

SESSION-5C

**Honolulu Rail Transit Project: Drilled
Shaft Design Considerations and
Challenges**

Presented By:

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Ahmad Abdel-Karim, Ph.D., P.E

OUTLINE

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

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PROJECT INTRODUCTION

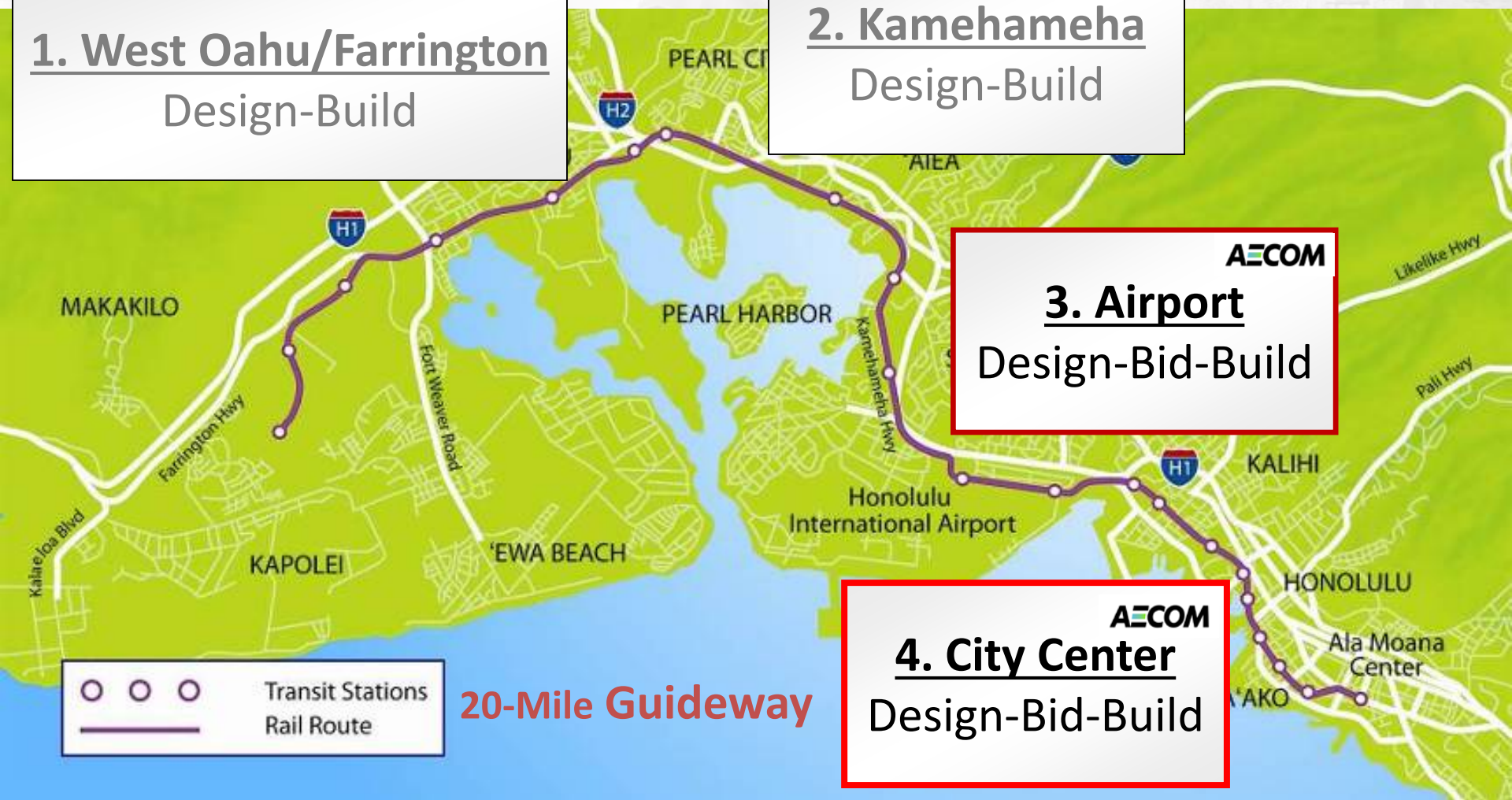
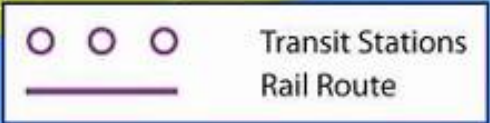
1. West Oahu/Farrington
Design-Build

2. Kamehameha
Design-Build

AECOM
3. Airport
Design-Bid-Build

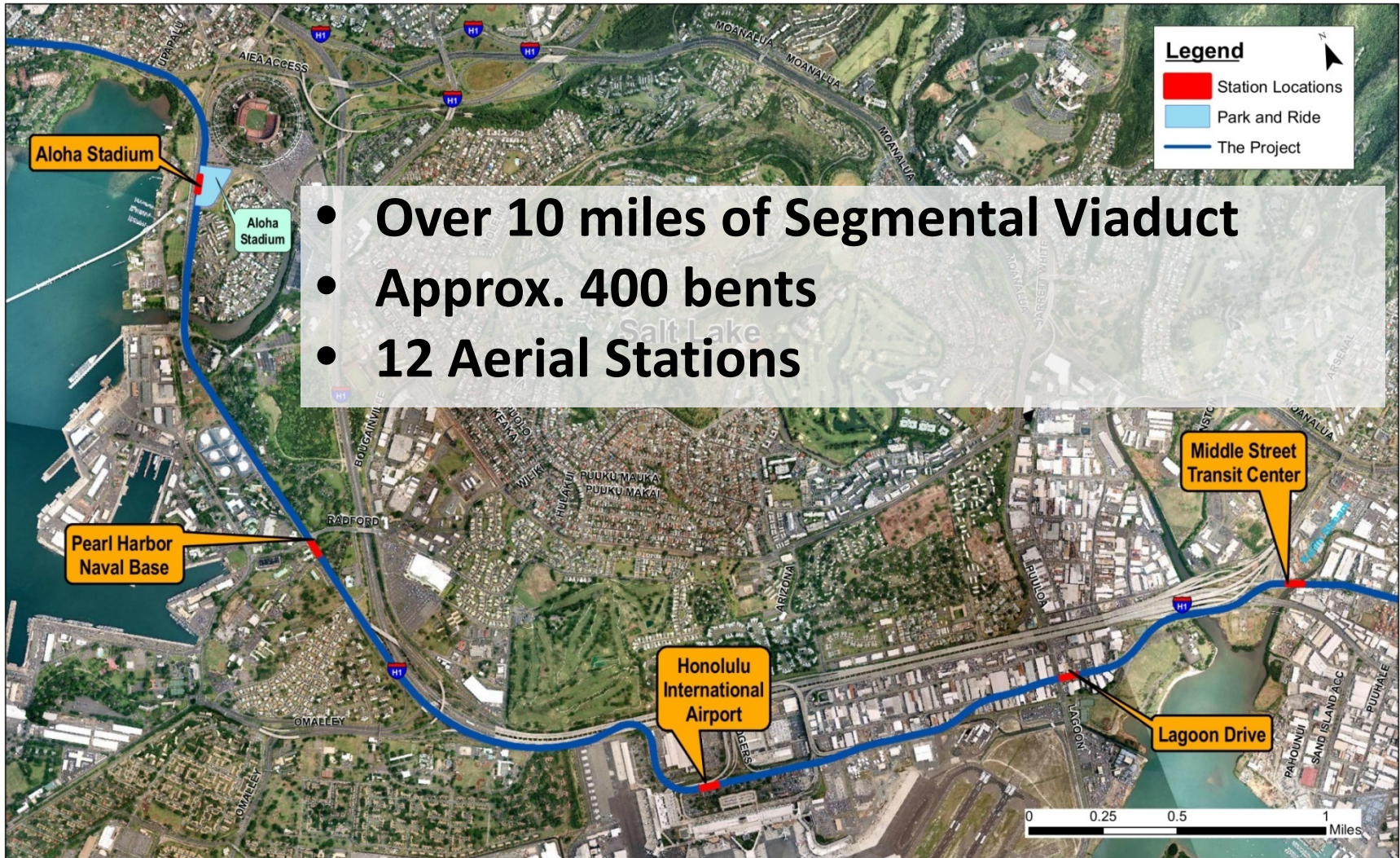
AECOM
4. City Center
Design-Bid-Build

20-Mile Guideway





PROJECT DESCRIPTION



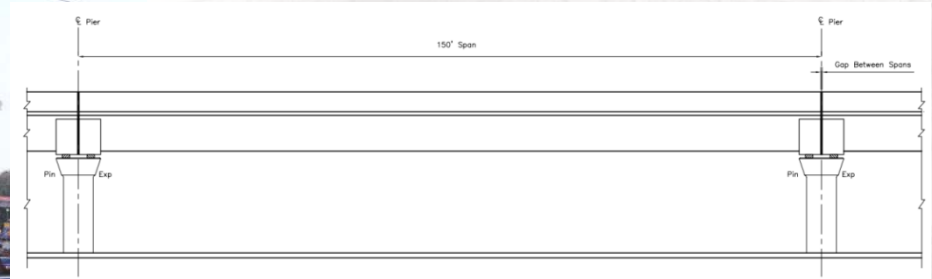
Honolulu High Capacity Transit Corridor Project

Prepared by Parsons Brinckerhoff

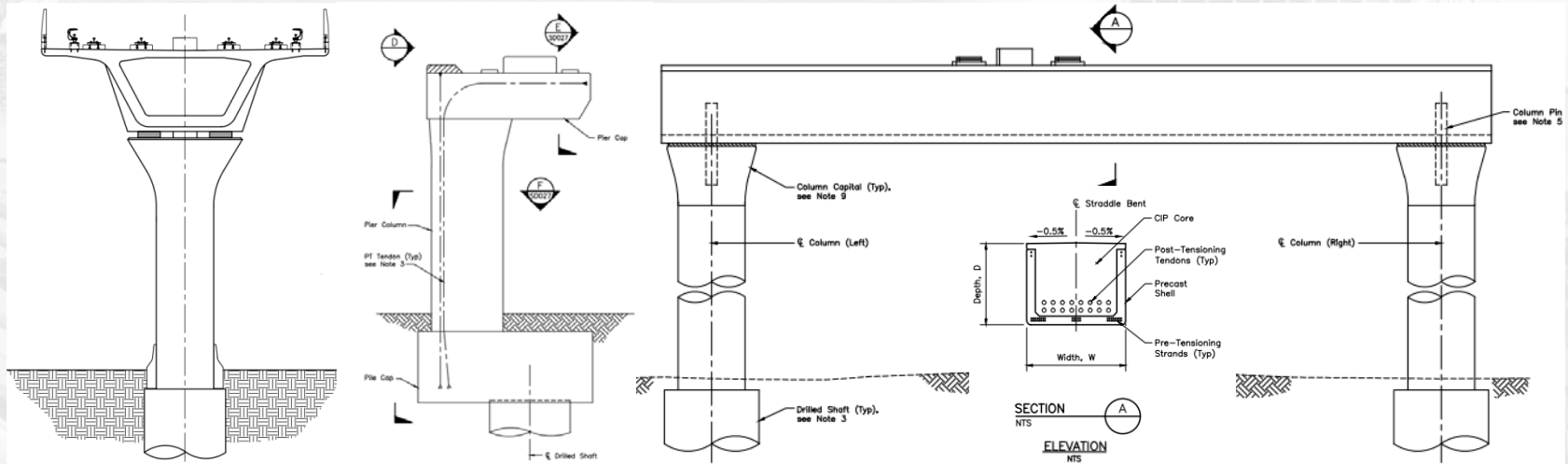
November 2010

Panel 3

GENERAL SPAN / PIER LAYOUT



Typical Span Layout



Typical Bent

C-Bent

Straddle Bent

Pier 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	Borings																						
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15								
G-1	30-Sep-13	20	433	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	
G-2	17-Oct-13	20	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493
G-3	25-Oct-13	20	508	511	513	562	565	568	571	574	577	580	583	586	589	592	595	598	601	604	607	610	613	616	619
G-4	29-Oct-13	10	525	533	534	538	540	543	546	549	552	555	558	561	564	567	570	573	576	579	582	585	588	591	594
G-5	24-Nov-13	21	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606
G-6	27-Jan-14	20	423	424L	424R	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444
G-7	18-Apr-14	20	485	486	487L	487R	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506
G-8	30-May-14	20	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539
G-9	13-Jun-14	18	514	515	516	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547
G-9A	14-Jul-13	3	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563
G-10	17-Oct-14	20	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660
G-11	24-Oct-14	30	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680
G-12	31-Oct-14	20	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485
G-13	4-Nov-14	30	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710
G-14	7-Nov-14	30	738	739L	739R	740	741	742	743	744L	744R	745	746	747	748	749	750L	750R	751	752	753	754	755	756	757
G-15	7-Nov-14	20	427	428	429	430	431	432	433L	433R	434L	434R	435L	435R	436	437	438	439	440	441	442	443	444	445	446
G-16	14-Nov-14	25	614	615	616	617	618	619L	619R	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635
G-17	5-Dec-14	30	760	760R	761	762	763	764	765	766	767	768L	768R	769	770	771	772	773	774	775	776	777	778	779	780
G-18	8-Dec-14	30	787	788	789	790	792	793	794	795	797	798	799L	799R	800L	800R	801	802	803	804	805	806	807	808	809
G-19	25-Dec-14	1	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659
G-20	10-Feb-15	3	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487
G-21	10-Feb-15	23	697	697R	698	699	702	705	706	707	708	709	710L	710R	711	712	713	714	715	716	717	718	719	720	721
G-22	10-Feb-15	2	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738

