U Mass Lowell
Lowell, MA

The Evolution of Drilled Shaft Construction Techniques and Equipment in the Northeast

Including the Introduction of Slurry Shafts, and the challenges of the Big Dig

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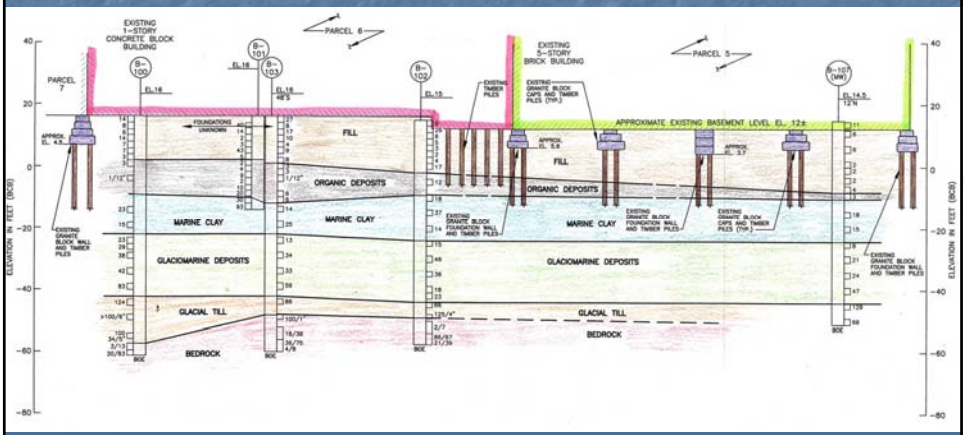
Underpinning & Foundation Skanska
New England Division
Woburn, MA

20 February 2014

1

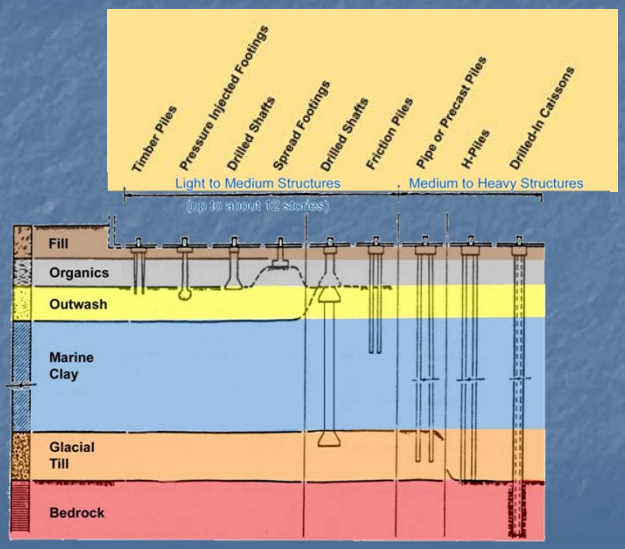
Stratigraphy of Boston



Courtesy of Haley & Aldrich

2

Boston Area Common Deep Foundations



H & A *From: "Geological Characteristics of the Boston Area" Edmund G. Johnson, BSCES Journal, Spring 1989*

3

Shafts "in-the dry"

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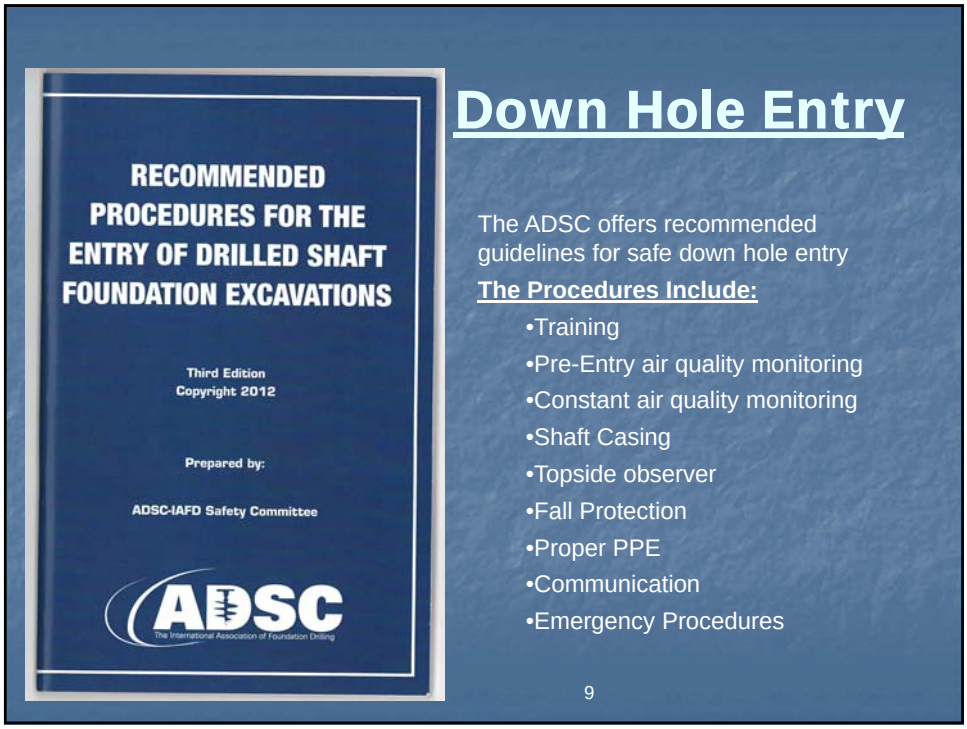
RECOMMENDED PROCEDURES FOR THE ENTRY OF DRILLED SHAFT FOUNDATION EXCAVATIONS
Third Edition
Copyright 2012
Prepared by:
ADSC-IAFD Safety Committee
ADSC
The International Association of Foundation Drilling
Down Hole Entry
The ADSC offers recommended guidelines for safe down hole entry
The Procedures Include:
•Training
•Pre-Entry air quality monitoring
•Constant air quality monitoring
•Shaft Casing
•Topside observer
•Fall Protection
•Proper PPE
•Communication
•Emergency Procedures
9


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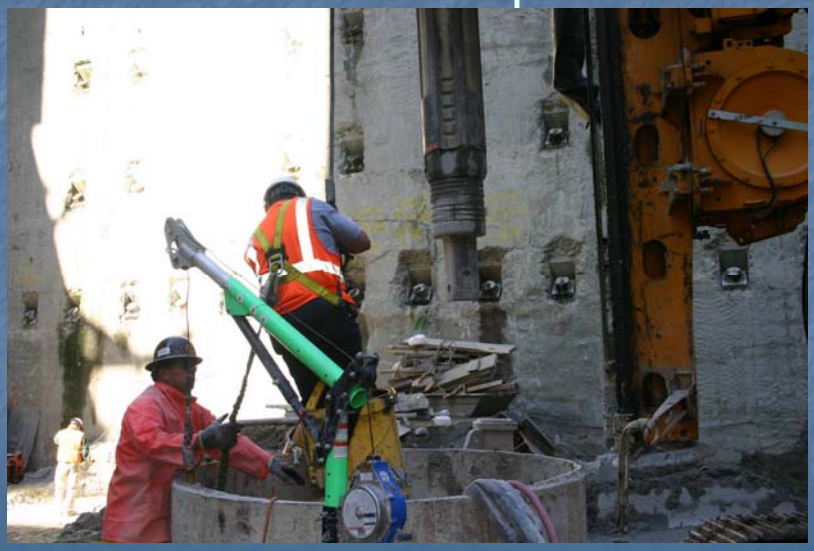
Down Hole Inspection



15

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Free Fall of Concrete

17

Prior to 1985, Boston was a "Pile Town"

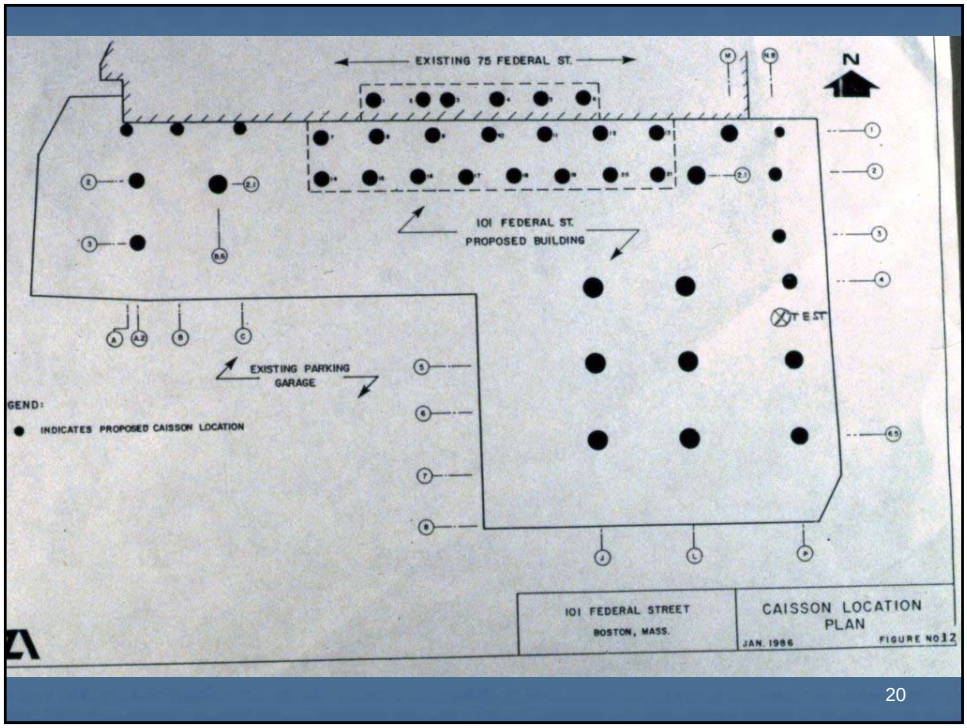
- Introduction of slurry caissons by Eric O'Neill
- Location of slurry caissons
  - 101 Federal St.– Straight shafts
  - 101 Arch St. – Belled under slurry

18

Drilled Shaft Design Values

- Early load tests as prototypes
  - Had to test both the validity of technique
  - Establish design values for:
    - Glacial Till
    - Rock
    - Friction
    - End-Bearing

