Western Bridge Engineers' Seminar

PRACTICAL SOLUTIONS TO BRIDGE ENGINEERING CHALLENGES

September 9–11, 2015 | Peppermill Hotel | Reno, Nevada

SESSION-5C

Honolulu Rail Transit Project: Drilled Shaft Design Considerations and Challenges

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AECOM

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OUTLINE

- Project Introduction
- Shaft Configurations / Details
- Design Criteria / Process
- Shaft Construction
- Post-Grouting (Sac RT Project)
- Conclusions

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PROJECT INTRODUCTION

1. West Oahu/Farrington
Design-Build

2. Kamehameha
Design-Build

AECOM
3. Airport
Design-Bid-Build

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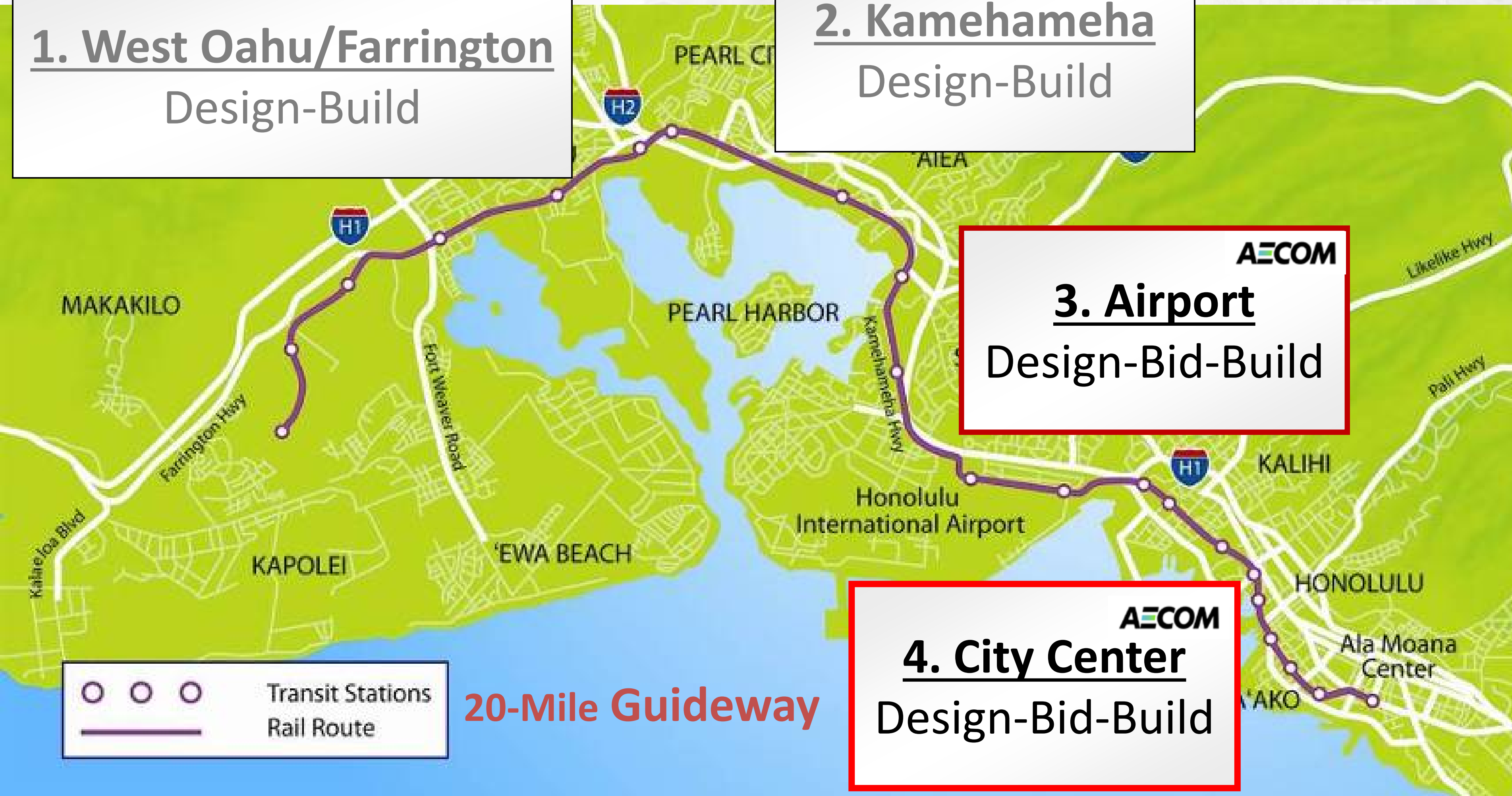
4. City Center
Design-Bid-Build



20-Mile Guideway

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PROJECT DESCRIPTION

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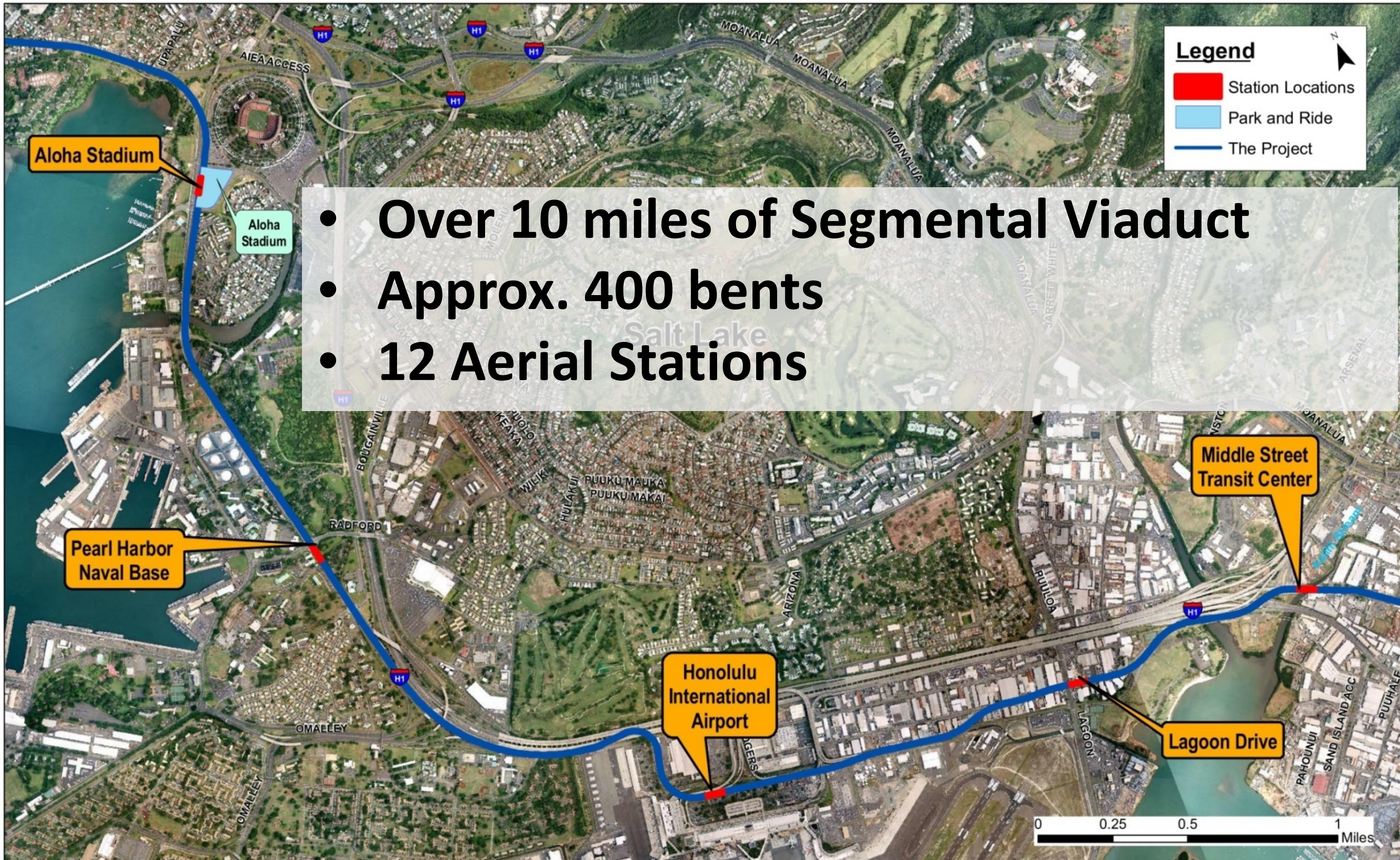
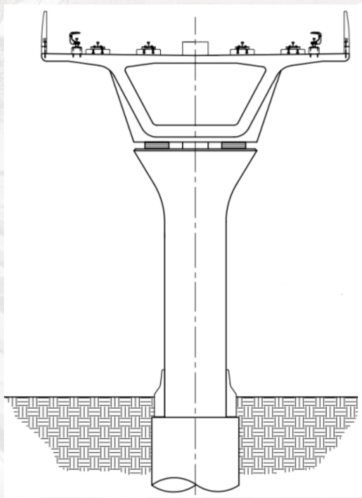
- Over 10 miles of Segmental Viaduct
- Approx. 400 bents
- 12 Aerial Stations



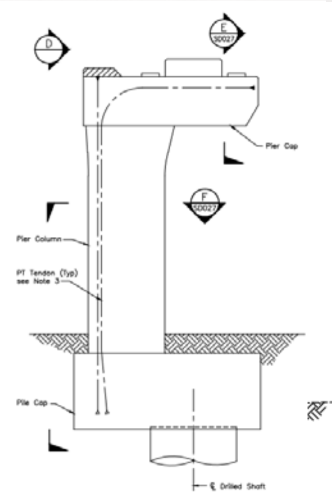
Honolulu High Capacity Transit Corridor Project   Prepared by Parsons Brinckerhoff   November 2010   Panel 3

General Span / Pier Layout

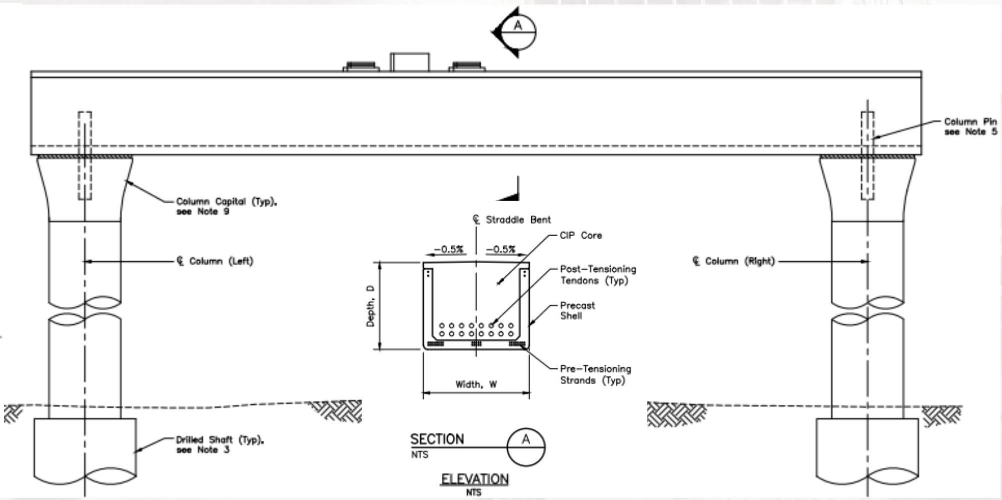
Typical Span Layout



Typical Bent



C-Bent



Straddle Bent

PIER SUMMARY

Pier Type	Airport	City Center
	(Pier 423-Pier 636)	(Pier 637-Pier 808)
Typical Pier	163	107
C-Pier	15	19
Hammerhead Stations	11	20
Hammerhead Transition Piers	0	2
Straddle Station Piers	7	8
Straddle Piers	18	13
C - Straddles	0	3
Total Piers	214	172
Total Shafts	239	196

GEOTECHNICAL SUMMARY

Type	Date	No. of Piers	1
G-1	30-Sep-13	20	439
G-2	17-Oct-13	20	471
G-3	25-Oct-13	20	508
G-4	29-Oct-13	10	525
G-5	24-Nov-13	21	584
G-6	27-Jan-14	20	423
G-7	18-Apr-14	20	485
G-8	30-May-14	20	517
G-9	13-Jun-14	18	514
G-9A	14-Jul-13	3	541
G-10	17-Oct-14	20	638
G-11	24-Oct-14	30	658
G-12	31-Oct-14	20	463
G-13	4-Nov-14	30	688
G-14	7-Nov-14	30	738
G-15	7-Nov-14	20	427
G-16	14-Nov-14	25	614
G-17	5-Dec-14	30	760L
G-18	8-Dec-14	30	787
G-19	25-Dec-14	1	637
G-20	10-Feb-15	3	465
G-21	10-Feb-15	23	697L
G-22	10-Feb-15	2	716
TOTAL:		435	

435 Borings

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DRILLED SHAFT CONFIGURATIONS