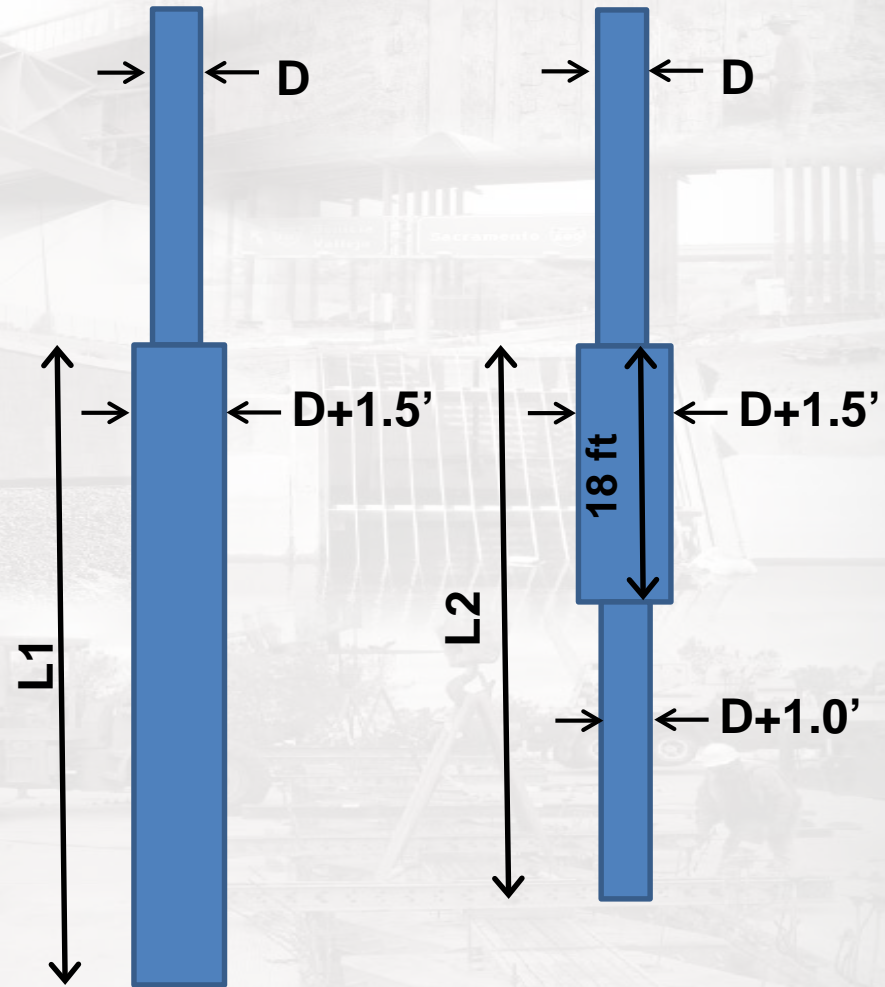
435 Borings

Type	Date	No. of Piers	Borings				
			1	2	3	4	
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	684	685	686	687
G-10	17-Oct-14	20	638	734	735	736	737
G-11	24-Oct-14	30	658	757	758	759L	759R
G-12	31-Oct-14	20	463	783	784	785	786
G-13	4-Nov-14	30	688	807L	807R	808L	808R
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					

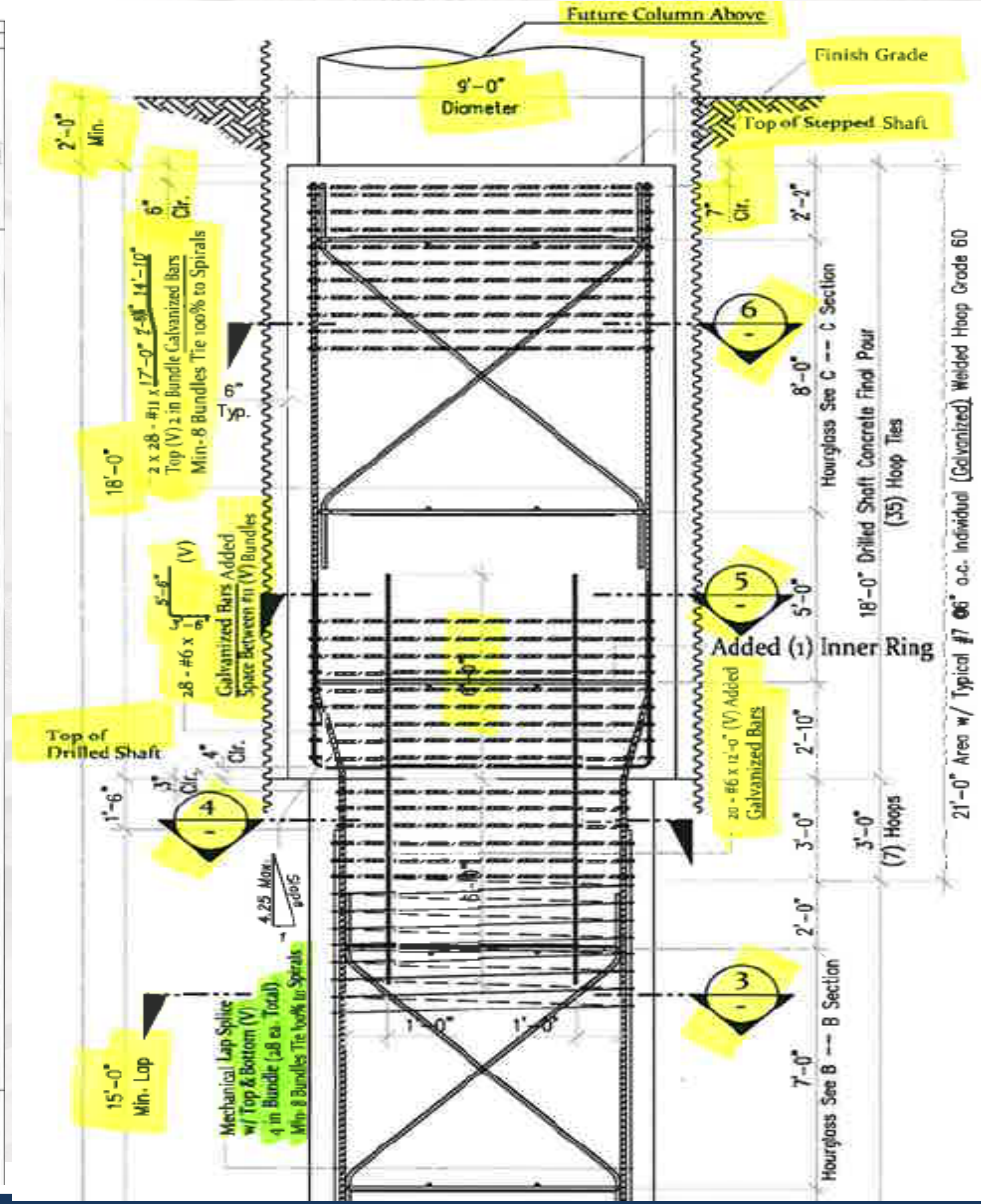
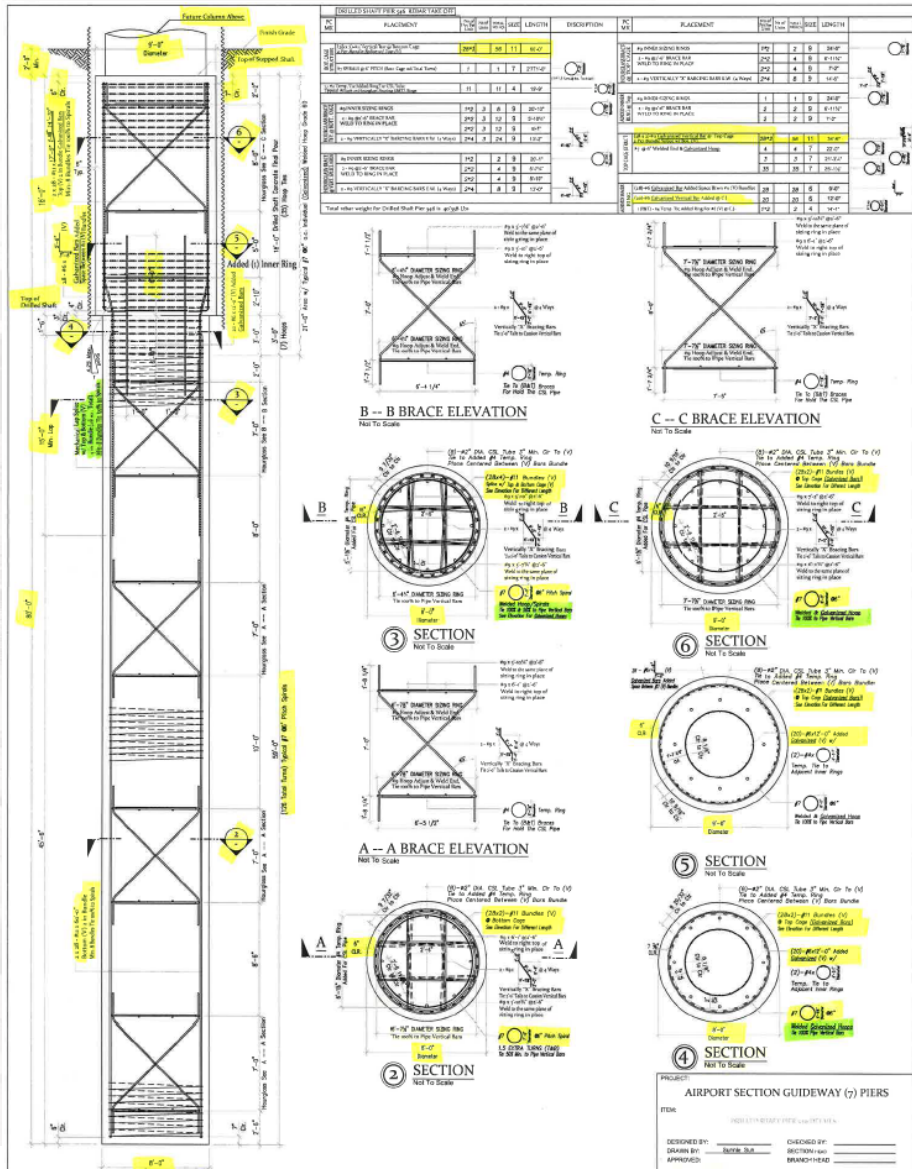
OUTLINE

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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