19



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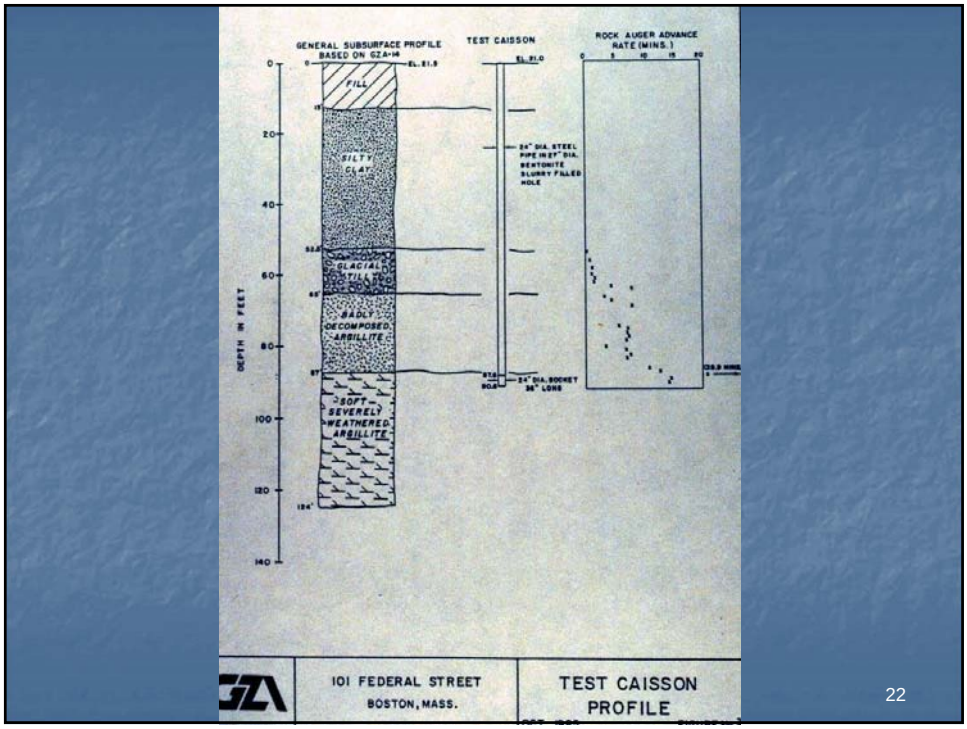
GENERAL SUBSURFACE PROFILE
BASED ON GZA-14
TEST CAISSON
ROCK AUGER ADVANCE RATE (MINS.)
DEPTH IN FEET
FILL
SILTY CLAY
GLACIAL TILL
BADLY DECOMPOSED ARGILLITE
SOFT SEVERELY WEATHERED ARGILLITE
24" DIA. STEEL PIPE IN 27" DIA. BENTONITE SLURRY FILLED HOLE
24" DIA. SOCKET 36" LONG
GZA
101 FEDERAL STREET
BOSTON, MASS.
TEST CAISSON PROFILE

22

23

24

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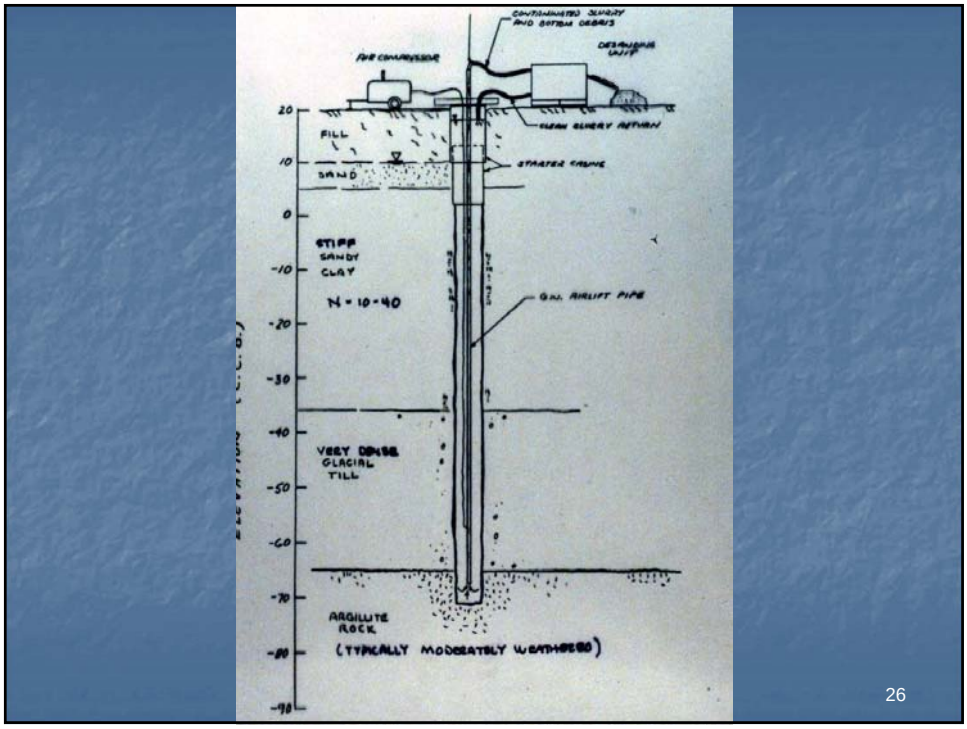
AIR COMPRESSOR
CONTAMINATED SLURRY AND BOTTOM DEBRIS
DESANDING UNIT
CLEAN SLURRY RETURN
STRATEX CASING
FILL
SAND
STIFF SANDY CLAY
N = 10-40
D.D. AIRLIFT PIPE
VERY DENSE GLACIAL TILL
ARGILLITE ROCK
(TYPICALLY MODERATELY WEATHERED)
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90

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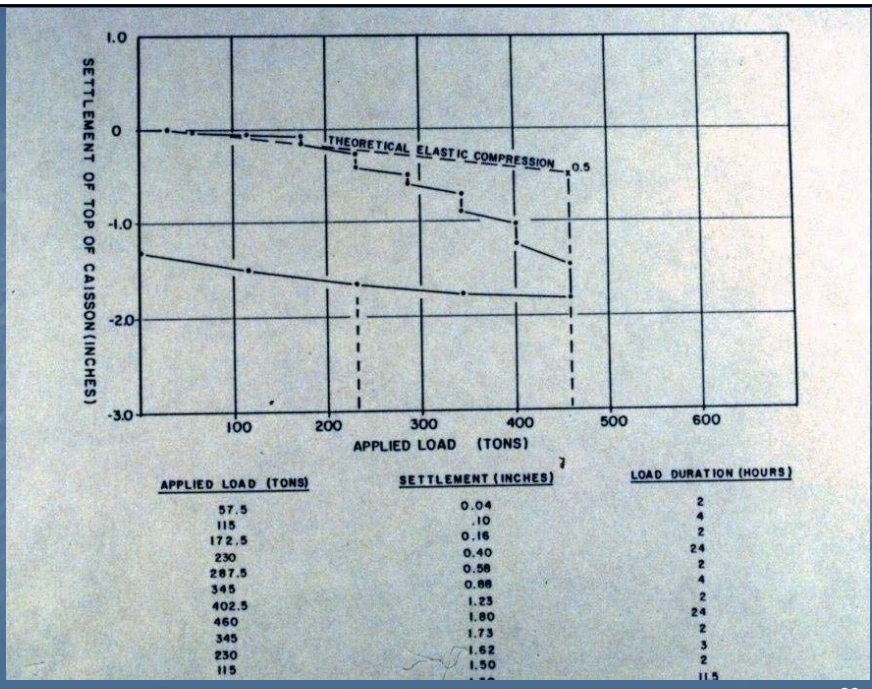

APPLIED LOAD (TONS)	SETTLEMENT (INCHES)	LOAD DURATION (HOURS)
57.5	0.04	2
115	.10	4
172.5	0.16	2
230	0.40	24
287.5	0.58	2
345	0.88	4
402.5	1.23	2
460	1.80	24
345	1.73	2
230	1.62	3
115	1.50	2
		11.5

29

30

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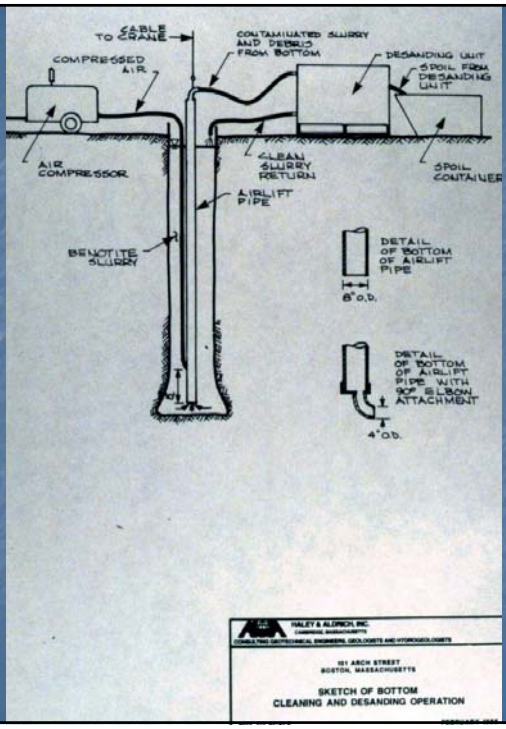
TO CABLE CRANE
CONTAMINATED SLURRY AND DEBRIS FROM BOTTOM
DESANDING UNIT
SPOIL FROM DESANDING UNIT
COMPRESSED AIR
AIR COMPRESSOR
CLEAN SLURRY RETURN
SPOIL CONTAINER
AIRLIFT PIPE
BENTONITE SLURRY
DETAIL OF BOTTOM OF AIRLIFT PIPE
6" O.D.
DETAIL OF BOTTOM OF AIRLIFT PIPE WITH 90° ELBOW ATTACHMENT
4" O.D.
HALEY & ALDRICH, INC.
101 ARCH STREET
BOSTON, MASSACHUSETTS
SKETCH OF BOTTOM CLEANING AND DESANDING OPERATION

32


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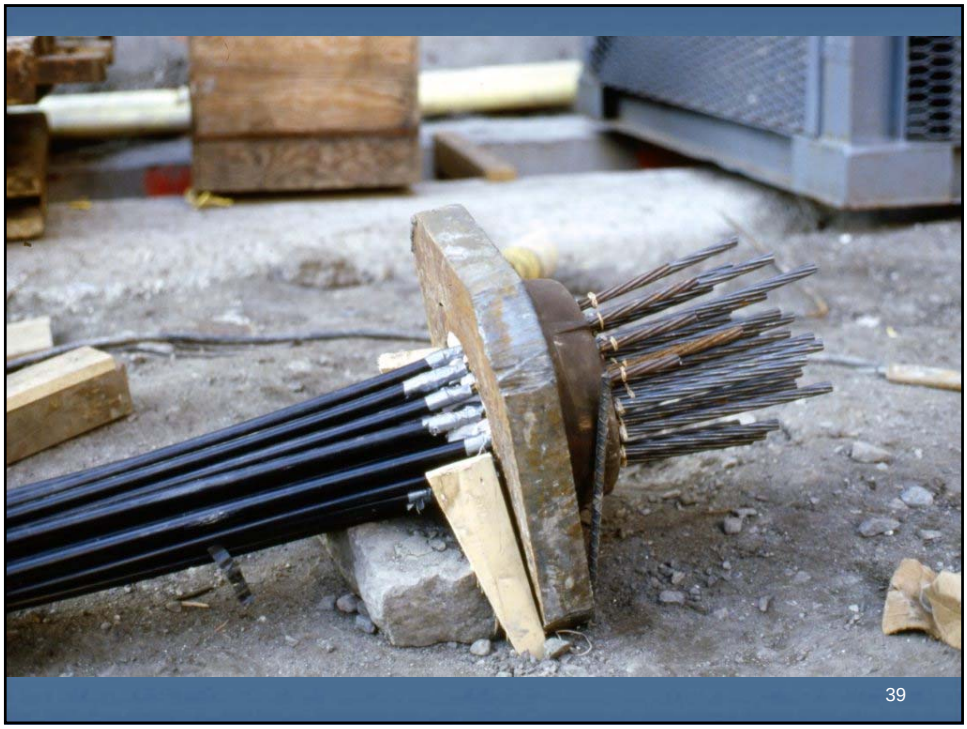

