

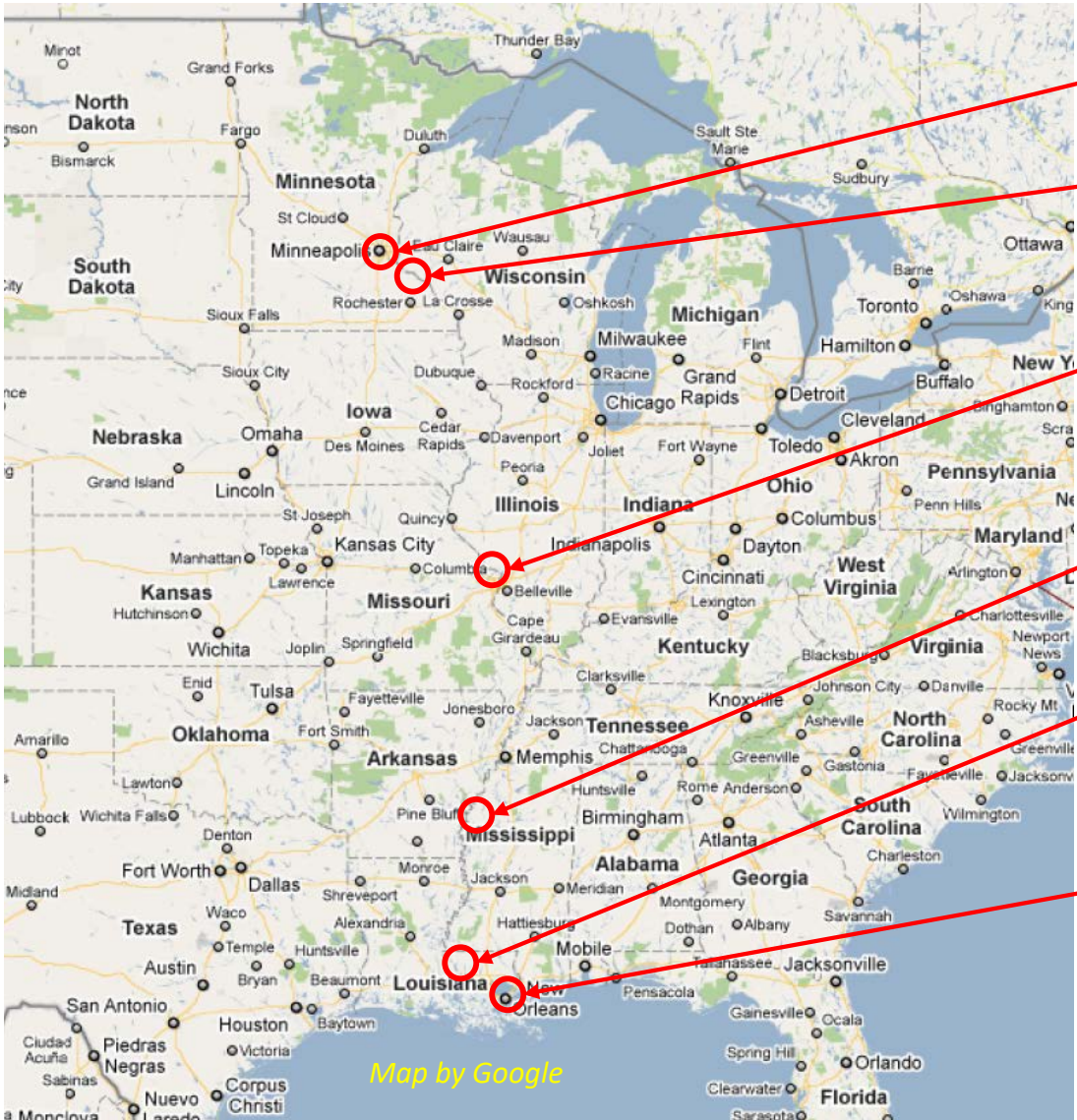
# A Foundation Engineering Trip down the Mississippi River

Dan Brown, P.E.

Dan Brown and Associates



# Our Tour Stops



I-35W Minneapolis

U.S. 61 Bridge, Hastings, MN

Eads Bridge and Stan Musial Bridge (I-70), St. Louis

Greenville Bridge, Greenville, MS

John James Audubon Bridge, St. Francisville, La.

Huey P. Long Bridge, New Orleans

# Characteristics of Miss. River

- Deep scour
- Vessel collision
- High flow velocities
- River fluctuations

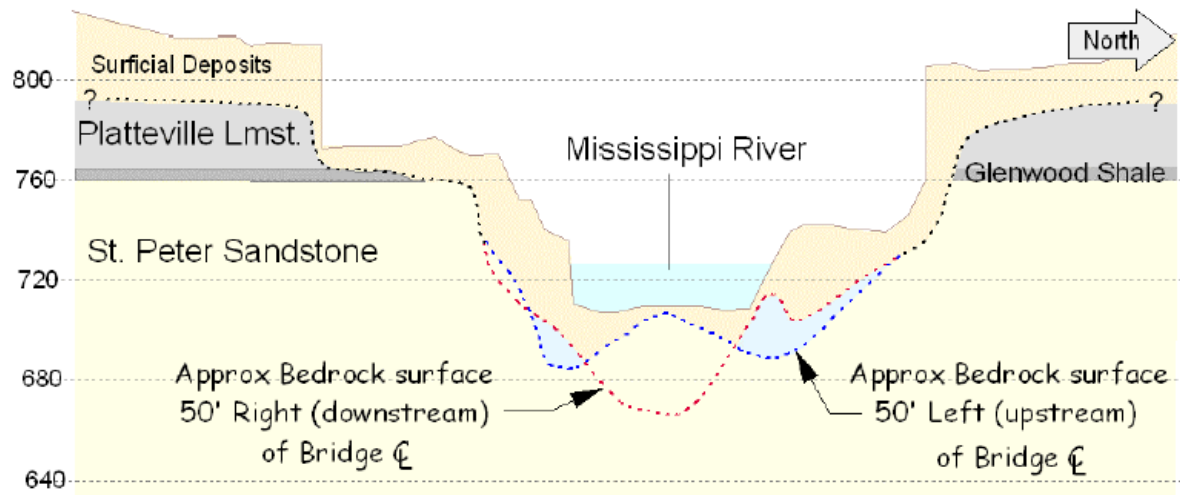
# MN I-35W Replacement

- Emergency Design-Build Contract
- ***\$200,000/day*** bonus/penalty



# Testing Plan

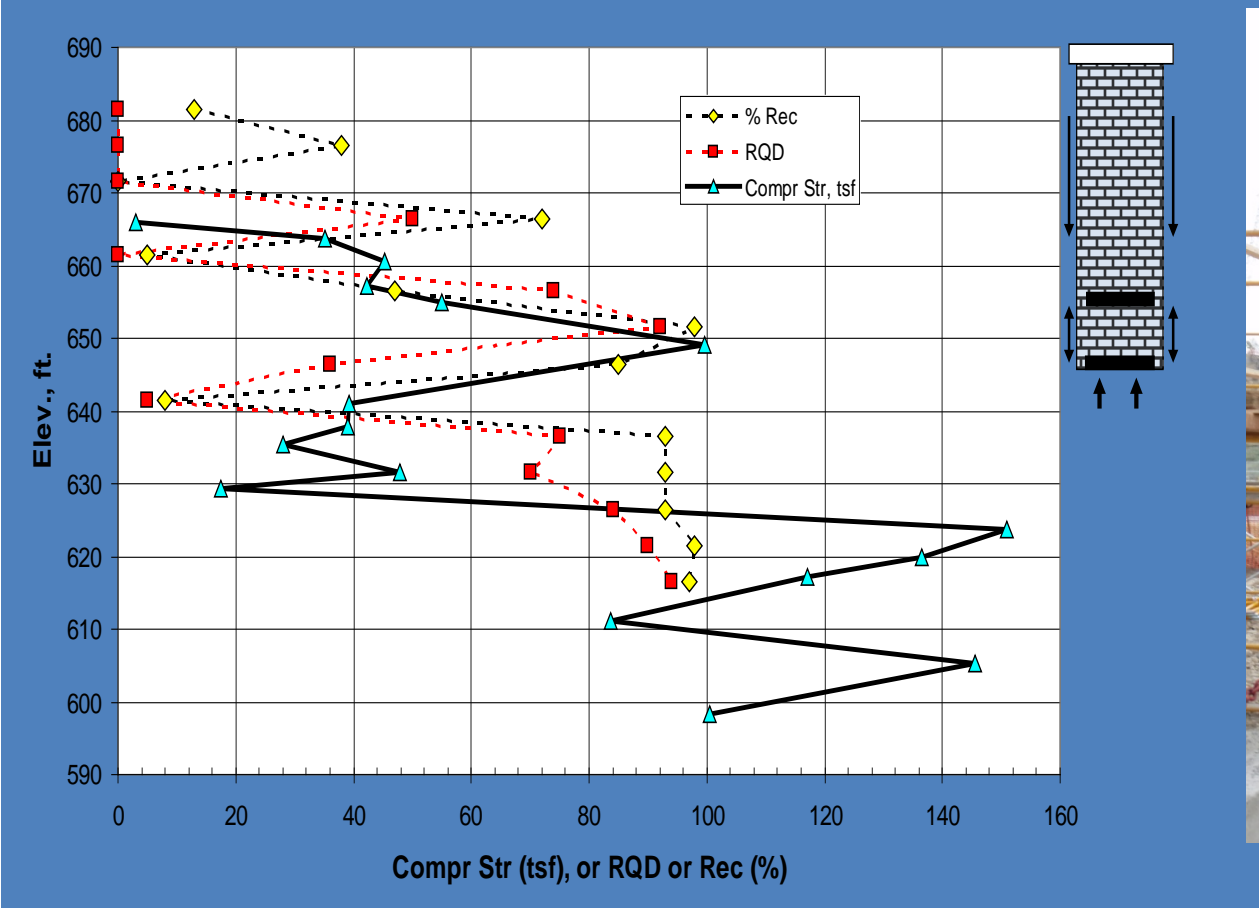
- Testing important to:
  - Verify required embedment into sandstone
  - Demonstrate reliability of installation
- But timing was critical
- Allowed contractor to test prototype shaft



# Early Issue – Artesian Groundwater



# Test Shaft



# Key Issues

- Top portion of rock extremely weathered & “soil-like”, easy to drill with earth auger
- Socket defined from “good rock” as indicated by drilling resistance with rock auger

