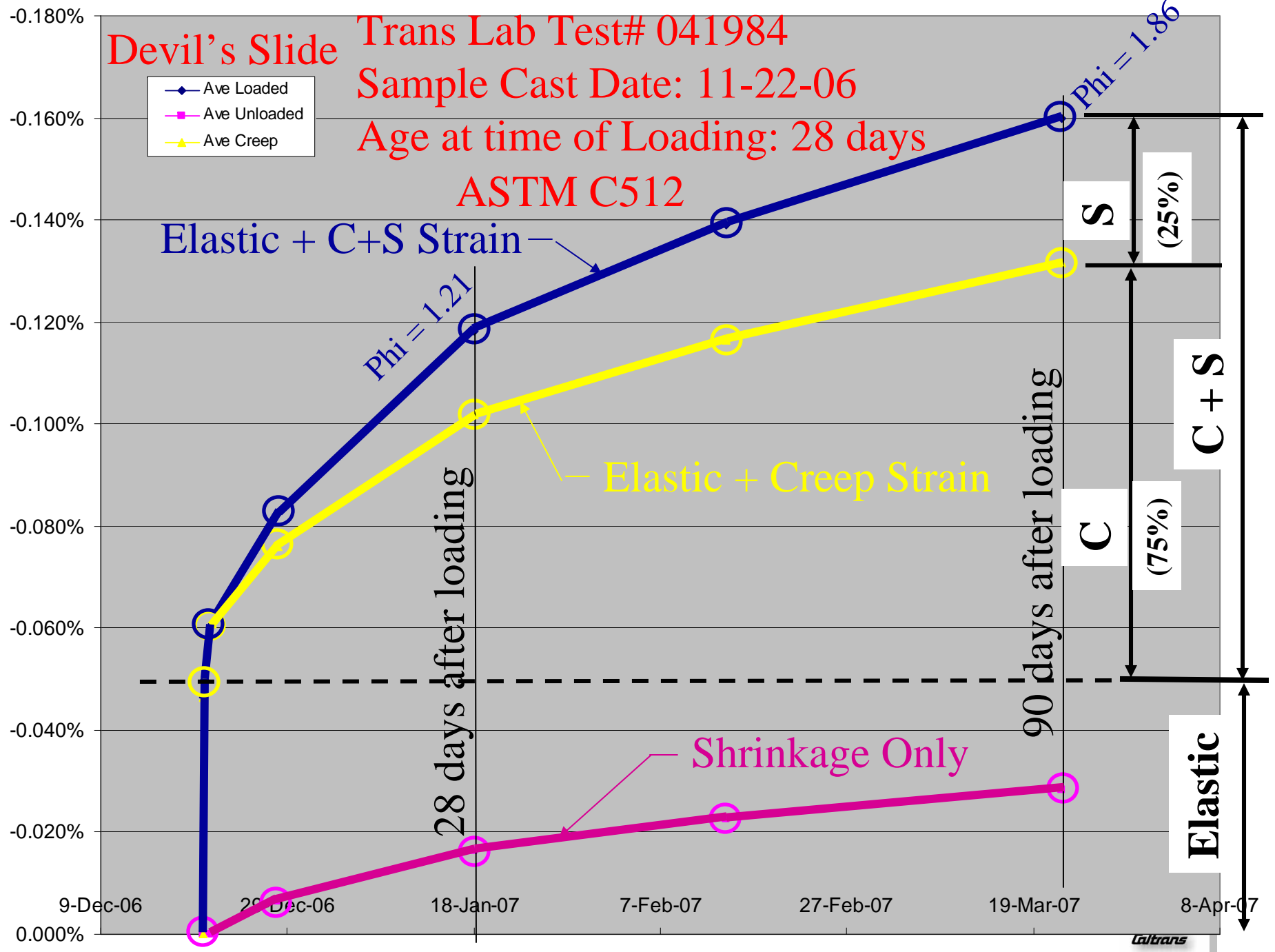
# Devil's Slide

Trans Lab Test# 041984

Sample Cast Date: 11-22-06

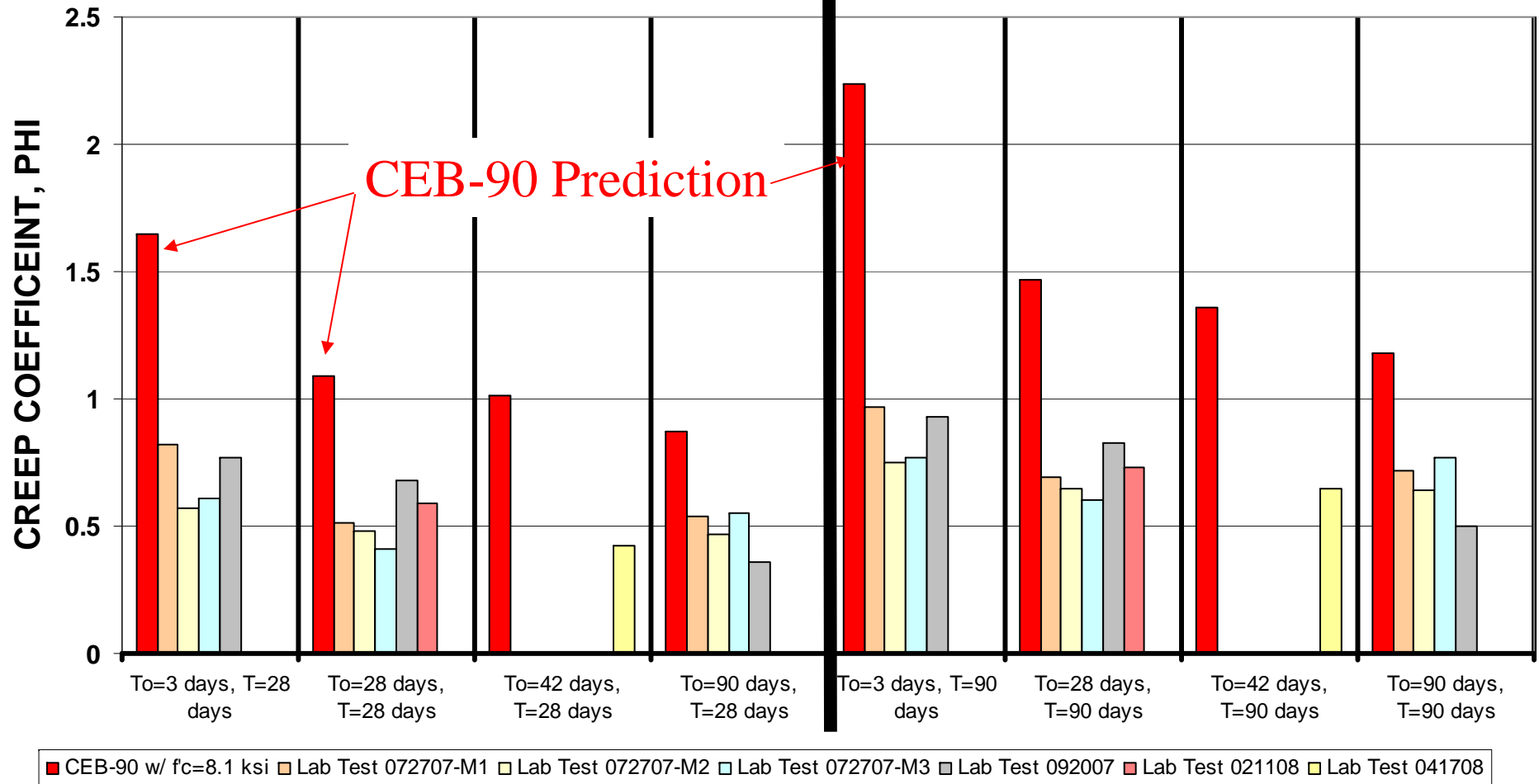