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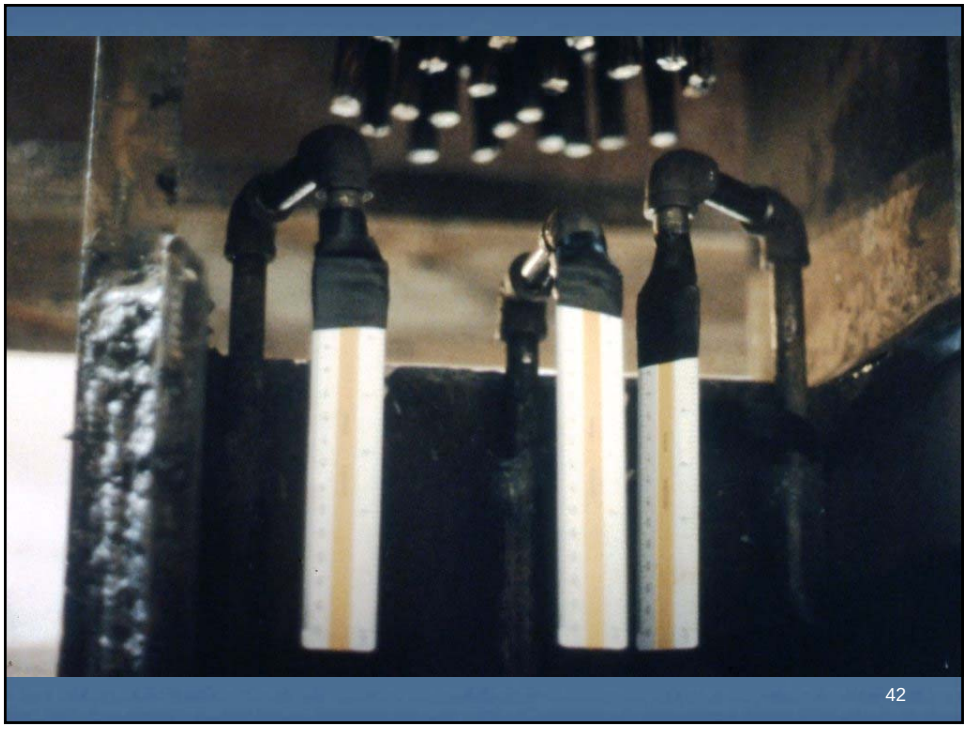

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NEFCO caisson load tests

- 101 Federal St. GZA Sept 1985
- Marina Bay Geotech Nov
- 101 Arch St. H&A Dec
- 1 Cambridge Center H&A July 1986
- Mass General Hosp. McPhail Jan 1987
- Kingston St. McPhail Jul
- 125 Summer St. H&A Oct
- 101 Merrimac St. H&A Dec 1988

43

	Test		Type	
	compression	tension	Straight shaft	belled
101 Federal St.	x		rock-slurry	
Marina Bay	x			till-slurry
101 Arch St.	x			till-slurry
1 Cambridge Center	x		rock-slurry	
Mass General Hosp.	x	x	rock-slurry	
Kingston St.	x		rock-slurry	
125 Summer St.		x	till-rock-dry	
101 Merrimac St.		x	rock-slurry	

44

Rock Design Values mid-1980's

	End-bearing (ksf)	Side-friction (ksf)	
101 Federal St.	60	14.4	Zone 1
	50	9.4	Zone 2
1 Cambridge Center	80	26	
Mass. General Hosp.	80	3.6	
Kingston St.	80	3.6	
125 Summer St.	50	13	
101 Merrimac St.	50	4	<10 ft
		10	>10 ft

45

Till Design Values mid-1980's

	end-bearing ksf	friction ksf
Marina Bay	20	
101 Arch St.	34	
125 Summer St.		3.5

46

Along came the O-Cell in late 80's

47

Statnamic Tests

- Charge set off above shaft
- Strain gauges determine friction & end-bearing capacity
- Be wary in an urban setting

48

Slurry Caissons started to replace driven piles as deep foundation of choice on many high-rise projects

- My rule of thumb for shafts to start to look economically attractive vs driven piles
- Load-Carrying Capacity
- Lateral Capacity
- Seismic Capability
- Scour

49

Trends of Drilled Shafts

- Greater Use
- Bigger Diameters
- Greater Depths
- Bigger Equipment in Unlimited Headroom
- Bigger Equipment in Limited Headroom

50

Importance of a Good Geotechnical Report

51

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The " Big Dig"

- First project on piles
- Just about all the rest on Drilled Shafts
- About $150 million of Drilled Shafts installed

53

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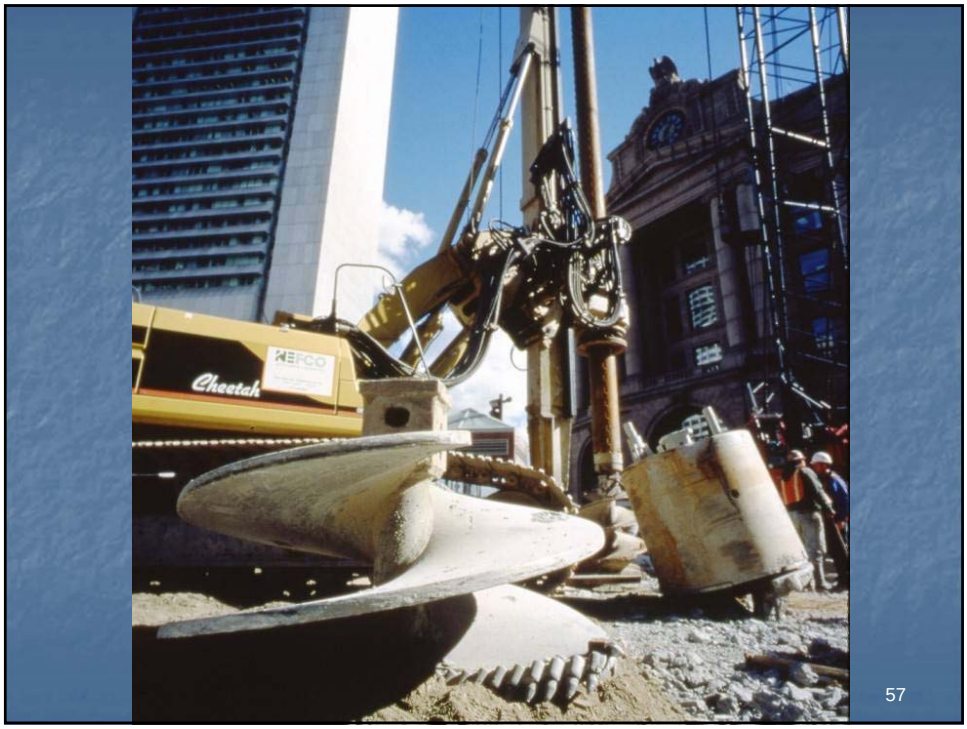
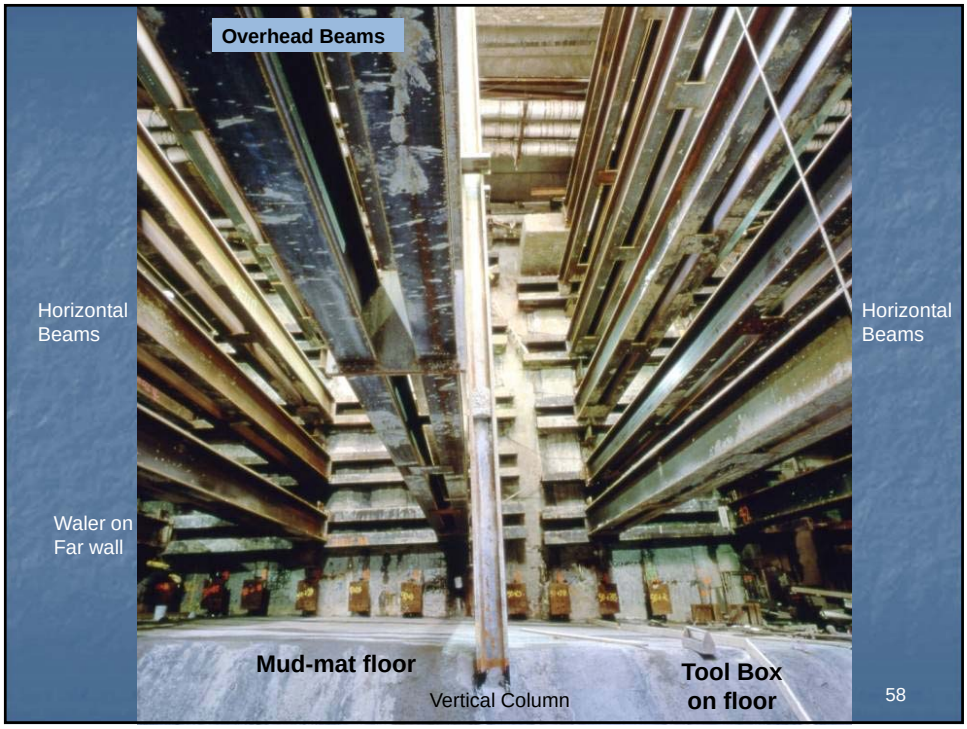

Cheetah
57


Overhead Beams
Horizontal Beams
Horizontal Beams
Waler on Far wall
Mud-mat floor
Vertical Column
Tool Box on floor
58

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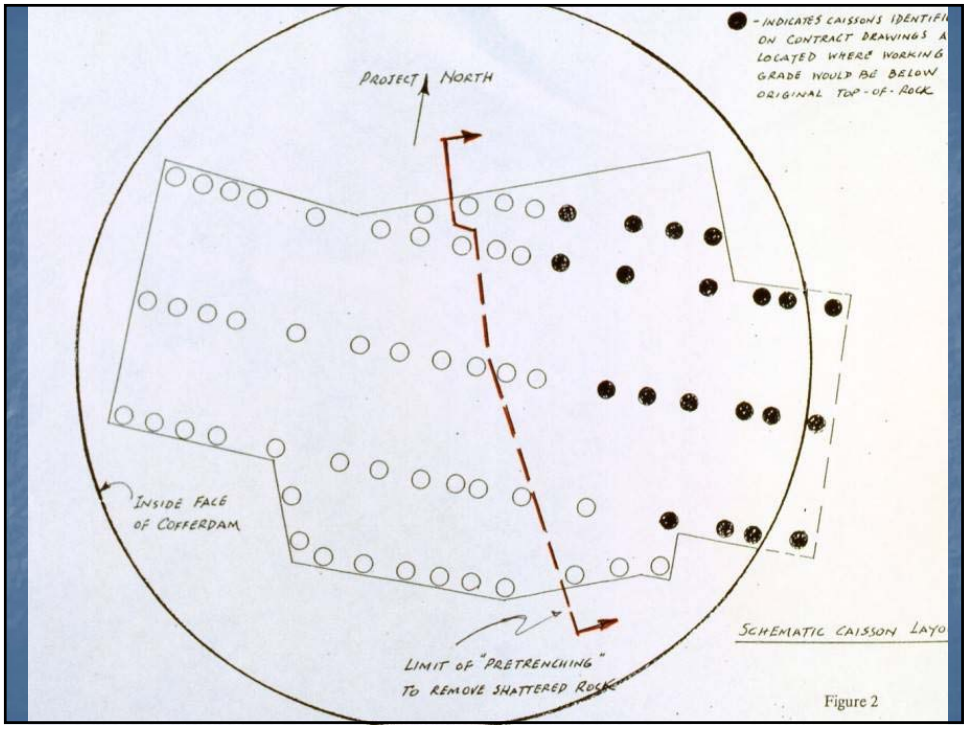
PROJECT NORTH
INSIDE FACE OF COFFERDAM
LIMIT OF "PRETRENCHING" TO REMOVE SHATTERED ROCK
Figure 2