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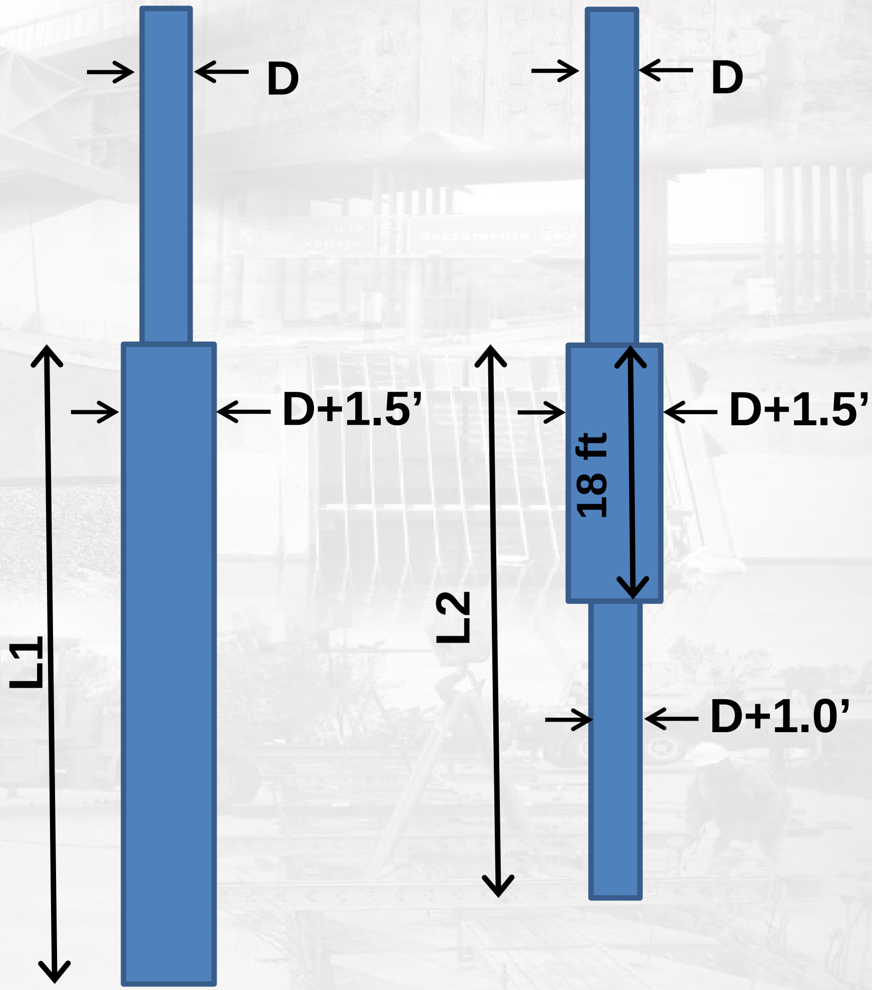
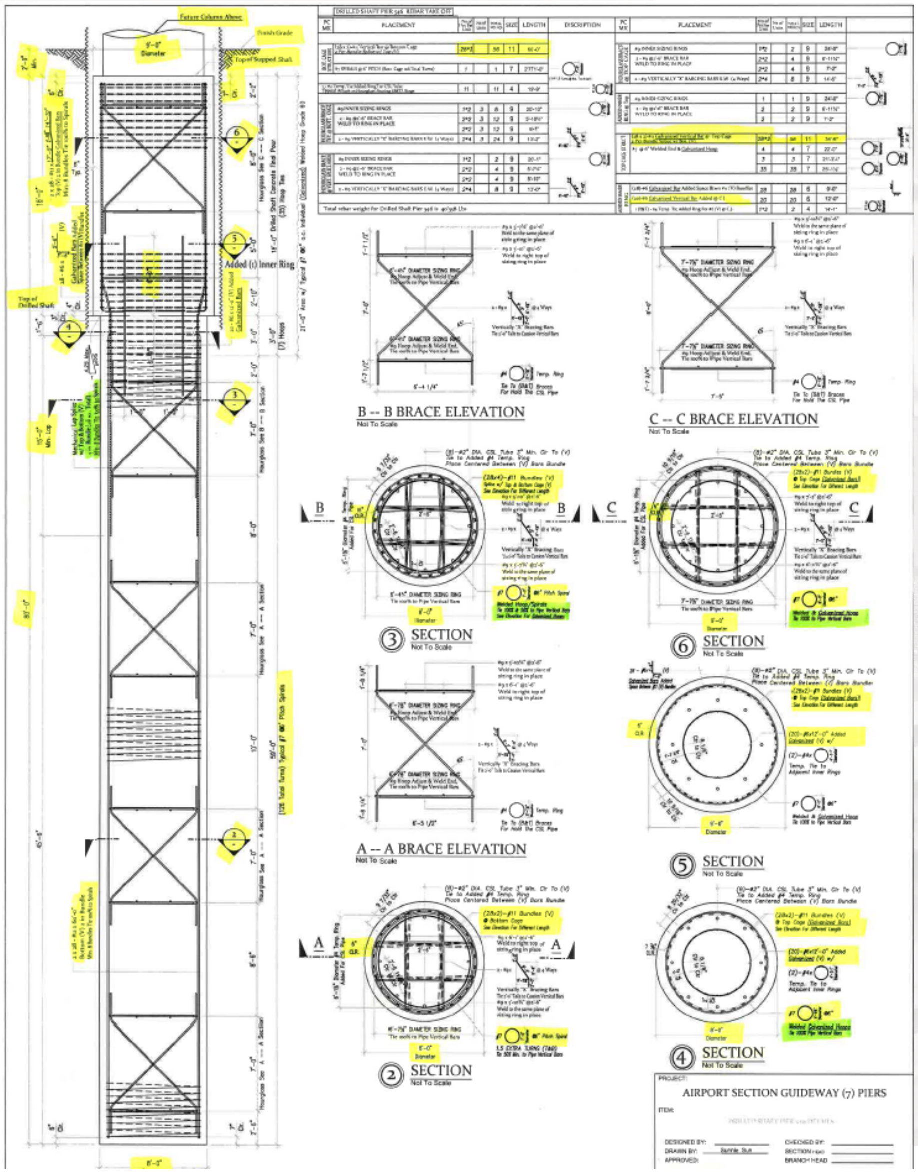
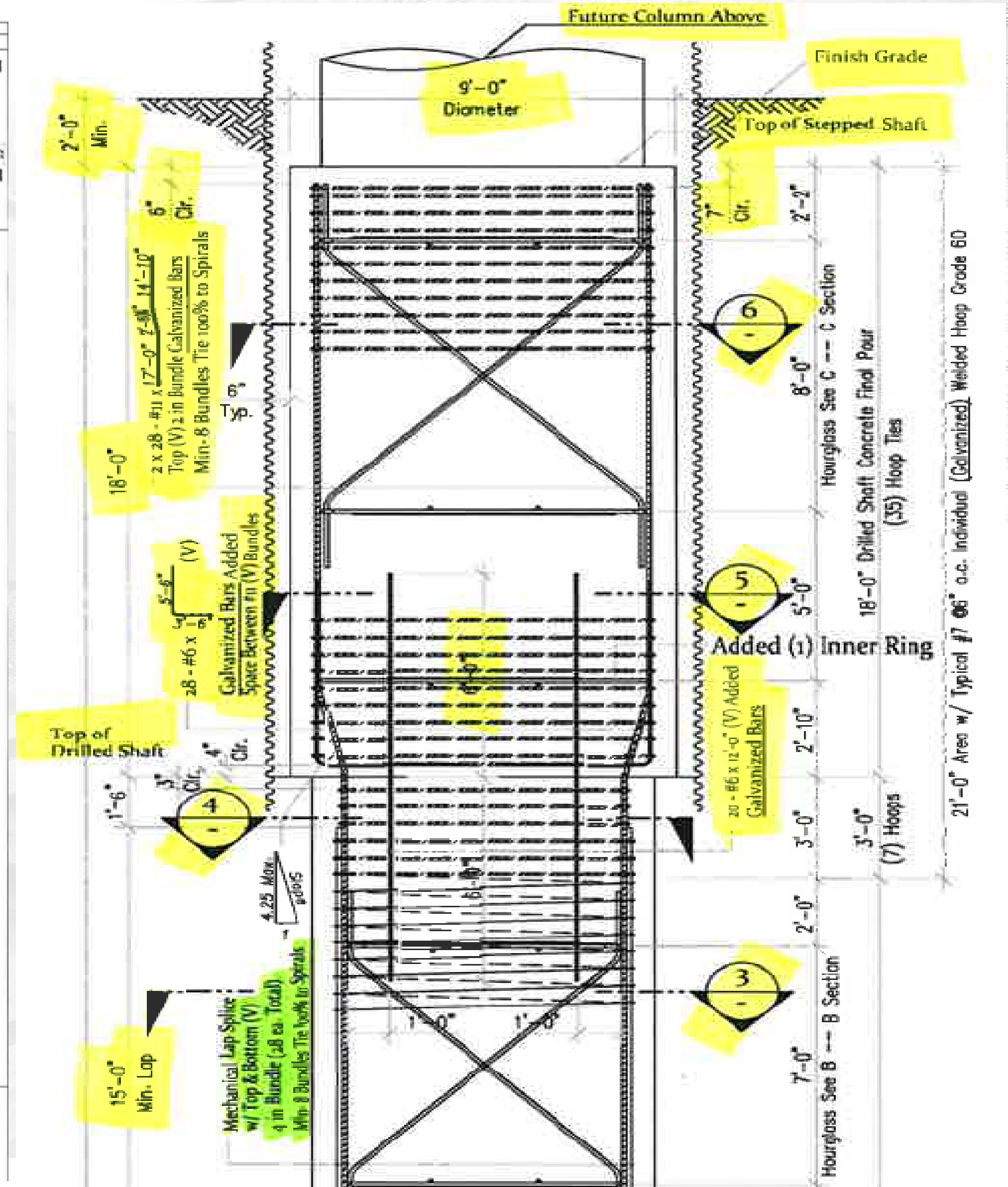
- Two Basic Shaft Configurations:
  - Prismatic
  - Stepped

- Stepped Shaft used to reduce the total shaft length based on the stability considerations ($L_2 < L_1$).



Stepped Shaft Reinforcement





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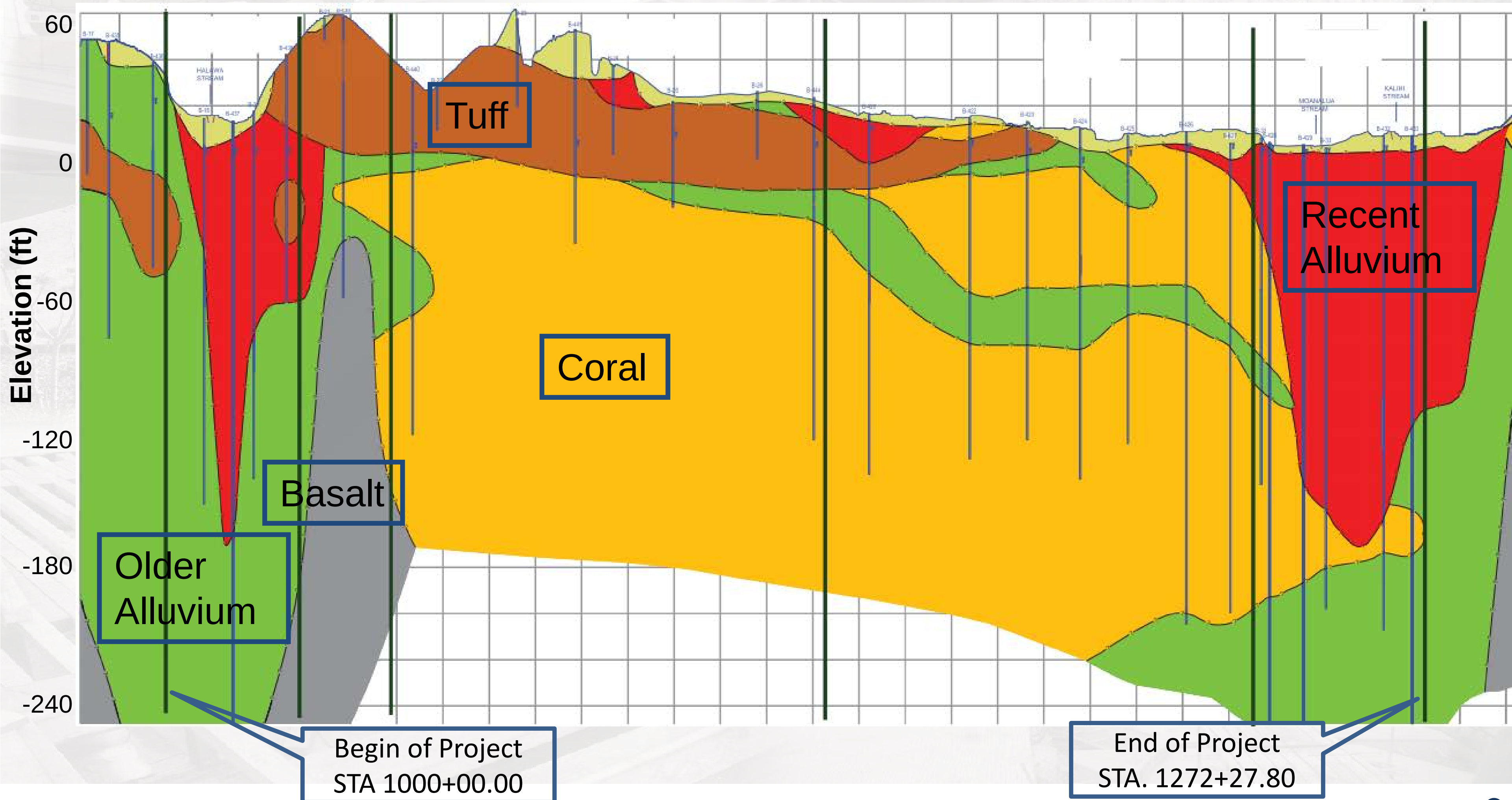
Design Criteria

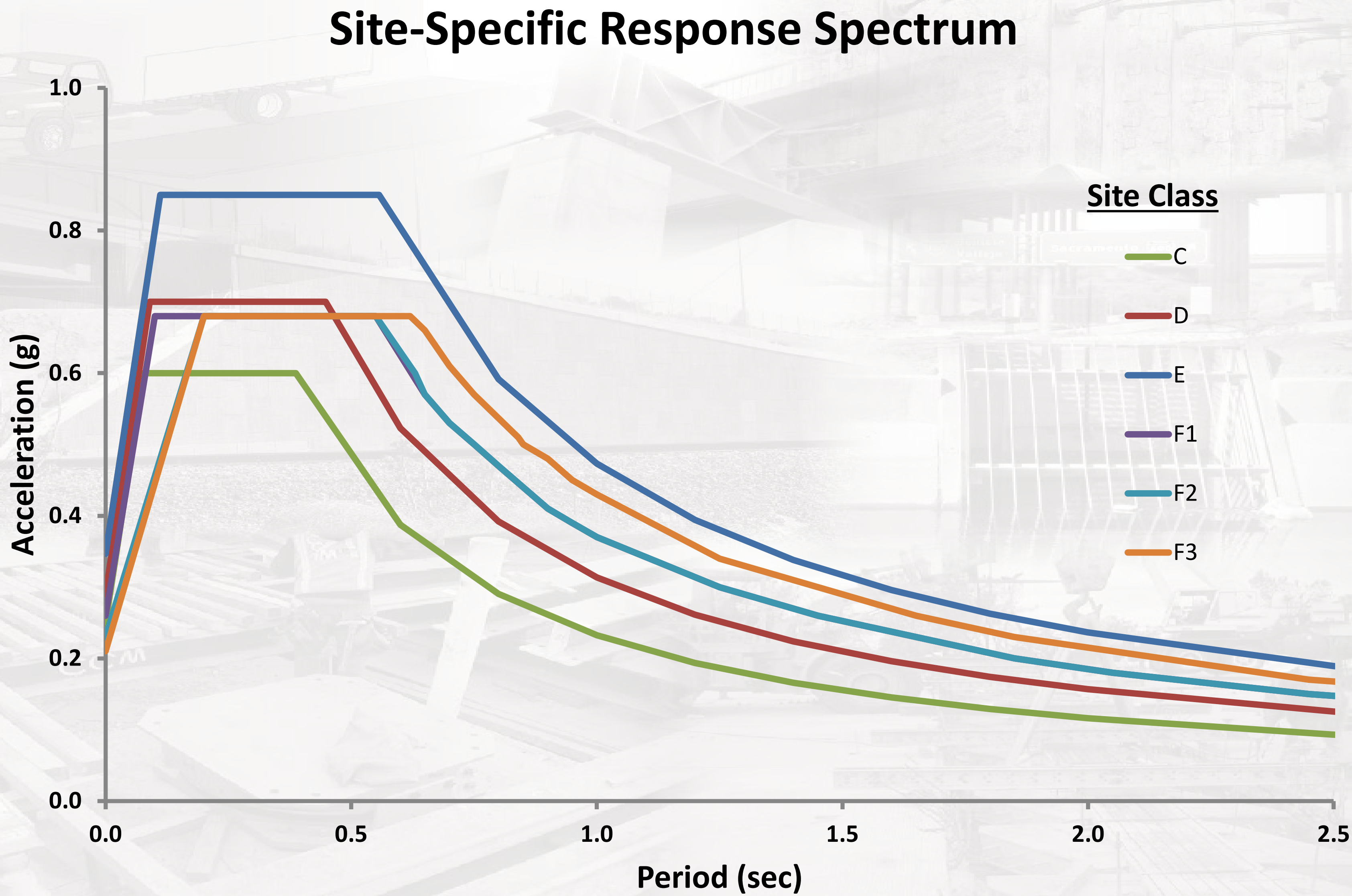
Criteria	Limit State
Axial-Flexural-Shear Capacity	Strength and Extreme Limit States
Lateral Stability	Strength and Extreme Limit States
Buckling Capacity	Strength and Extreme Limit States
Lateral Deflections	• Service Limit State- 1" (excluding wind effects) • Extreme (Seismic) Limit State- 18" at Top of Rail (Seismic)