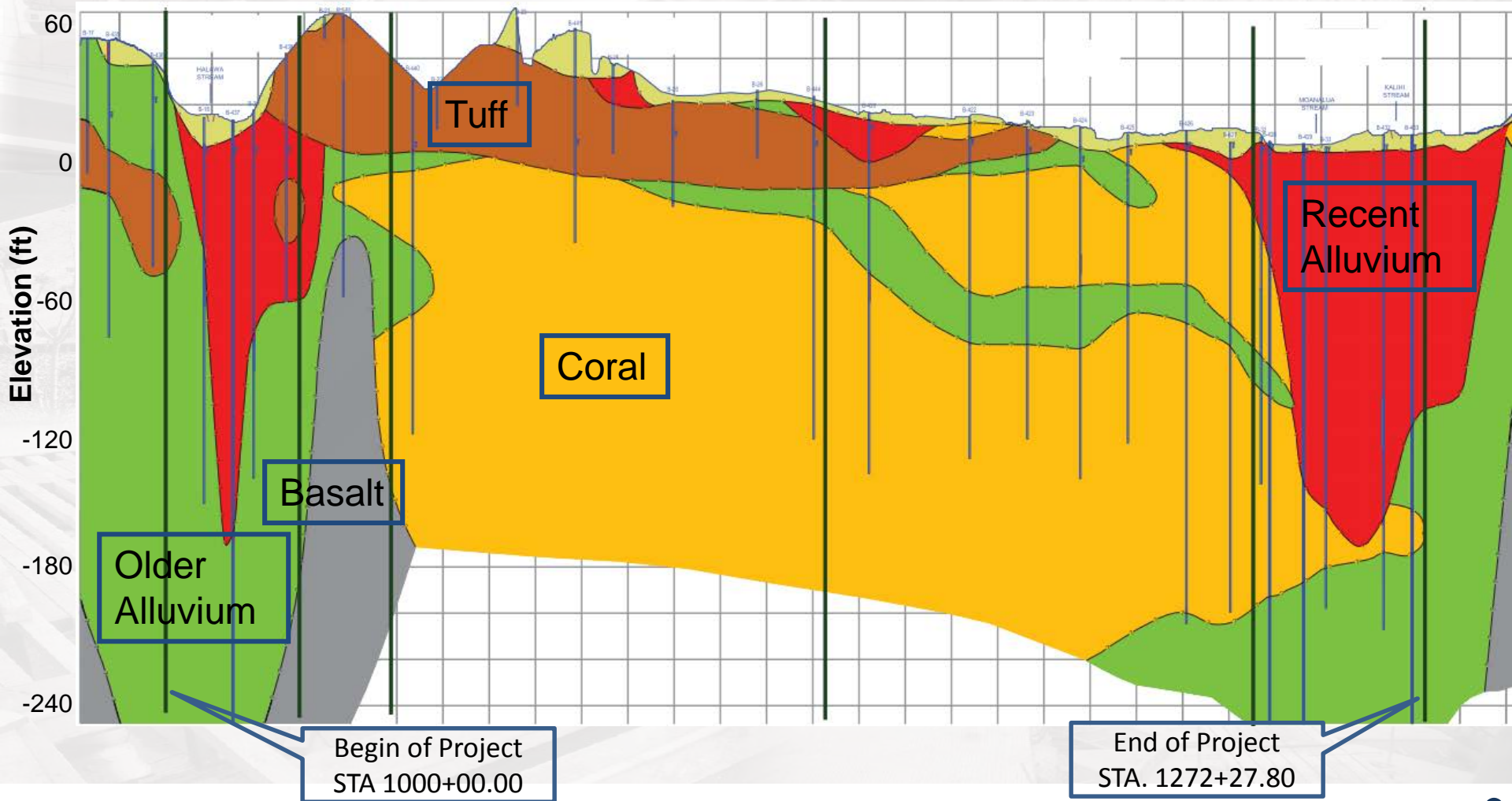
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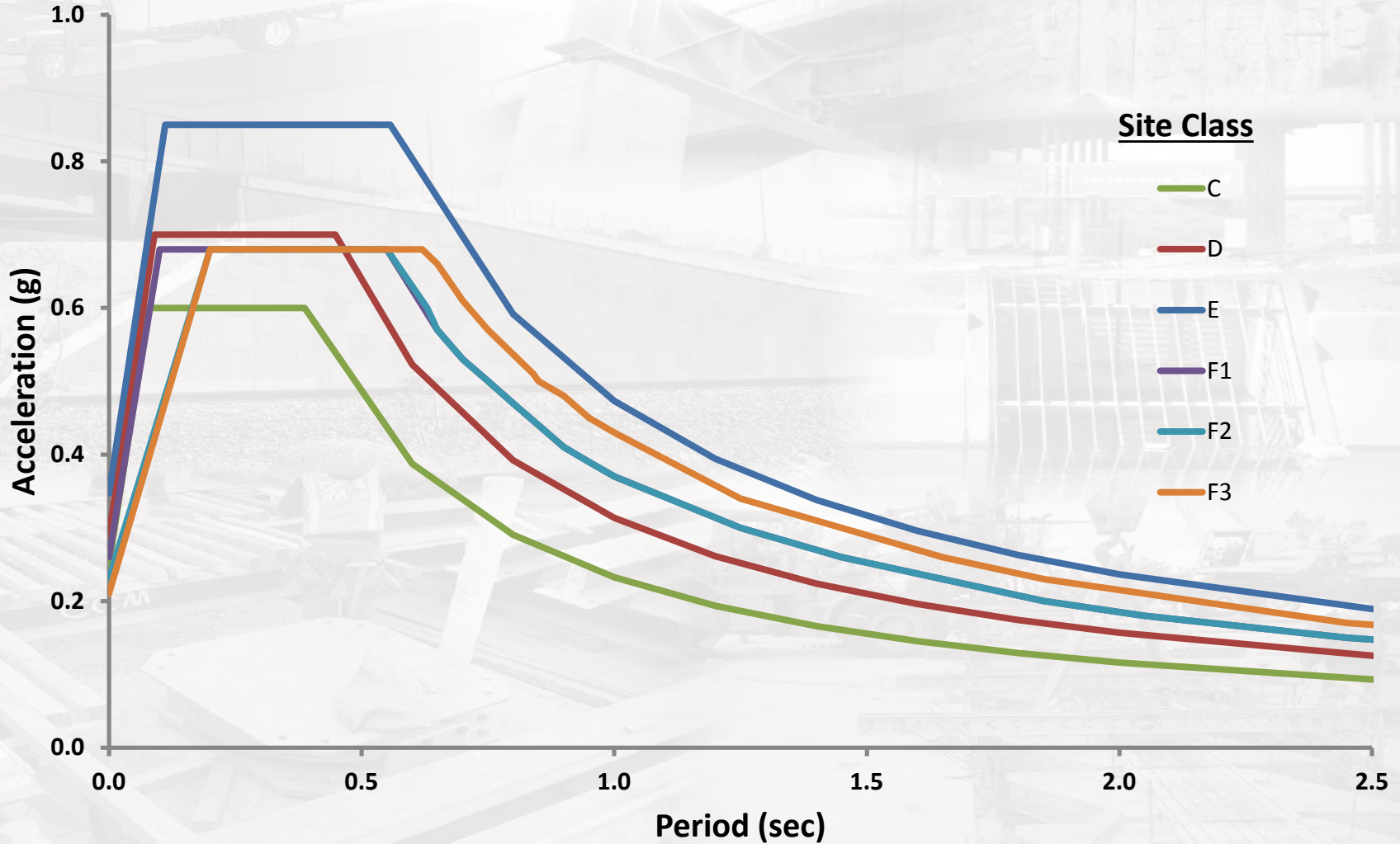
DESIGN CRITERIA

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	<ul style="list-style-type: none">• Service Limit State- 1" (excluding wind effects)• Extreme (Seismic) Limit State- 18" at Top of Rail (Seismic)

Project Subsurface Profile



Site-Specific Response Spectrum

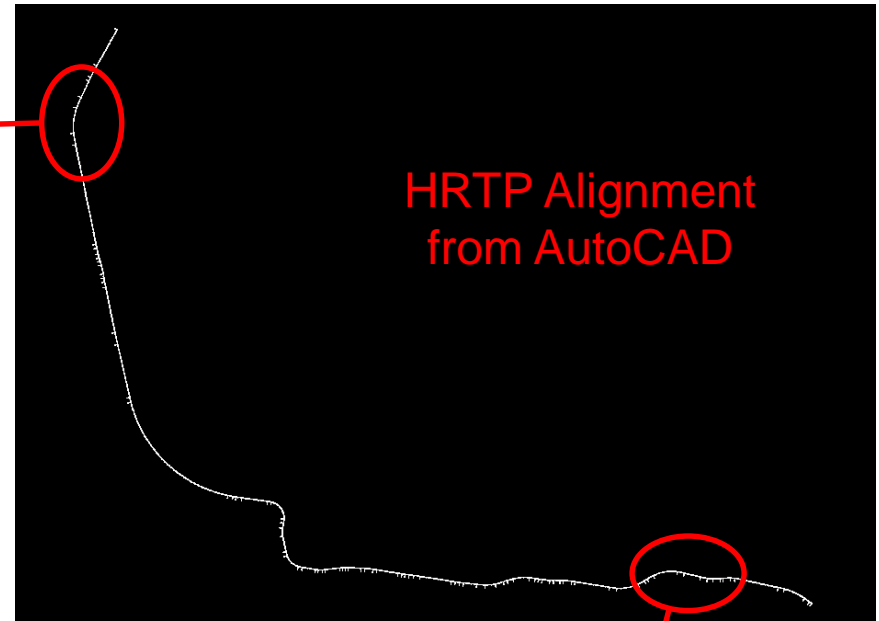
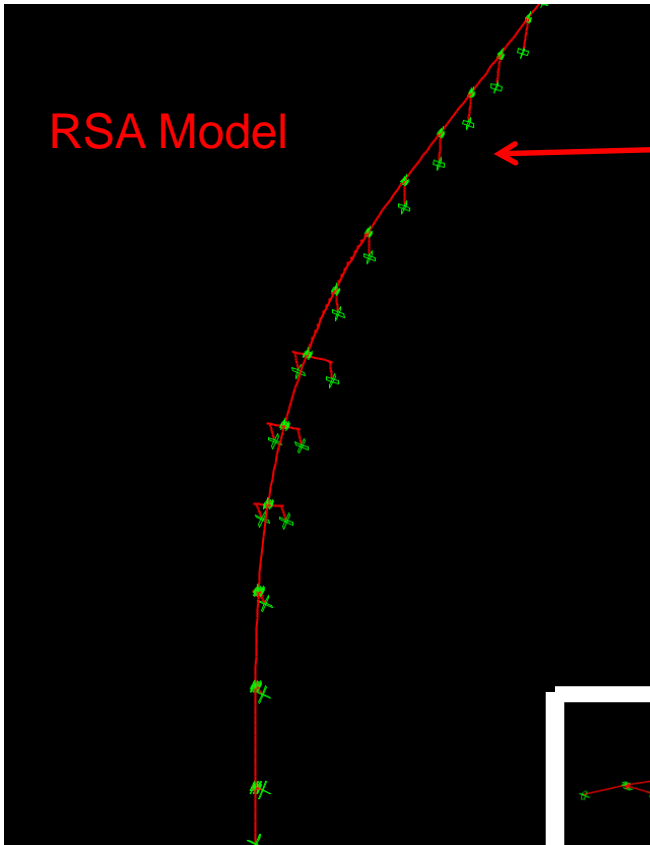


FLEXIBLE DESIGN PROCESS TO ACCOMMODATE CHANGES:

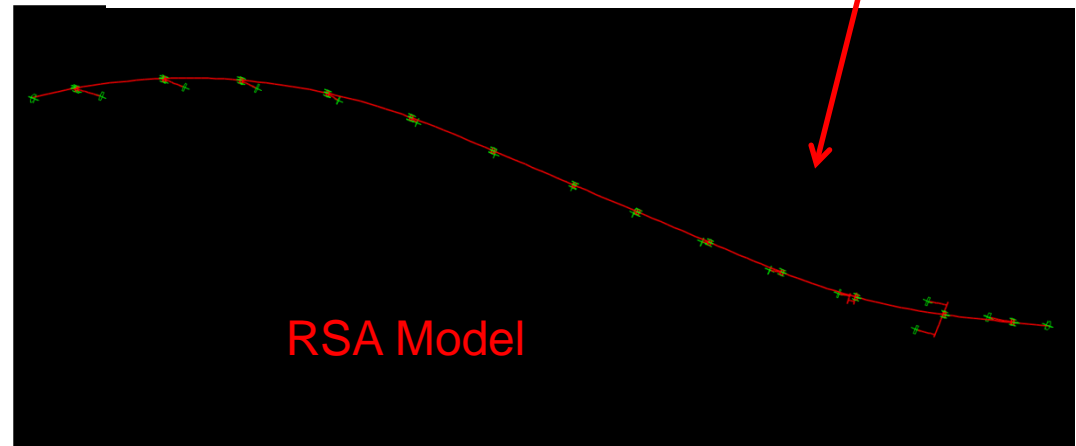
- Layout
- Profile
- Utilities
- Roadways
- Geotechnical
- Parametric Studies