63

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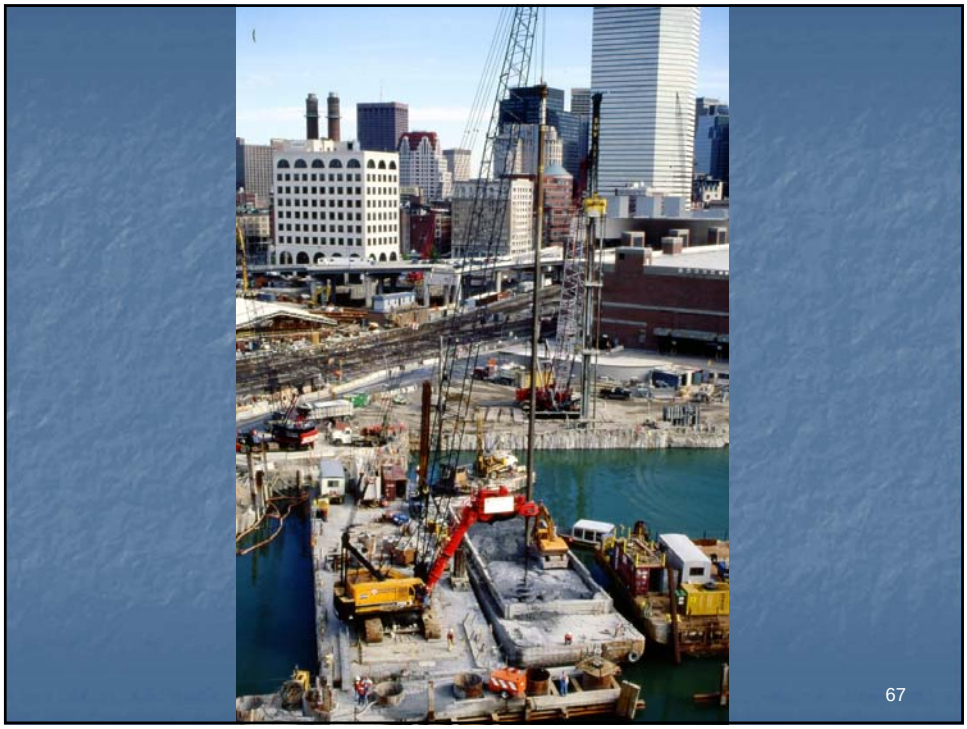

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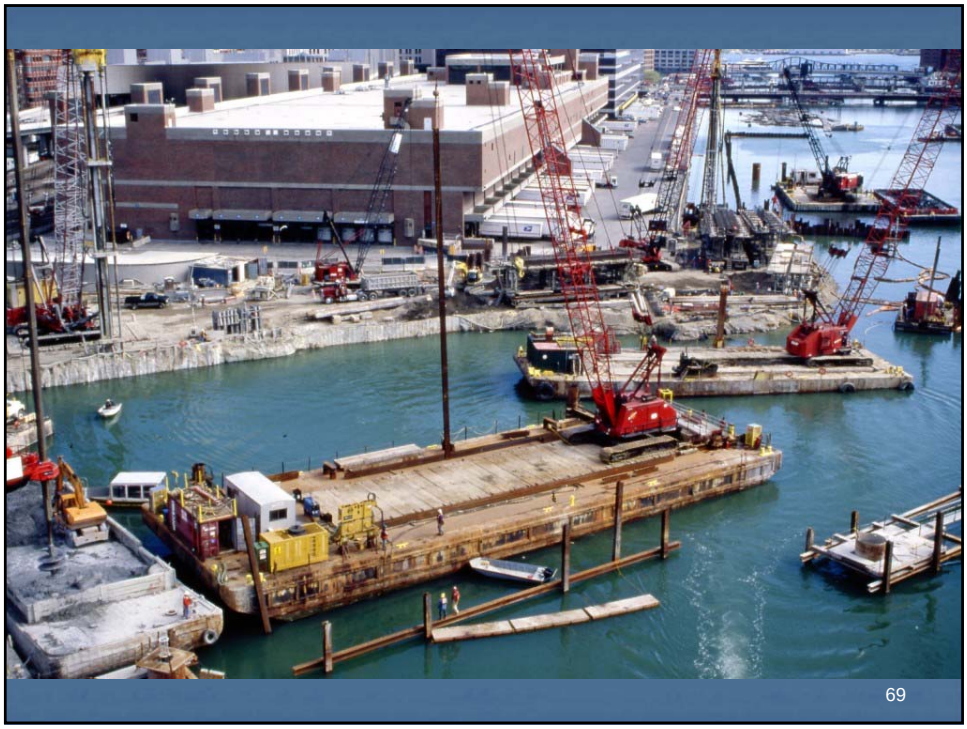

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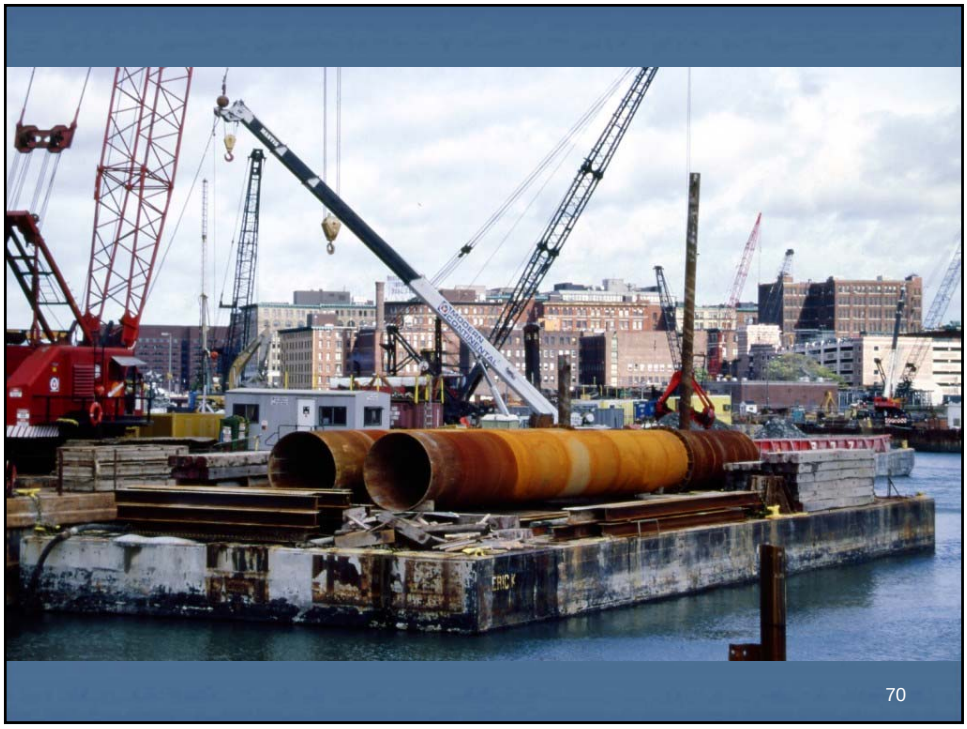

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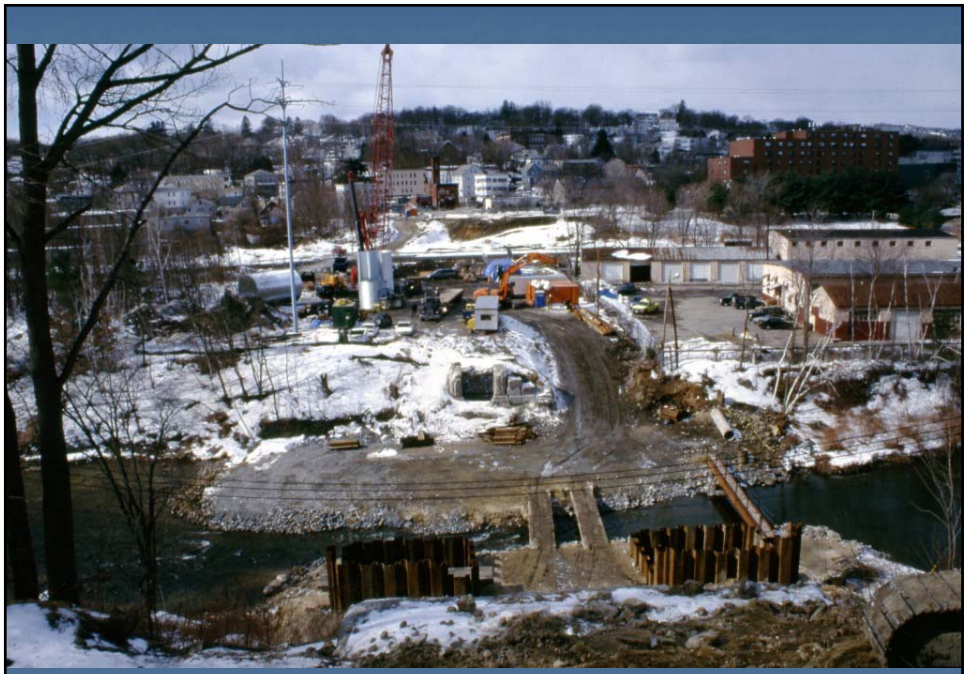

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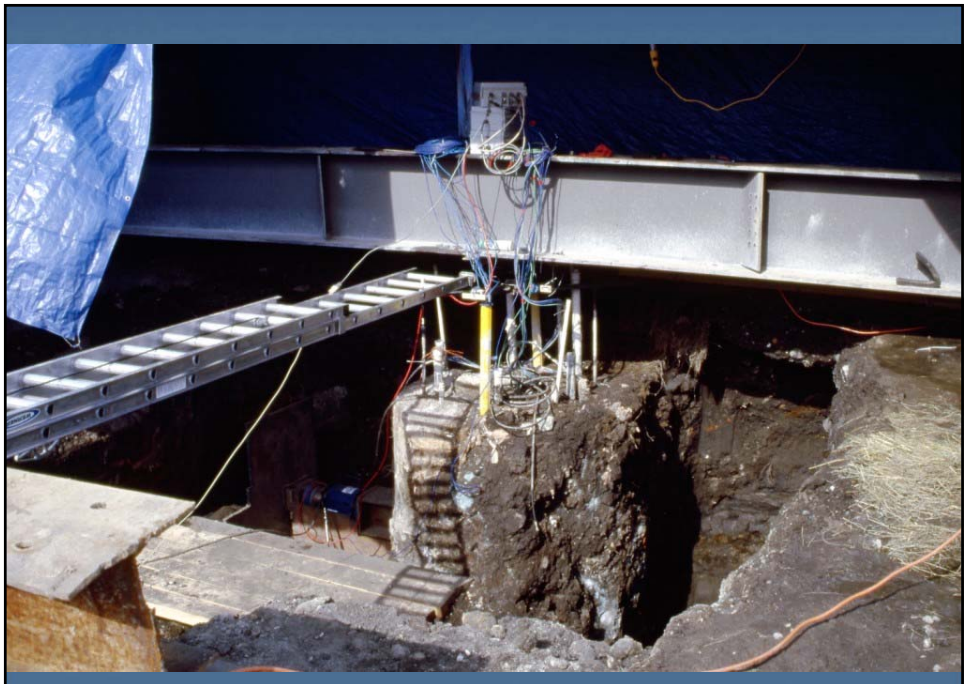