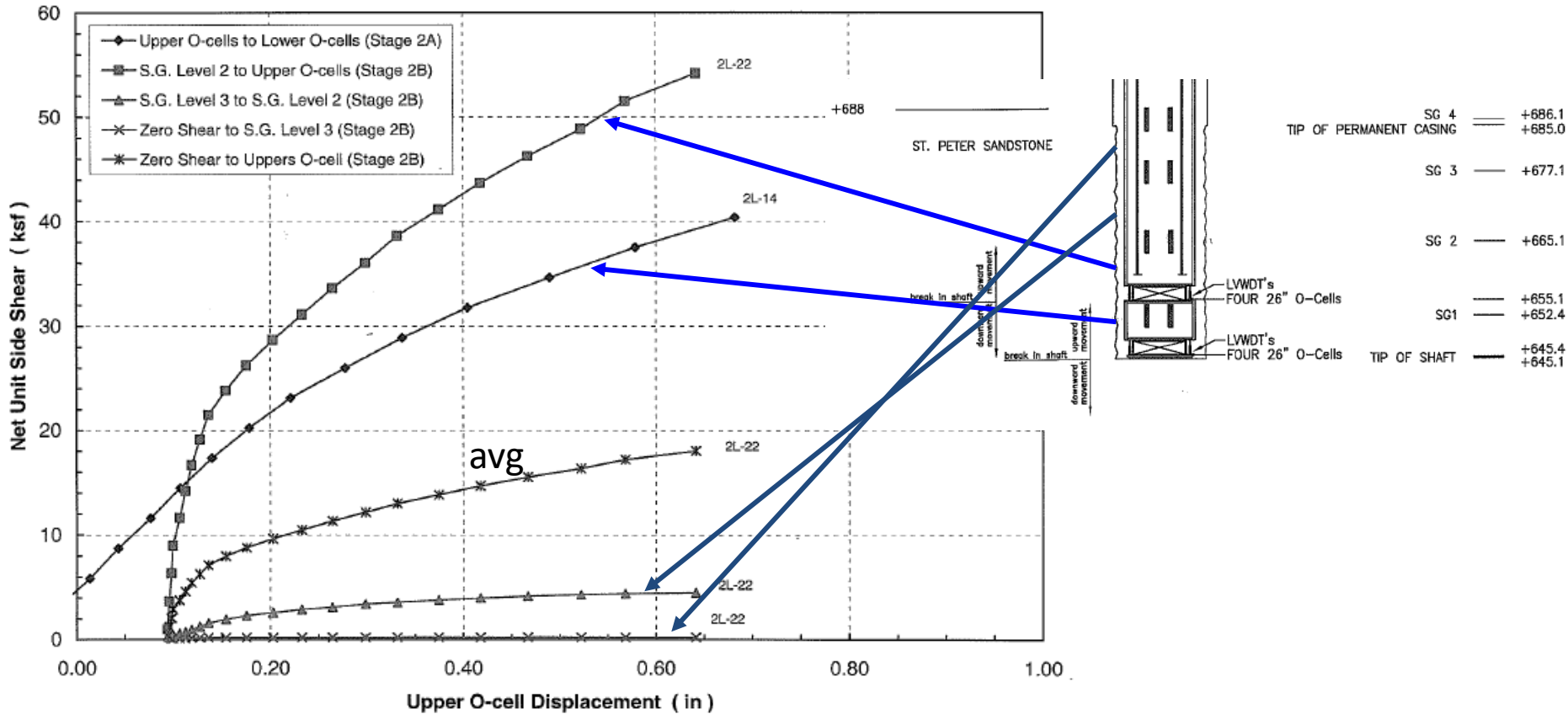




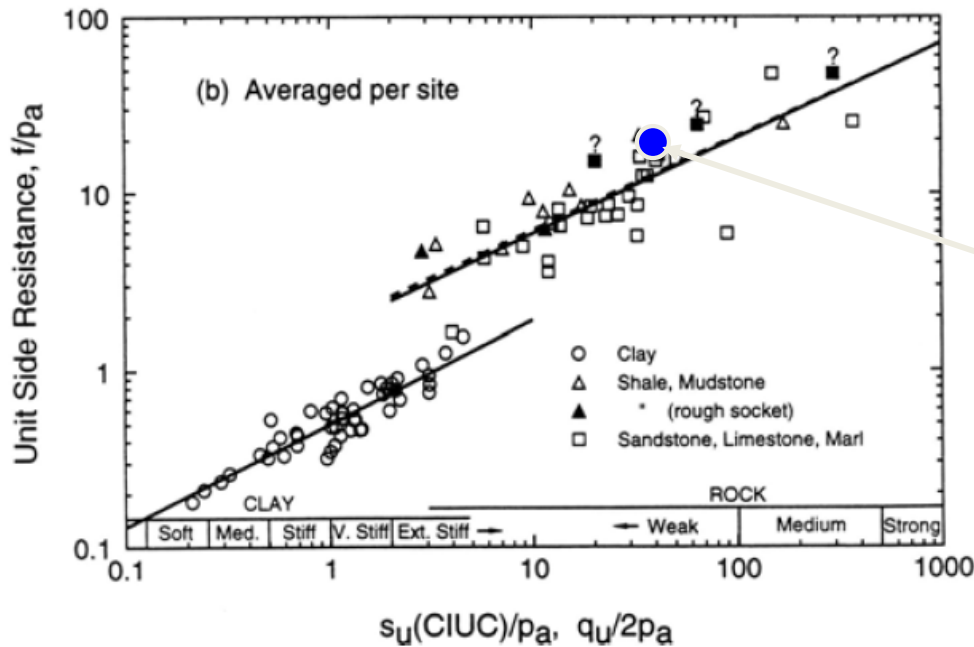
# 35W – Side Resistance

## Net Unit Side Shear Curves

Test Shaft 2 - I-35 W o/ Mississippi River - Minneapolis, MN



# 35W Side Resistance

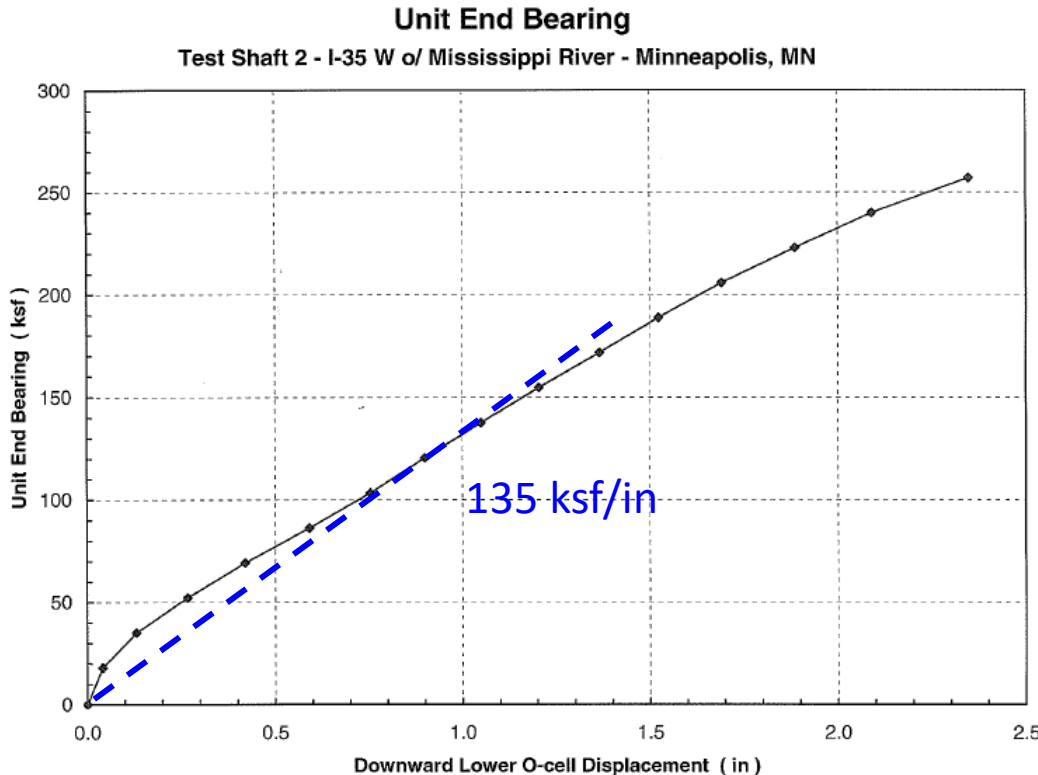


$$\frac{f_{SN}}{p_a} = C \sqrt{\frac{q_u}{p_a}}$$

Elev 665-645,  
 $C \approx 2.5$  to  $2.8$

FIGURE 24 Unit side resistance versus strength (Kulhawy and Phoon 1993).

# 35W Base Resistance



With 78" dia,  
 $\rho/B \approx 0.01$  at  $\rho=0.78''$

For rigid circular footing on elastic half-space:

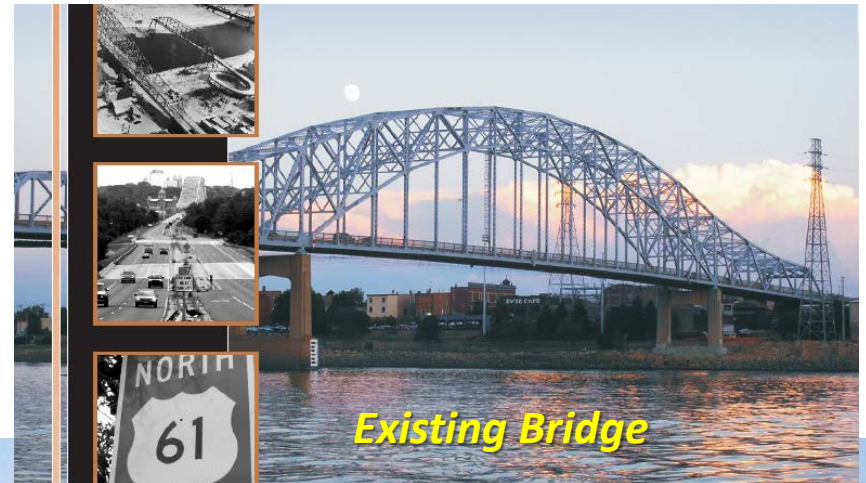
With  $\nu = \frac{1}{4}$  :  $E = 7,800\text{ksf} = 54 \text{ ksi}$   
 $E \approx 100q_u$  for  $q_u \approx 550\text{psi}$

$$\rho_s = 0.79 \cdot \frac{qB(1-\nu^2)}{E}$$

# U.S. 61 Bridge over Mississippi River Hastings, Minnesota



*First Bridge (the "Spiral Bridge")*



*Existing Bridge*

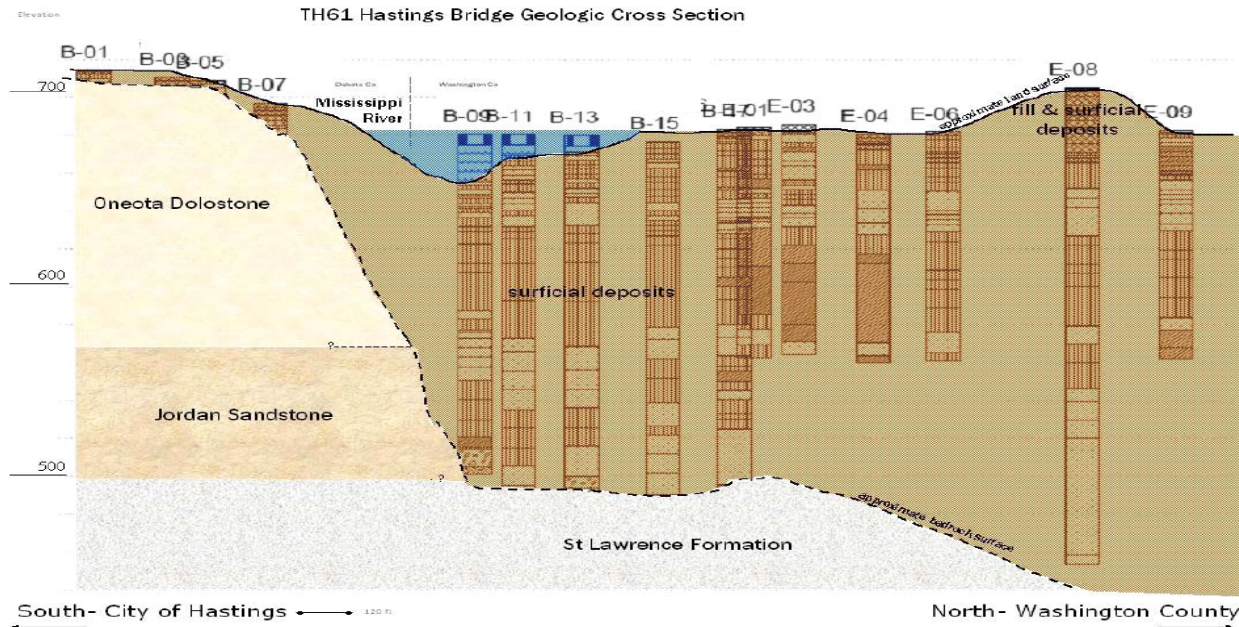
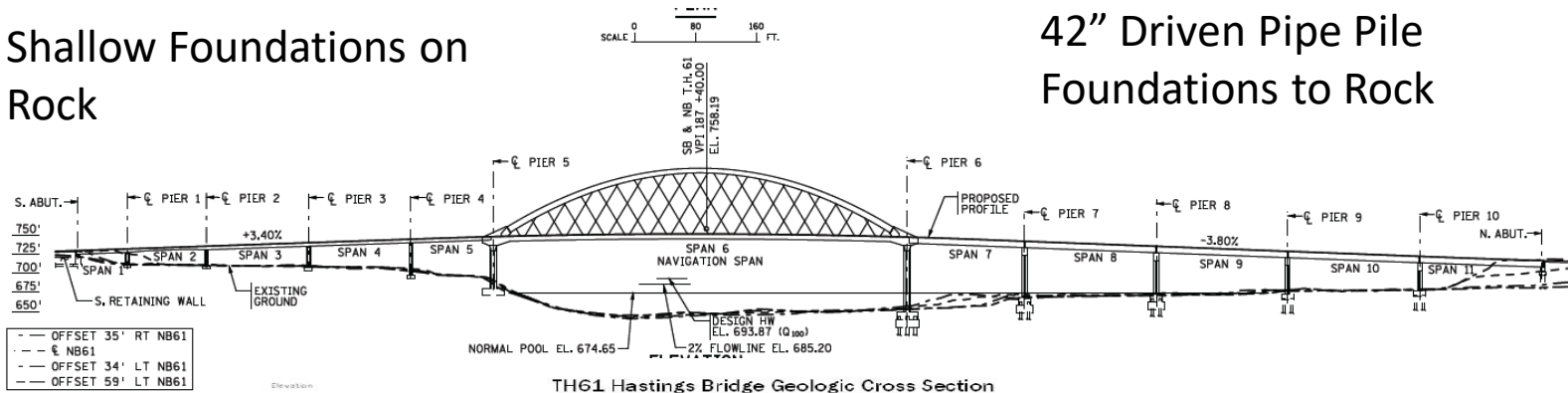


*New Arch Bridge (under construction)*

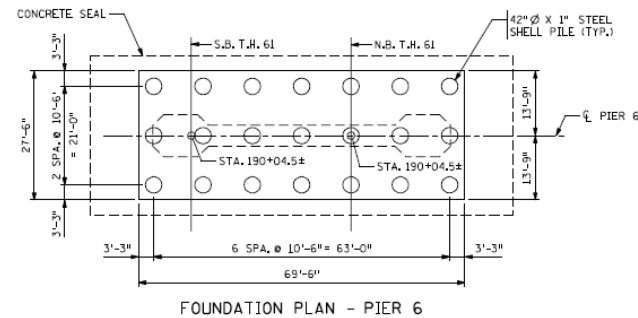
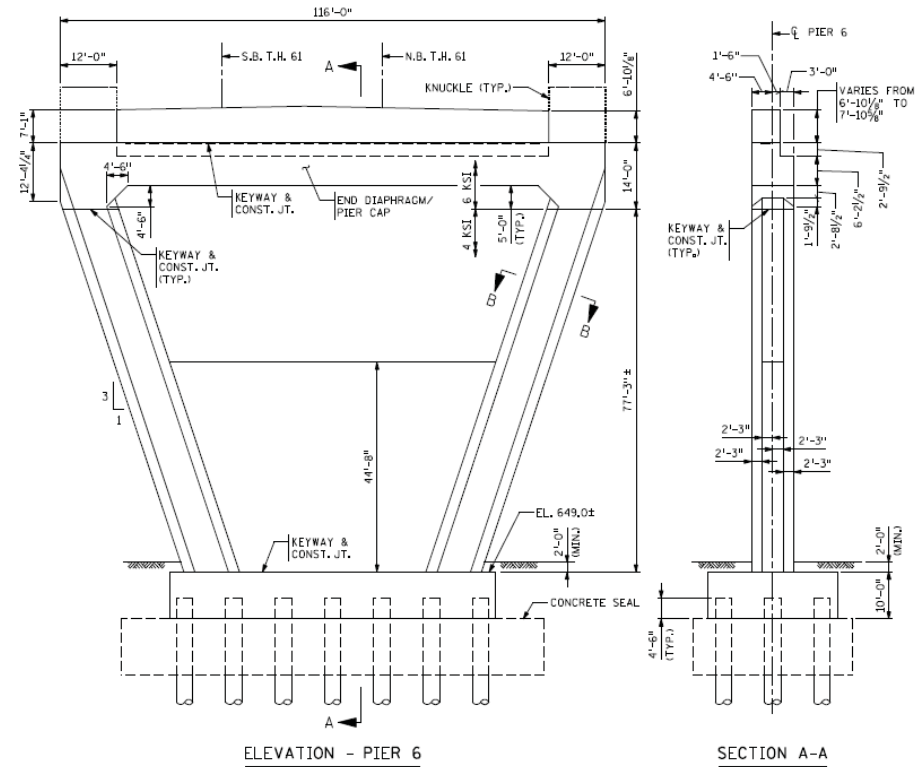
# Subsurface Profile at Bridge