Seismic Analysis

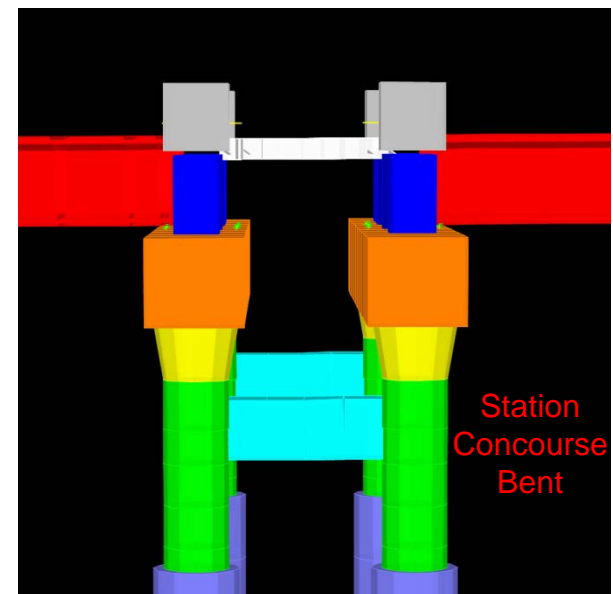
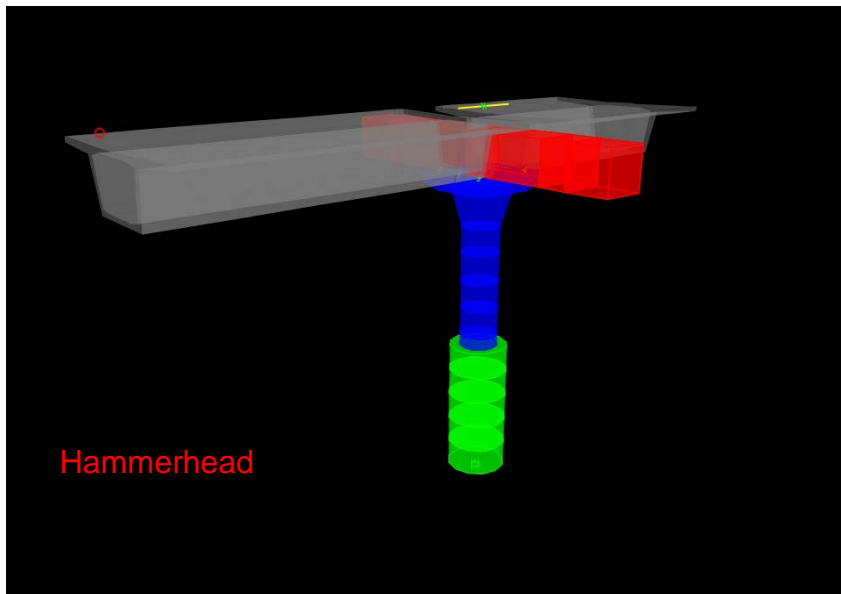
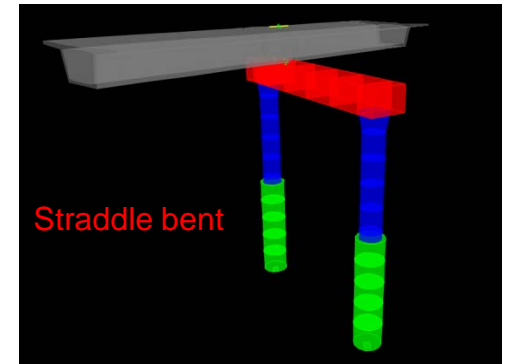
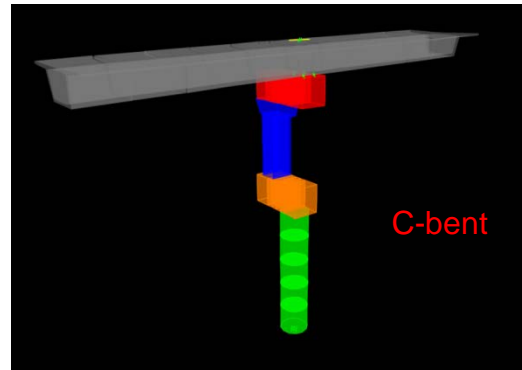
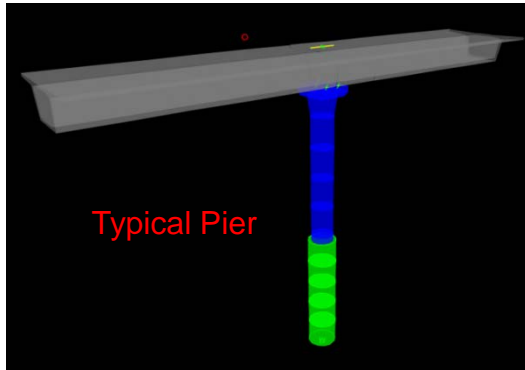
- Setting Up Automation Procedure
 - Large Scale Project
 - Near 400 Piers with Varying Configurations/Design Data
 - Time Consuming
 - Response Spectrum Analysis (RSA)
 - 12-Span Finite Element Modeling (FEM)
 - Possible Re-work Due To Changes In
 - Pier Geometry
 - Soil Data



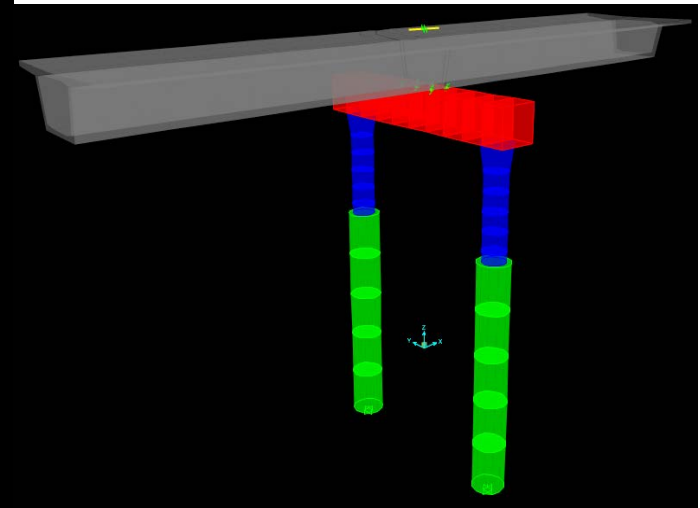
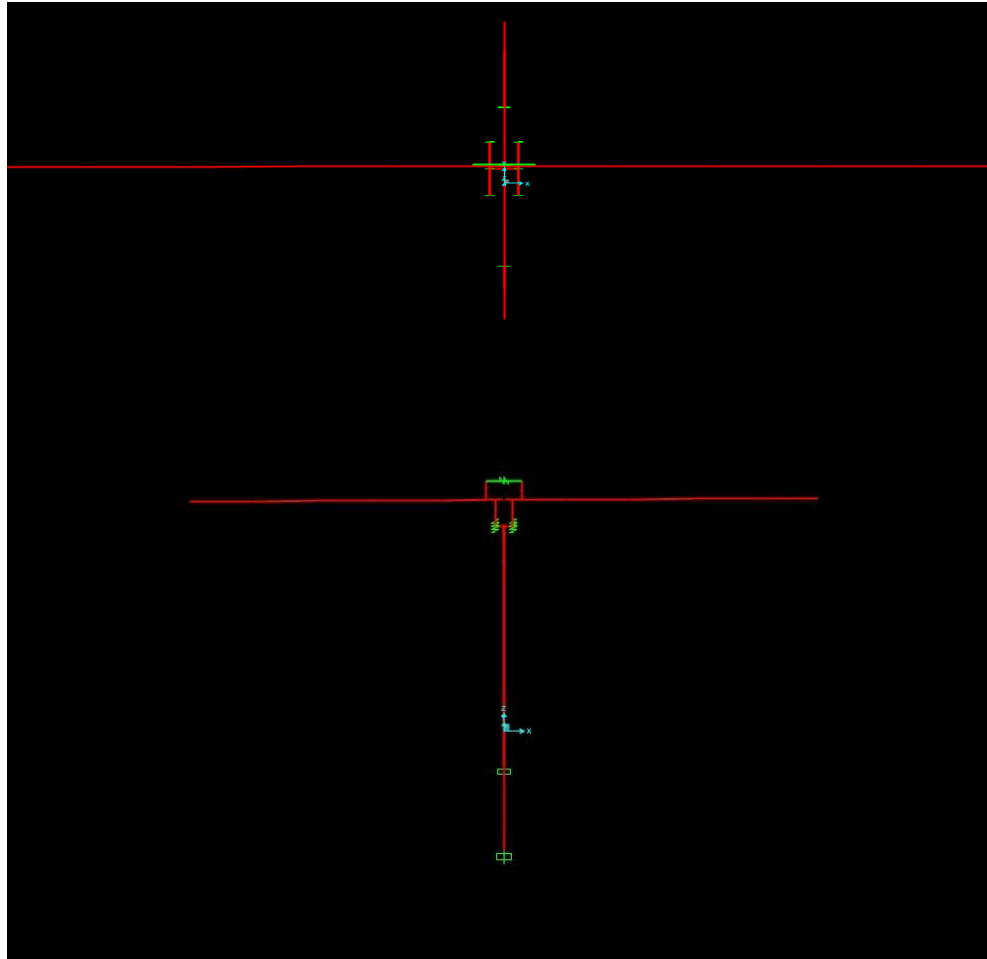
RSA Models Match
Project Alignment and Profile



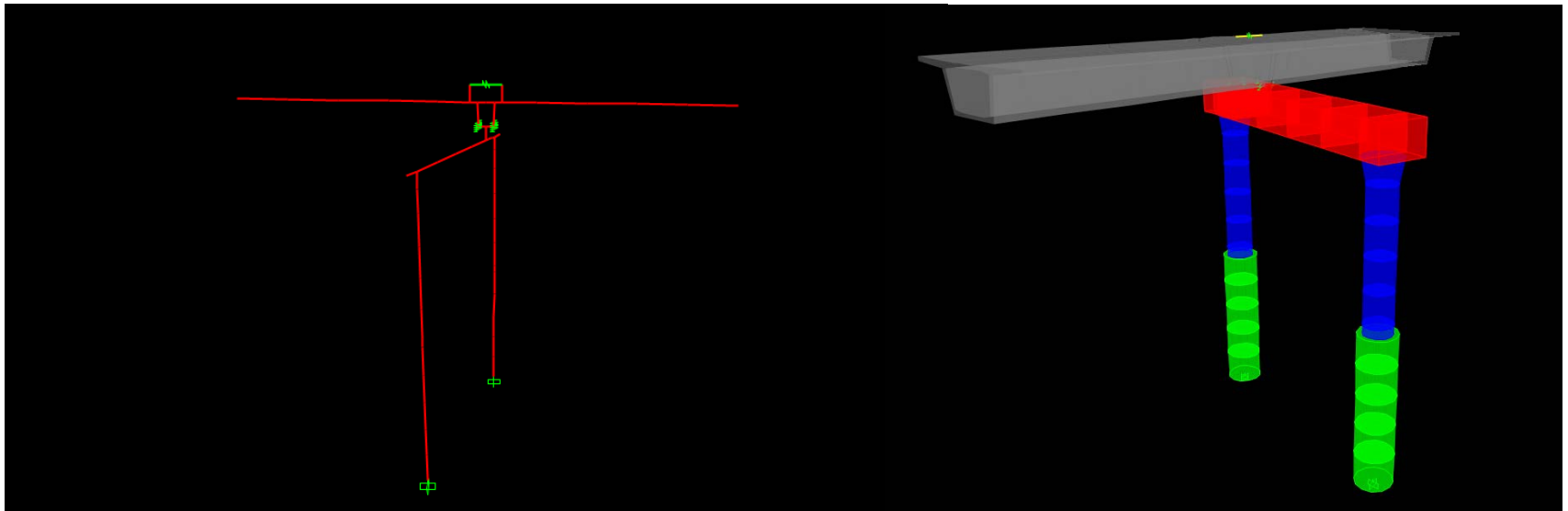
Pier Models (Templates)



Straddle Bent - Template



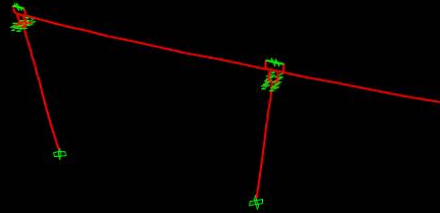
Straddle Bent - Modified



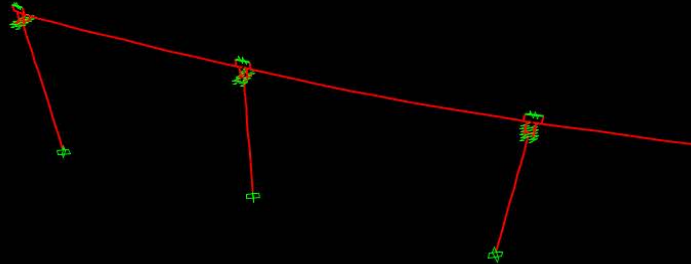
Modifications Include:

- Horizontal Curve
- Vertical Profile
- Pier Offsets / Properties

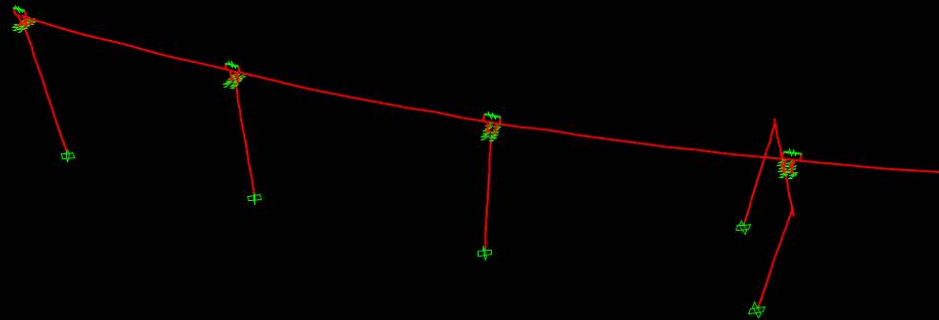
Assembling Pier Models



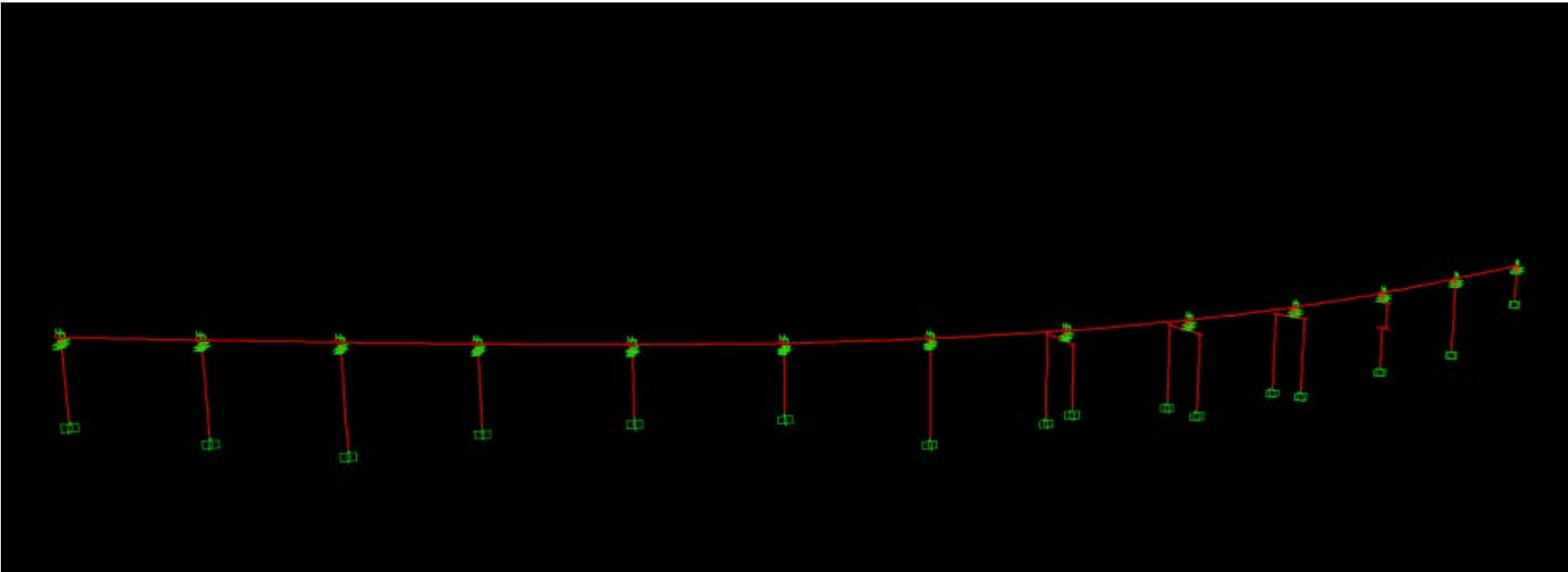
Assembling Pier Models



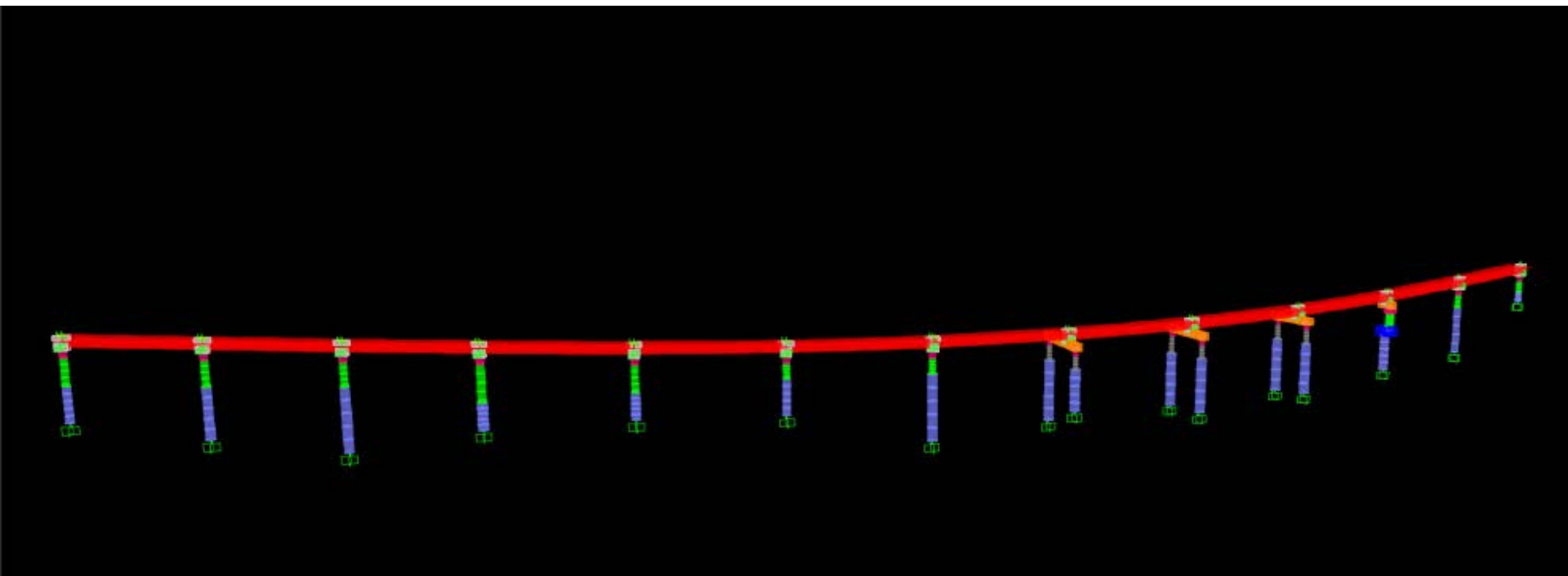
Assembling Pier Models



Assembled RSA Model



Assembled RSA Model



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
...

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

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
...

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Step 3: Run All Assembled Models

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

Pier #	Pier type	Col Height	Col Diameter	Top of Rail	Top of Column	Bottom of Column	Top of Column		Bottom of Column		Bottom Col.
				Max Disp.	Max Disp.	Max Disp.	Max Shear	Max Moment	Max Shear	Max Moment	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

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

**OTHER DESIGN PROCEDURES
WERE ALSO AUTOMATED IN A
SIMILAR FASHION.**

Step 3: Run All Assembled Models

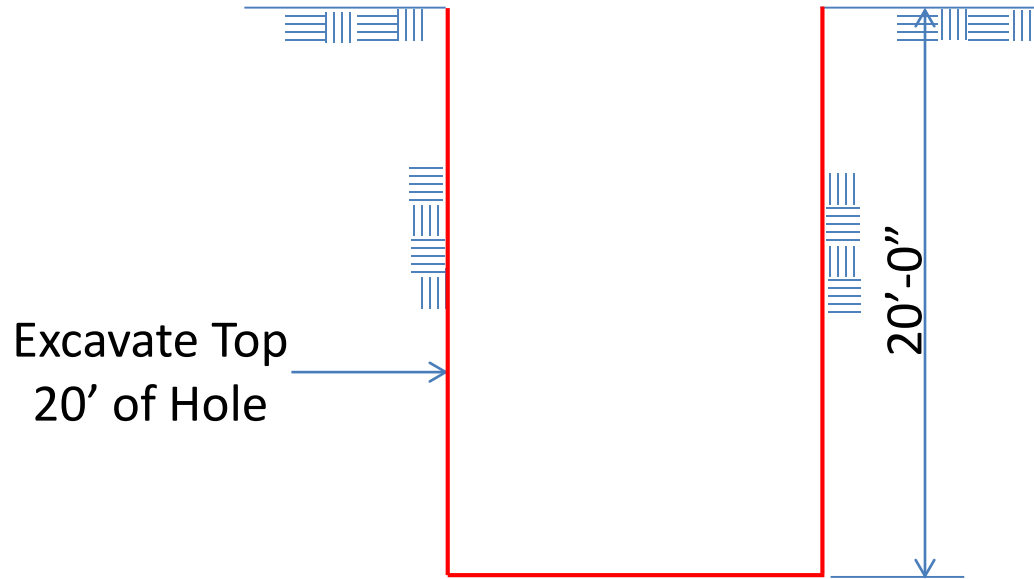
- Runs Assembled Models From Step 2
- **Read and Summarize Results**

Pier #	Pier type	Col Height	Col Diameter	Top of Rail	Top of Column	Bottom of Column	Top of Column		Bottom of Column		Bottom Col.
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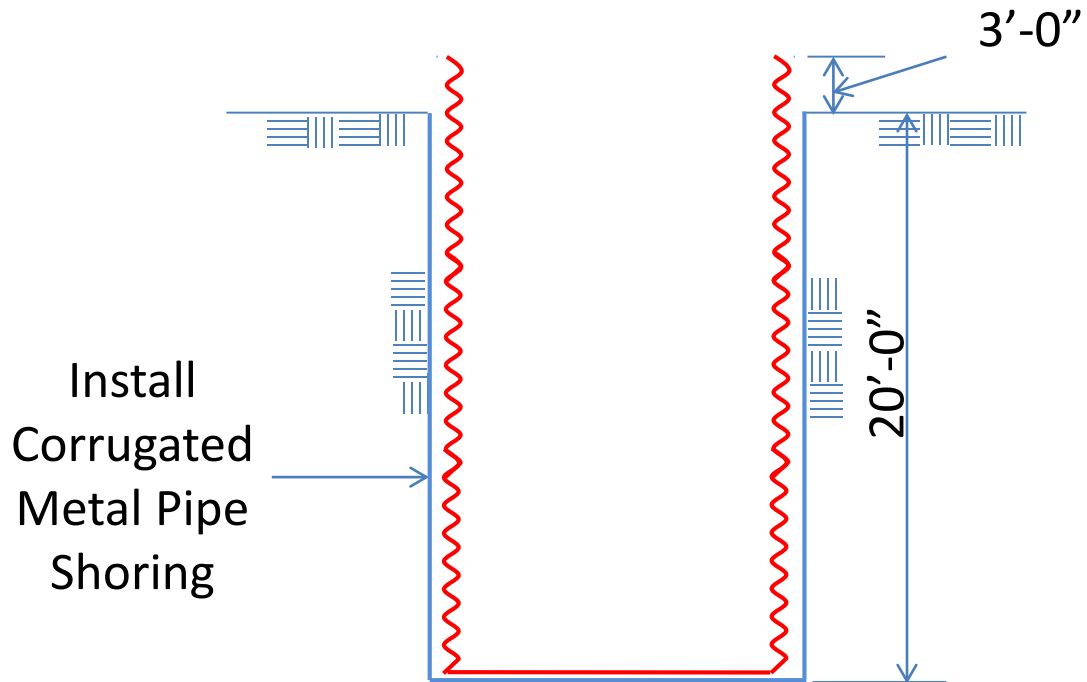
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Typical Shaft Construction Step 1