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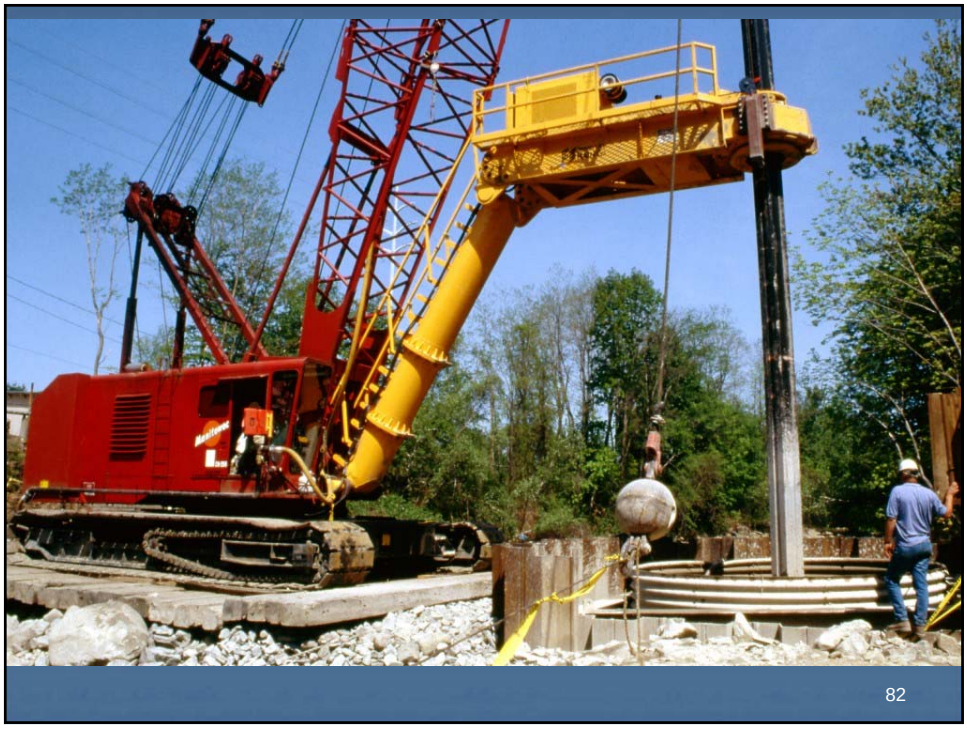
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Wirth PBA 928 Reverse Circulation Drill (RCD)

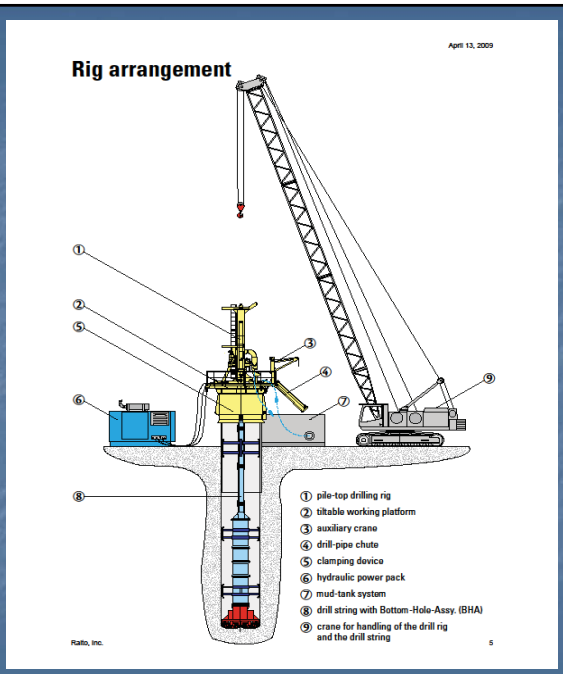
- Water passively added to the top of the drilled shaft
- Weighted roller-cutters are turned and break up the rock
- Air is introduced into the drill string
- This creates an airlift, which lifts cuttings from the roller-cutters up through the drill string
- The cuttings are expelled through the top of the drill head
- Water flow capacity of 7000 gal/min

95

Reverse Circulation Drilling Cross Section

1. Pile-Top Drill Rig
2. Working Platform
3. Auxiliary Crane
4. Drill-pipe Chute
5. Clamping Skirt
6. Hydraulic Power Pack
7. Settlement Reservoir
8. Drill String with Bottom Hole Assembly (BHA)
9. Assist Crane

(Courtesy Aker Wirth)



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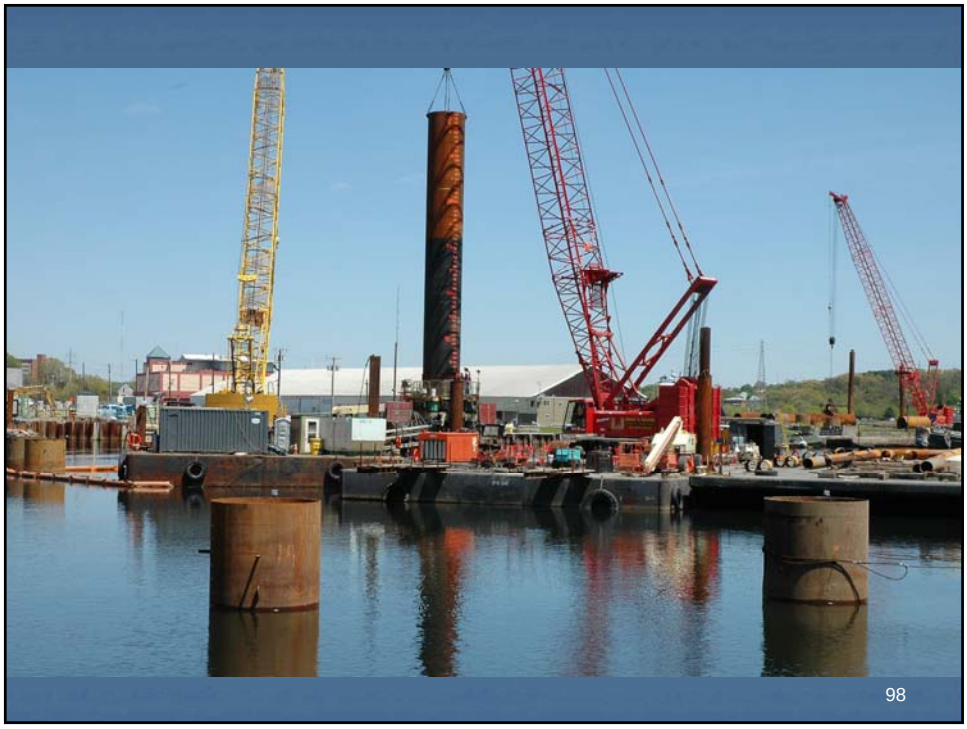
98


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16 3:36 AM

101

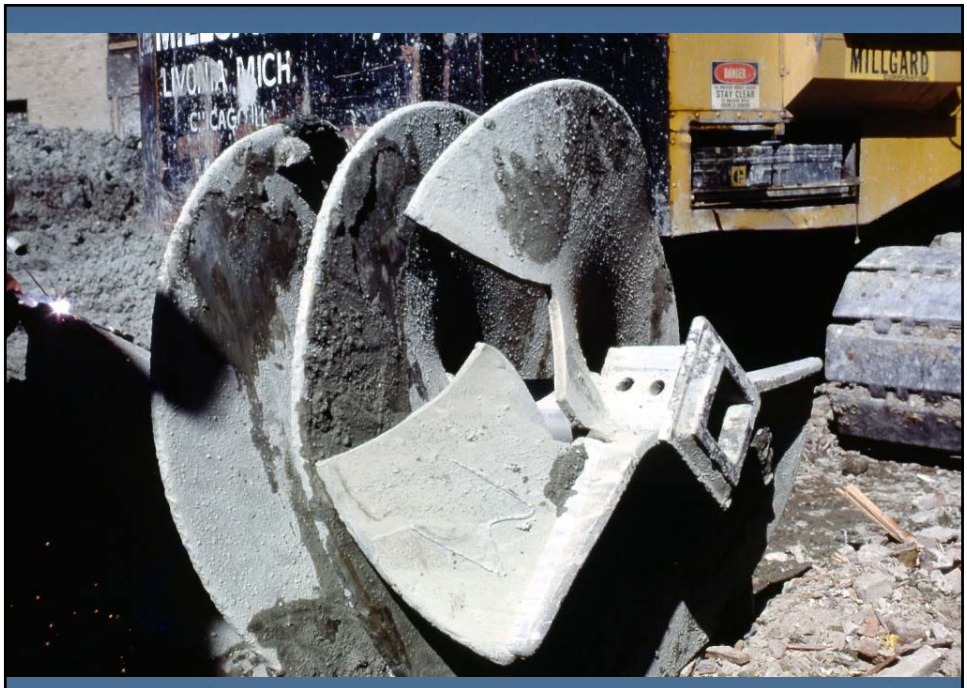
Obstructions

- Man-made
- Naturally occurring boulders

- Compensation on an hourly basis

102

103



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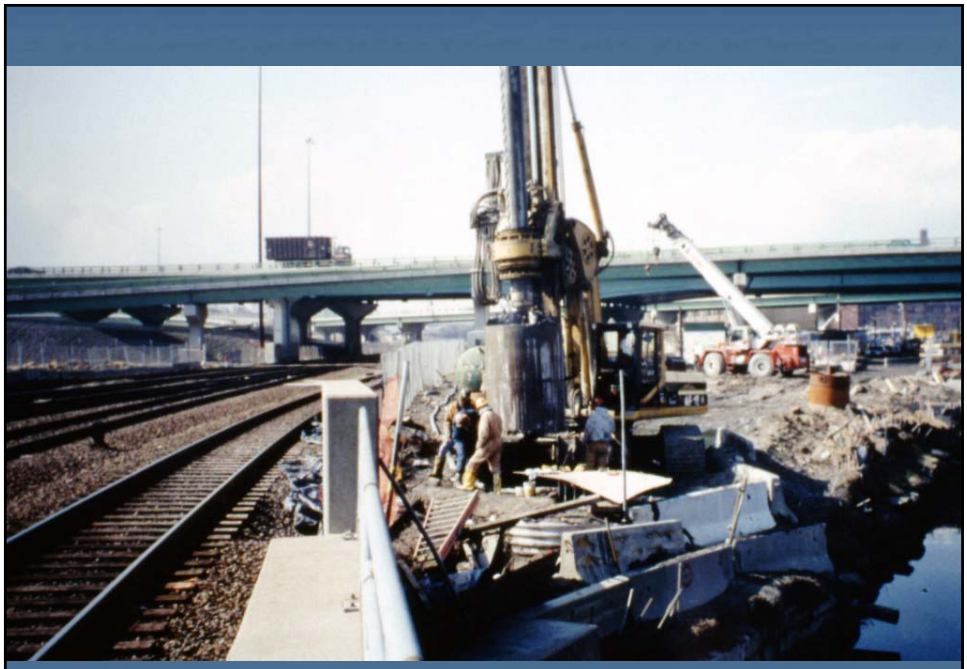