Age at time of Loading: 28 days

ASTM C512



# SOUTH FORK EEL RIVER BRIDGE CREEP TEST RESULTS (ASTM C512)

4" x 4" specimen

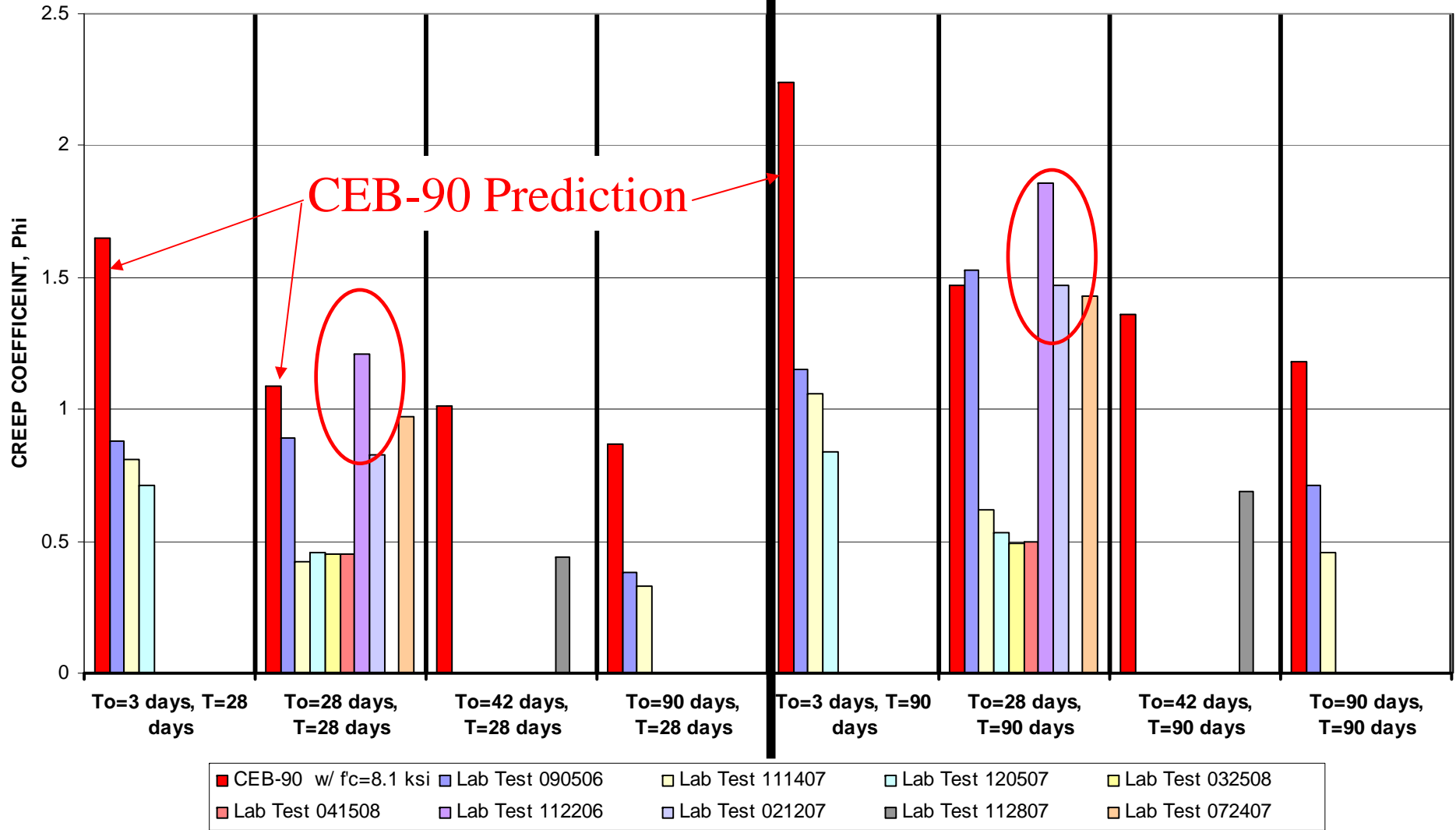


To = Concrete age at time of loading

T = Time after being loaded



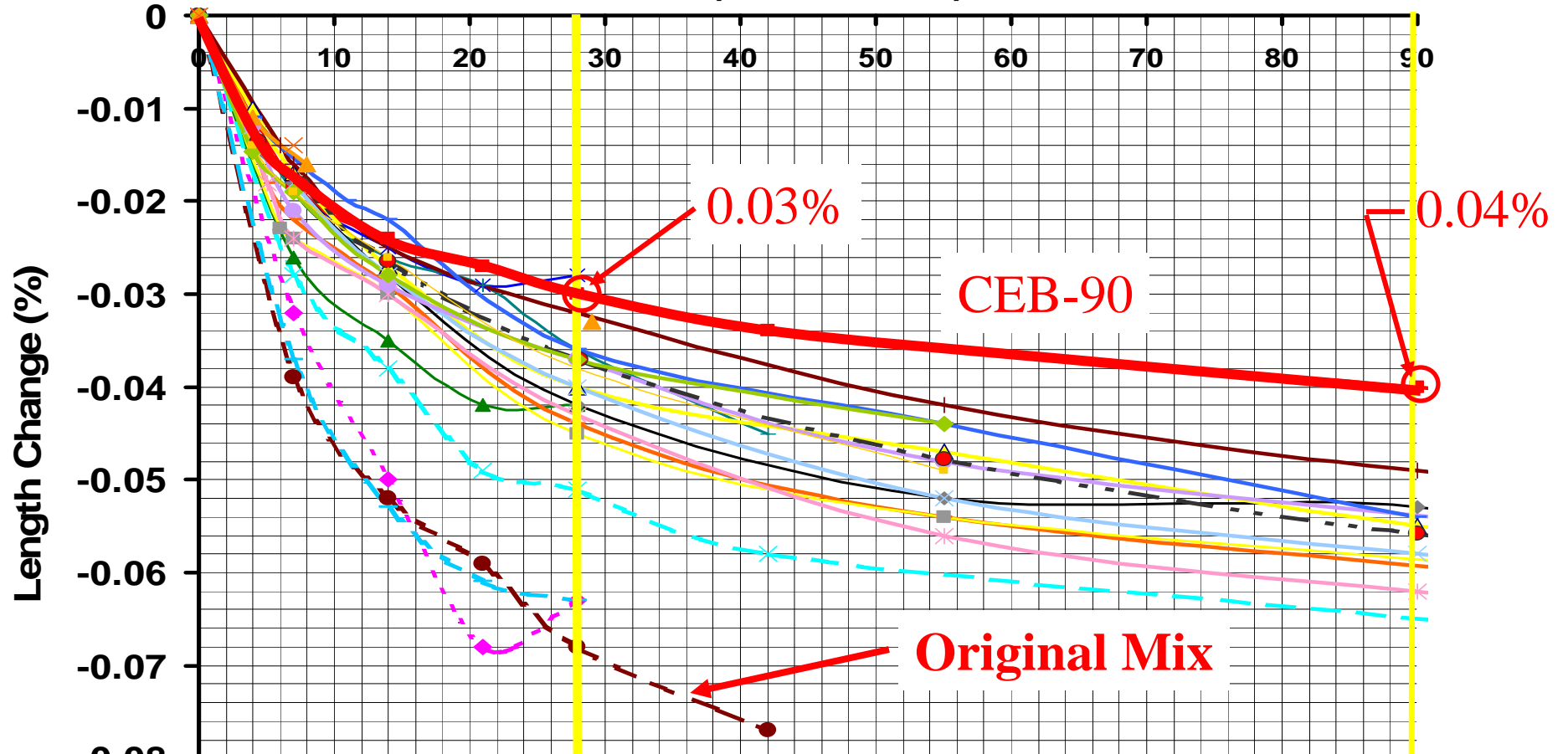
### DEVIL'S SLIDE BRIDGE CREEP TEST RESULTS (ASTM C512)



# South Fork Eel River Bridge Linear Drying Shrinkage Results

28 days (ASTM C157)