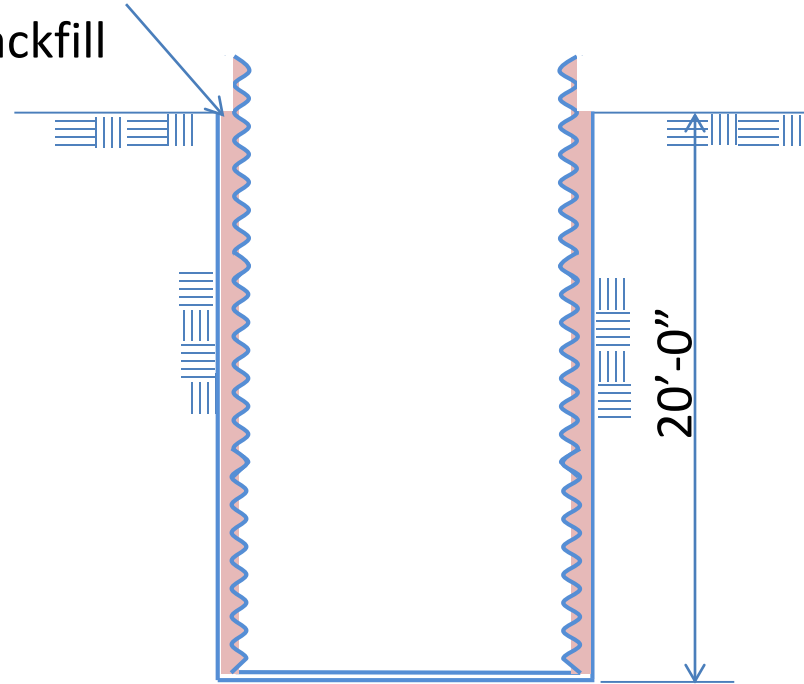


Typical Shaft Construction Step 2

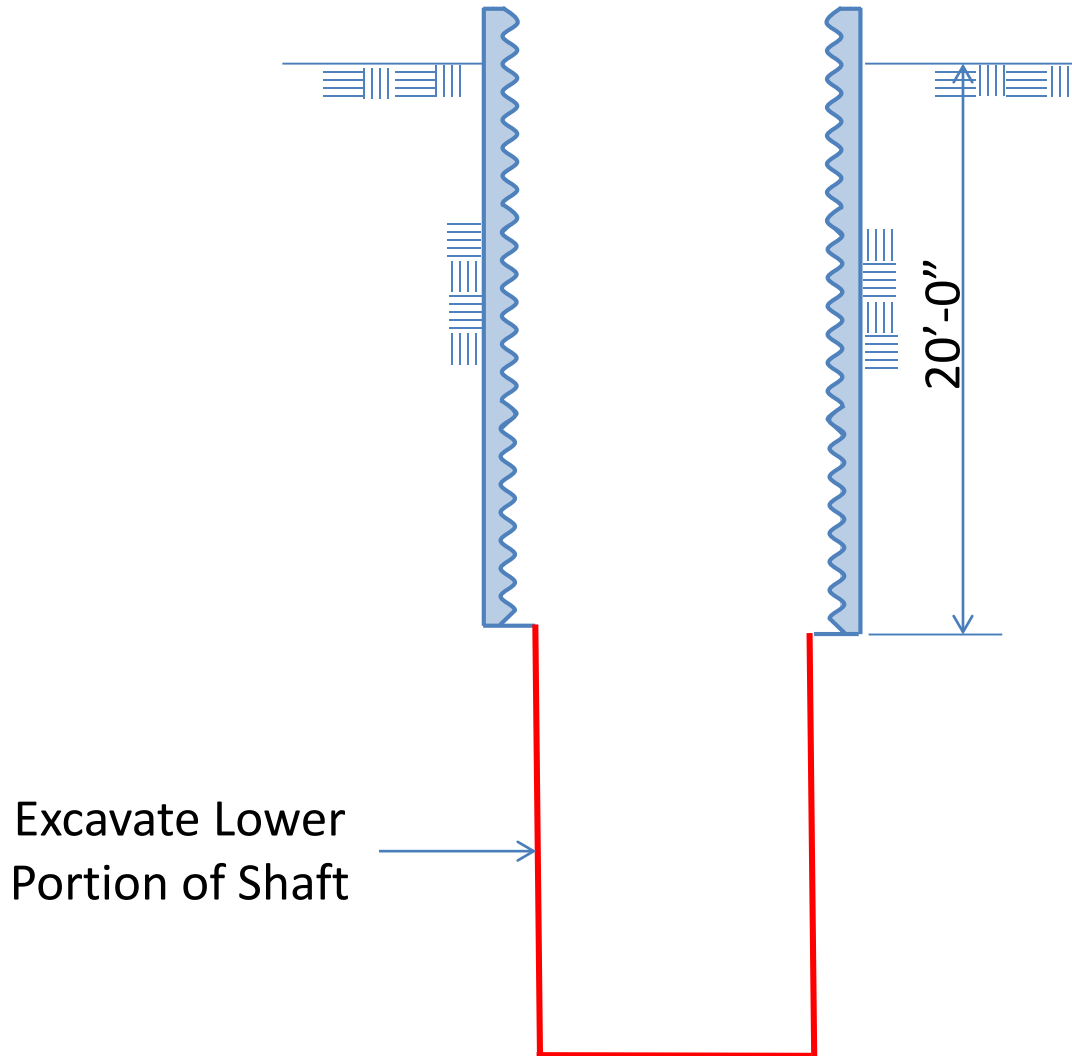


Typical Shaft Construction Step 3

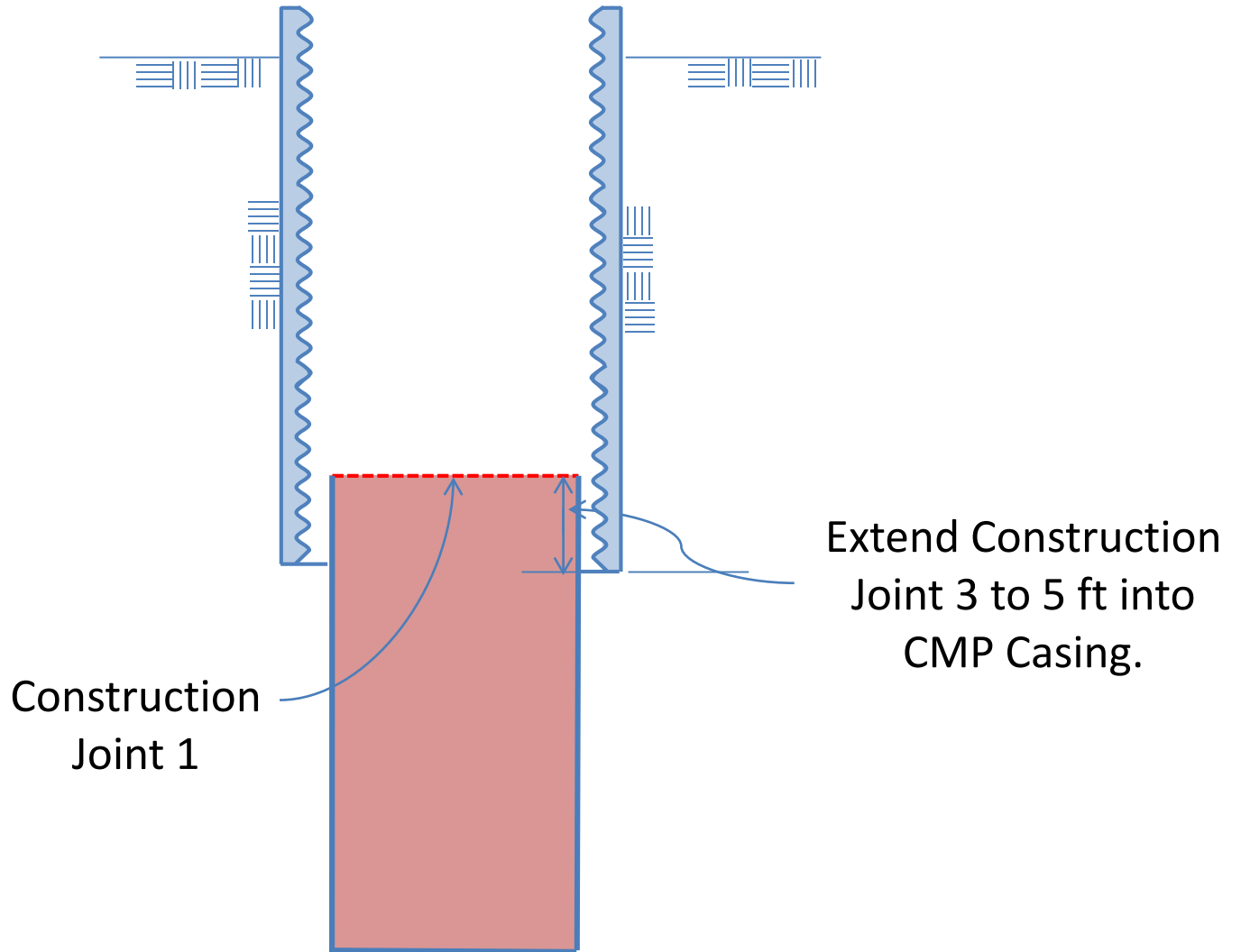
Place
CLSM
Backfill



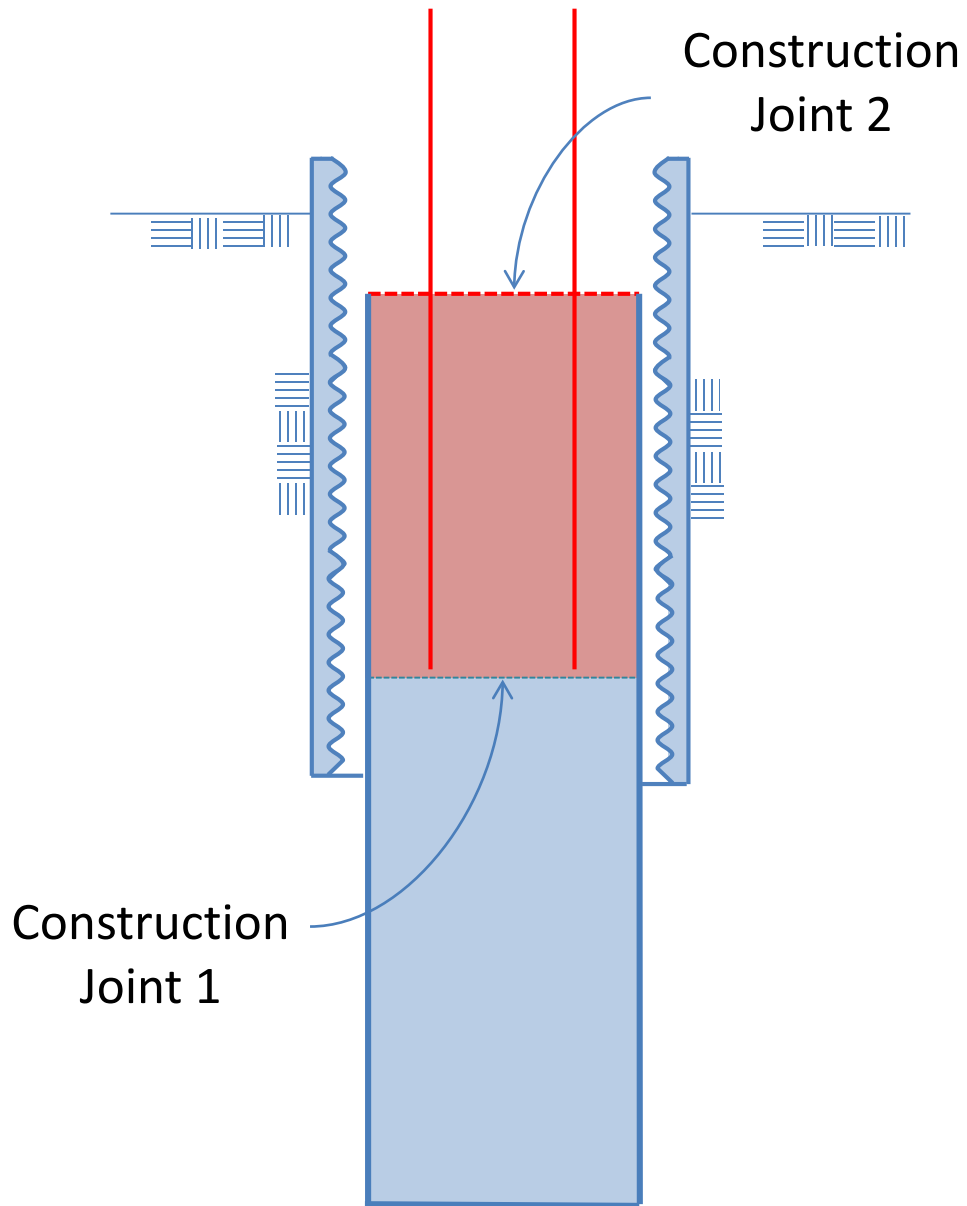
Typical Shaft Construction Step 4



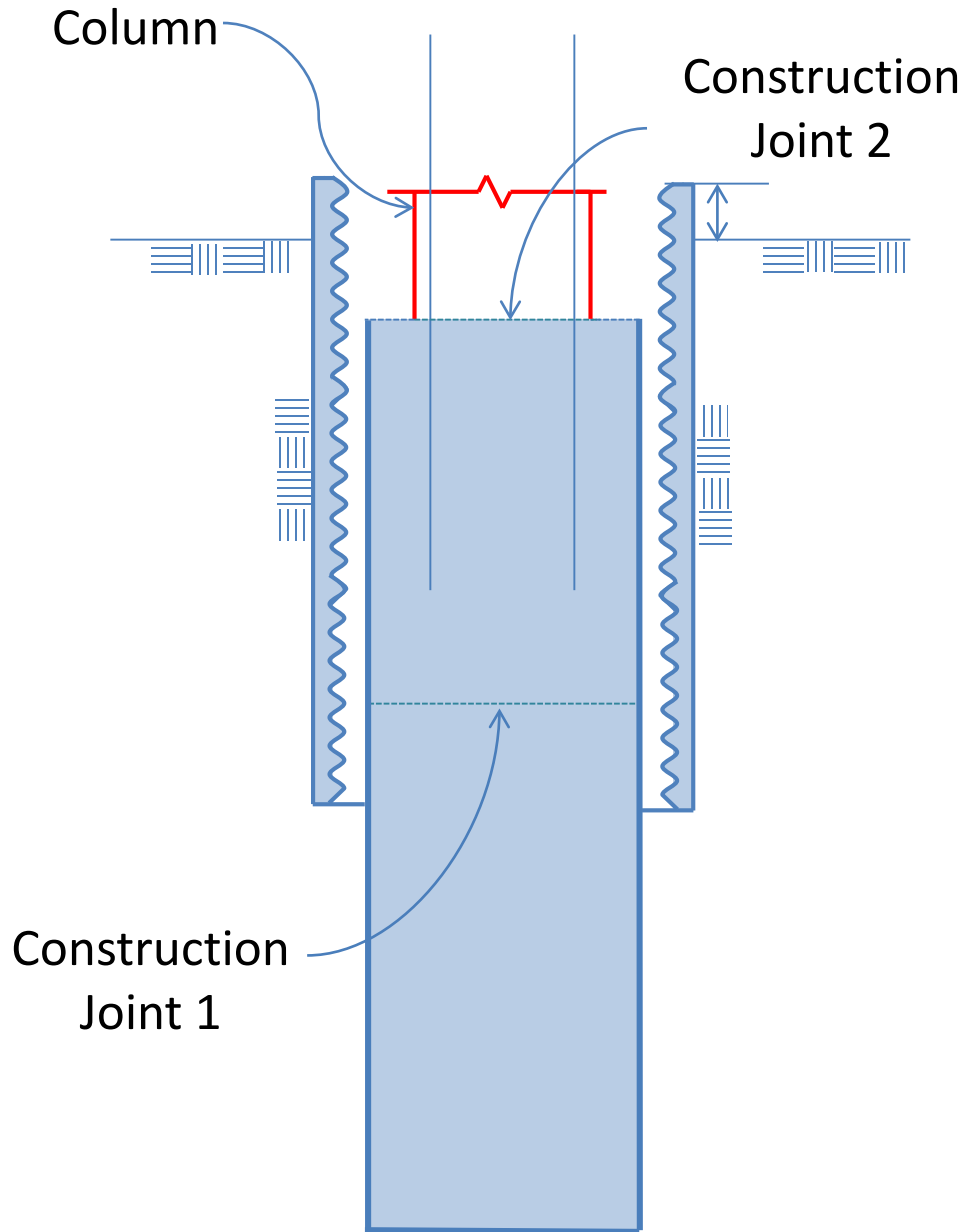
Typical Shaft Construction Step 5



Typical Shaft Construction Step 6



Typical Shaft Construction Step 7





CONSTRUCTION PHOTOS



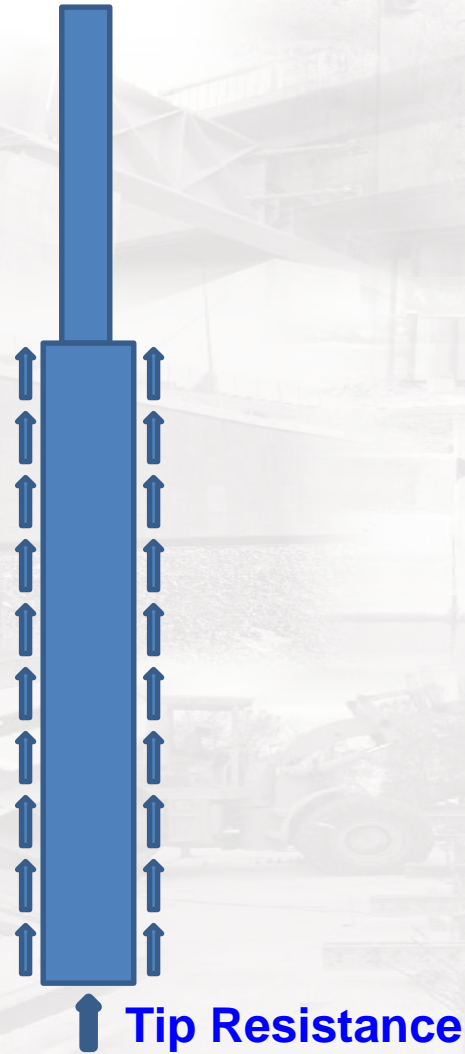


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SHAFT CAPACITY