Shallow Foundations on Rock

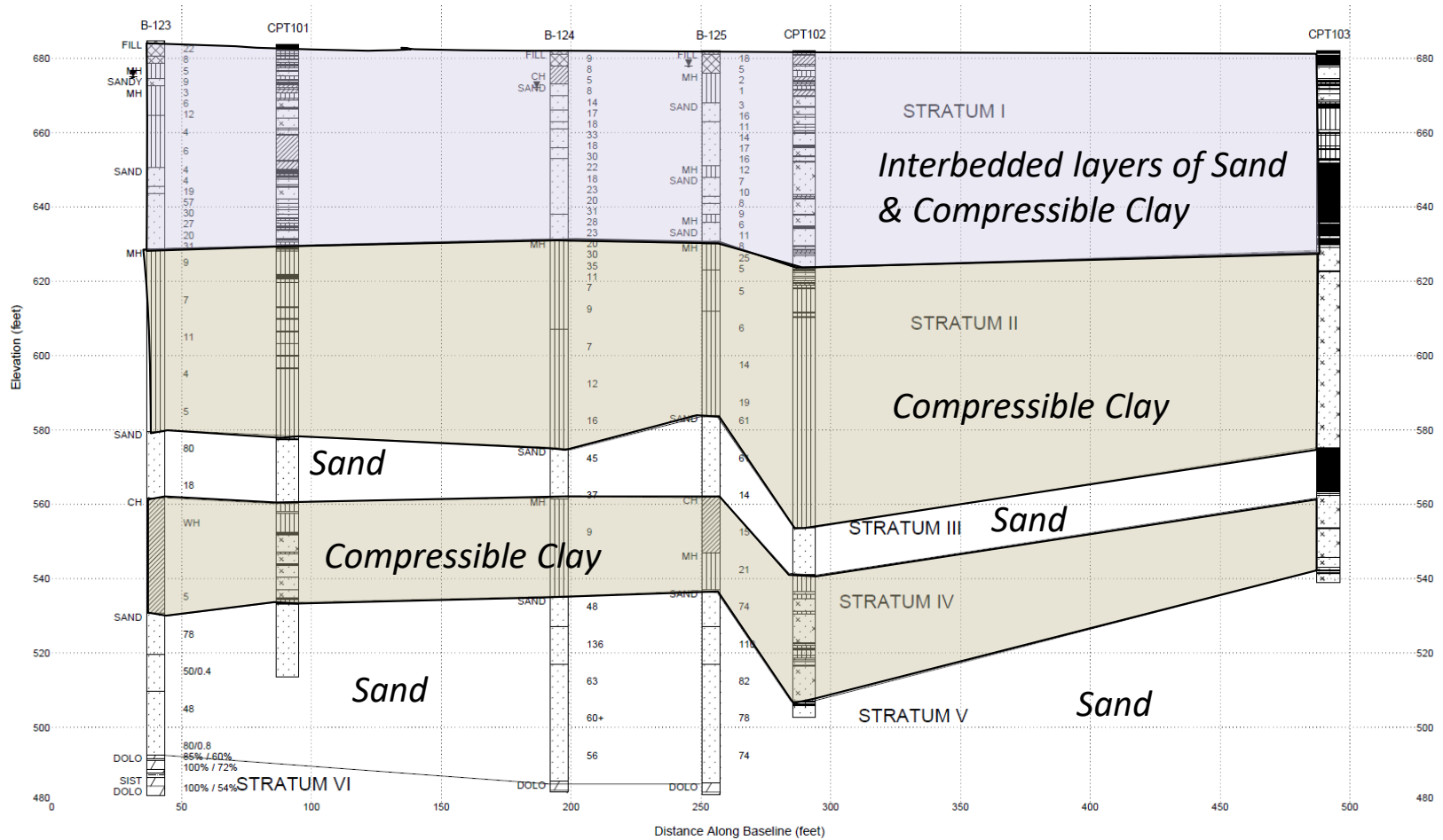
42" Driven Pipe Pile Foundations to Rock