SEISMIC PARAMETERS

Project Subsurface Profile



SEISMIC PARAMETERS



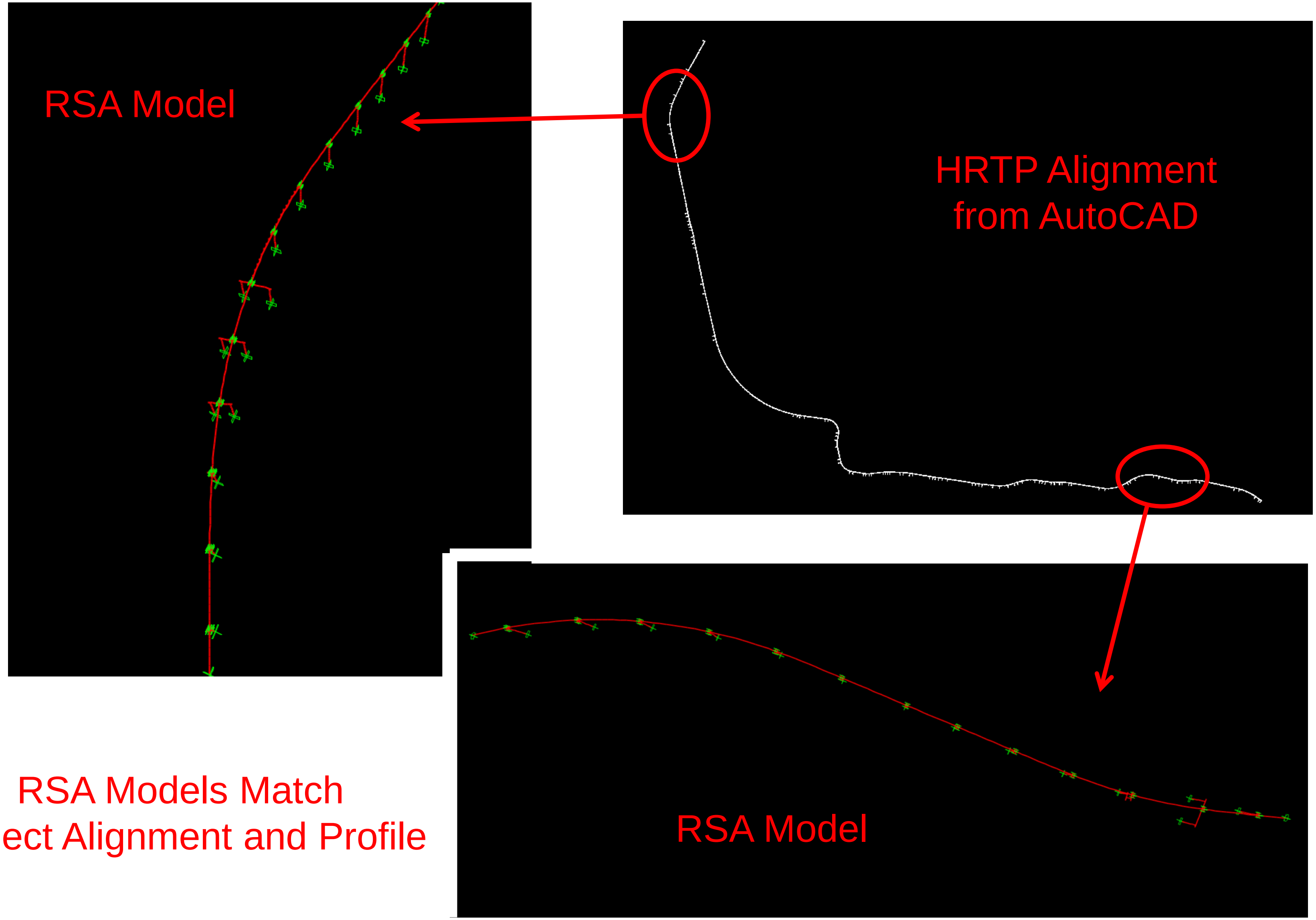
Flexible Design Process to Accommodate Changes:

- Layout
- Profile
- Utilities
- Roadways
- Geotechnical
- Parametric Studies

Seismic Analysis

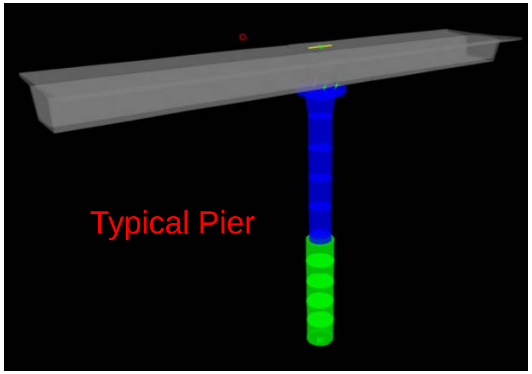
- Setting Up Automation Procedure
  - Large Scale Project
    - Near 400 Piers with Varying Configurations/Design Data
  - Time Consuming
    - Response Spectrum Analysis (RSA)
    - 12-Span Finite Element Modeling (FEM)
  - Possible Re-work Due To Changes In
    - Pier Geometry
    - Soil Data

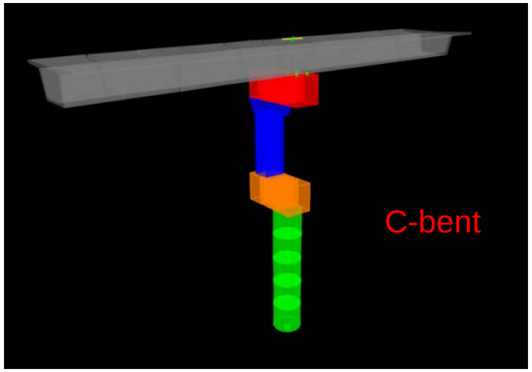
Seismic Analysis 3-step Automation

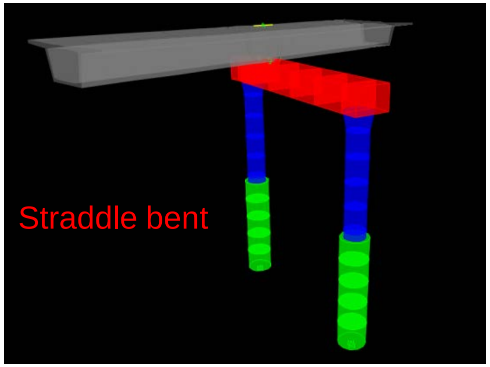


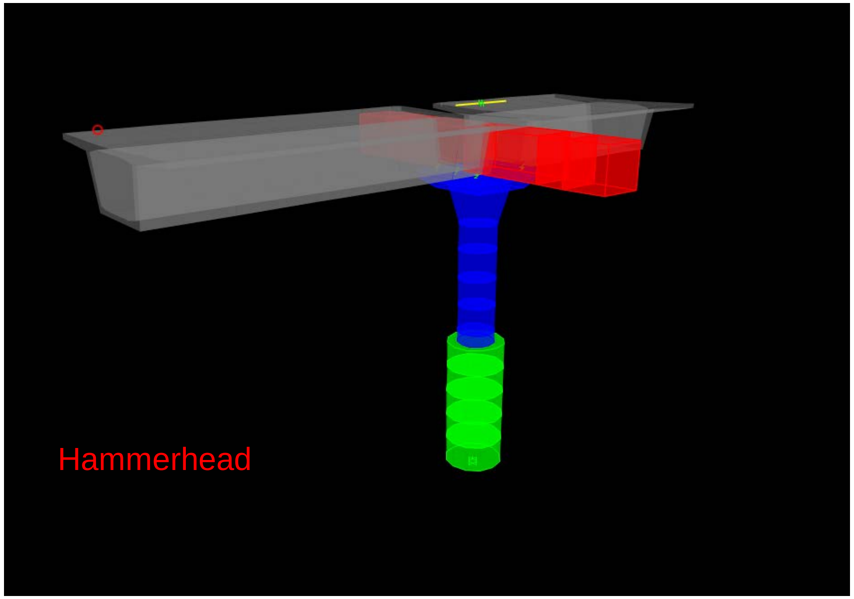
RSA Models Match Project Alignment and Profile

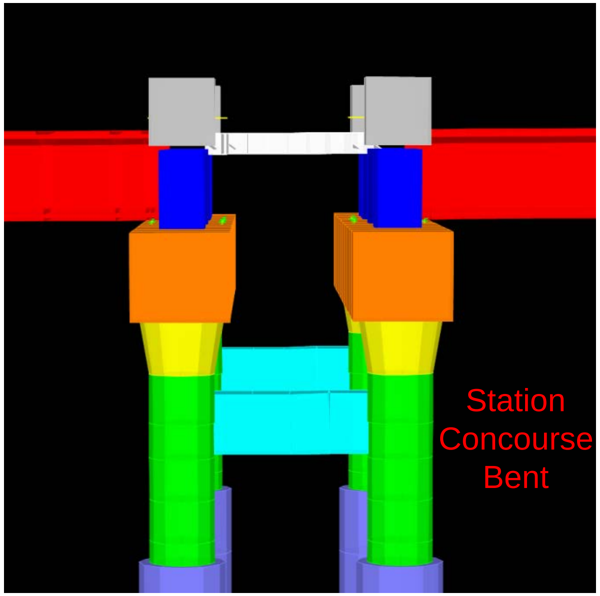
Pier Models (Templates)