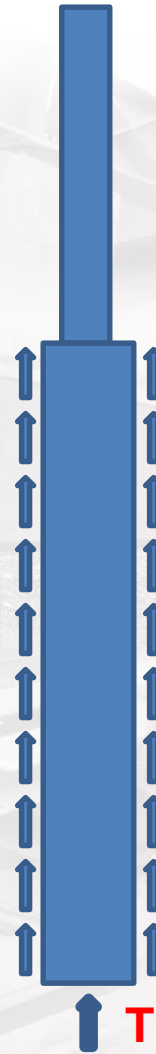
Side Resistance



Tip Resistance

TIP RESISTANCE

Side Resistance



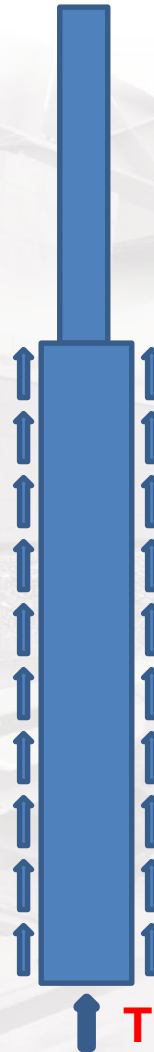
Tip Resistance Typically Ignored-

- Hard to Estimate
- Conservative

Tip Resistance

TIP RESISTANCE

Side 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

TIP RESISTANCE

Side Resistance

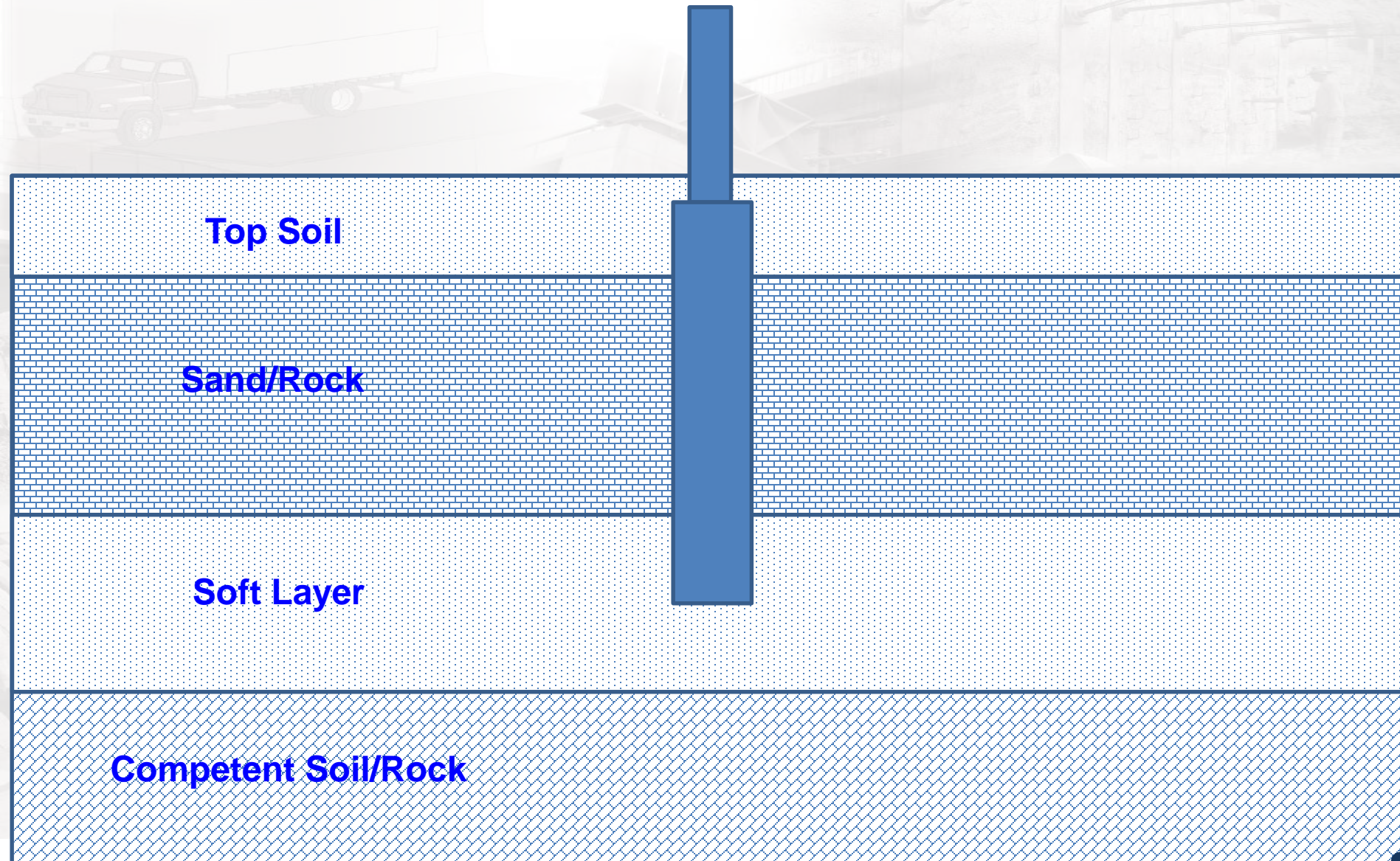


Significant Potential Savings w/:

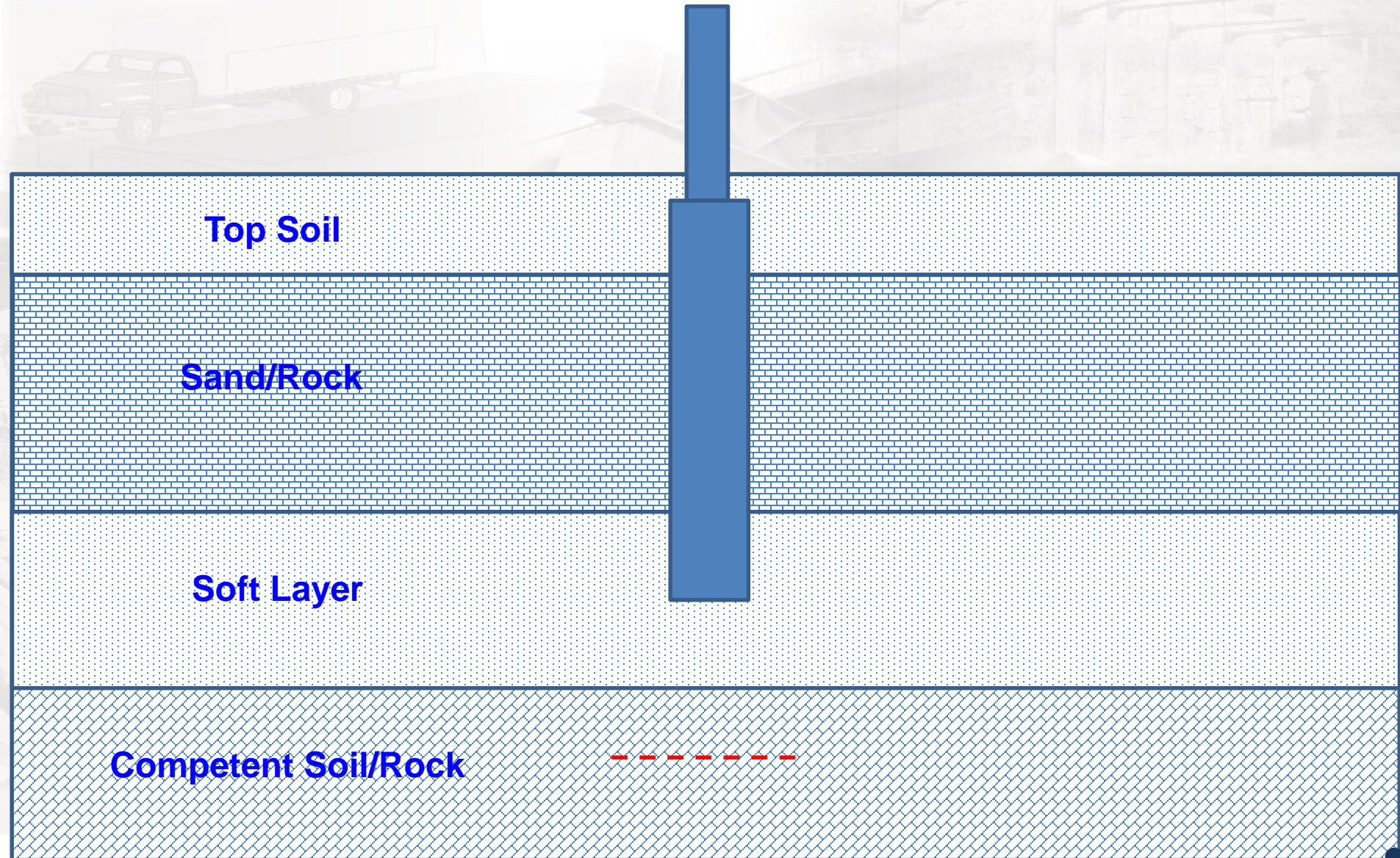
- In-Situ Testing
- Post-Grouting
- Better Construction Practices