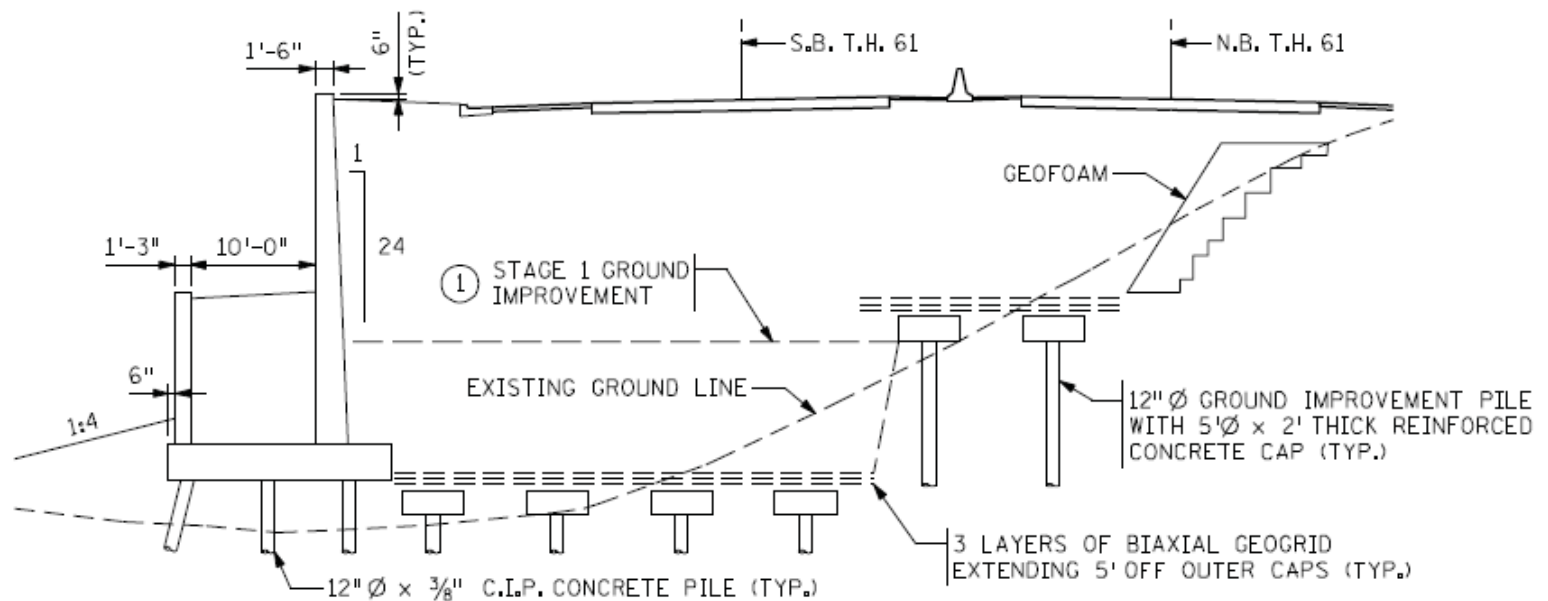
# LDOEP Bridge Foundations



# North Embankment



# Column Supported Embankment Plan



SECTION B-B

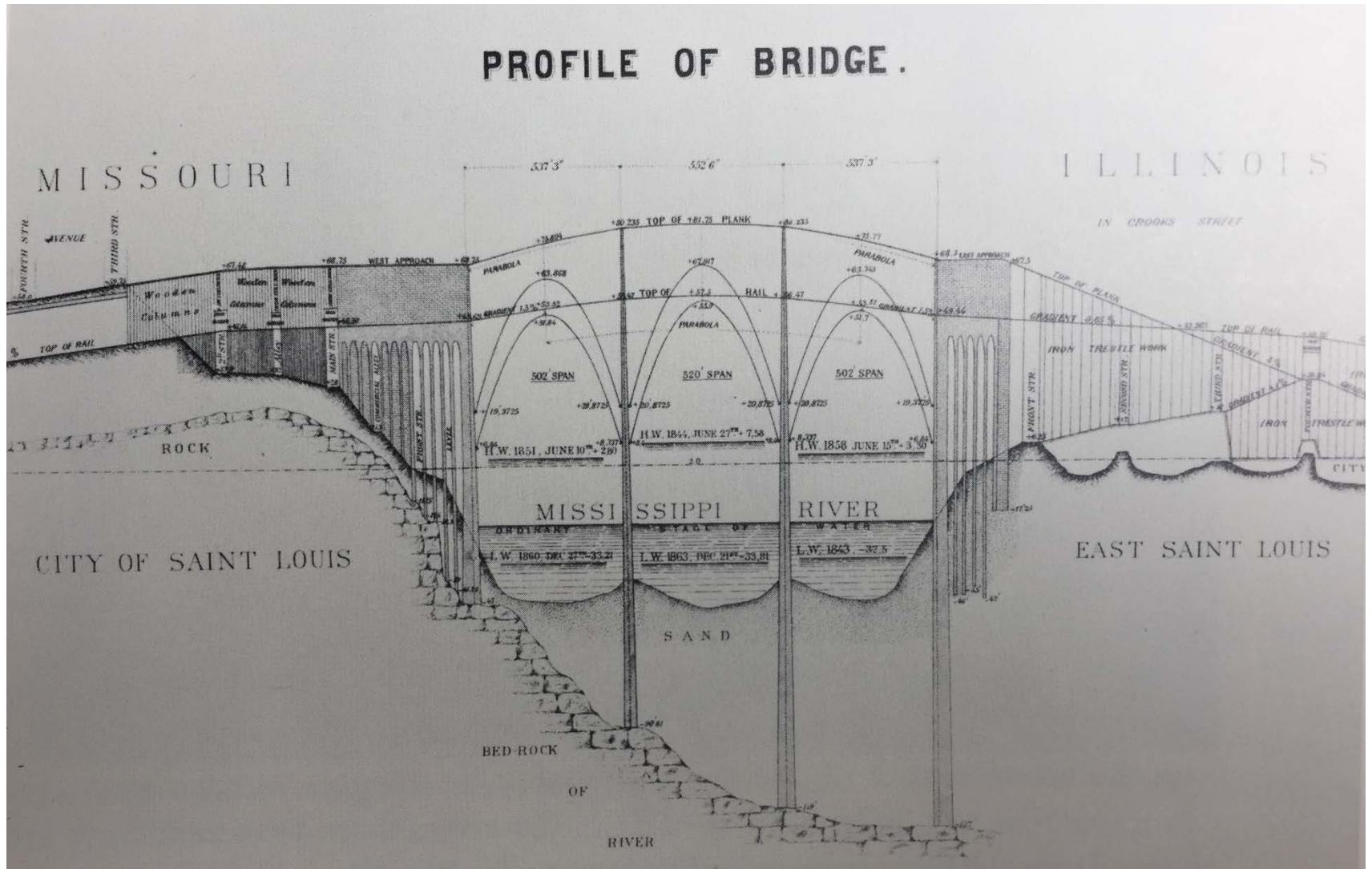


# Welcome to St. Louis!



MoDOT photo

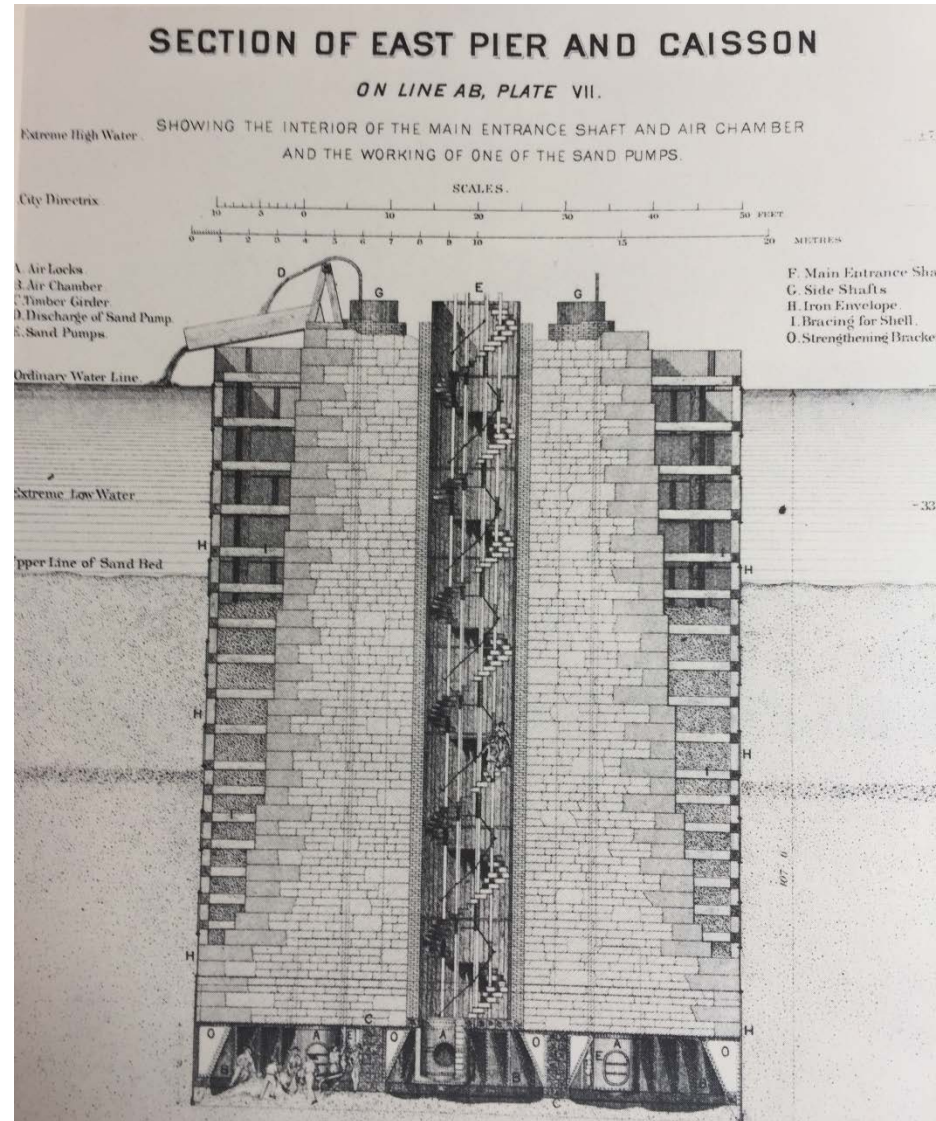
# Eads Bridge



# Eads Bridge (Constr 1868-74)

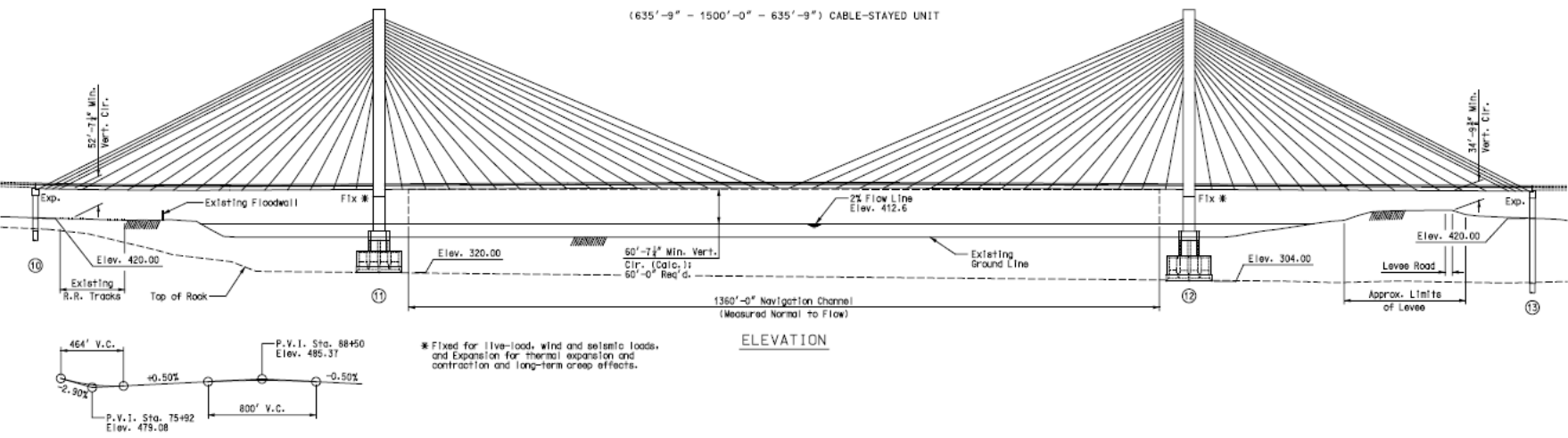
- National historic landmark
- Pioneering use of pneumatic caissons
- Eads adopted techniques from salvage diving
- Per Alphonse Jaminet (physician)
  - 600 men worked in the caissons;
  - 119 were stricken with “caisson disease”;
  - 14 died

Sketches and photos from Miller and Scott, *The Eads Bridge*, Missouri Historical Press



# Stan Musial/Veterans Memorial Bridge

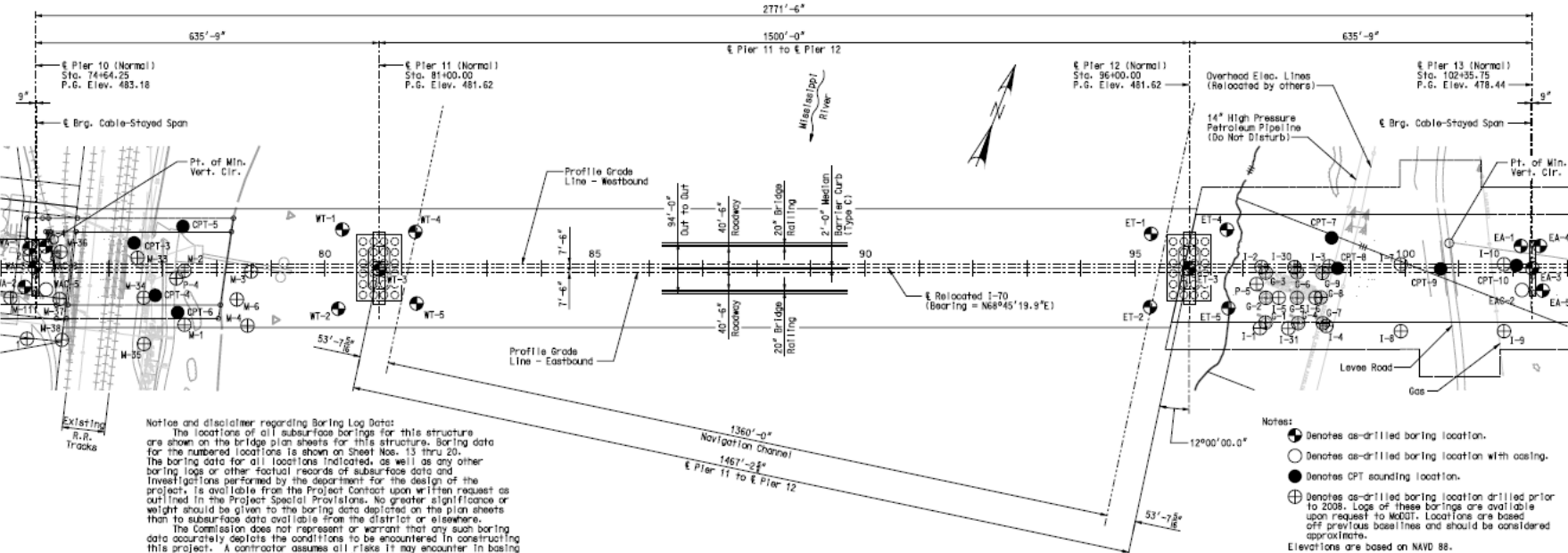
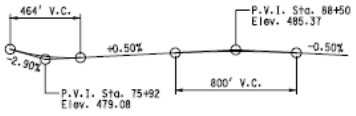
(635'-9" - 1500'-0" - 635'-9") CABLE-STAYED UNIT



### ELEVATION

\* Fixed for live-load, wind and seismic loads, and Expansion for thermal expansion and contraction and long-term creep effects.

### PROFILE GRADE - RELOCATED I-70



### PLAN

- Notes:
- Denotes as-drilled boring location.
  - ⊙ Denotes as-drilled boring location with casing.
  - Denotes CPT sounding location.
  - ⊕ Denotes as-drilled boring location drilled prior to 2008. Logs of these borings are available upon request to M&DOT. Locations are based off previous baselines and should be considered approximate.
- Elevations are based on NAVD 88.

### GENERAL PLAN & ELEVATION

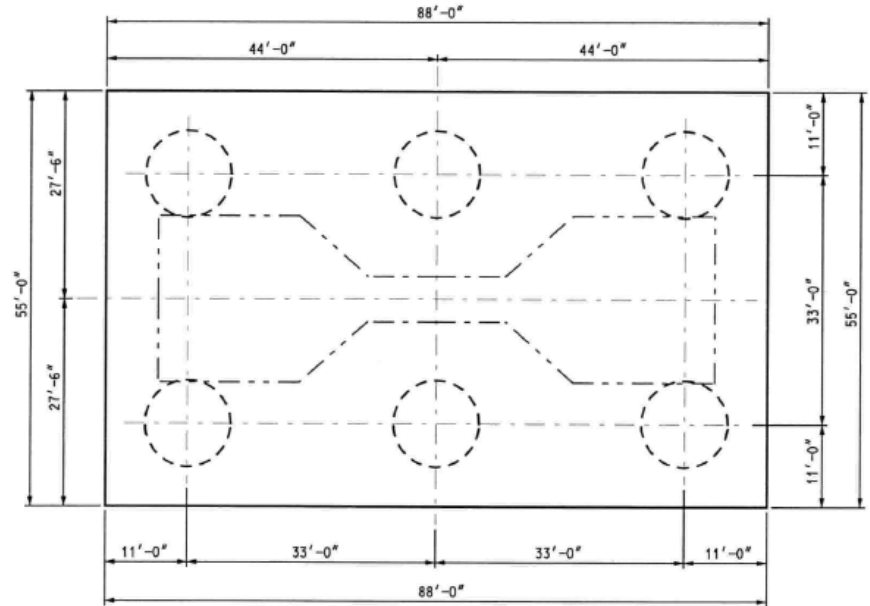
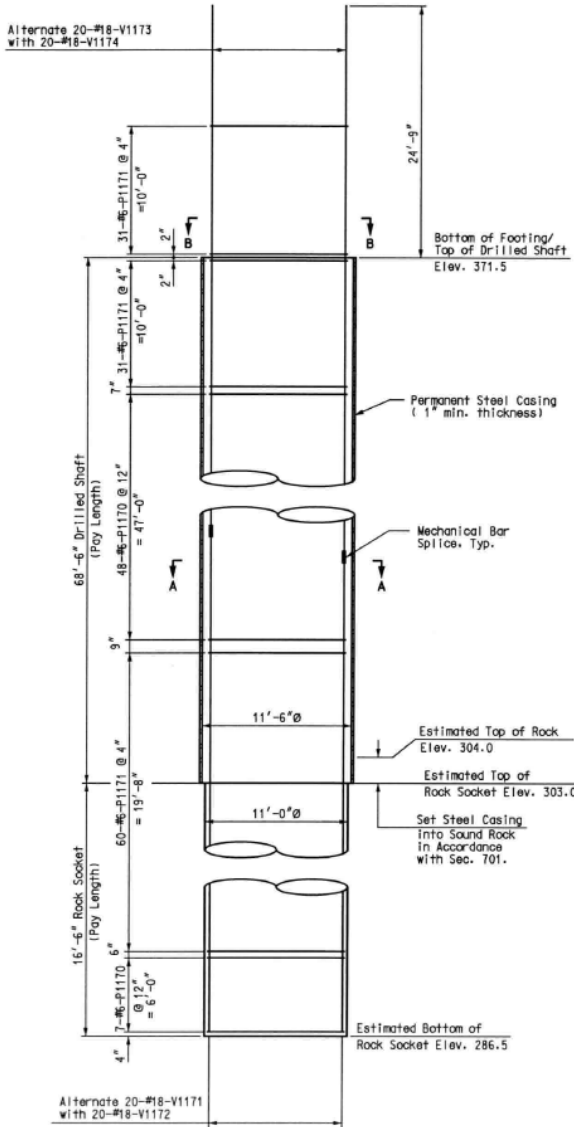
Notice and disclaimer regarding Boring Log Data:  
 The locations of all subsurface borings for this structure are shown on the bridge plan sheets for this structure. Boring data for the numbered locations is shown on Sheet Nos. 13 thru 20. The boring data for all locations indicated, as well as any other boring logs or other factual records of subsurface data and investigations performed by the department for the design of this project, is available from the Project Contact upon written request as outlined in the Project Special Provisions. No greater significance or weight should be given to the boring data depicted on the plan sheets than to subsurface data available from the district or elsewhere. The Commission does not represent or warrant that any such boring data accurately depicts the conditions to be encountered in constructing this project. A contractor assumes all risks if any encounter in basing its bid or loss, time or schedule of performance on the boring data depicted here or those available from the district, or on any other documentation not expressly warranted, which the contractor may obtain from the Commission.

\* THIS MEDIA SHOULD NOT BE CONSIDERED A CERTIFIED DOCUMENT. \*  
 DATE PREPARED: 7/9/09  
 ROUTE: I-70 STATE: MO/IL  
 DISTRICT: 6 SHEET NO: BR4  
 COUNTY: ST. LOUIS CITY - MO  
 ST. CLAIR - IL  
 JOB NO.: J610984  
 CONTRACT ID:  
 PROJECT NO:  
 BRIDGE NO.: A6500  
 MISSOURI HIGHWAYS AND TRANSPORTATION COMMISSION  
 105 WEST CAPITOL JEFFERSON CITY, MO 65102  
 1-888-ASK-MODOT (1-888-275-6566)  
 HNTB  
 115 LIX DRIVE  
 KANSAS CITY, MO 64105-1310  
 TELEPHONE: (816) 472-1201  
 FACSIMILE: (816) 472-1201  
 MO. REG. NO. 000000000000  
 NOT FOR CONSTRUCTION  
 07-09-09  
 REV.