106

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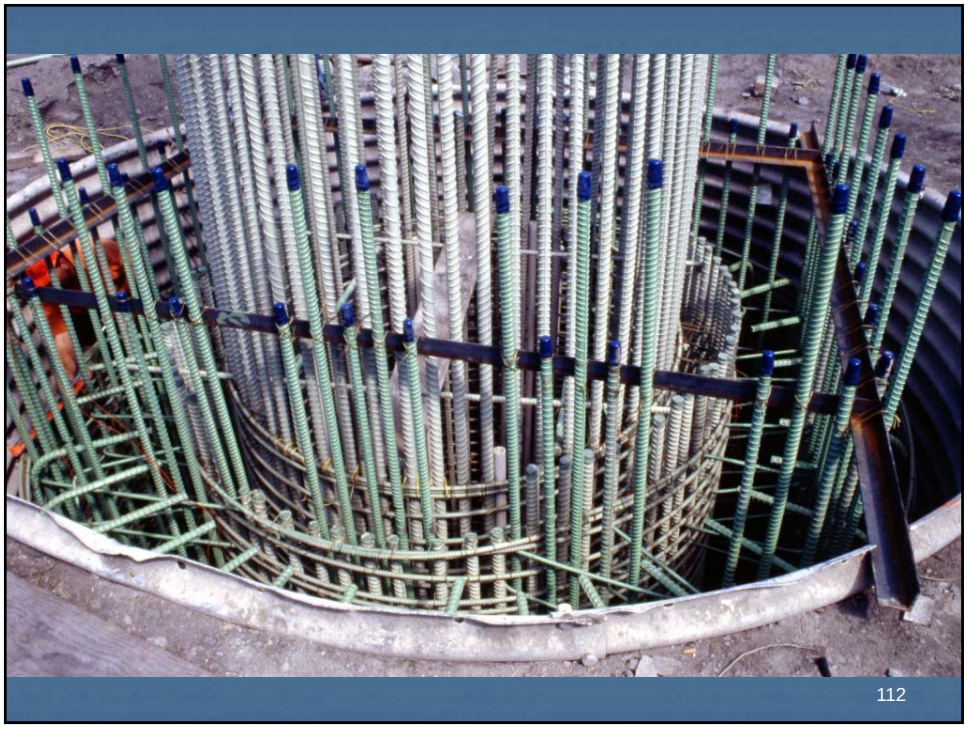
109

Constructibility Issues

- Flow of concrete through cages
  - -Peastone
- Time to set cages
- Time to place concrete
  - -8 to 10 inch slump
  - -retarder for life of placement
- Is SCC the answer?

110

111

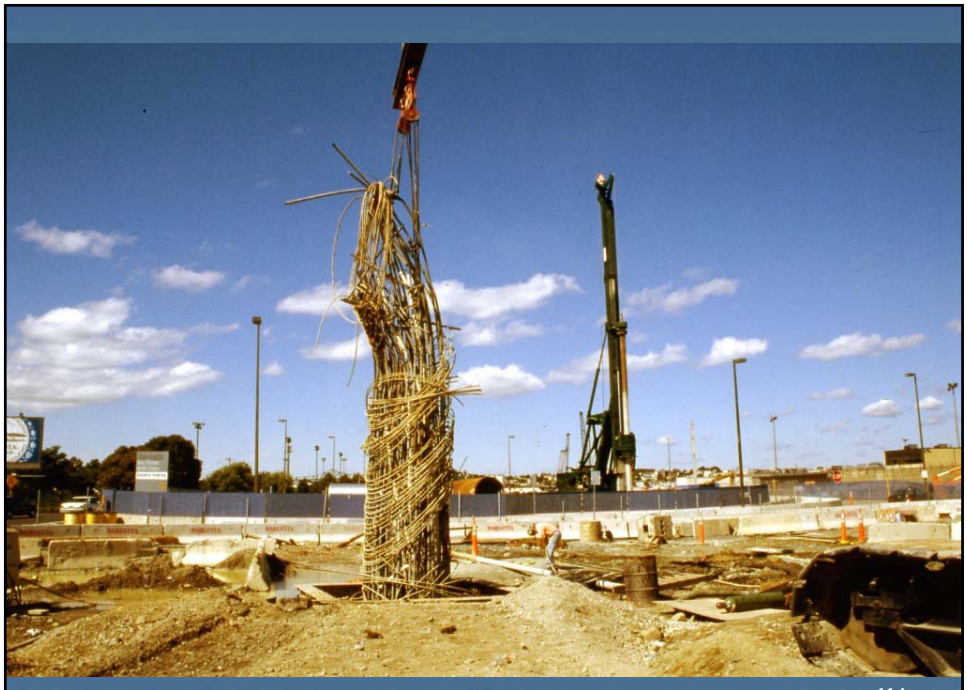


112

Problems

- All does not always go well

113



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Design

- Much (mis) interpretation of Codes

115

Repair of Big Shafts

- Broken tremie pipe

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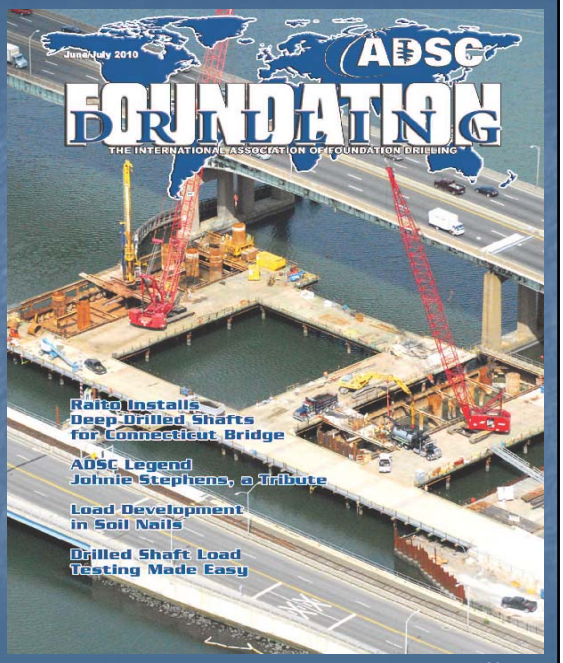
Q-Bridge (Phase 1) New Haven, CT

New Q-Bridge Artist's Rendition: www.i95newhaven.com

119

PROJECT SCOPE

- 42 drilled shafts
- 8'-00" diameter
- Up to 220' deep
- Permanent casing
- Rock sockets up to 25' in length
- Two Osterberg load tests
- Trial shaft to verify means and methods
- Constructed from work trestle



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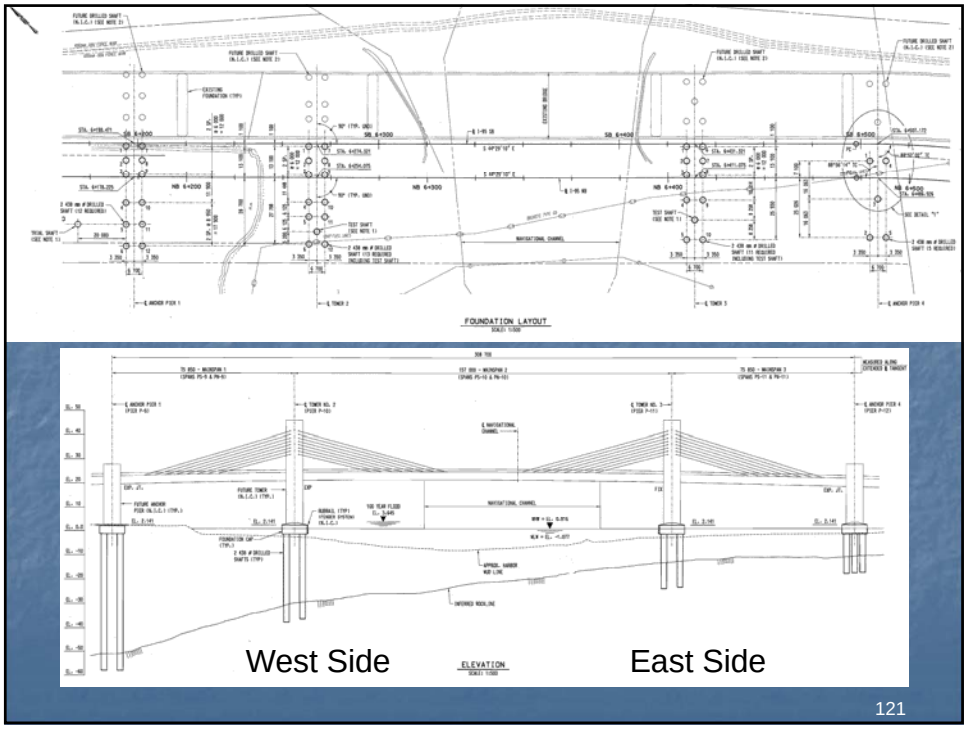

FOUNDATION LAYOUT
ELEVATION
West Side
East Side

121


West Side
East Side

122

Overburden

Fill and sandy clay transitioning to cobbles and boulders

123

Arkose Sandstone

Very abrasive, granite and gneiss inclusions, quartzite seams

124

Quartzite Seams and Inclusions

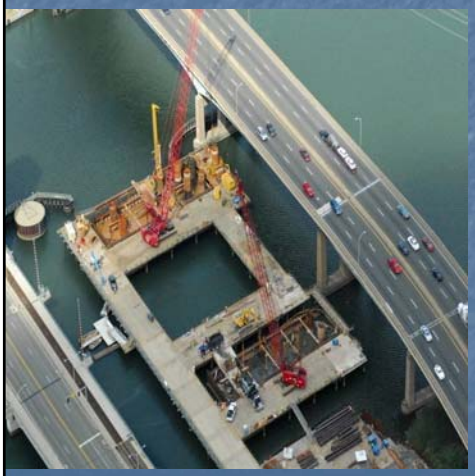
Exploratory core with inclusions

Quartzite seams

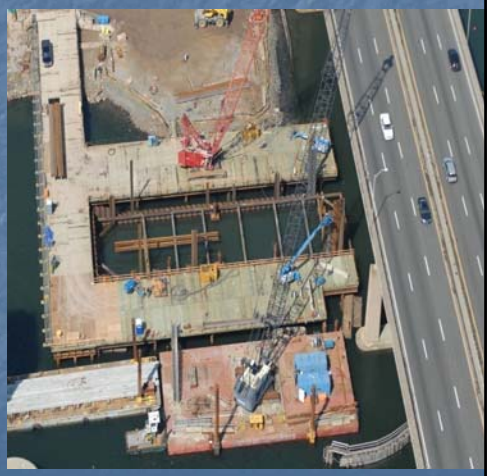
125

Work Trestle and Work Bridge Access

East work trestle



West work trestle



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Means and Methods: Excavation

Casing Installation

Excavation

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NIPPON SHARYO RT260 SUPERTOP ROTATOR

- 450 Ton meters torque
- 128 Tons crowd
- Komatsu RTP 480 power pack
- Spoils excavated and removed with the hammer grab as casing is advanced
- Additional casing in 50’ to 65’ lengths added and spliced as casing advanced
- Casing fitted with teeth and a driving shoe and seated into rock.