90 days

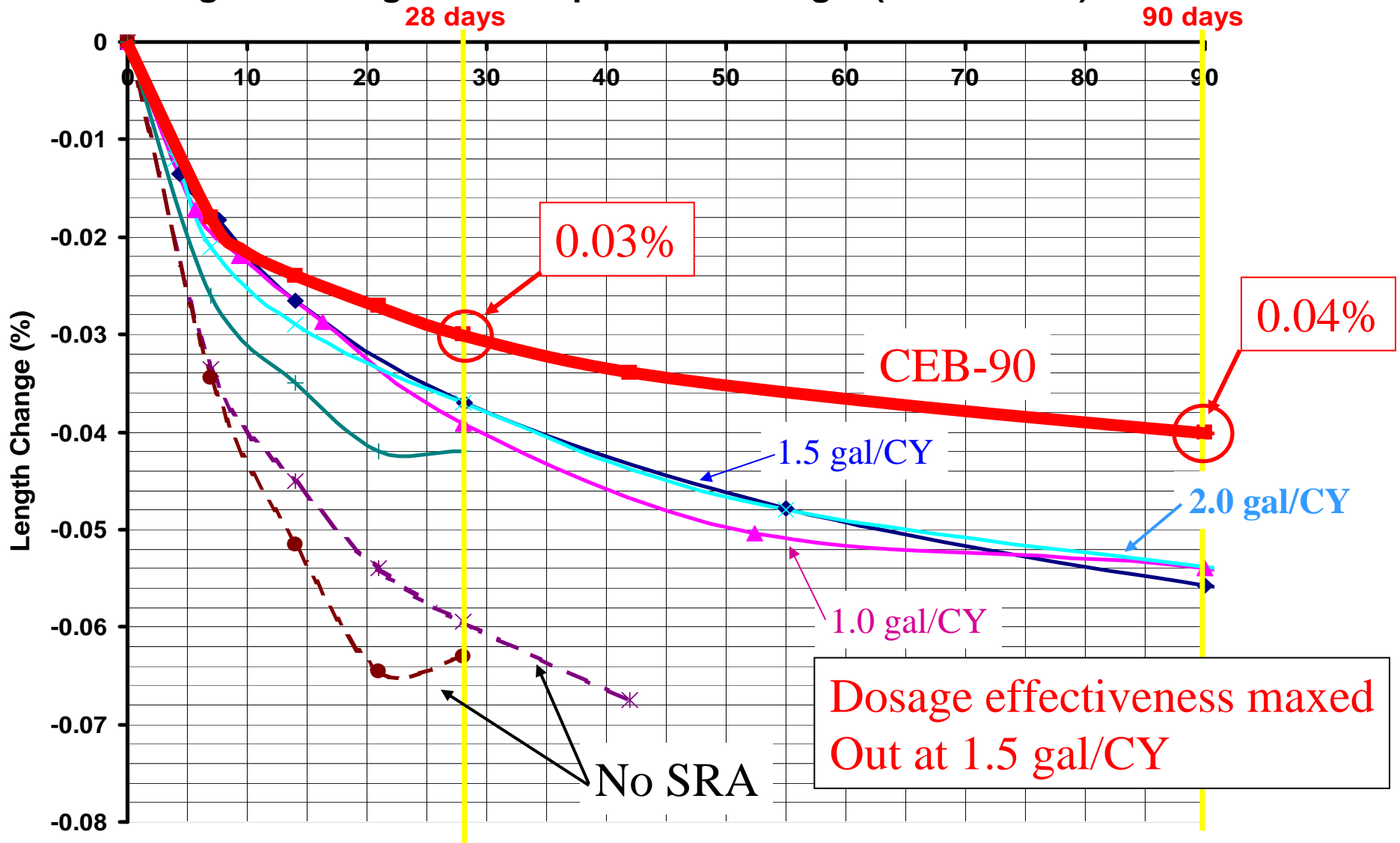


- ◆- Orig Mix w/o SRA SE\_021307
- \* High rock/Less sand w/ SRA-1.0gal\_ SE\_072707
- x DCI\_91707
- + DCI\_030508 w/ SRA-1.0gal
- x Orig Mix w/o SRA SE\_072707
- TransLab\_8728 w/ SRA-1.0gal
- x TransLab\_8733 w/ SRA-1.5gal
- TransLab\_8735 w/ SRA-2.0gal
- x TransLab\_8747 w/ SRA-1.5gal
- ◆ CTI lab\_162374 w/ SRA-1.5gal
- ▲ Orig Mix w/ SRA-1.0 gal\_ SE\_072707