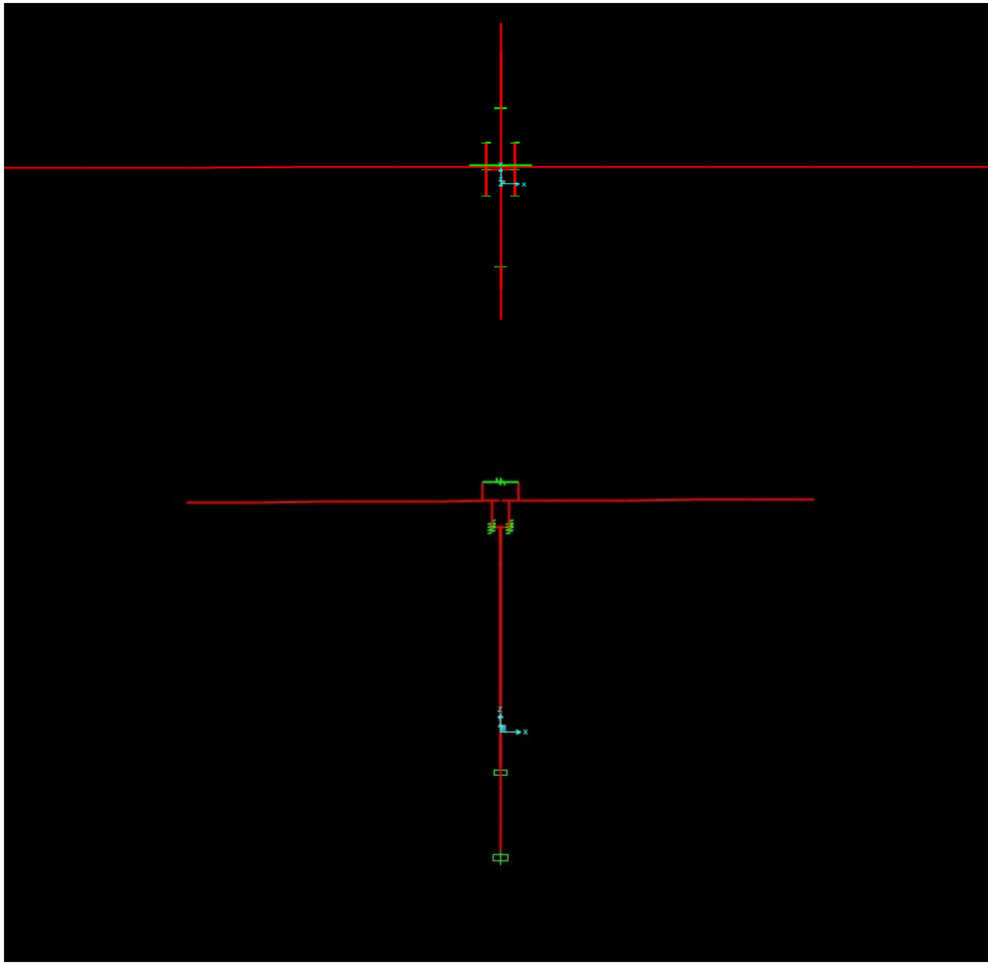


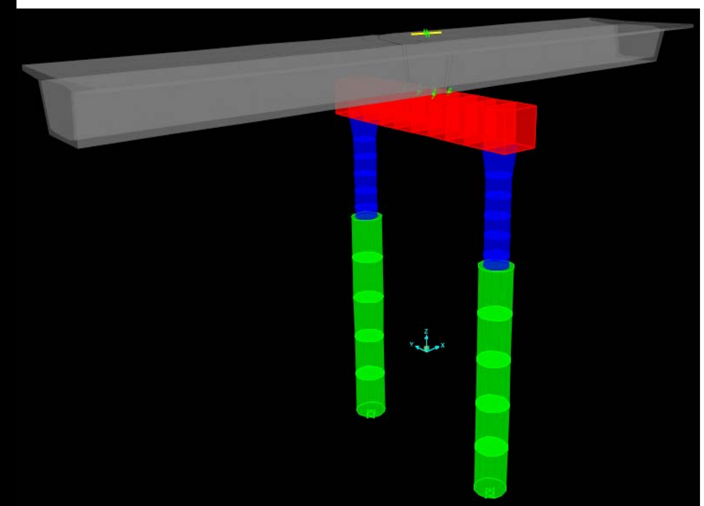




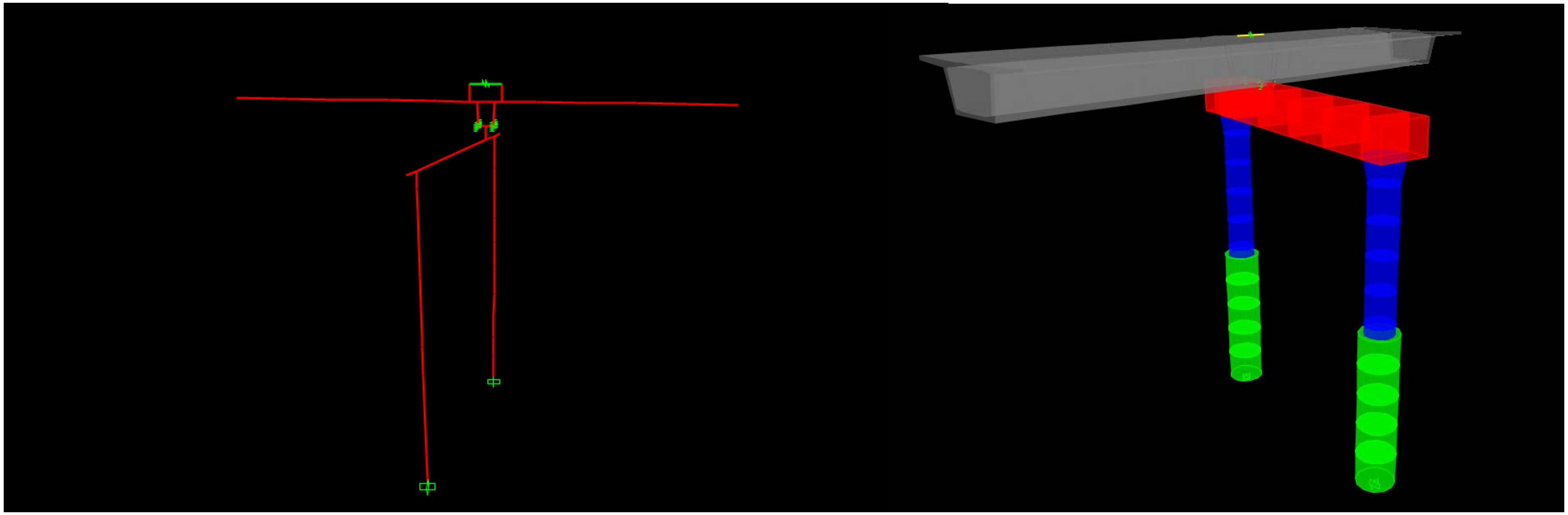


Straddle Bent - Template





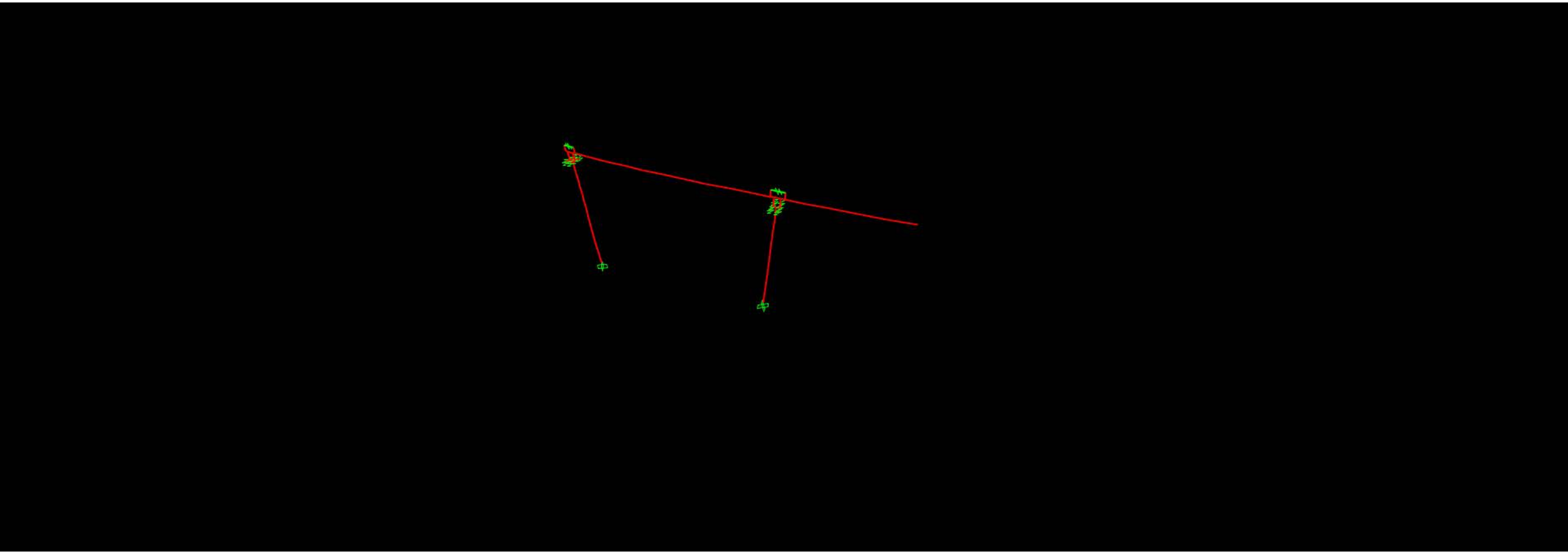
Straddle Bent - Modified



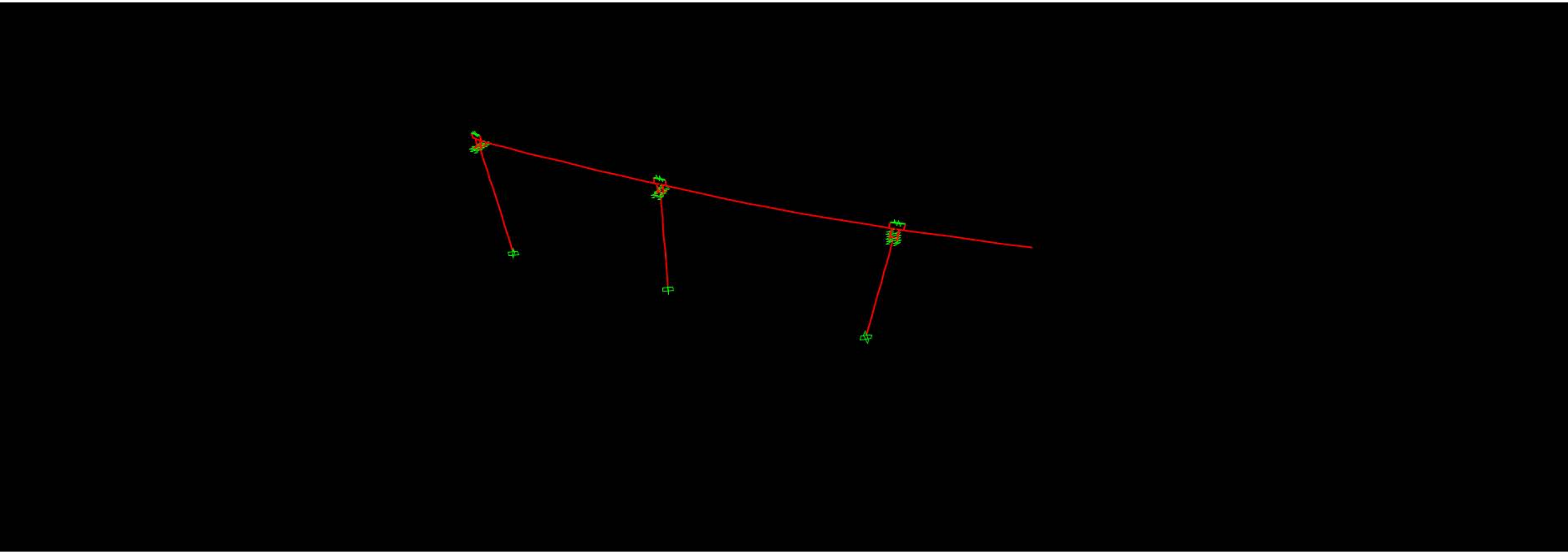
Modifications Include:

- **Horizontal Curve**
- **Vertical Profile**
- **Pier Offsets / Properties**

Assembling Pier Models



Assembling Pier Models



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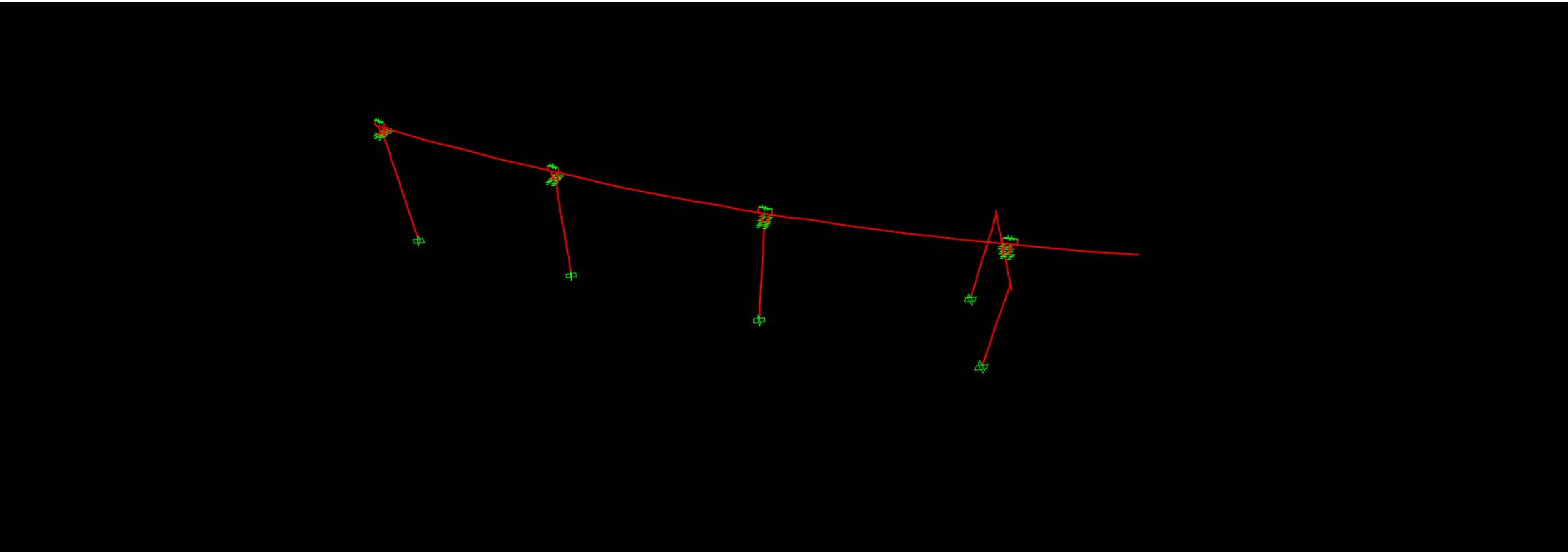
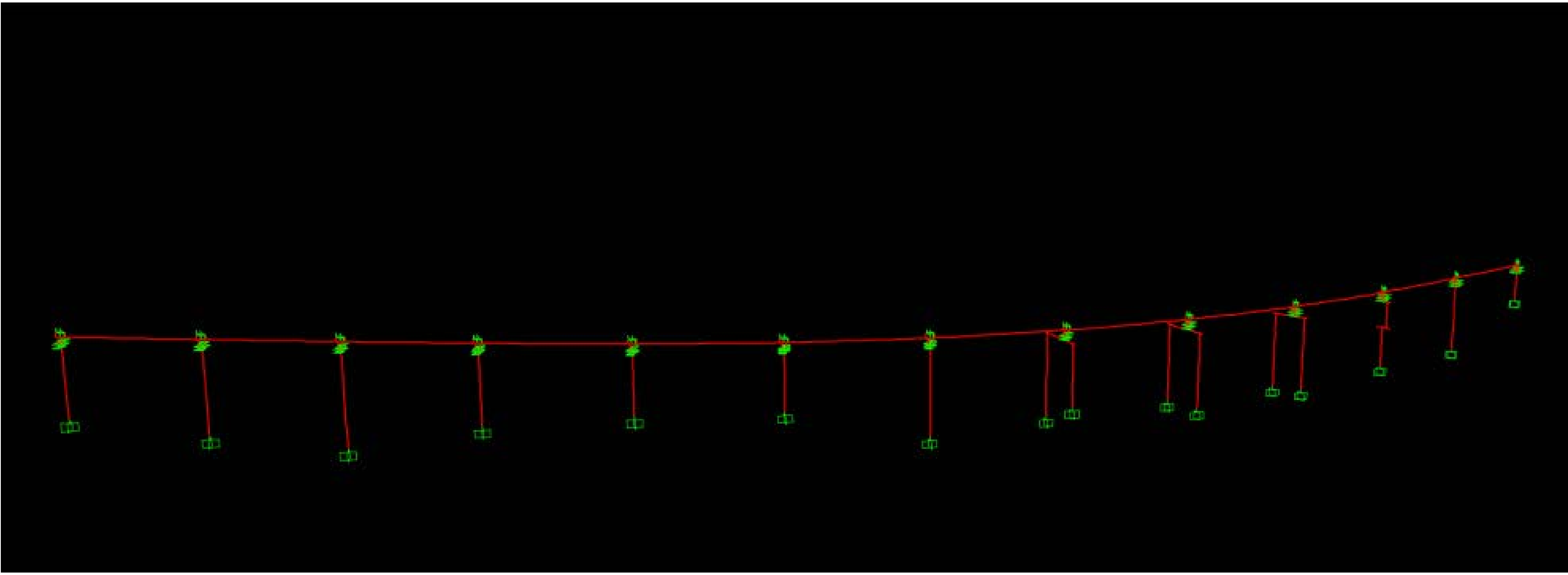
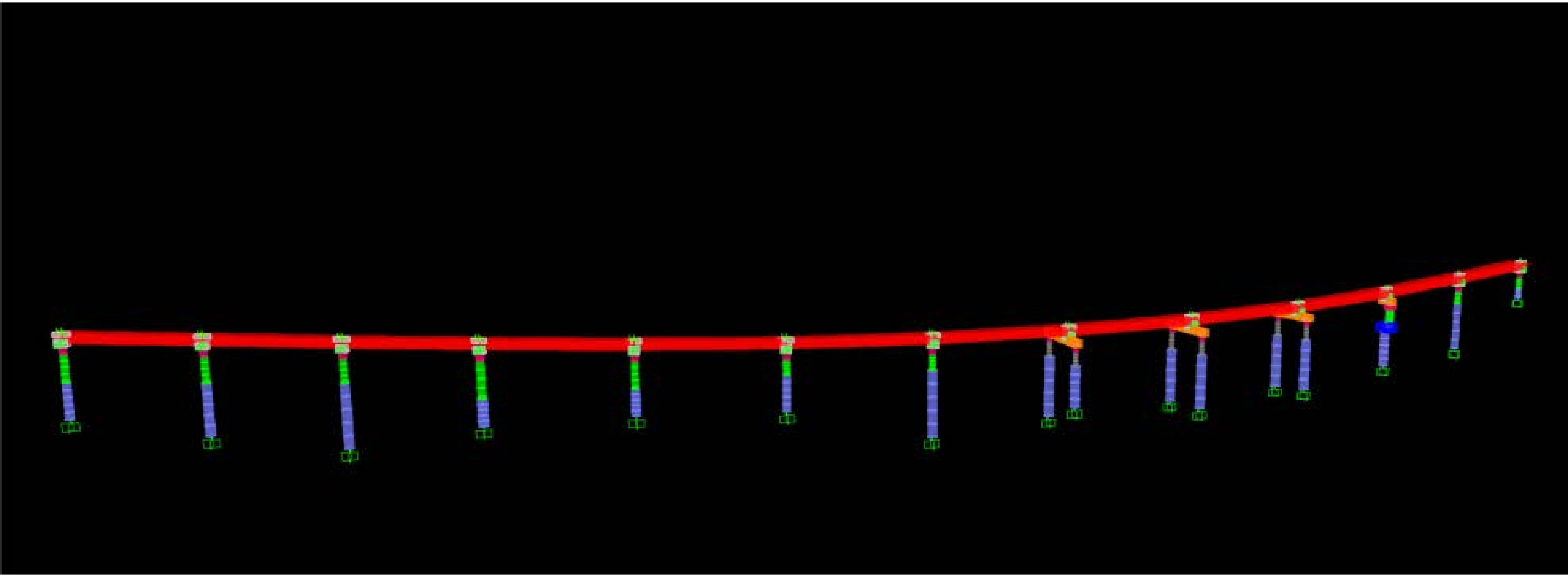


Assembled RSA Model



Assembled RSA Model



Seismic Analysis 3-step Automation

Model for Each Pier #

Pick Which Pier to Analyze

Model #	Model Name	Begin Pier	End Pier	# of Spans	Run	
1	M422	416	428	12	X	1
2	M423	417	429	12		0
3	M424	418	430	12		0
4	M425	419	431	12	X	1
5	M426	420	432	12		0
6	M427	421	433	12		0
7	M428	422	434	12	X	1
8	M429	423	435	12		0
9	M430	424	436	12		0
10	M431	425	437	12	X	1
11	M432	426	438	12		0
12	M433	427	439	12		0
13	M434	428	440	12		0
14	M435	429	441	12		0
15	M436	430	442	12		0
16	M437	431	443	12		0
…	…	…	…	…	…	…

SEISMIC ANALYSIS 3-STEP AUTOMATION

Step 1: Generate Pier Models

- Creates Pier Templates.
- Modify Templates to Match Actual Alignment & Profile and Pier Properties.