128

Casing

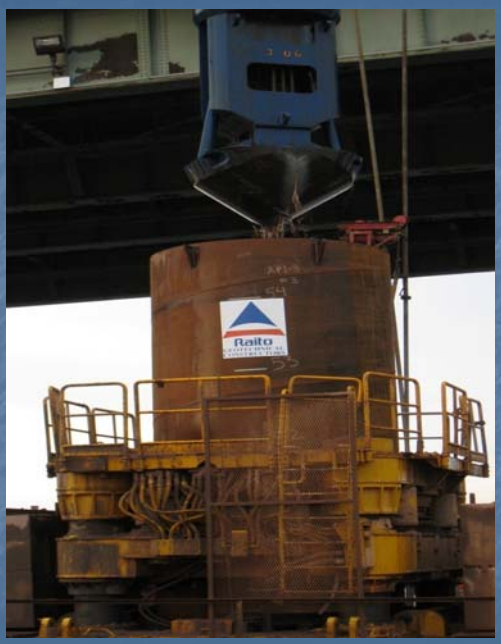
Tripping casing

Cutting shoe arrangement

129

Hammer Grab

- Sanwa SKS-II Hammer Grab
- 2.3 meter shell opening
- 6.6 ton bare weight, 1.1 cubic yard capacity



130

Excavation with Hammer Grab

- Linkbelt 308 duty cycle crane used for excavation
- Spoils discharged into an awaiting truck
- Material classified and disposed

131

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Splicing Casing

1. Conform to AWS D1.1
2. Partial penetration weld
3. No backing ring
4. Connecticut certified welders
5. Periodic inspection by CWI

133

Access Work Bridge

134

Rock Socket Excavation

Track-mounted hydraulic drill

Pile-top reverse circulation drill

135

Bauer BG40 Drilling

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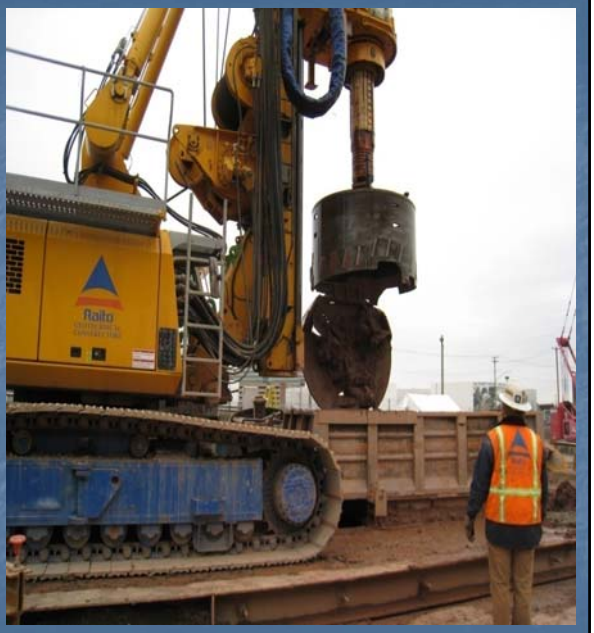
Bauer BG 40

- 72-Meter (236 ft.) kelly bar
- Core barrels, rock augers, rock buckets used to excavate rock socket.
- Required an access bridge to span cofferdam and reach each shaft location
- Encountered difficulty on shafts over 200' deep, especially shafts with inclusions and core stones.



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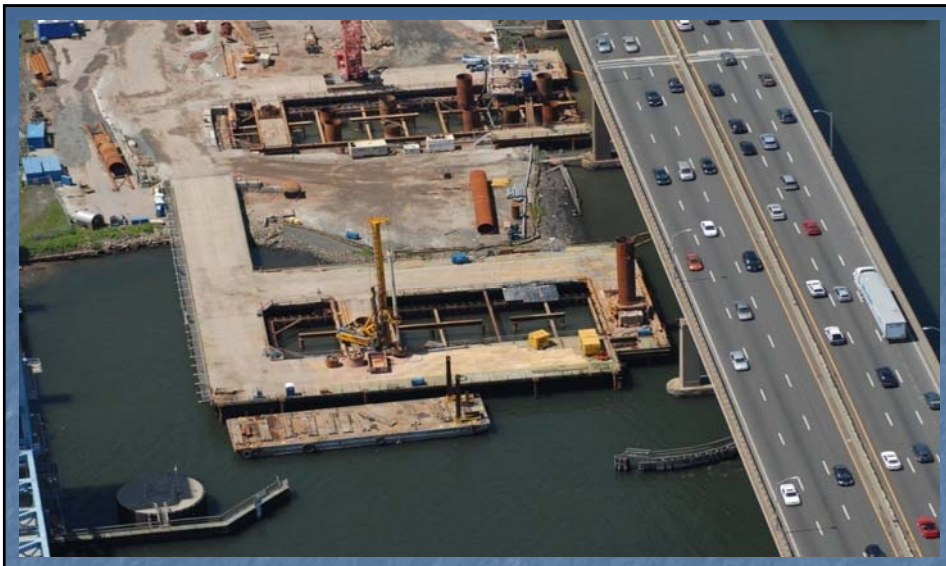
RCD drawing water from river and expelling drill cuttings into marine enclosure

138



Wirth RCD and Bauer BG40 At Work

- Wirth RCD used for deeper shafts, no work bridge necessary
- Bauer BG40 used for test shafts and shallow shafts, less setup time

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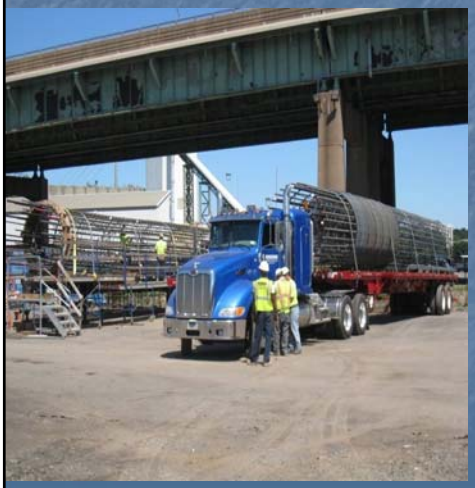
Rebar Cage Placement

Cages fabricated off site in 65' sections



Up to four cage sections spliced over shaft

140

Concrete Placement

141

Concrete

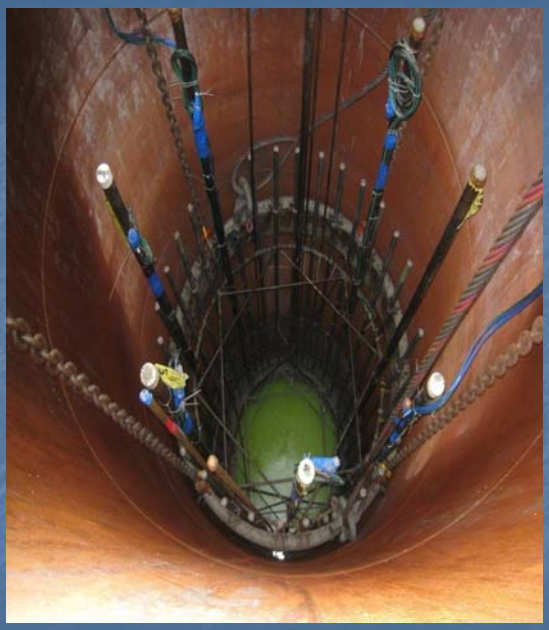
High slump and spread

Extended life to 12 hours

142

Concrete Issues

- Bleed water
- Pumpability
- Tremie embedment
- Adequate mix time



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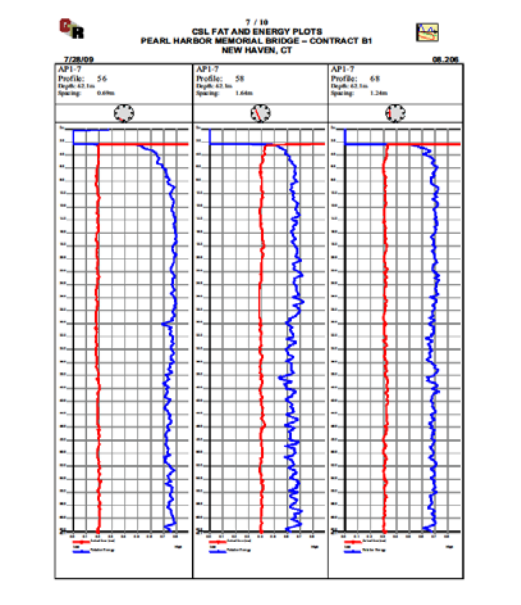
Tailing CSL Tests

- Relative energy consistently tailed in the top 1-3 meters of concrete.
- First arrival times showed little deviation
- Cored shaft AP1-10, showed some small air pockets
- Broke over 6000 psi



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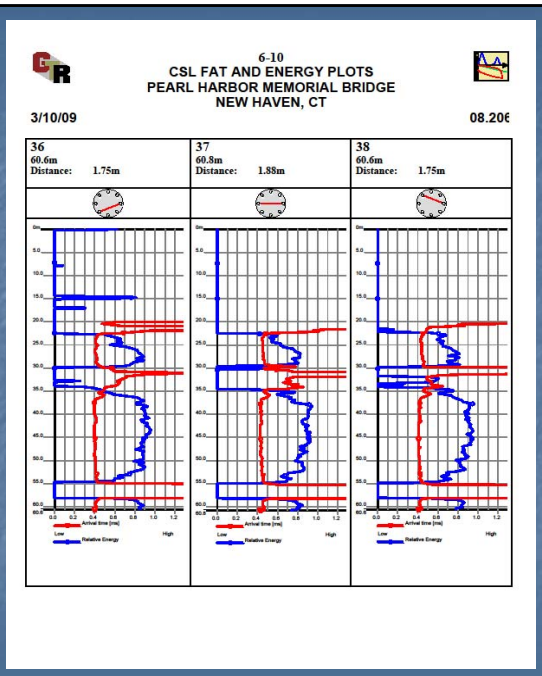
Broken Tremie Drilled Shaft AP1-10

- Last section of tremie pipe sheared at joint, both safety cables also broken.
- Not determined until after concrete pour when final section removed.
- CSL plots determined two regions where embedment compromised, at 100' depth and at 180' depth.
- Shaft abandoned and additional reinforcing bar added to other shafts in Anchor Pier 1.
- Schedule maintained