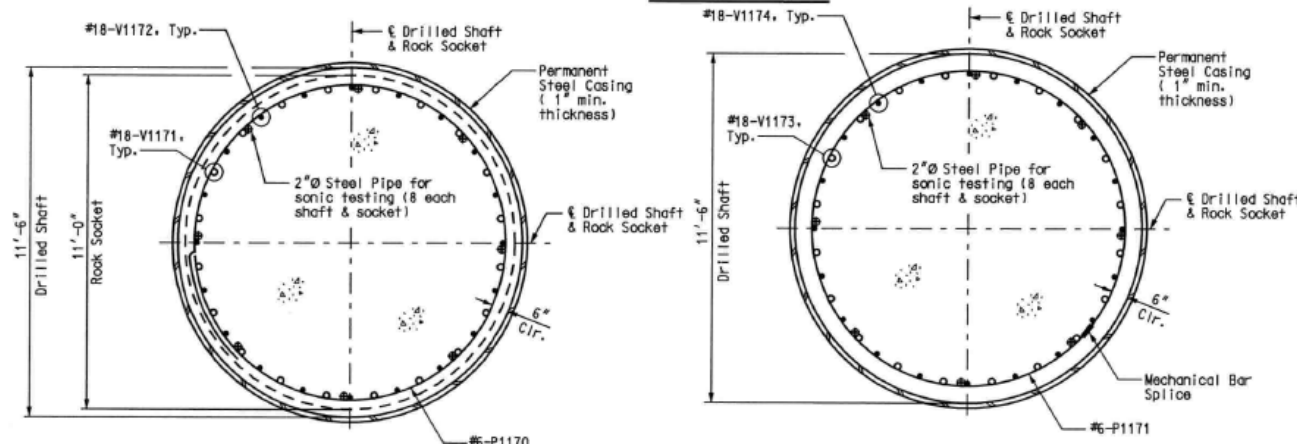
# Alternate Technical Concept (ATC)

- Prequalified Contractors only
- Pre-bid *confidential* submittal of ATC for owner evaluation & approval
- Contractor may bid base design and/or pre-approved ATC design
- DBA worked for Massman-Traylor-Alberici to develop ATC foundation design

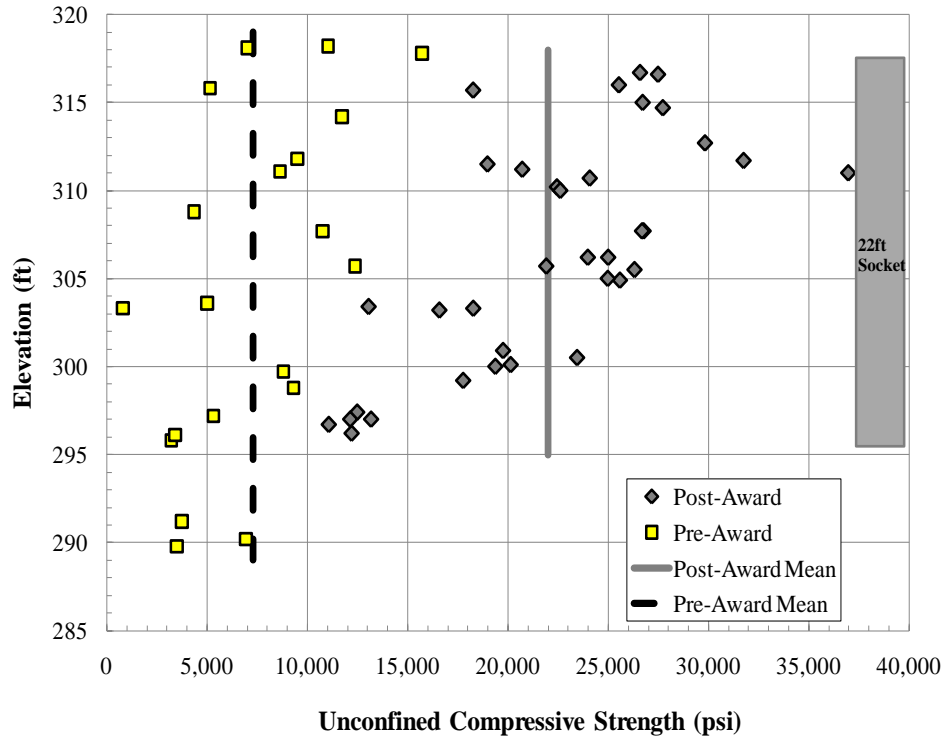
# Alternate Design



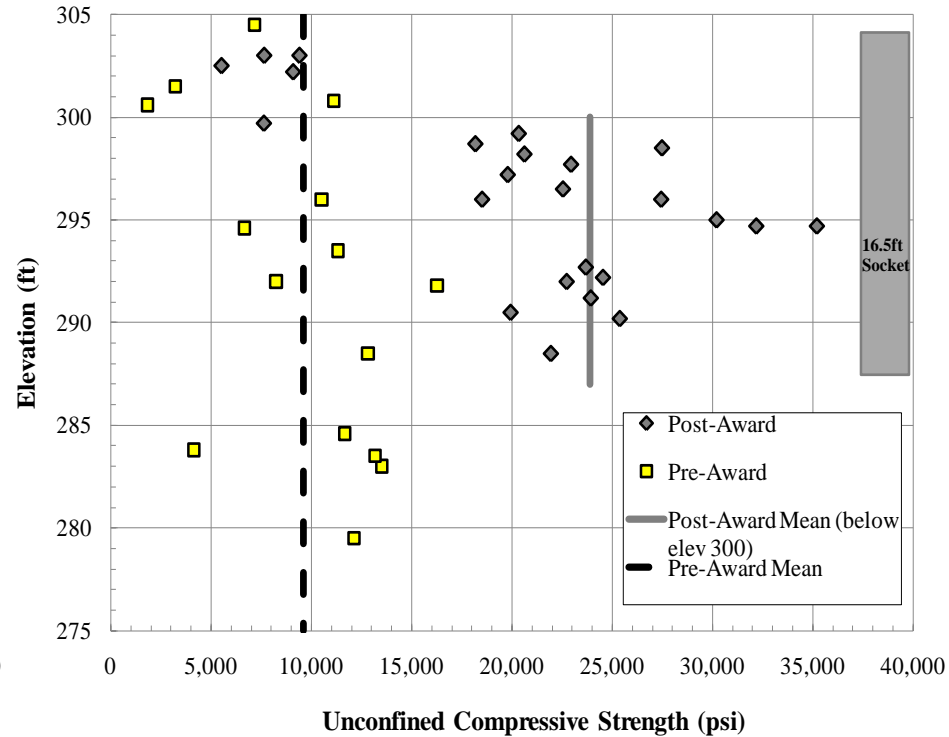
**FOOTING PLAN**



# Limestone Bedrock Compressive Strength Data



Pier 11



Pier 12

# Load Test Shaft Construction





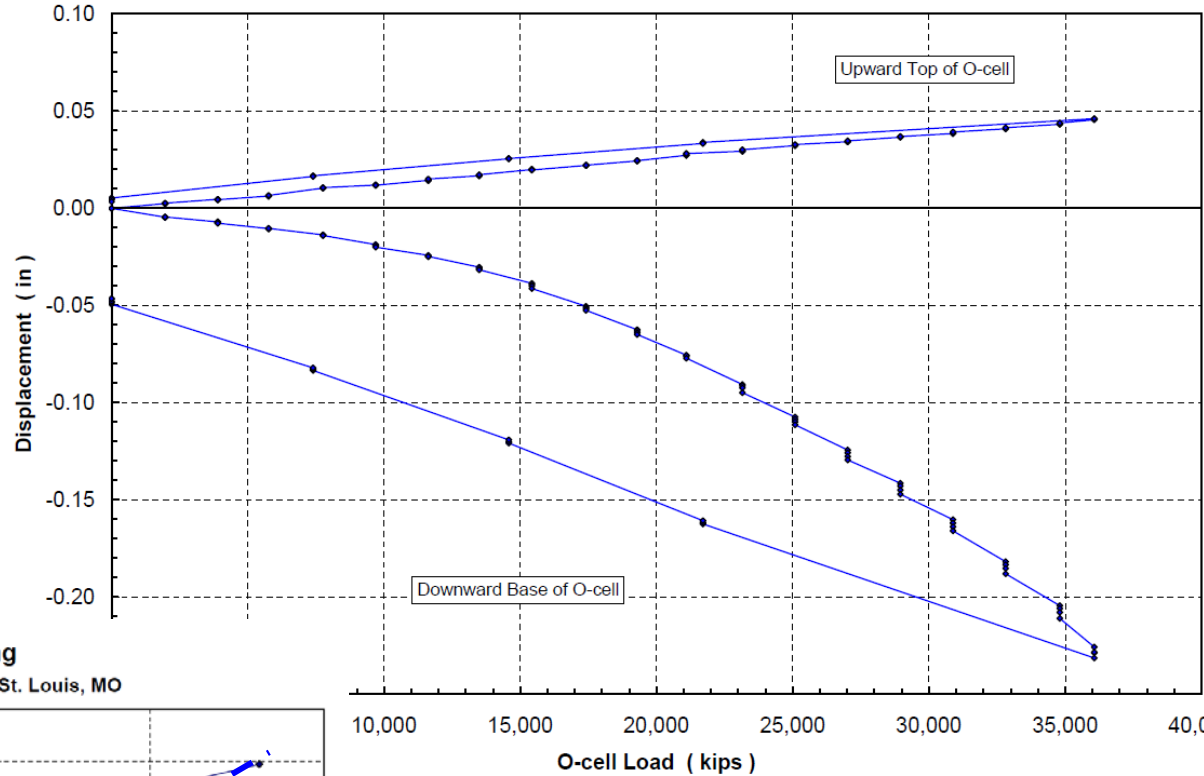
# Load Test Shaft Construction





## Osterberg Cell Load-Displacement

Test Shaft 1 - I-70 Mississippi River Bridge - St. Louis, MO



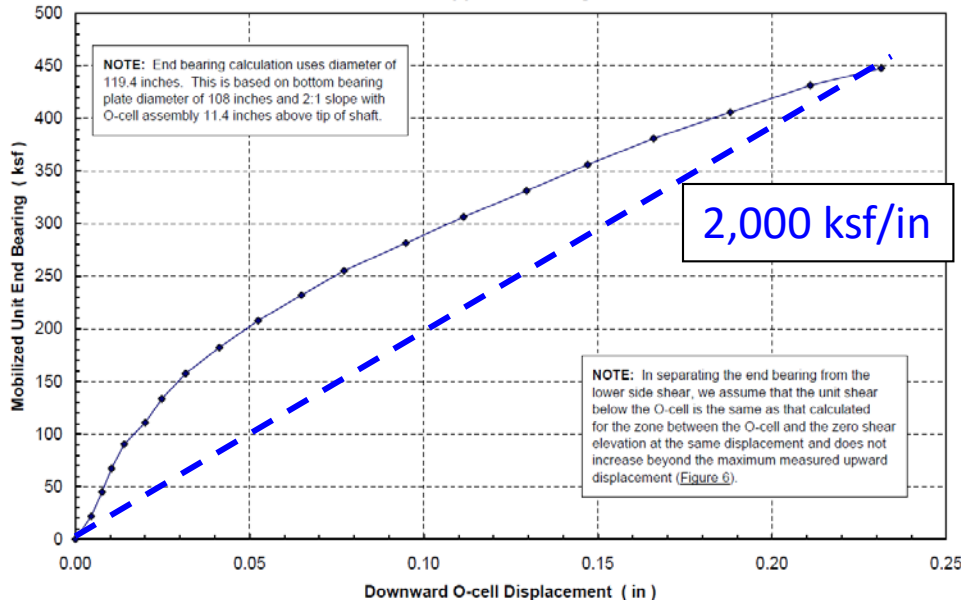
Over 40ksf avg mobilized unit side resistance

450ksf base resistance mobilized at < ¼ inch displ



## Mobilized Unit End Bearing

Test Shaft 1 - I-70 Mississippi River Bridge - St. Louis, MO



$$\rho_s = 0.79 \cdot \frac{qB(1-\nu^2)}{E}$$

For rigid circular footing on elastic half-space with  $\nu = \frac{1}{4}$  :

$E = 191,000 \text{ksf} = 1330 \text{ksi}$   
 $E \approx 100q_u \text{ for } q_u \approx 13 \text{ksi}$

# Footing Construction



# Greenville, MS Bridge



Ref: F.K. Jacoson, 2013. "Construction of the Main Tower Pier Caissons for the Greenville Bridge in Mississippi," 38<sup>th</sup> Annual Conference on Deep Foundations, DFI