Step 2: Assemble Model

- "Splice" Pier Models

Step 3: Run All Assembled Models

- Runs Assembled Models From Step 2
- Read and Summarize Results

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Pick Which Pier to Analyze

Model #	Model Name	Begin Pier	End Pier	# of Spans	Run	
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5	M426	420	432	12		0
6	M427	421	433	12		0
7	M428	422	434	12	X	1
8	M429	423	435	12		0
9	M430	424	436	12		0
10	M431	425	437	12	X	1
11	M432	426	438	12		0
12	M433	427	439	12		0
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- **Read and Summarize Results**

Pier #	Pier type	Col Height	Col Diameter	Top of Rail Max Disp.	Top of Column Max Disp.	Bottom of Column Max Disp.	Top of Column Max Shear	Top of Column Max Moment	Bottom of Column Max Shear	Bottom of Column Max Moment	Bottom Col. Axial
422	Transition Pier	29.05	6								
423	Typical	30.66	6.5	11.51	11.06	3.65	495.64	3189.90	524.33	15900.25	-1400.547
424_L	Straddle Bent	29.08	6	11.51	9.41	3.09	337.50	4179.25	351.35	10586.23	-1659.885
424_R					9.05	2.95	314.21	4355.38	327.48	10243.27	-1535.425
425	C-Pier	31.17	6.5	21.21	16.40	9.36	655.47	16987.05	700.76	26728.65	-1739.524
426	Typical	36.61	6.5	17.87	14.57	4.44	545.11	4799.96	583.71	16930.53	-1363.617
427	Typical	35.06	6.5	17.23	13.86	4.14	525.12	4045.77	563.66	17433.87	-1267.738
428	Typical	33.17	6.5	16.04	12.67	3.82	497.14	2561.16	529.84	17248.10	-1255.023

SEISMIC ANALYSIS 3-STEP AUTOMATION

Step 1: Generate Pier Models

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Step 2: Assemble Model

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Step 3: Run All Assembled Models

- Runs Assembled Models From Step 2
- **Read and Summarize Results**

OTHER DESIGN PROCEDURES WERE ALSO AUTOMATED IN A SIMILAR FASHION.

Pier #	Pier type	Col Height	Col Diameter	Top of Rail Max Disp.	Top of Column Max Disp.	Bottom of Column Max Disp.	Top of Column Max Shear	Top of Column Max Moment	Bottom of Column Max Shear	Bottom of Column Max Moment	Bottom Col. Axial
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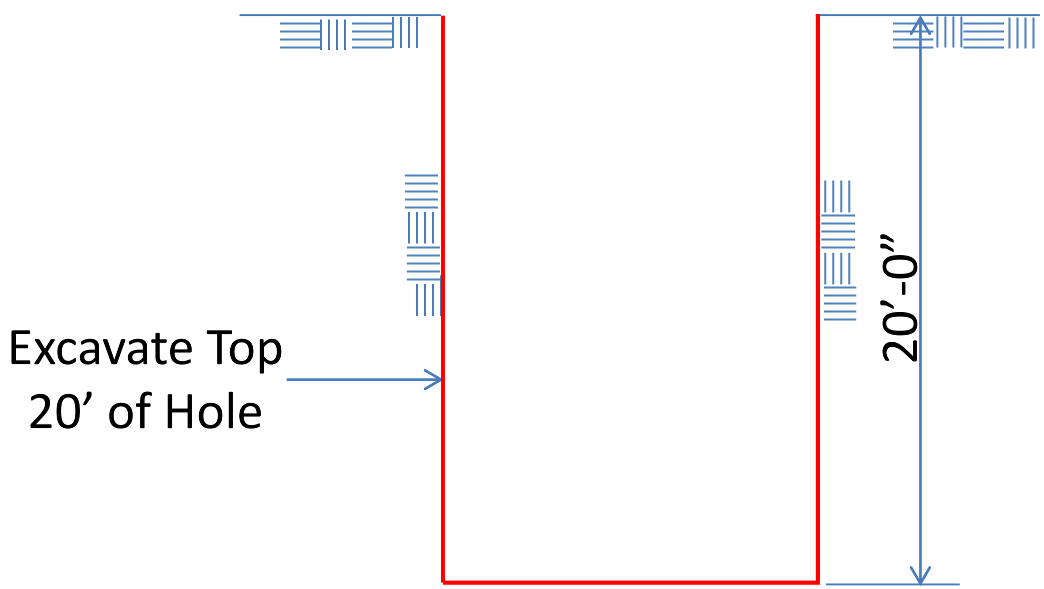
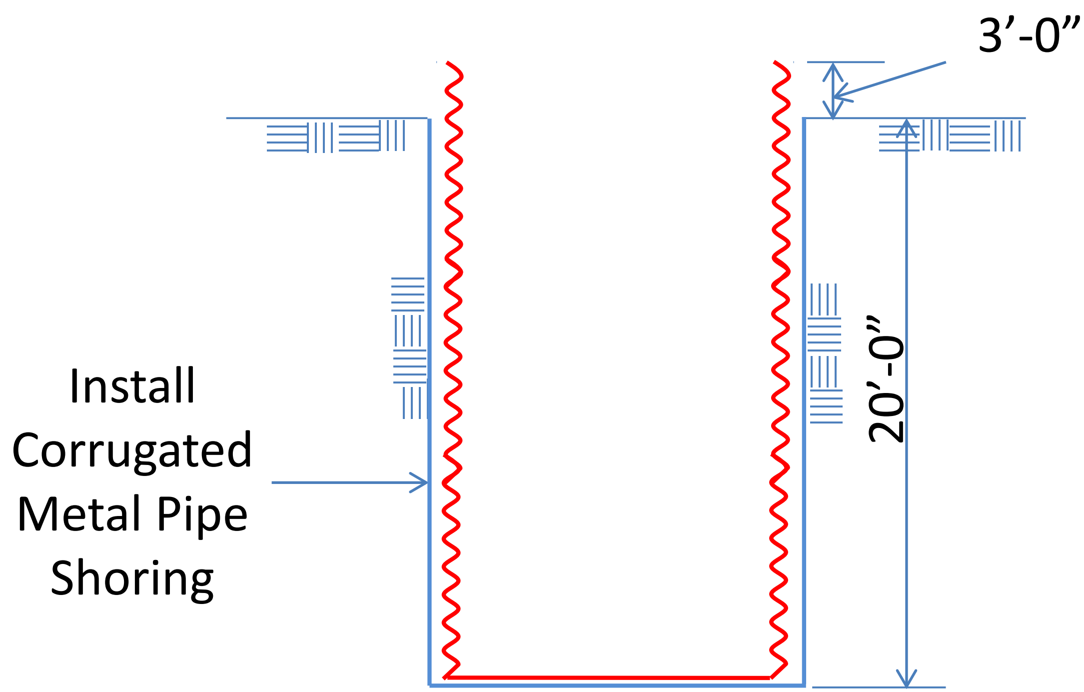
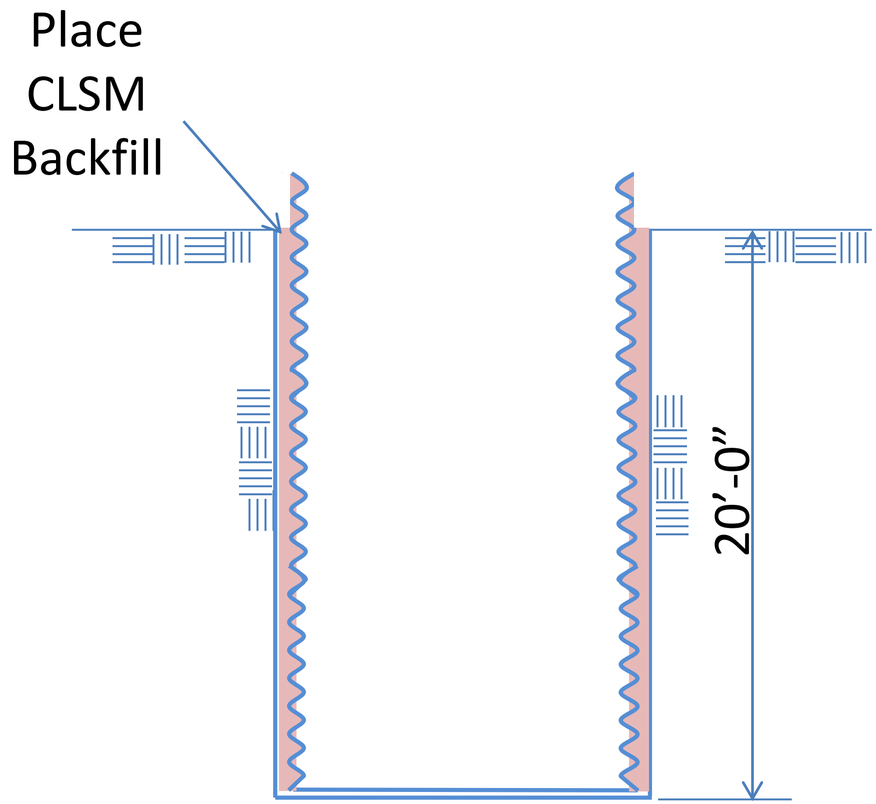
Typical Shaft Construction
Step 1