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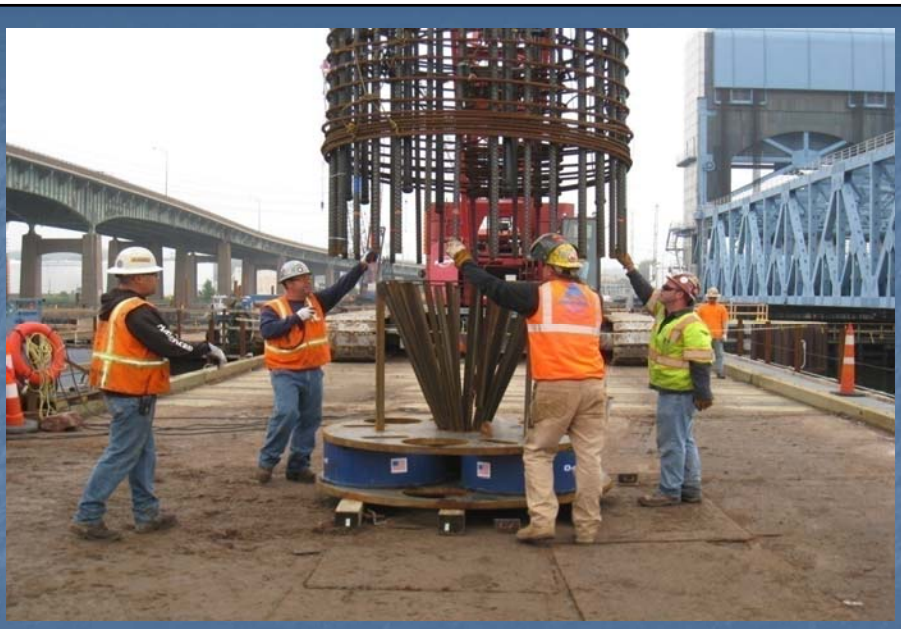

Osterberg Load Test

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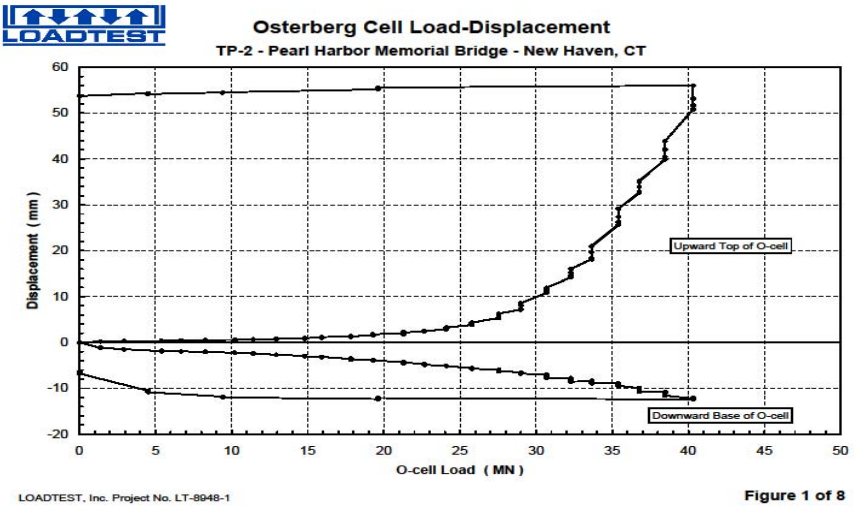

Osterberg Load-Displacement Curve

Rock sockets shortened by 4 meters at Tower Pier 3

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Additional Quality Control

Mini-SID Testing

Air Lift, Vacuum Truck, CSL Testing

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Drilled shaft after marine enclosure pumped dry

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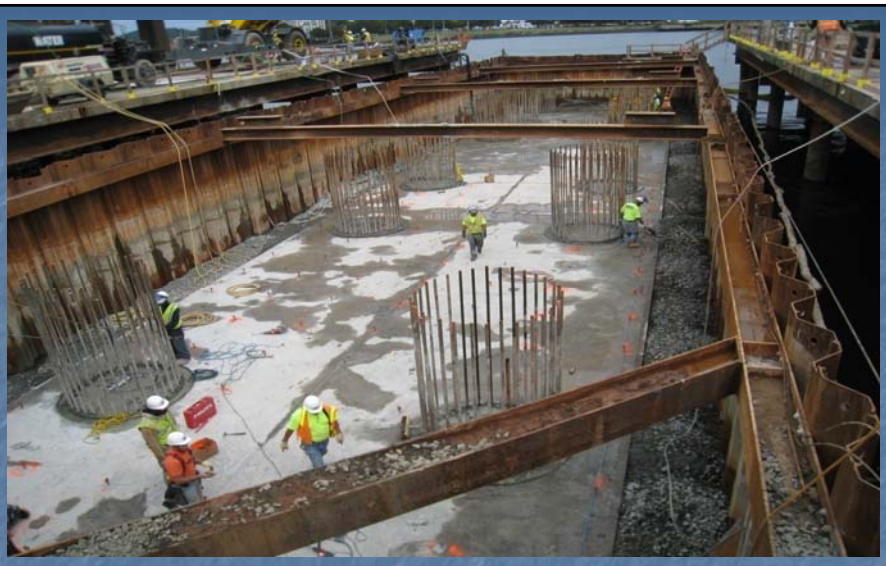

Marine enclosure dry with shafts ready for construction at Tower Pier 2

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Workforce

Staff from 4 countries (United States, Japan, Trinidad, The Netherlands)

Six Unions (Operators Local 478, 4, 57; Laborers Local 455, 88; Pile Drivers Local 24),

Capable of six different languages (English, Japanese, Spanish, Portuguese, Dutch, German)

RAITO, INC. 151

Jefferson Memorial - Washington DC Seawall Rehabilitation

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February 1941 – 72 years ago

Photo from Soils Investigation Report

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March 1941
72 years ago

Photo from Soils Investigation Report

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Photo 19: Construction of the Ashlar Seawall 5/1/1941

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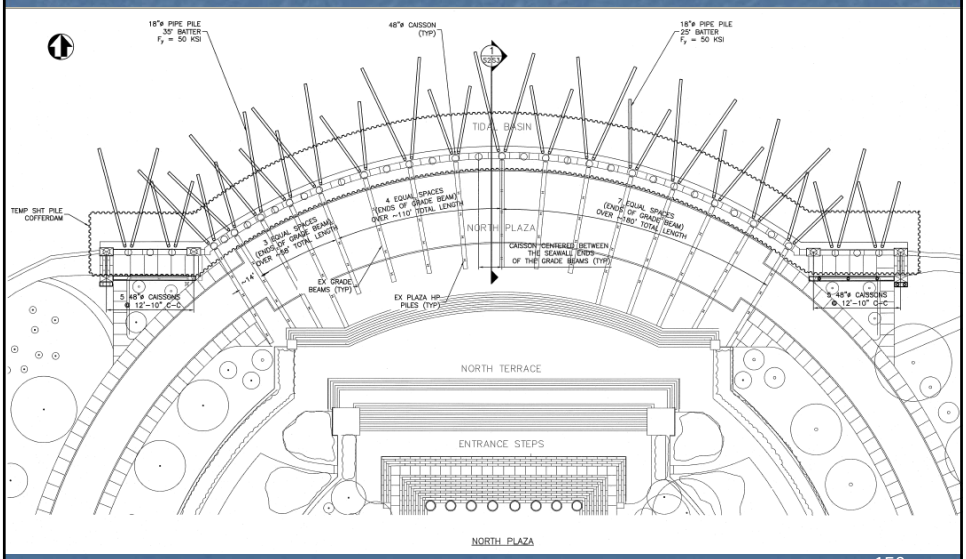
39 Drilled Shafts – up to 100ft
10 ft minimum rock socket



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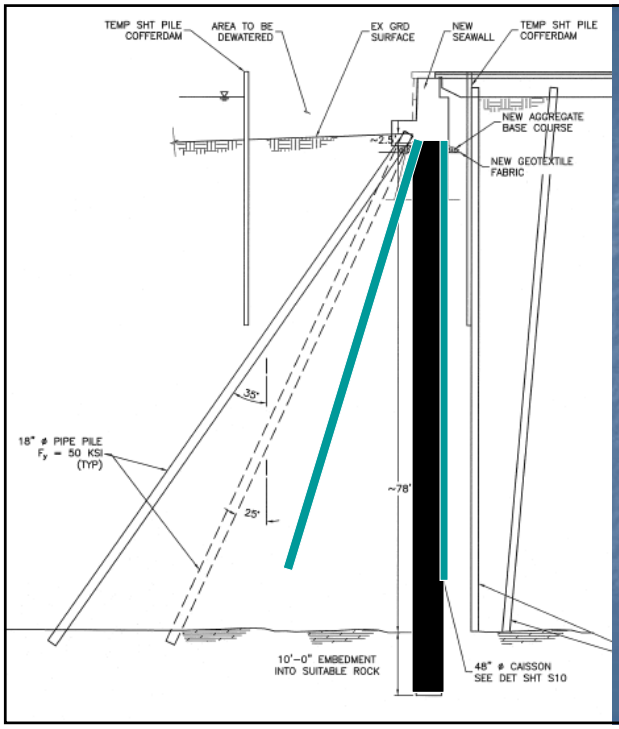

Working Grade El +13'

Top of Cofferdam El +7'

Top of Shaft El -6.42'

Alluvial - Soft Organics - Clayey sand

Wood Piles 60 LF to 75 LF

Tip of Wood Piles El -60' to 75'

Top of Till with gravel El -80'
(Till on east side of project)

Top of Rock El -80' to -96'
Schist with mica, green and black, coarse grained

Tip of Shaft El -90' to -106' 157

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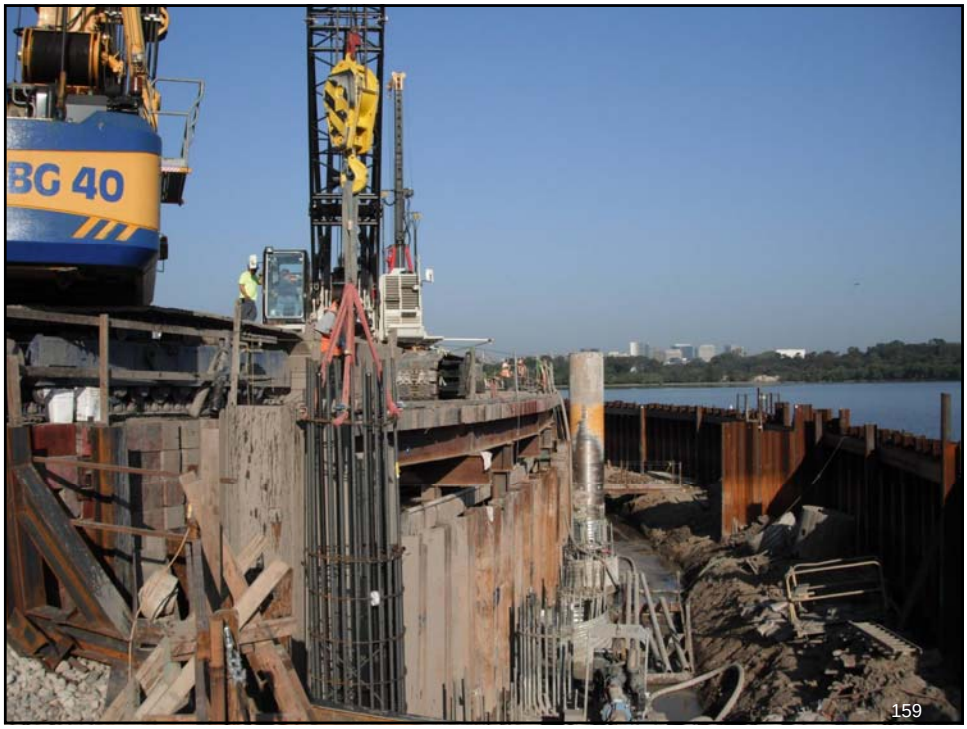
BG 40
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Moses Wheeler Bridge
Milford-Stratford, CT

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Columbia University, NYC

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What has all this experience given me?

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The Evolution of Drilled Shaft Construction Techniques and Equipment in the Northeast

Questions???

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