# Open-well Caisson



# Caisson Cutting Edge showing Half-cylinder Air Domes



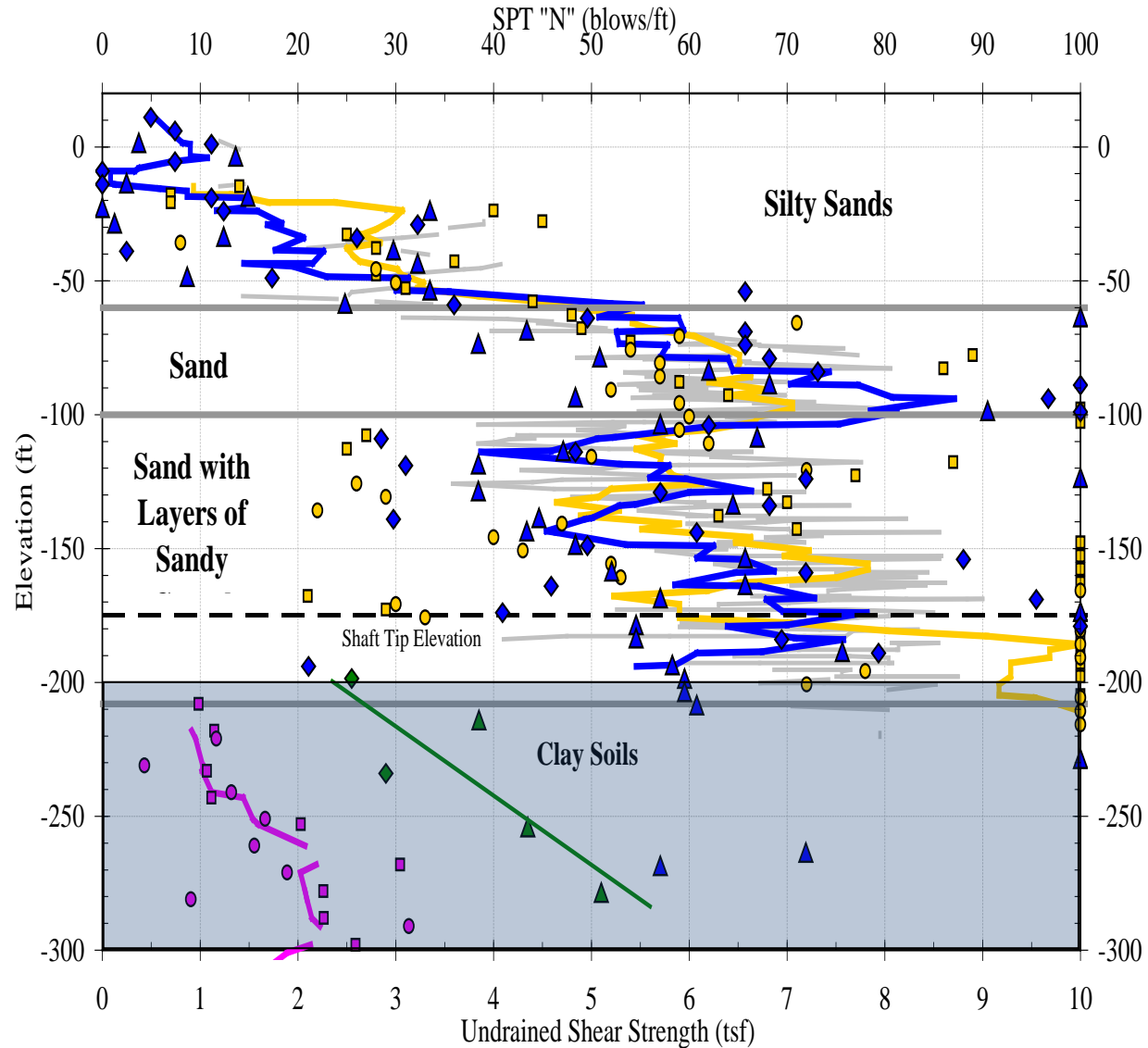
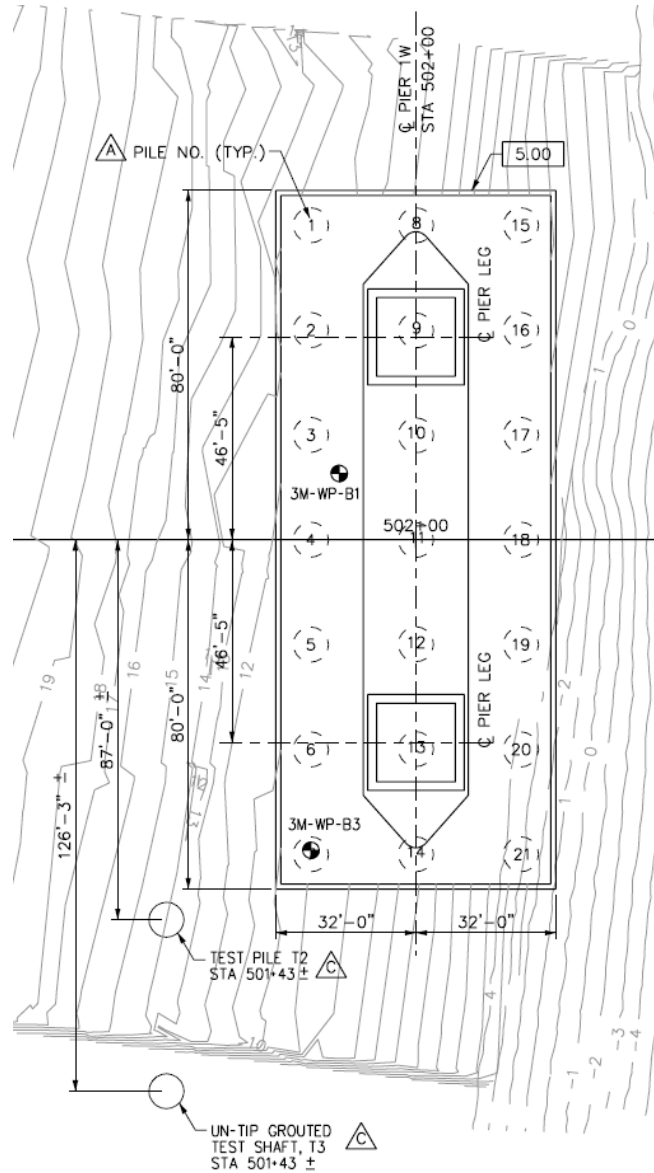
# Audubon Bridge

Cable-stayed bridge, 1583' main span  
Two pylons: 3 x 7 group of 7.5' dia. Shafts  
High approach: 2 column piers



Photo courtesy Flatiron Corp.

# Soil Conditions at Pylons





# Base Grouting

- Enhance Axial Resistance
- Improve Reliability
- Mitigate Imperfections in Base Conditions

## Criteria:

- *Target Pressure*
- *Minimum Net Volume*
- *Limit Upward Shaft Movement*



# Base Grouting

Tube á Manchette  
(using CSL tubes)

Cover Plate



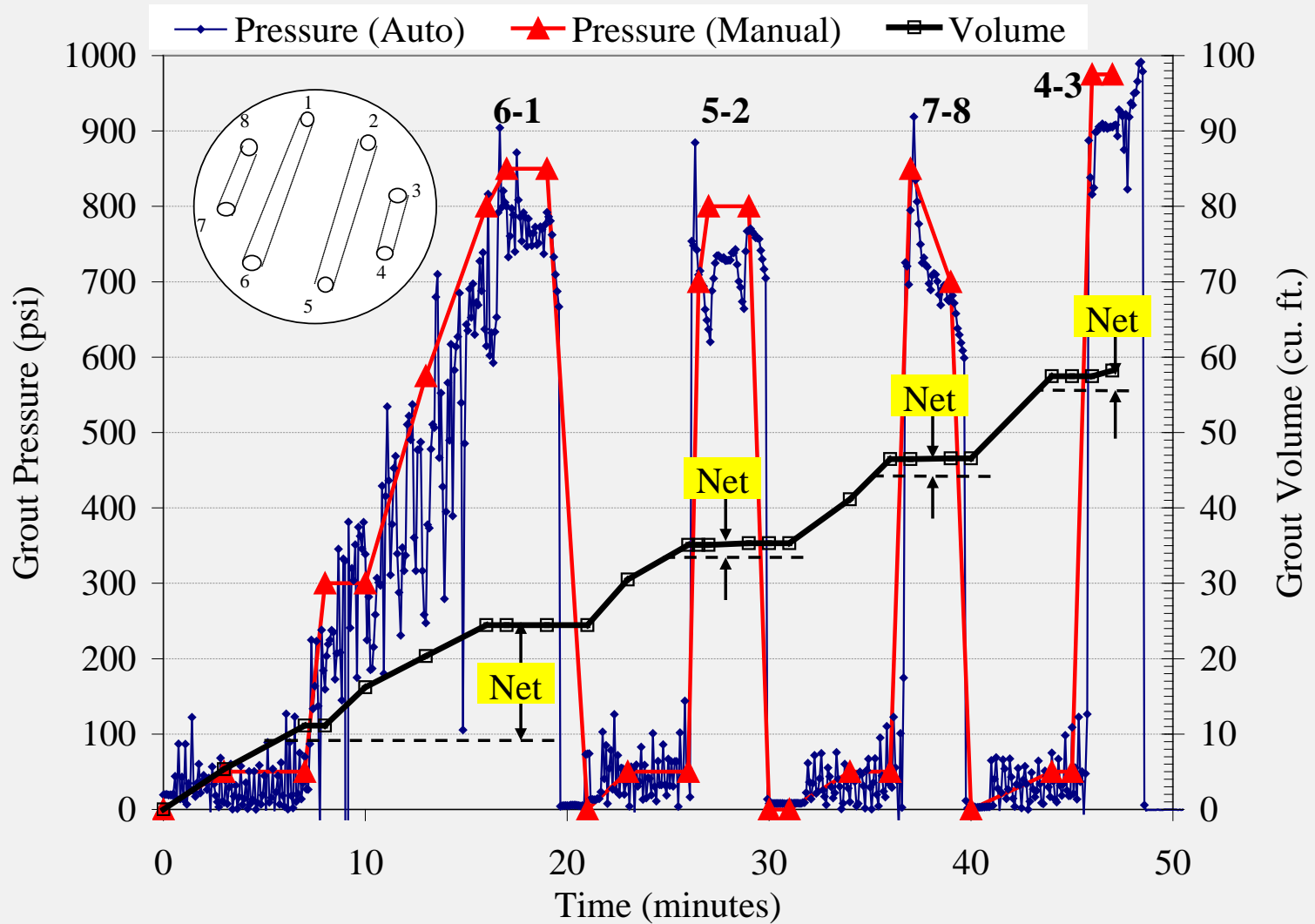
# Casing & Oscillator System



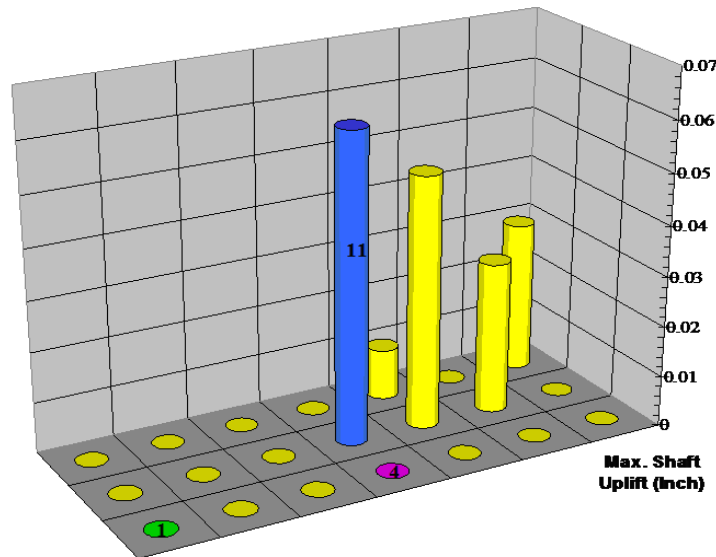
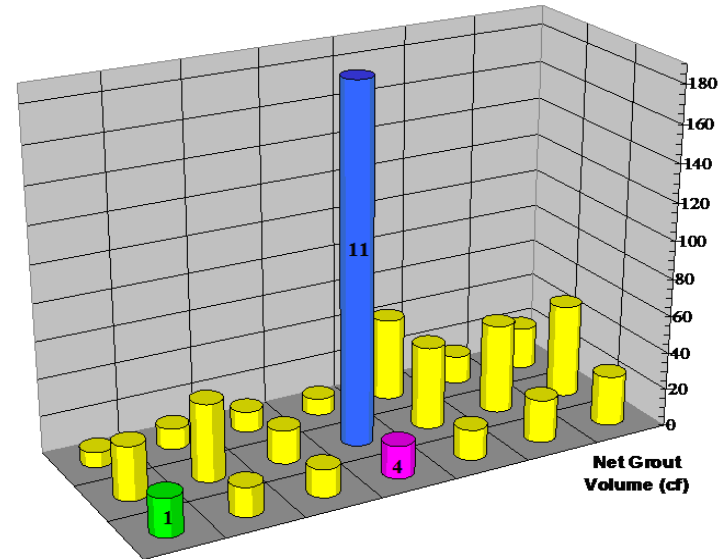
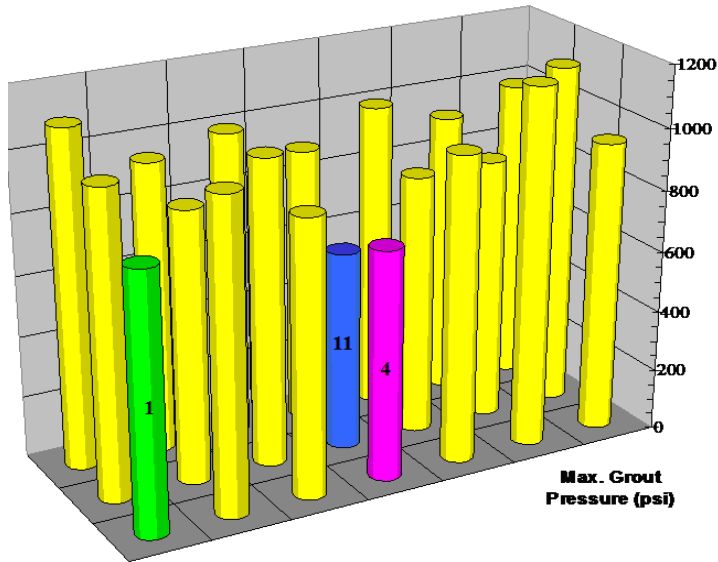