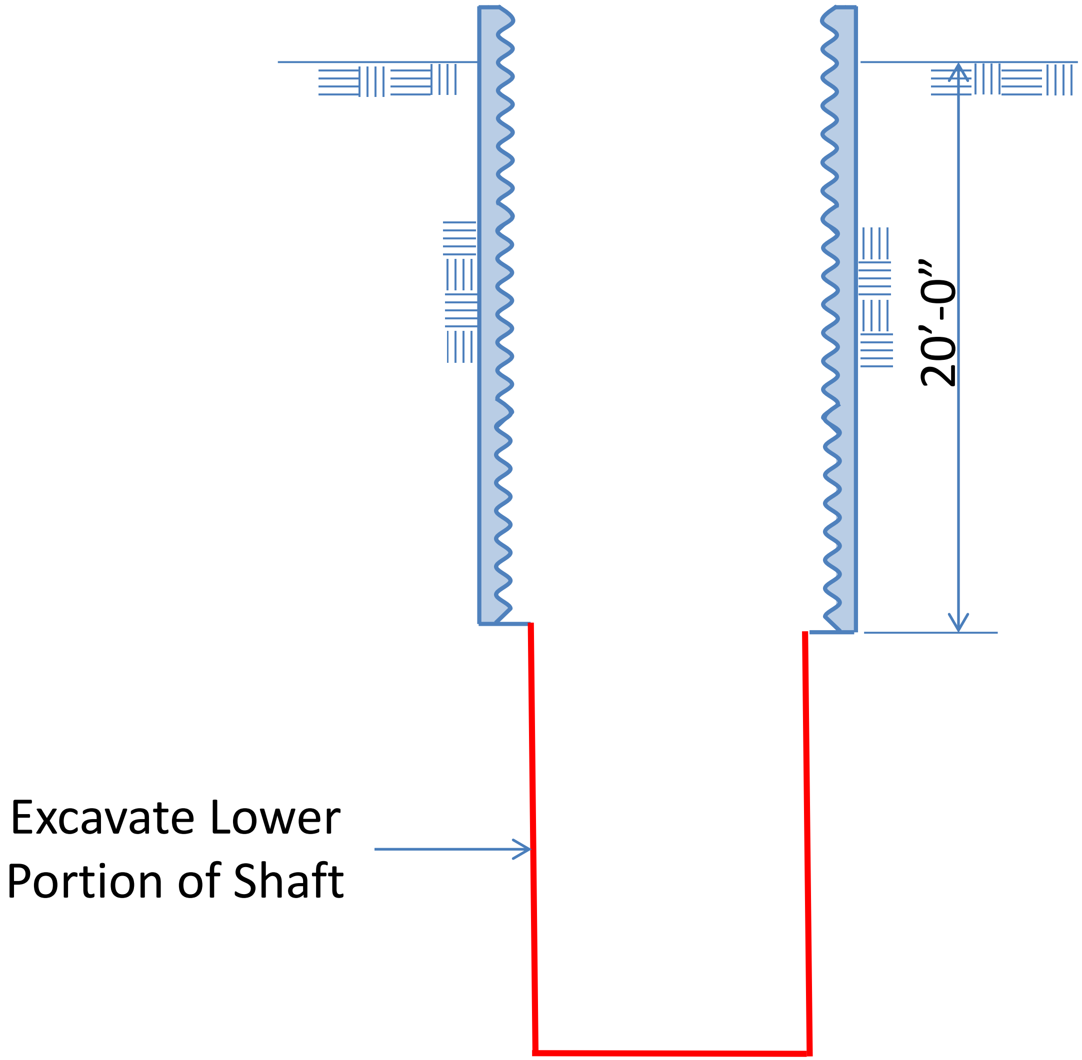
Typical Shaft Construction
Step 2



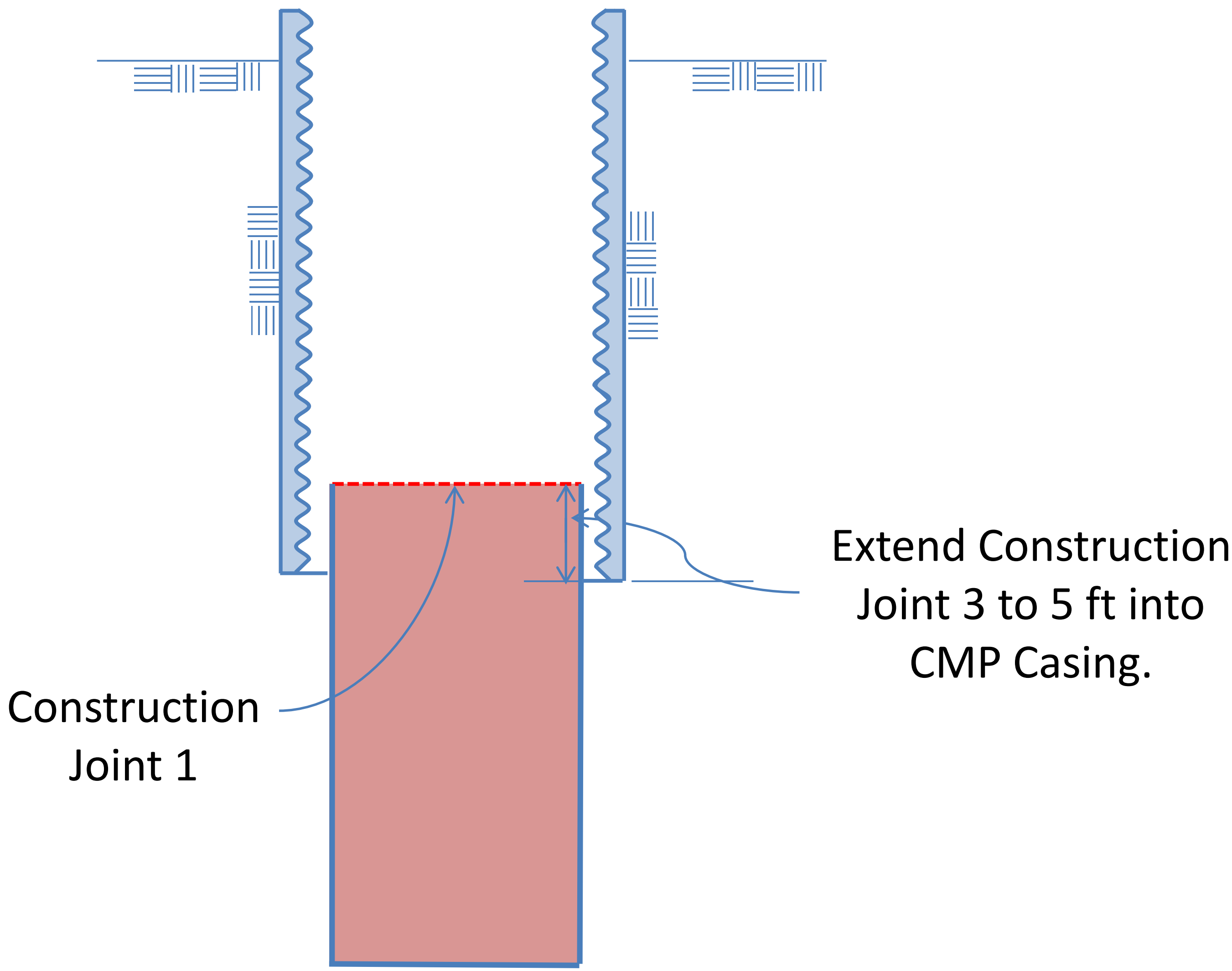
Typical Shaft Construction
Step 3



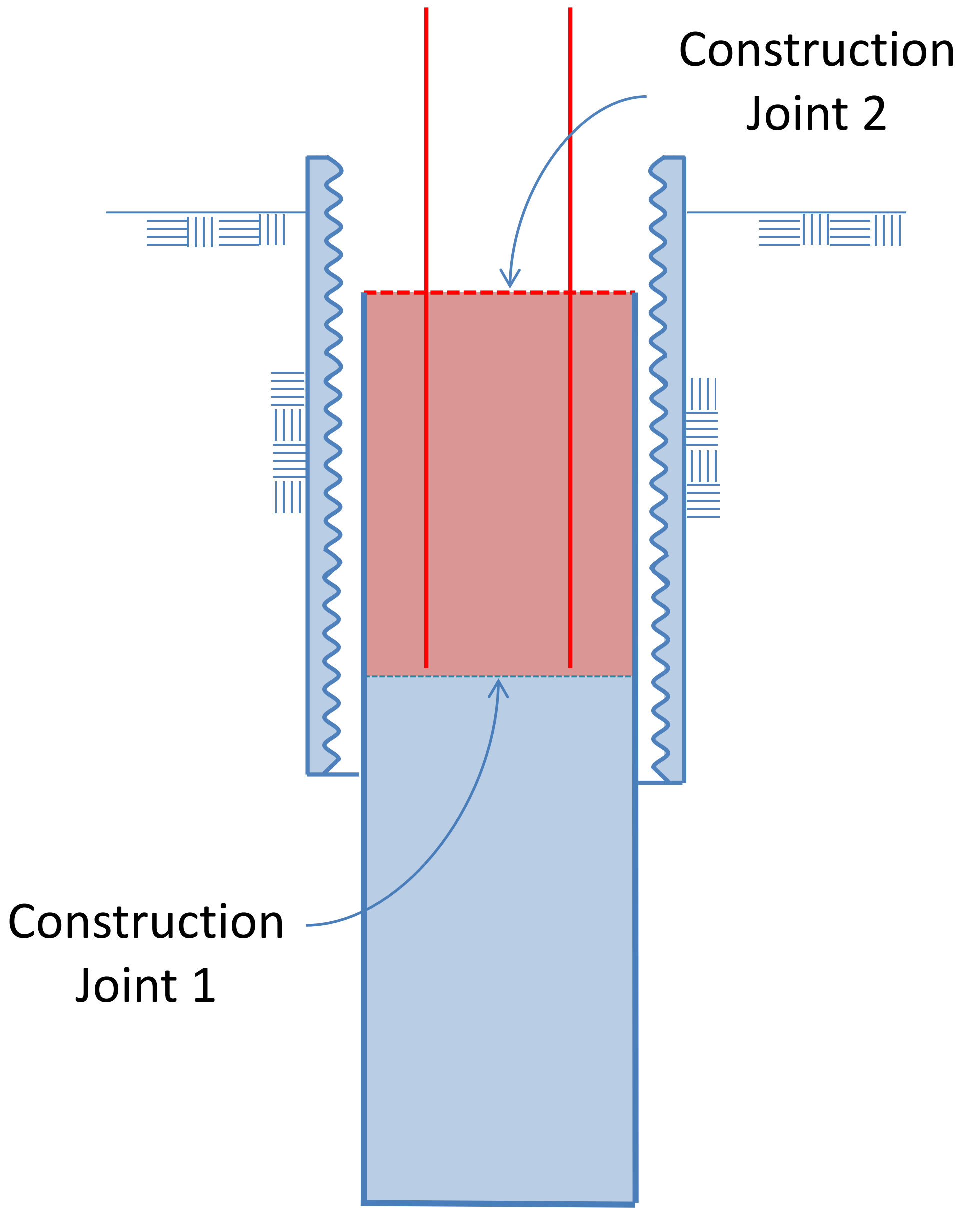
Typical Shaft Construction
Step 4



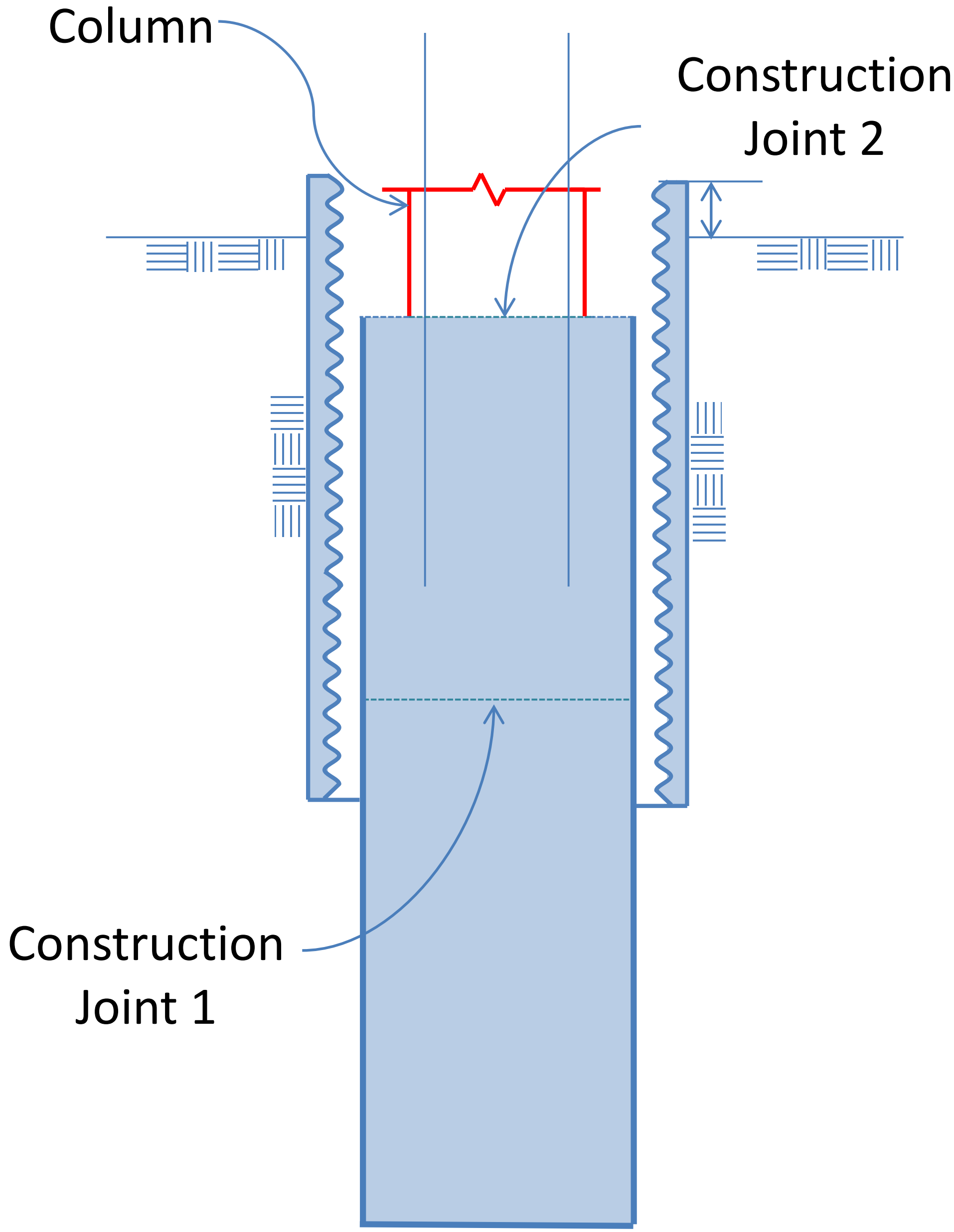
Typical Shaft Construction
Step 5



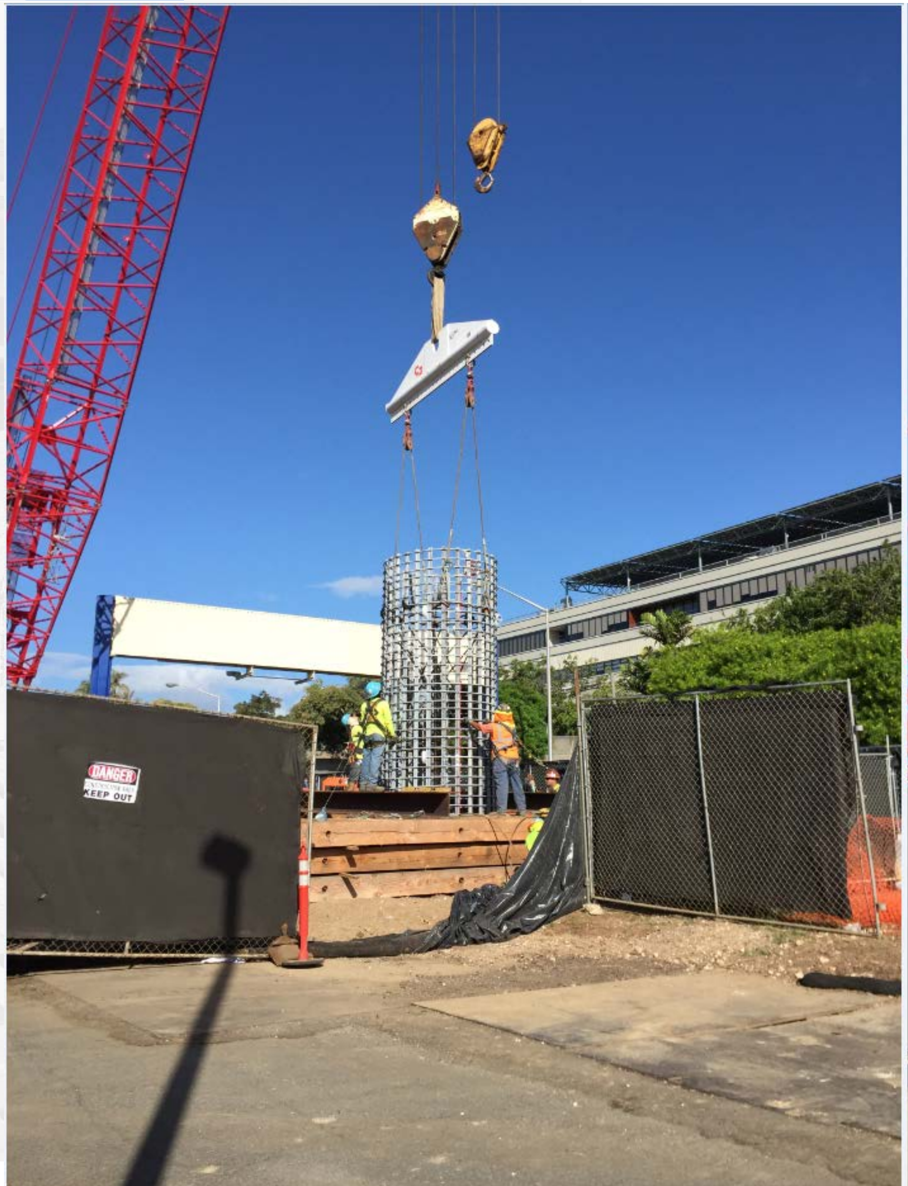
Typical Shaft Construction
Step 6



Typical Shaft Construction Step 7



CONSTRUCTION PHOTOS



Final Inspection Photos