- Shrinkage Specification Limit
- DCI\_030508 w/o SRA
- TransLab\_C708530 w/ SRA-1.0 gal
- ◇ TransLab\_C708532 w/ SRA-1.0gal
- ▲ TransLab\_8729 w/ SRA-1.0gal
- \* TransLab\_8732 w/ SRA-1.5gal
- + TransLab\_8741 w/ SRA-1.5gal
- Average SRA 1.5gal
- CTI lab\_162382 w/ SRA-1.5gal



# South Fork Eel River Bridge

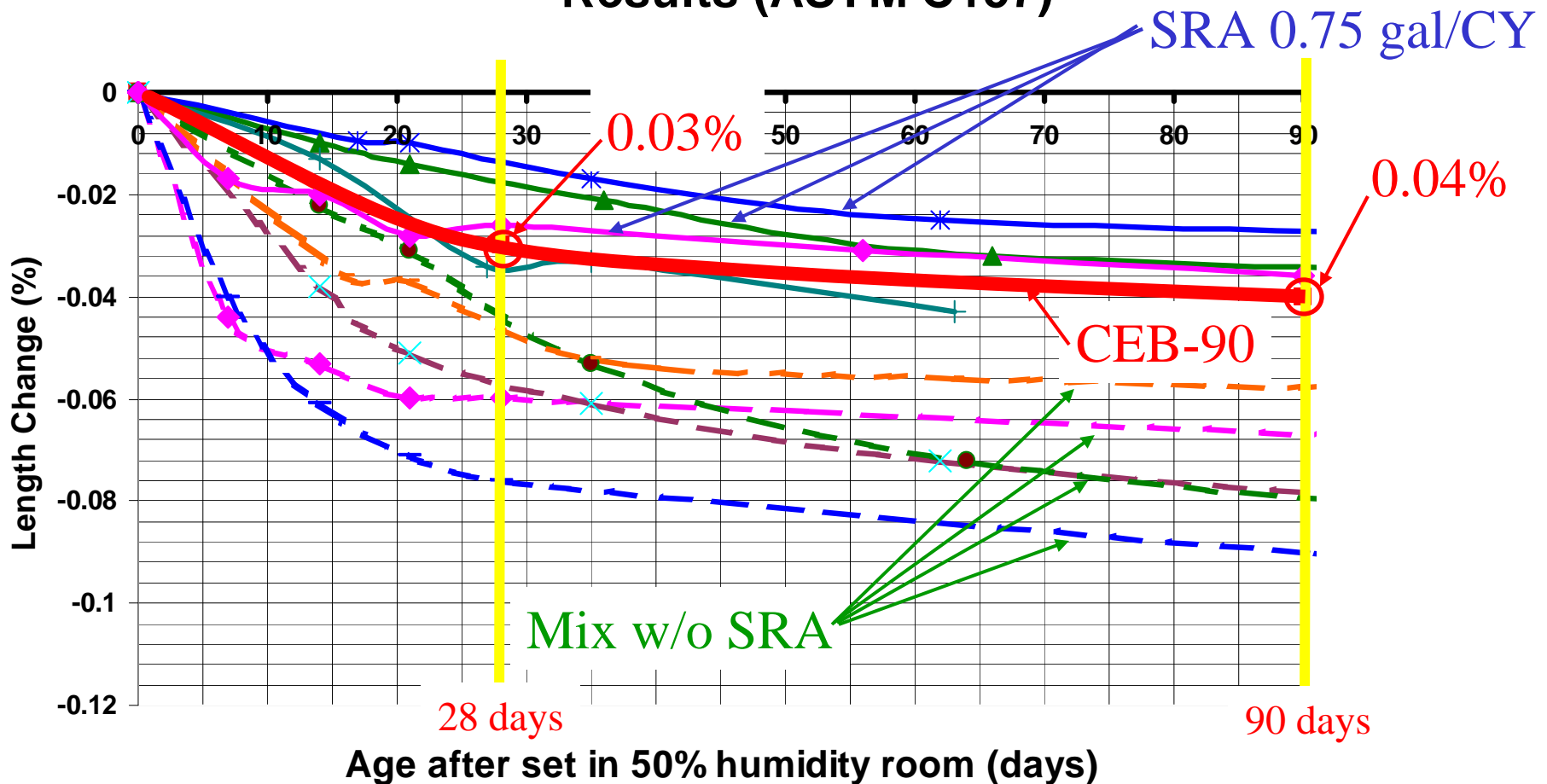
## Average Shrinkage Results per SRA Dosage (ASTM C157)