Tip Resistance

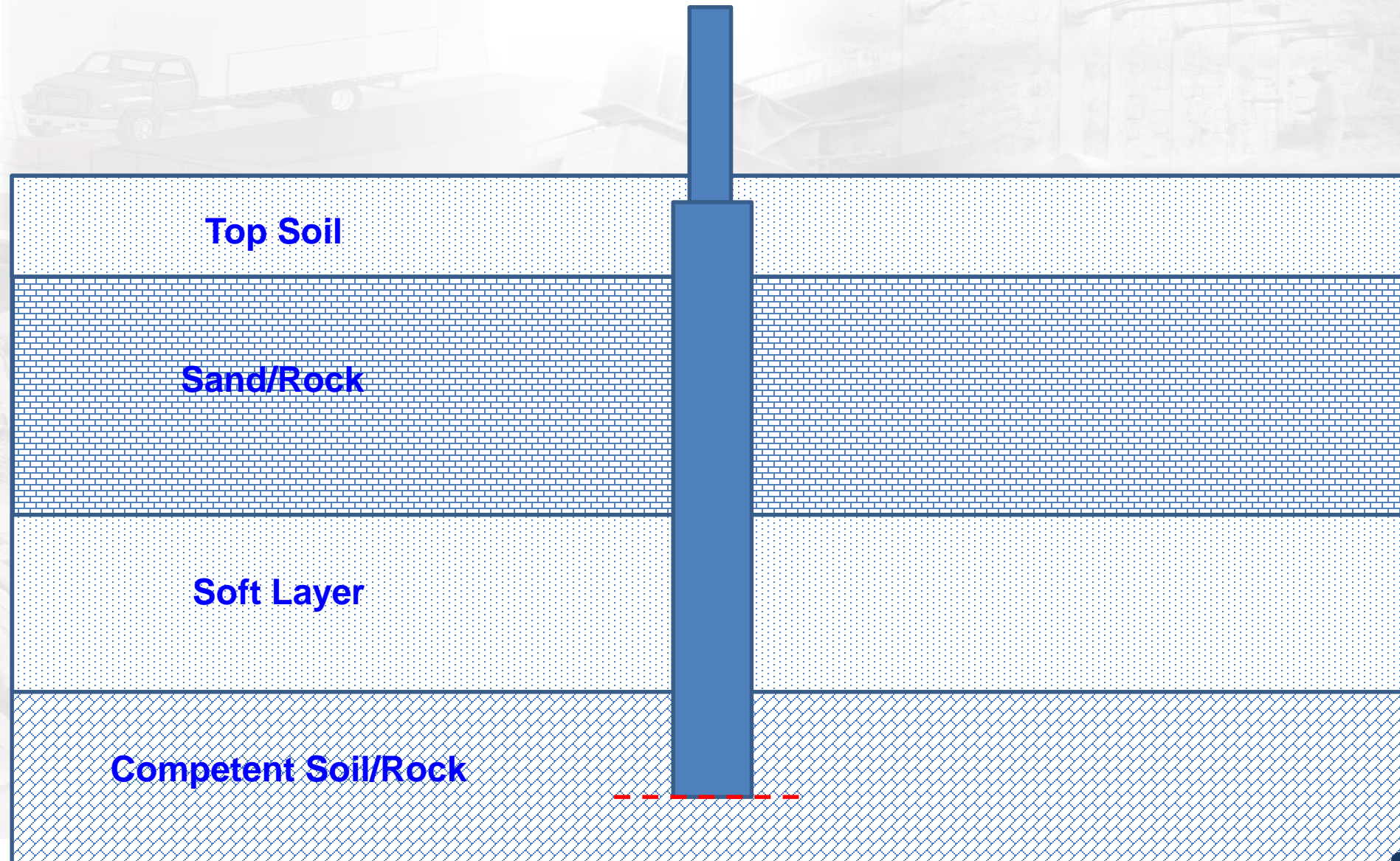
PILE CAPACITY SCENARIOS - NOT ENOUGH CAPACITY



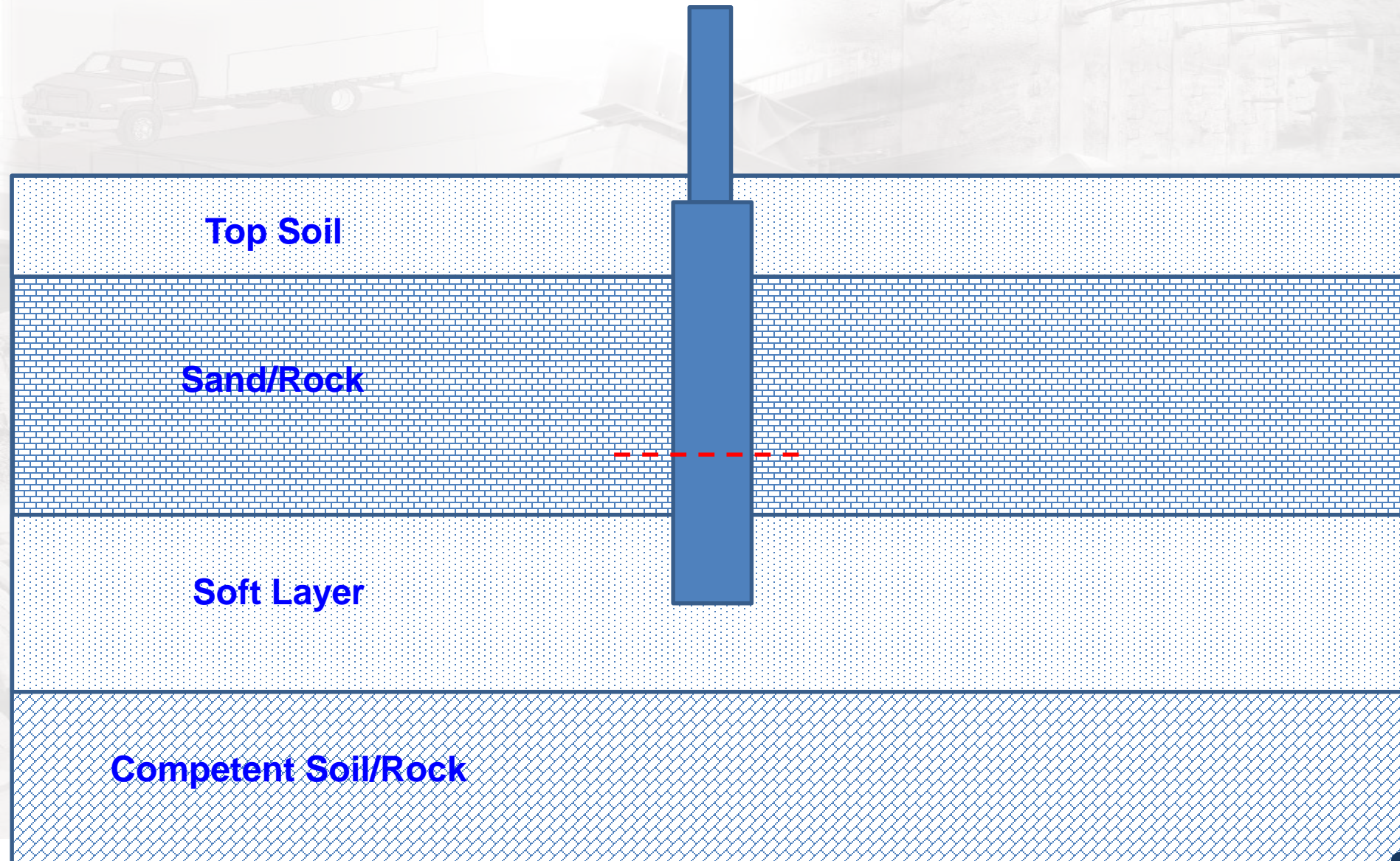
PILE CAPACITY SCENARIOS - ZERO TIP EXTEND SHAFT TO COMPETENT SOIL



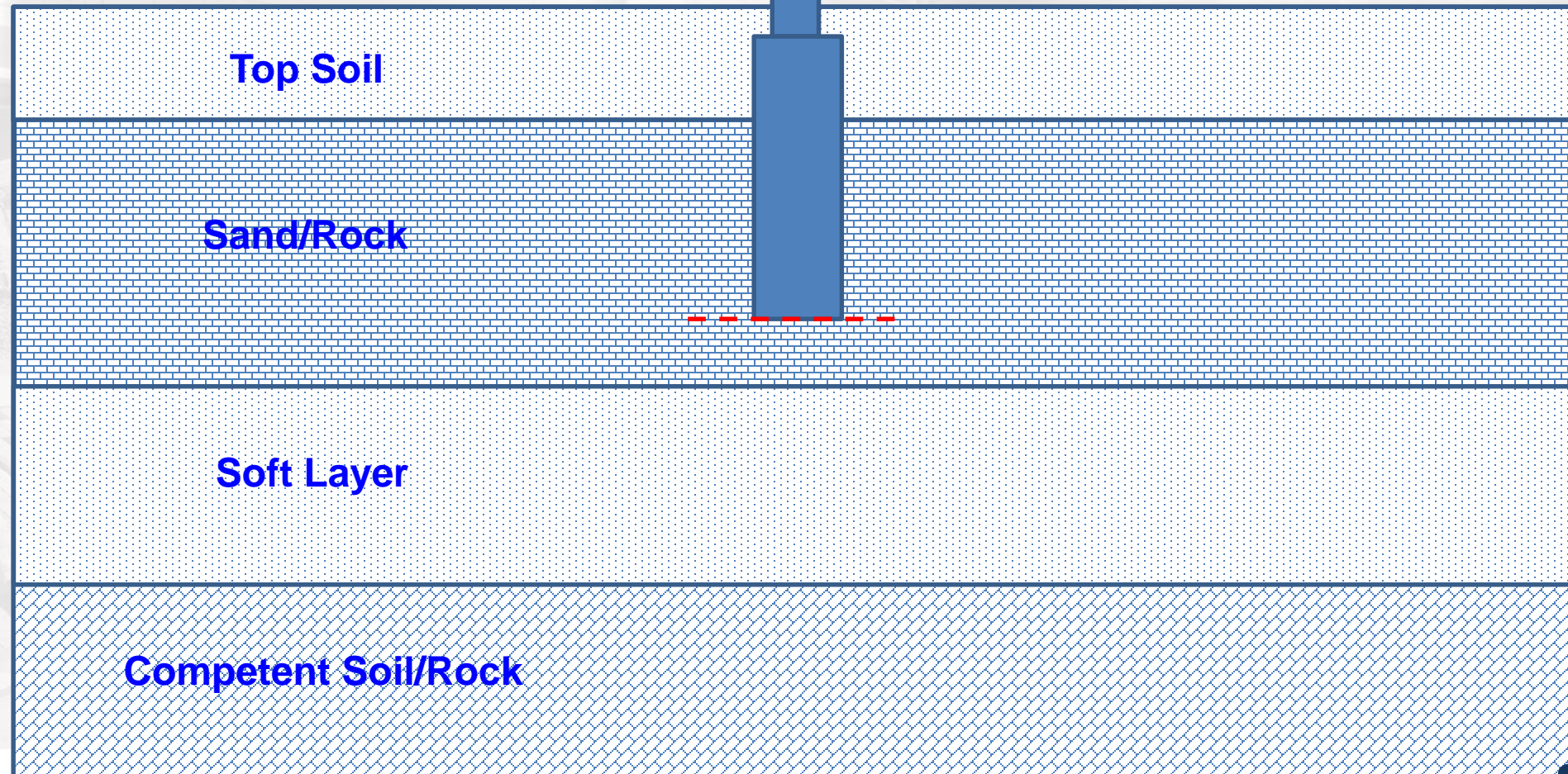
POST-GROUTING SCENARIOS - PILE IS SIGNIFICANTLY LONGER



PILE CAPACITY SCENARIOS - W/ TIP-RESISTANCE OR IN-SITU TESTING



PILE CAPACITY SCENARIOS - **SHORTER PILE**



IN-SITU TESTING: PRESSURE METER





IN-SITU TESTING: PRESSURE METER



IN-SITU TESTING: PRESSURE METER



POST-GROUTING



06 20 2012



POST-GROUTING





POST-GROUTING – SAC RT



POST-GROUTING BENEFITS: SAC RT PROJECT



Construction Cost: \$22 Million

Post-Grout Savings: \$2 Million!

CONCLUSION

- H RTP 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 \$\$

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QUESTIONS & ANSWERS