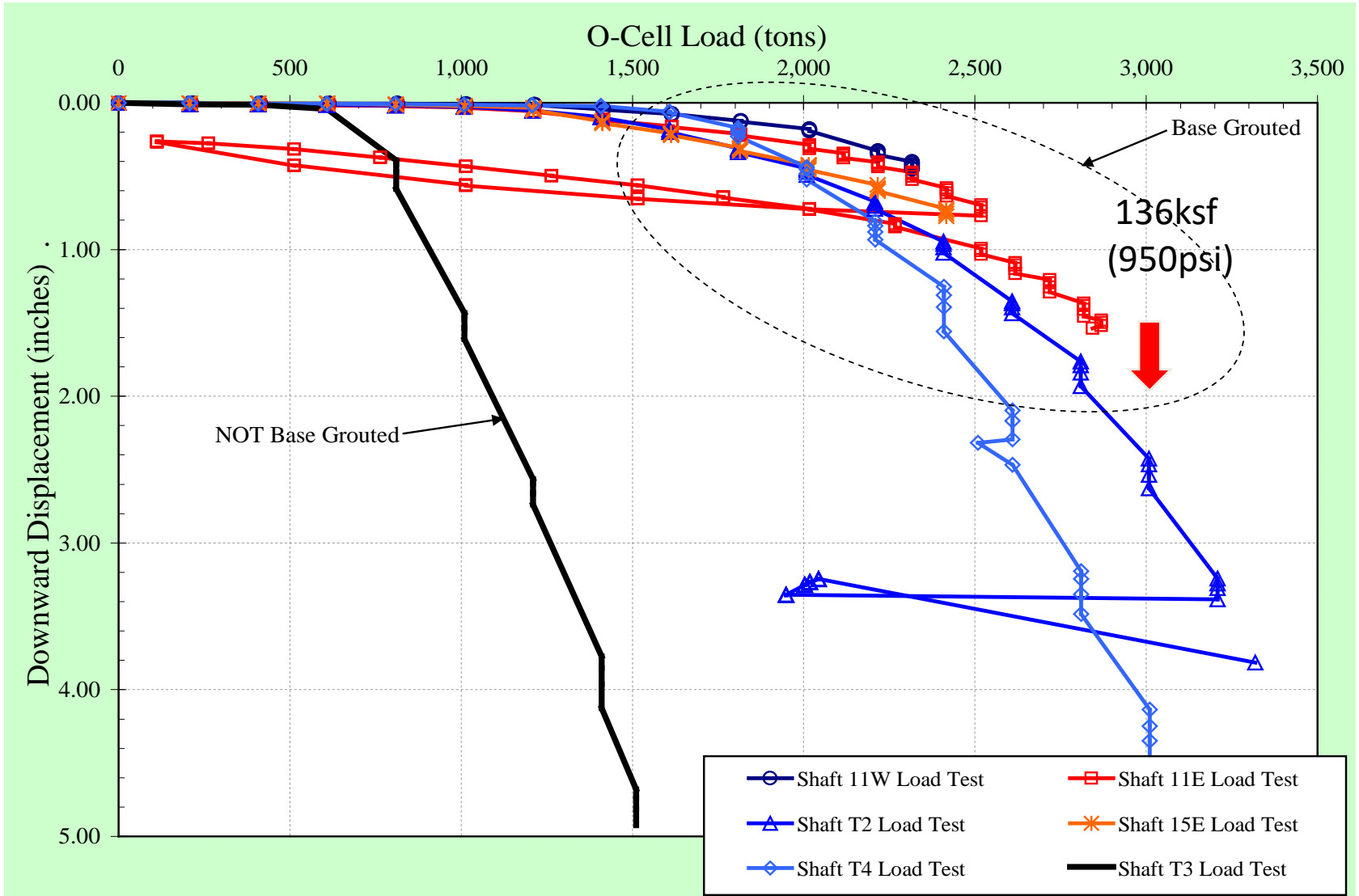
# Base Grouting Measurements



# Performance During Grouting



# Load Test Results





# Huey P. Long Bridge Widening

*Owner:*

La. DOTD

*Structural Engineers:*

Modjeski and Masters

*Geotechnical Engineers:*

Eustis Engineering

*General Contractor:*

Kiewit/Massman/Traylor

*Subcontractor:*

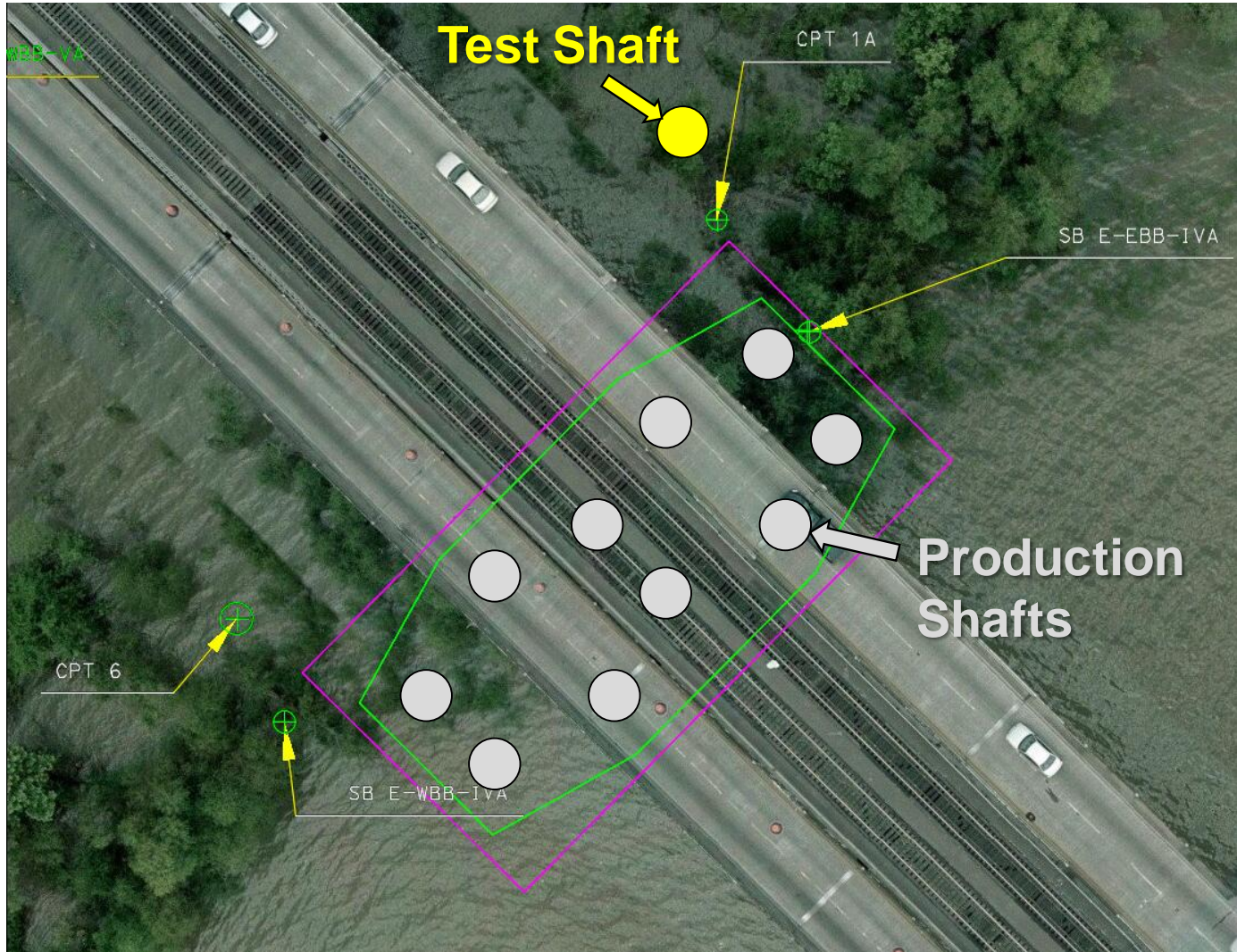
Malcolm Drilling Company

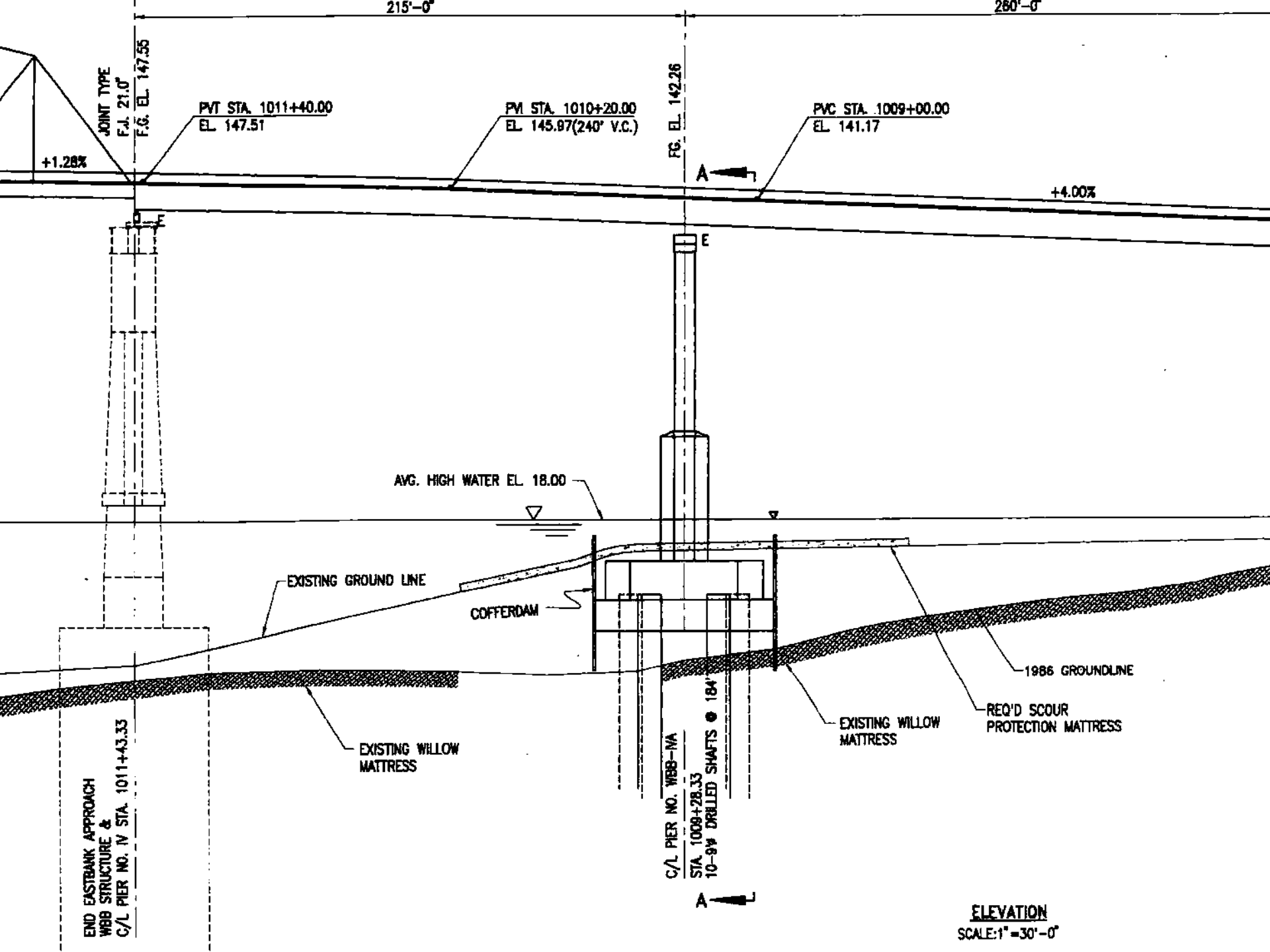
*Foundation Consultant:*

Dan Brown and Associates



# Pier IVA





215'-0"

280'-0"

JOINT TYPE  
F.J. 21.0'  
F.G. EL. 147.55

PVI STA. 1011+40.00  
EL. 147.51

PVI STA. 1010+20.00  
EL. 145.97(240' V.C.)

PVC STA. 1009+00.00  
EL. 141.17

FG. EL. 142.26

+1.28%

+4.00%

AVG. HIGH WATER EL. 18.00

EXISTING GROUND LINE

COFFERDAM

EXISTING WILLOW  
MATTRESS

C/L PIER NO. WEBB-1A  
STA. 1009+28.33  
10-9/8 DRILLED SHAFTS • 18"

EXISTING WILLOW  
MATTRESS

REQ'D SCOUR  
PROTECTION MATTRESS

1986 GROUNDLINE

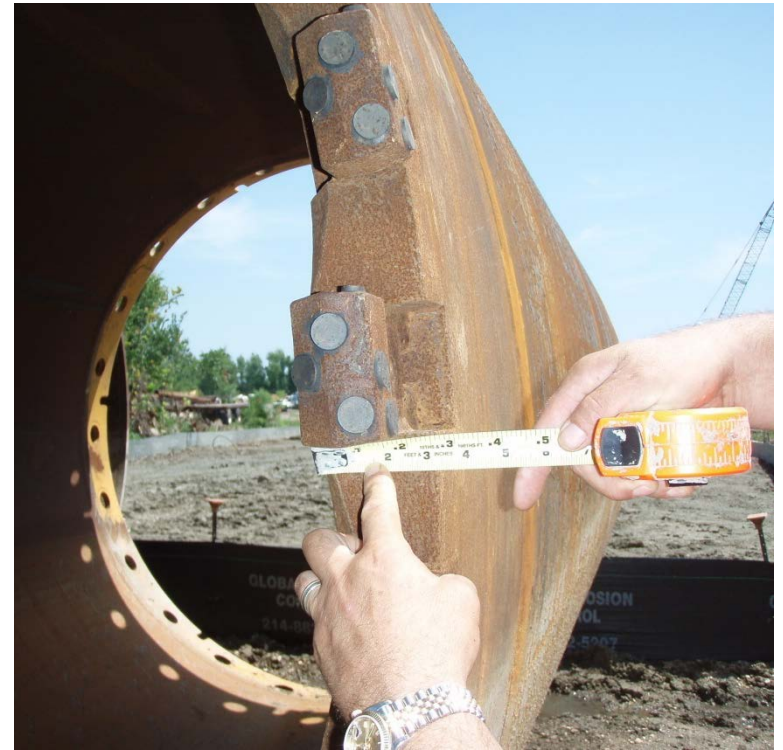
END EASTBANK APPROACH  
WEBB STRUCTURE &  
C/L PIER NO. IV STA. 1011+43.33

ELEVATION  
SCALE: 1" = 30'-0"

# Rotator System



# Casing



# Excavation Using Hammer-grab



# Shaft Cleaning & Inspection



Airlift



SID



'Bottle Brush'