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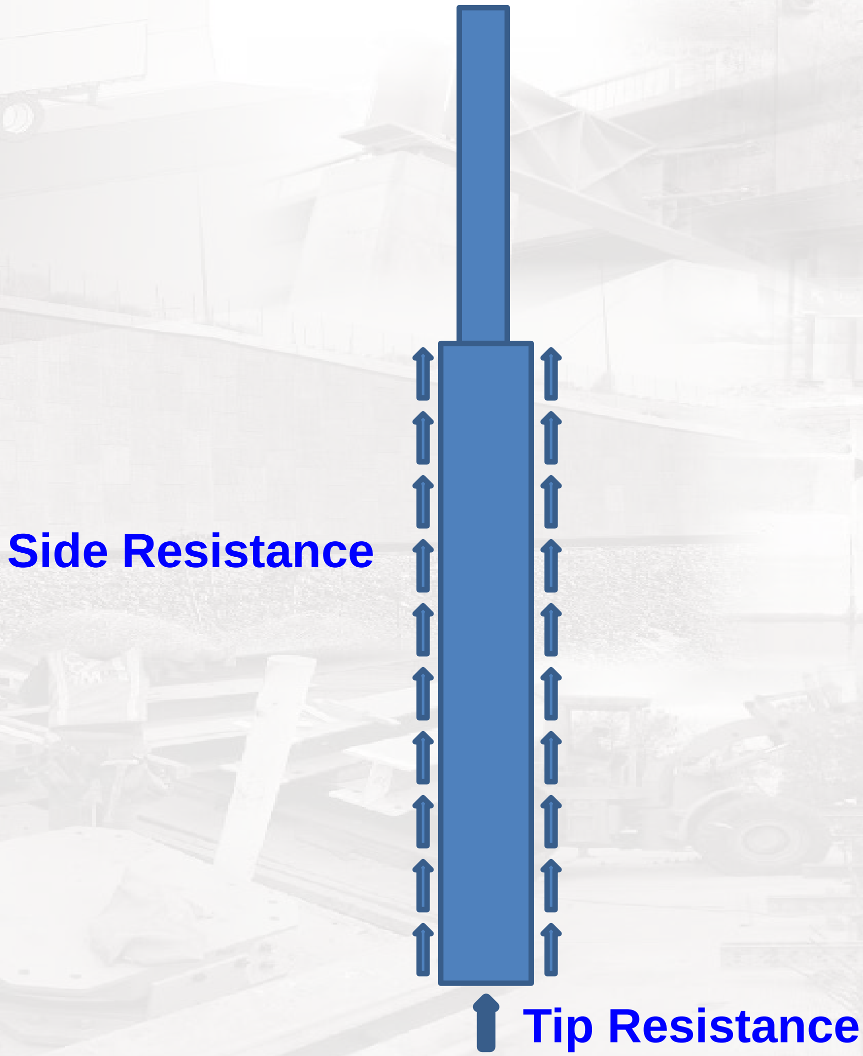
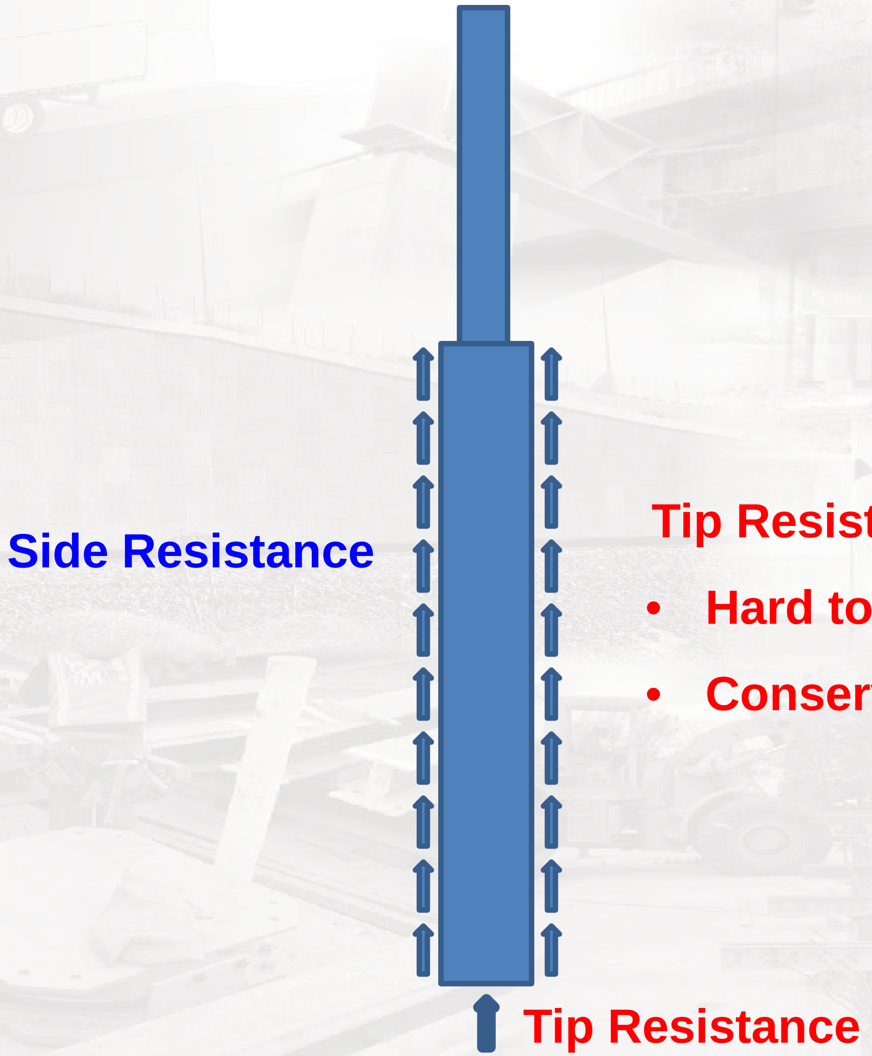
SHAFT CAPACITY



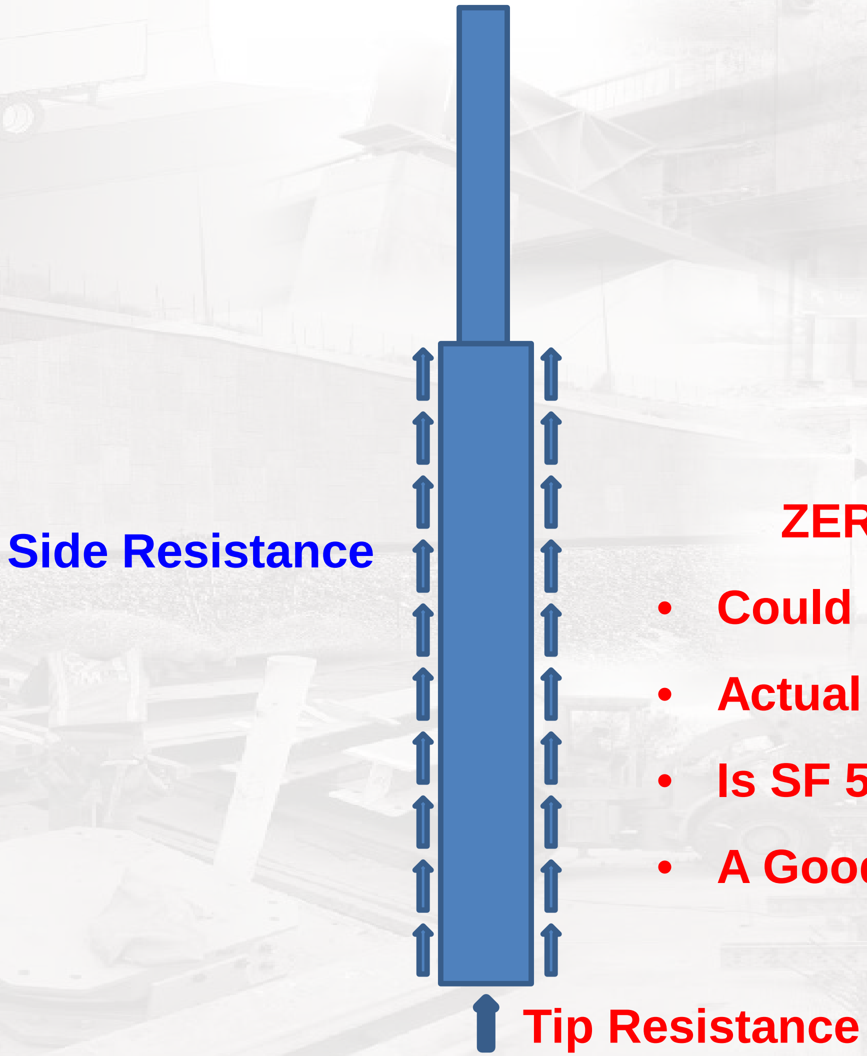
TIP RESISTANCE



Tip Resistance Typically Ignored-

- **Hard to Estimate**
- **Conservative**

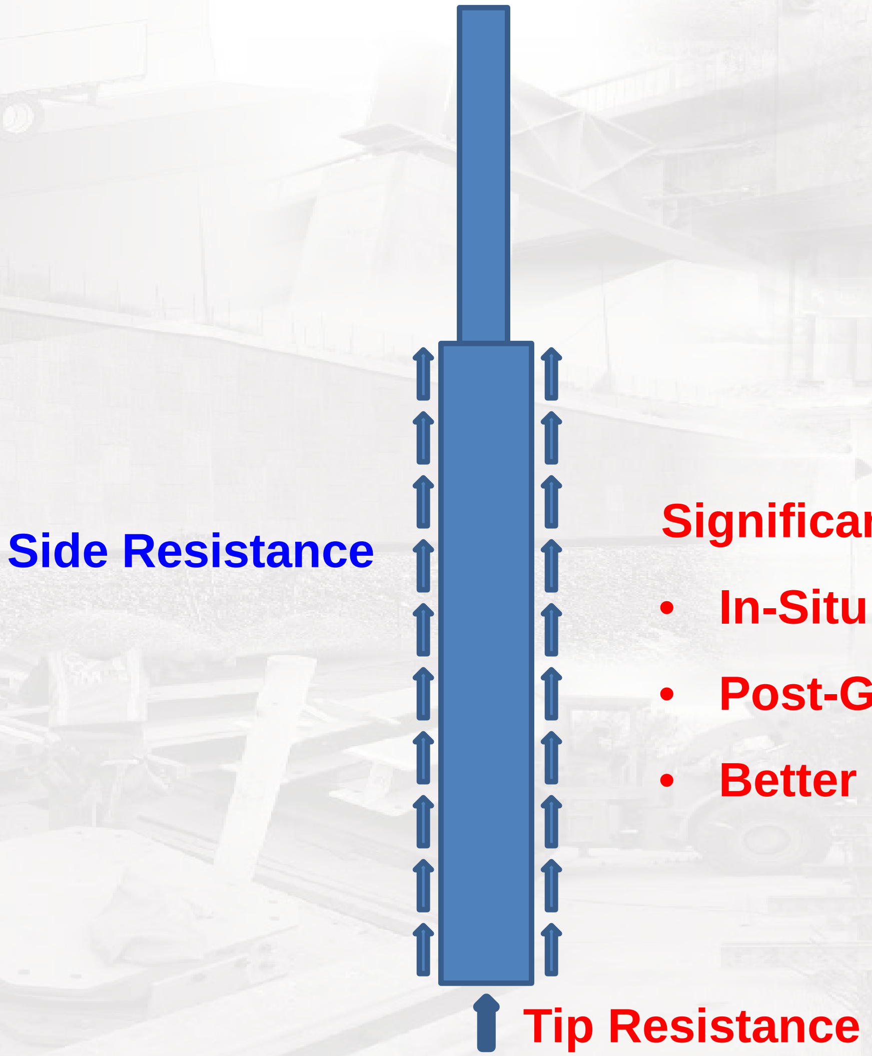
Tip Resistance



ZERO Tip Resistance:

- **Could be Very Conservative**
- **Actual SF Unknown**
- **Is SF 5 or 6 or > 6 OK?**
- **A Good Design is *Economical***