**Age after set in 50% humidity room (days)**

- |   |  |  |
|---|--|--|
| <ul style="list-style-type: none"> <li><span style="color: blue;">◆</span> Average SRA 1.5gal</li> <li><span style="color: cyan;">✕</span> TransLab_8735 w/ SRA-2.0gal</li> <li><span style="color: teal;">+</span> Orig Mix w/ SRA-1.0 gal_ SE_072707</li> </ul> | <ul style="list-style-type: none"> <li><span style="color: red;">■</span> Shrinkage Specification Limit</li> <li><span style="color: purple;">✱</span> Average Mod Mix No SRA</li> </ul> | <ul style="list-style-type: none"> <li><span style="color: magenta;">▲</span> Average SRA 1.0 gal</li> <li><span style="color: brown;">●</span> Average Orig Mix No SRA</li> </ul> |
|---|--|--|

# Devil's Slide Left Bridge Linear Drying Shrinkage Results (ASTM C157)



◆ Mix 3518F (DCI 2-12-07) w/o SRA	▲ Mix 135754 (7-30-07) w/ SRA	* Mix 135759 (8-3-07) w/ SRA
■ Shrinkage Specification Limit	× Mix 41988 (11-22-06) w/o SRA	● Mix 135752 (7-23-07) w/ SRA
+ Mix 135791 (10-31-07) w/ SRA	— Mix 148808 (2-12-07) w/o SRA	- Mix HF836290 (DCI 9-5-07) w/o SRA
◆ Dis sub489 (4-18-08) w SRA		

# CONCRETE SHRINKAGE LIMIT CCO

“The concrete mix for the superstructure concrete shall be designed to limit the shrinkage strain of the Portland cement concrete to 0.03% at 28 days and 0.04% at 90 days of drying in accordance with the requirements in ASTM Designation: C 157 with 4” x 4” specimens. At the Contractor’s option, shrinkage reducing admixtures may be used.”

On both projects the contractors elected to use a shrinkage reducing admixture (SRA): Master Builders Tetraguard





# CONCRETE SHRINKAGE CCO

Project	Qty of Concrete w/ SRA	Cost of CCO (SRA)	Original Bridge Bid Price	% Cost Increase of Bridge
Devil's Slide Bridges	10,173 CY	\$299,814	\$33.1 million	< 1%
South Fork Eel River Bridge	7062 CY	\$348,581	\$36.7 million	< 1%



# CONCRETE SHRINKAGE CCO

Project	SRA Dosage	SRA Cost	Additional Cost of Concrete with SRA	Unit Bid Price for Concrete	% Cost Increase of Concrete
Devil's Slide	0.75 Gal/CY	\$39 per Gal	\$29.47 per CY	\$765 per CY	+3.8%
South Fork Eel River	1.50 Gal/CY	\$39 per Gal	\$58.50 per CY	\$1956 per CY	+3.0%





**Devil's Slide Bridge Construction  
December 7, 2006 to September 10, 2008**



**South Fork Eel River Bridge Construction  
January 4, 2007 to October 6, 2008**