(Hydraulic)  
Cleaning Bucket

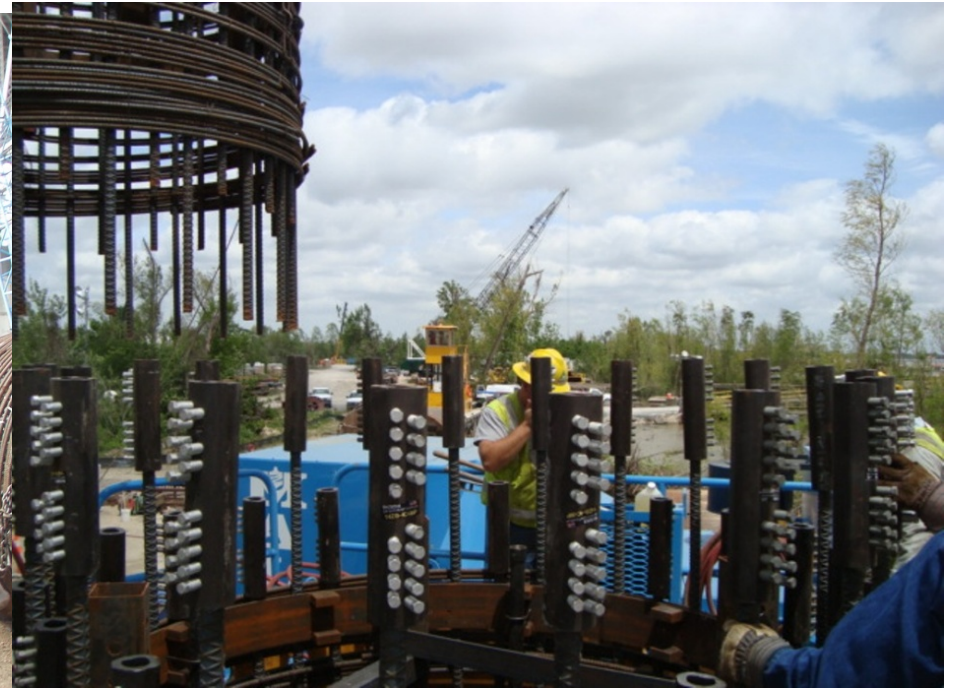


Place Gravel

# Reinforcement



Backbone Frame



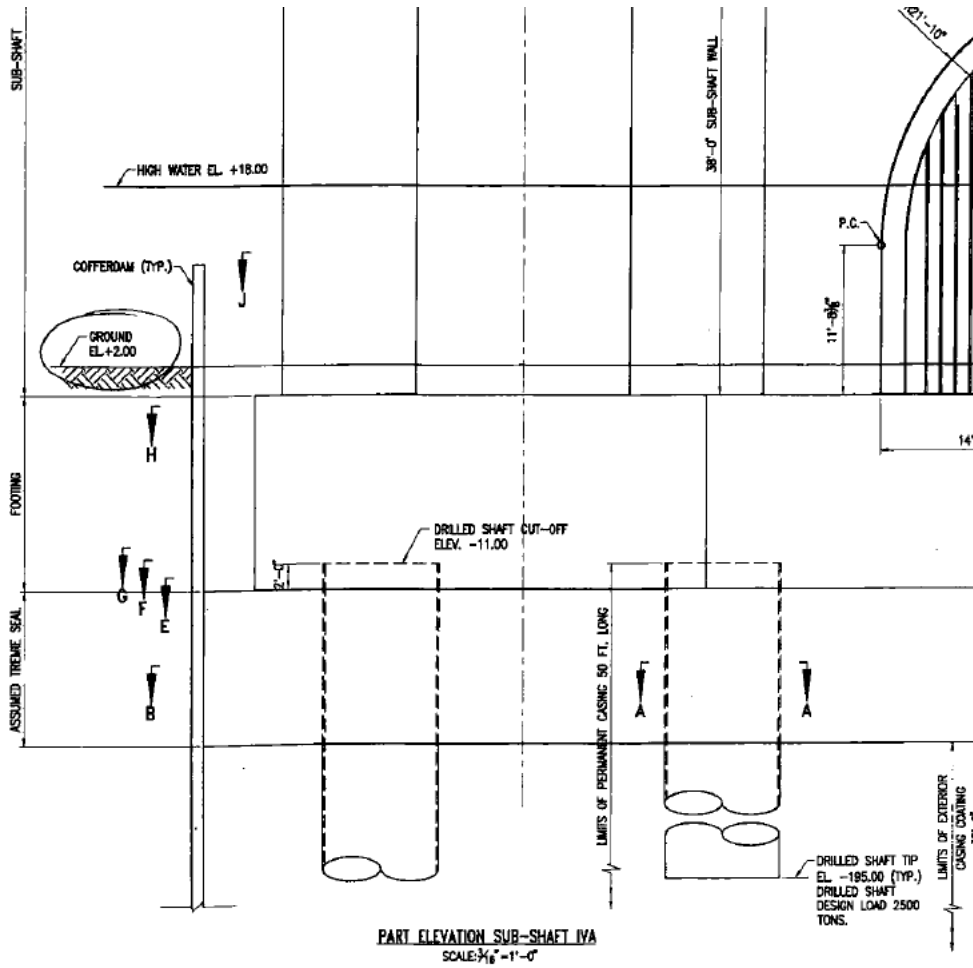
Bar Splices



# Placement of Reinforcement



# Shaft/Cap Connection



Isolation Casing

Shaft Cutoff at -11

# Concrete

Mix Proportions For One Cubic Meter (Cubic Yard) of Concrete				
Cement	455	kg (lb)		
Fly Ash		kg (lb)		
Slag	245	kg (lb)		
Fine Aggregate (SSD)	1150	kg (lb)		
Coarse Aggregate 1 (SSD)	1148	kg (lb)		
Coarse Aggregate 2 (SSD)		kg (lb)		
Water	35.1	L (gal)		
Water Reducer	114.0	mL (oz)		
Air Entrainer		mL (oz)		
Set Accelerator		mL (oz)		
Superplasticizer	121.0	mL (oz)		
Special Additive A	49.0			
Special Additive B	21.0			
Special Additive C				
Contractor	KIEWITT MASSMAN TRAYLOR			
Certified Concrete Technician	B. Echoldt		1120B	
Date Submitted	04-02-09		Code	

Recover (7 oz/cwt)

VMA (3 oz/cwt)



# Base Grouting



# Base Grouting QC/QA

## General Information

<b>Date:</b>	August 7, 2009
<b>AFT Project No.:</b>	808117
<b>Project Description:</b>	Huey P. Long Bridge Widening, State Project No.: 006-01-0021
<b>Client Name:</b>	Kiewit-Massman-Traylor Constructors (KMTC)
<b>Client Address:</b>	4910 Pontchartrain Avenue Suite T, Jefferson, LA 70123
<b>Client Contact:</b>	Mr. Luis Paiz
<b>Post Grout Date:</b>	July 29, 2009
<b>AFT Grout Specialist:</b>	Jason Frederick
<b>AFT Data Acquisition Specialist:</b>	Mike Muchard, P.E.
<b>AFT Responsible Engineers:</b>	Mike Muchard, P.E., Tom Santee, P.E.

## Drilled Shaft Information

Shaft Number	Bent/Pier Number	Diameter (inches)	Length (feet)	Installation Date
Test Shaft	N/A	110	~190	7/21/09
<b>Ground Surface Elevation (feet)</b>		<b>Approximate Top of Concrete Elevation (feet)</b>		
~+13.5				
<b>Cut Off Elevation (feet)</b>		<b>Tip</b>		
-11.0				

## Installation Records provided

Yes  No  Attached

## Instrumentation Installed in

<b>Strain Gages Installed:</b>	Yes
<b>Installed By:</b>	Jason Frederick, AFT
<b>Number and Location:</b>	4 gages at 9 feet above grout plate
<b>Other Instrumentation:</b>	Grout Pressure Transducer, LVDT's

## Post Grout Informa

<b>Grout Distribution Apparatus Type:</b>	Tube-a-Manchette with plate (also used for CSL testing)
<b>Grout Tube Type:</b>	2" steel (also used for CSL testing)
<b>Number of Grout Tubes:</b>	8 (4 - U-Tube pairs)
<b>Tube Reference:</b>	Northernmost tube designated #1
<b>Grout Plant Type:</b>	Hany IC 720 (note: had Hany IC 720)
<b>Grout Type:</b>	Type I/II Portland Cement and Water as needed in field as shown on field notes

## Post Grout Criteria

<b>Minimum Required Grout Pressure:</b>	650 psi (45 bar) (measured at pump)
<b>Maximum Permissible Displacement:</b>	0.25 inch (measured via survey at shaft top)
<b>Minimum Grout Volume:</b>	5 cubic feet (net pumped to the toe of the shaft)

## Post Grout Measurements

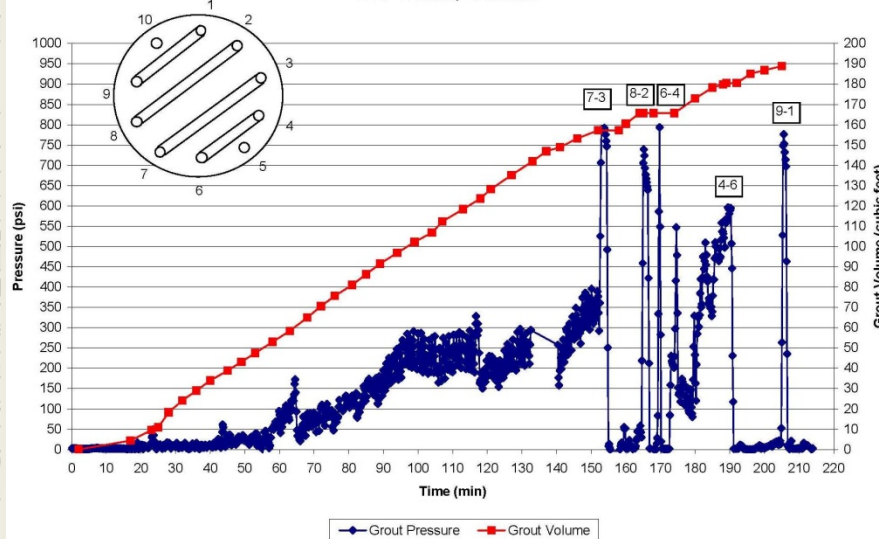
<b>Data Acquisition System Used:</b>	MEGADAC
<b>Pressure Transducer Used:</b>	Hewlett Packard
<b>Strain Gages :</b>	AFT Sisterbars
<b>Manual Grout Pressure:</b>	Micro-Measurements ¼ Bridge Resistance
<b>Survey Level:</b>	Manual Oil Filled Bourdon Gage
<b>Manual Grout Volume:</b>	By AFT
	Holding Tank Level Manual Measurement

## SUMMARY OF POST GROUT RESULTS

Maximum Grout Pressure (psi)	Upward Shaft Displacement (inches)	Maximum Gross Volume Placed (cubic feet)	Estimated Net Volume Placed <sup>(1)</sup> (cubic feet)
800	0.081	188.8	156.8

(1) Net volume calculated as follows:  
 Net Volume = Gross Volume - Theoretical Volume of Grout Tubes (cu. ft.)  
 Tube I.D. = 2.0 in., Avg. tube length 210 feet.  
 Theoretical volume per tube = 4.58 cu. ft. Note: tube #8 became blocked approximately 2hrs-40min.

Pressure and Volume During Base Grouting of Test Shaft  
 Huey P. Long Bridge Widening  
 New Orleans, Louisiana



became blocked approximately 2hrs-40min.  
 0 cu. ft.

**Comments**

Pressure at Shaft Bottom vs Time

Spread Sheet via email

**Comments**

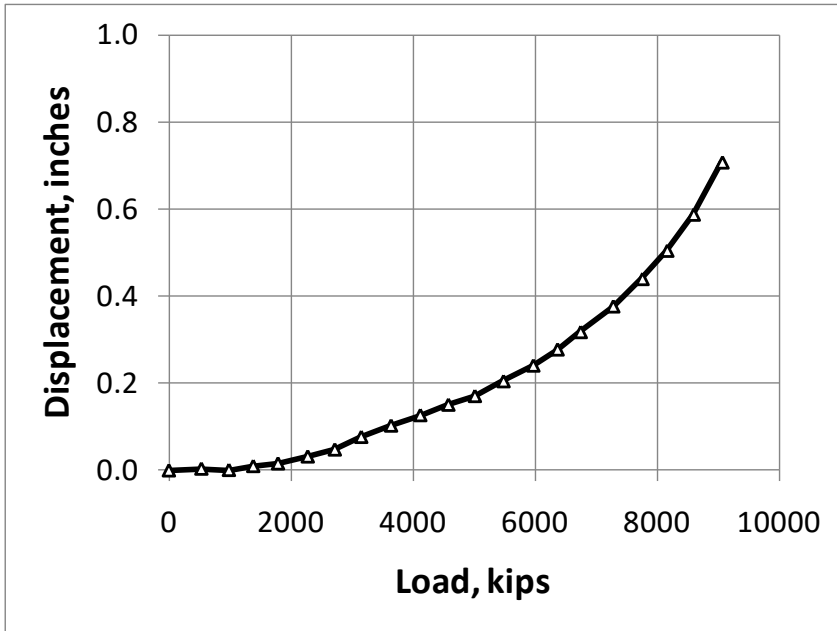
required minimum grout pressure, maximum permissible displacement.

grouted well except during grouting of

1/2 inch (1/2 mm) of each other. It is grouted 115 to 130 minutes into the grout.

grout pressure assumed to apply over the full base area. In addition, localized portions of the base where grout did not act on the full base area. We believe that the gravel pack below the base plate may have contributed to a more uniform

# Performance of Load Test





# Completed Foundation





# Summary

Foundations for large bridges  
present special challenges: key  
issues

- *Construction plan to minimize risks*
- *Constructability issues of design*
- *Coordinated effort of partners*
- *Performance verification requirements*



Don't get bit!