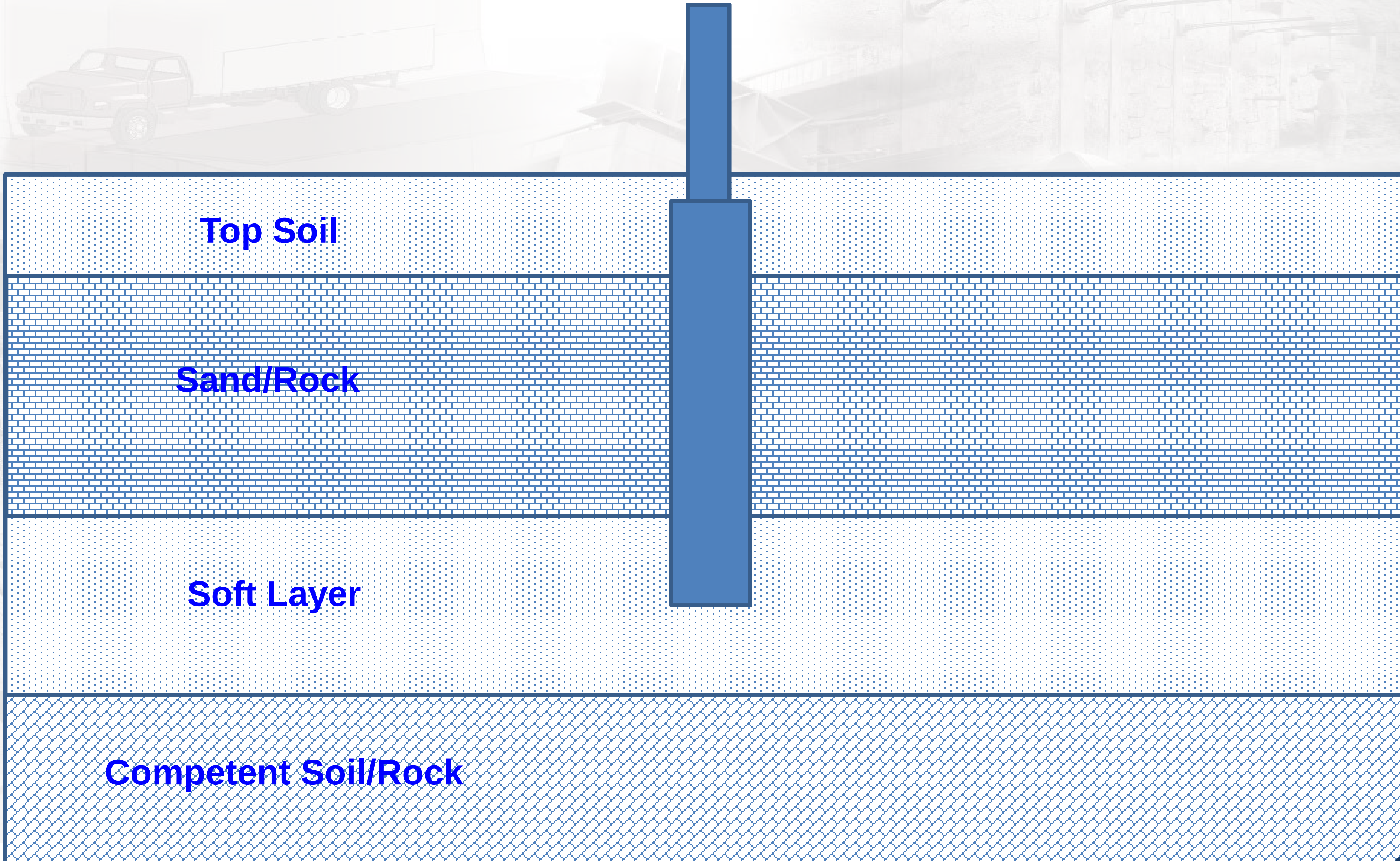
TIP RESISTANCE



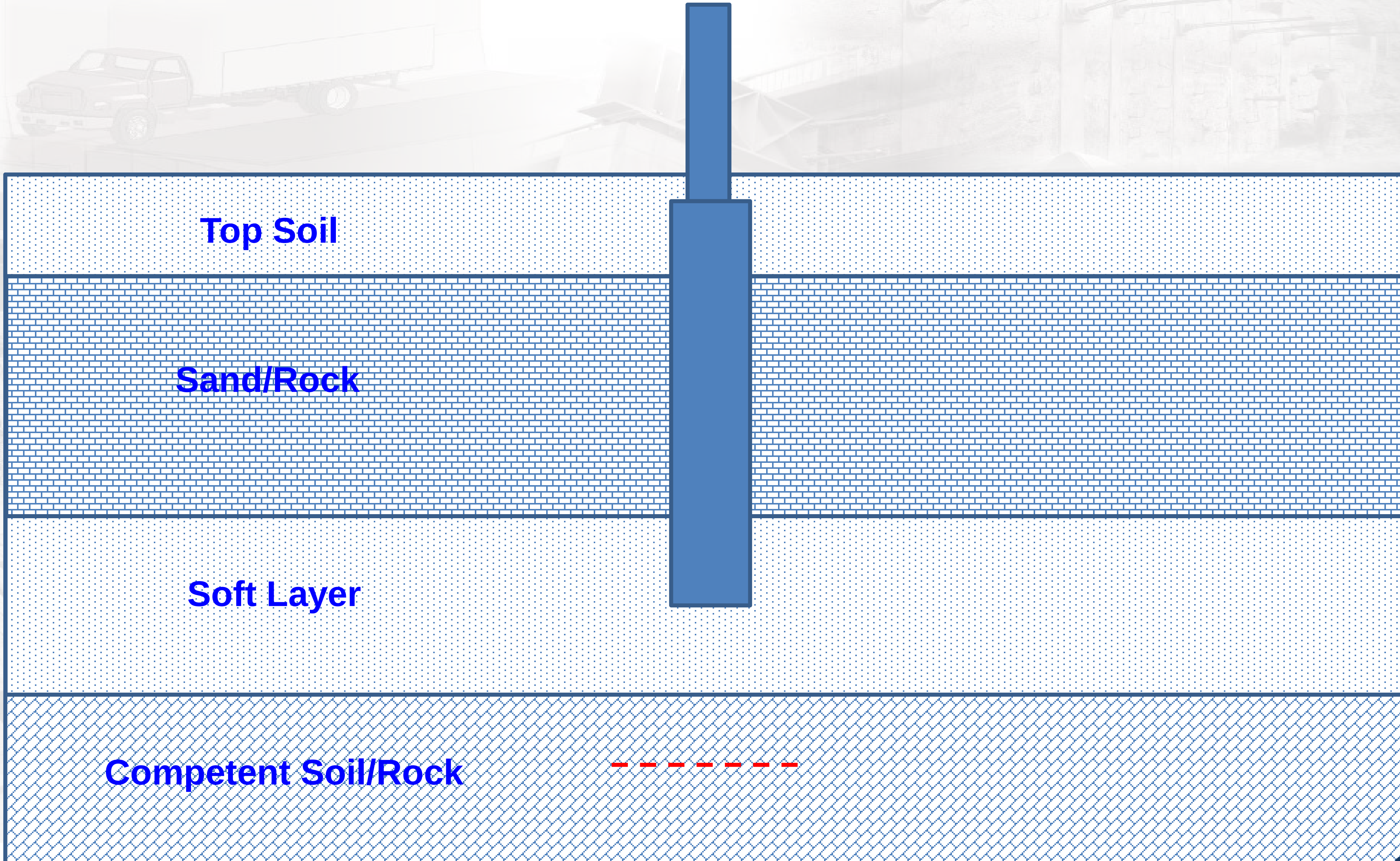
Significant Potential Savings w/:

- **In-Situ Testing**
- **Post-Grouting**
- **Better Construction Practices**

PILE CAPACITY SCENARIOS - NOT ENOUGH CAPACITY



Pile Capacity Scenarios -
Zero Tip Extend Shaft to Competent Soil



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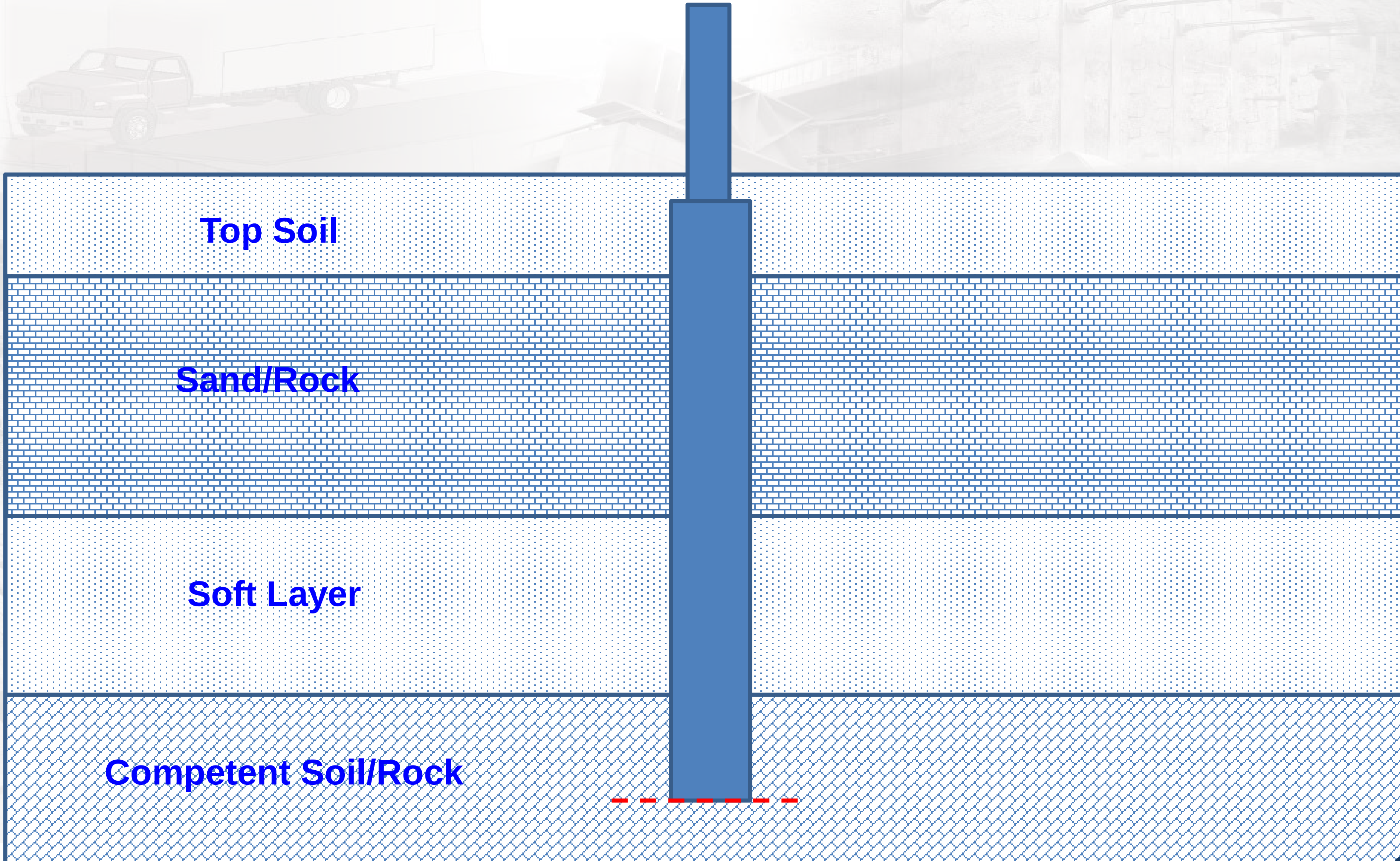
Post-Grouting Scenarios - Pile is Significantly Longer



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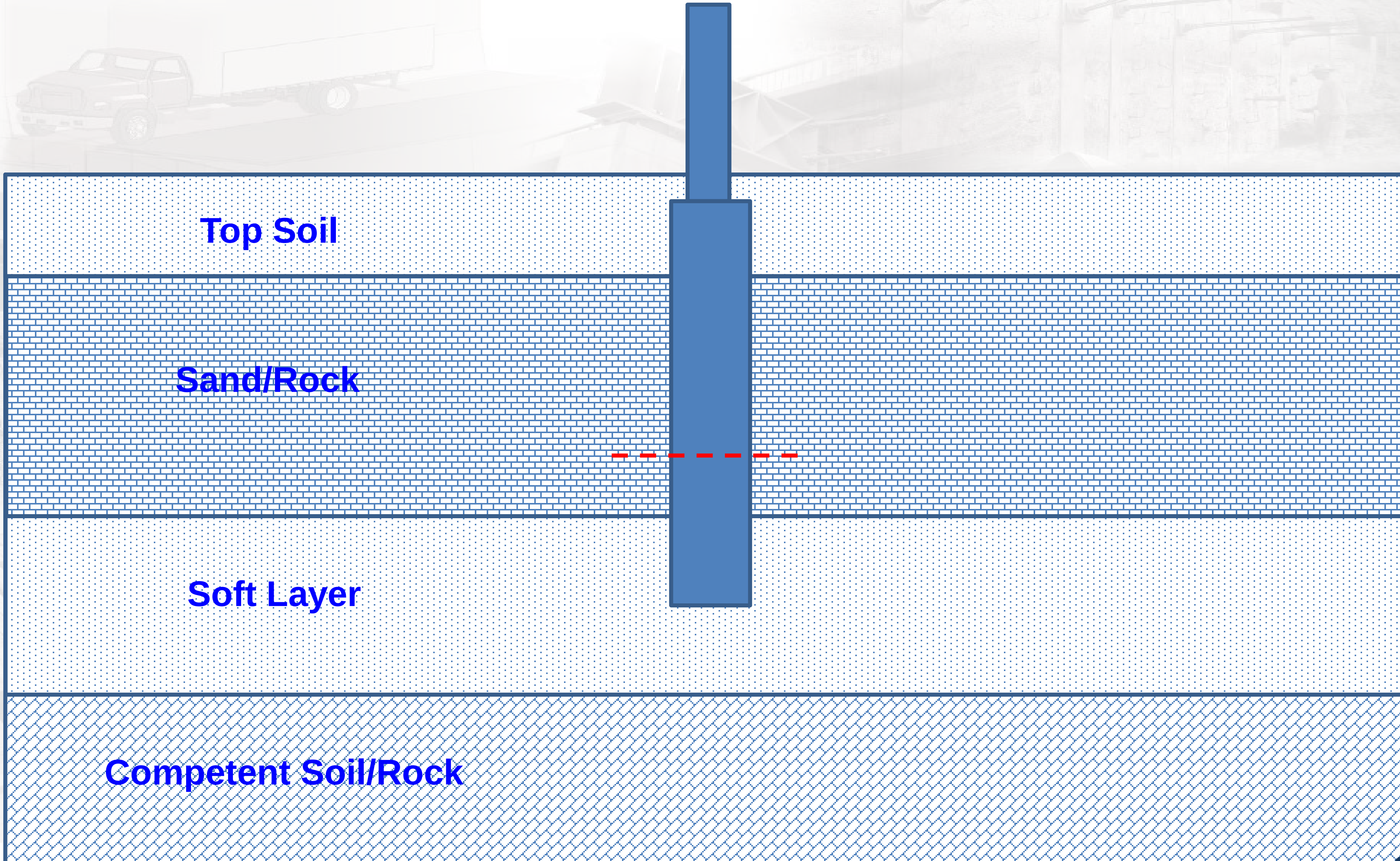
Pile Capacity Scenarios - w/ Tip-Resistance or In-situ Testing



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PILE CAPACITY SCENARIOS - SHORTER PILE

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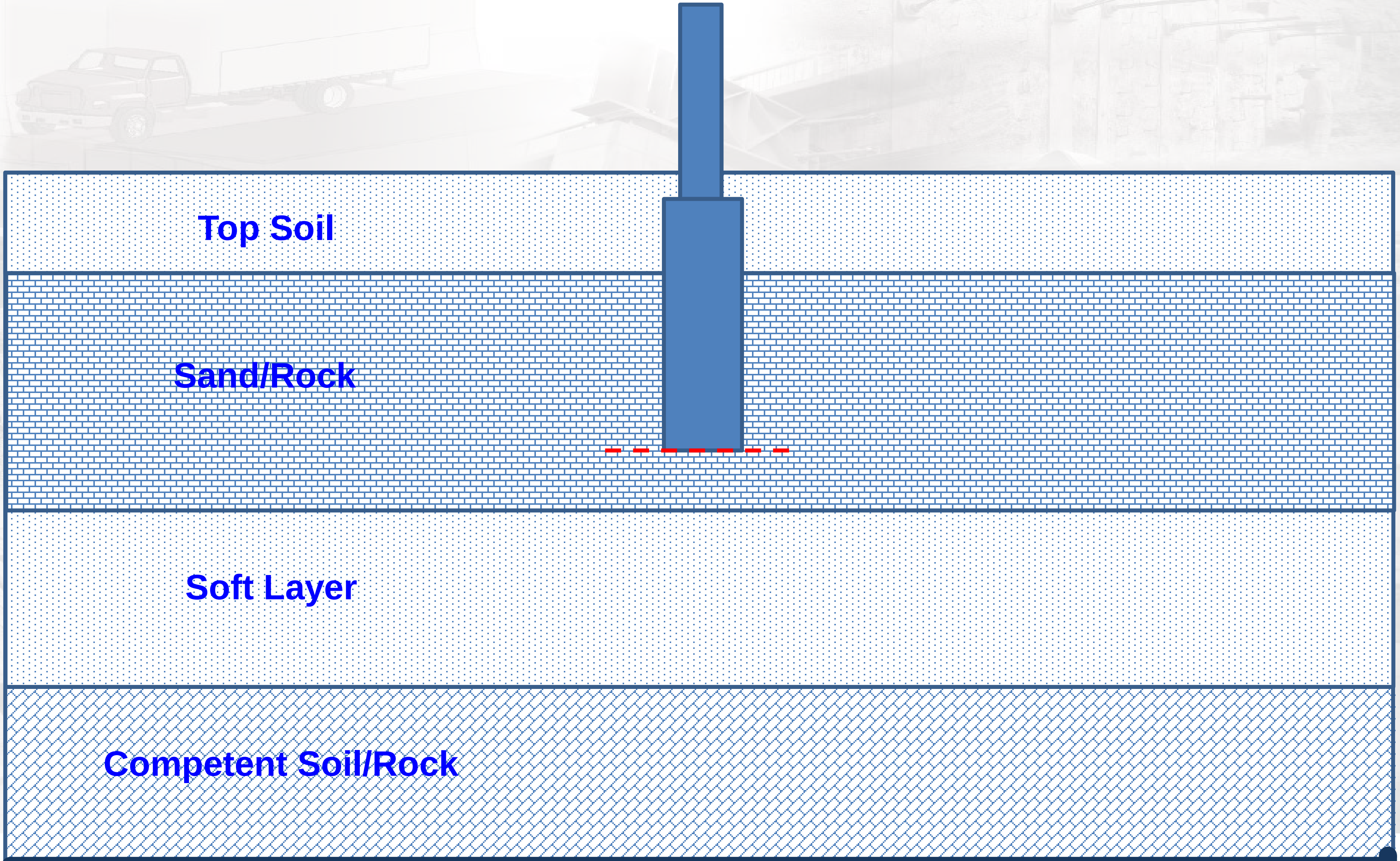

IN-SITU TESTING: PRESSURE METER

In-Situ Testing: Pressure Meter

IN-SITU TESTING: PRESSURE METER

POST-GROUTING

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POST-GROUTING

Post-Grouting – Sac RT

POST-GROUTING BENEFITS: SAC RT PROJECT

Construction Cost: $22 Million

Post-Grout Savings: $2 Million!

CONCLUSION

- HRTP Project Shafts were each designed with pier-specific geotechnical boring data.
- VBA Excel Macros proved very effective for
  - Designing a Large Number of Shafts
  - Accommodating Many Changes Quickly
  - Enhancing Quality Control
- SacRT: In-Situ Testing / Post-Grouting Saved $$

ACKNOWLEDGEMENTS

State of Hawaii
Department of Transportation

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