Case Study

DISPLACEMENT CAST-IN-PLACE PILES IN COASTAL PLAIN SOILS, LESSONS LEARNED AT NATIONAL HARBOR CASINO

Presenters:
Karl A. Higgins, III, PE, D. GE
James P. Racine, PE

PROJECT FACTS

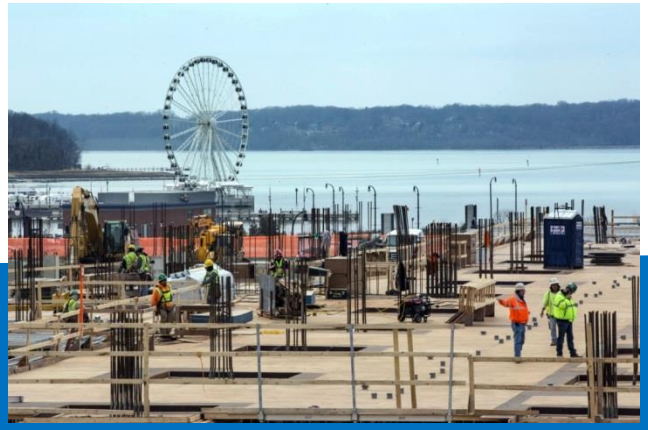
$1.3 billion

19.5 acres

5 levels of parking

26 story hotel tower

2600+ Deep Foundation Elements



2014 foundations started

2015 foundations finished

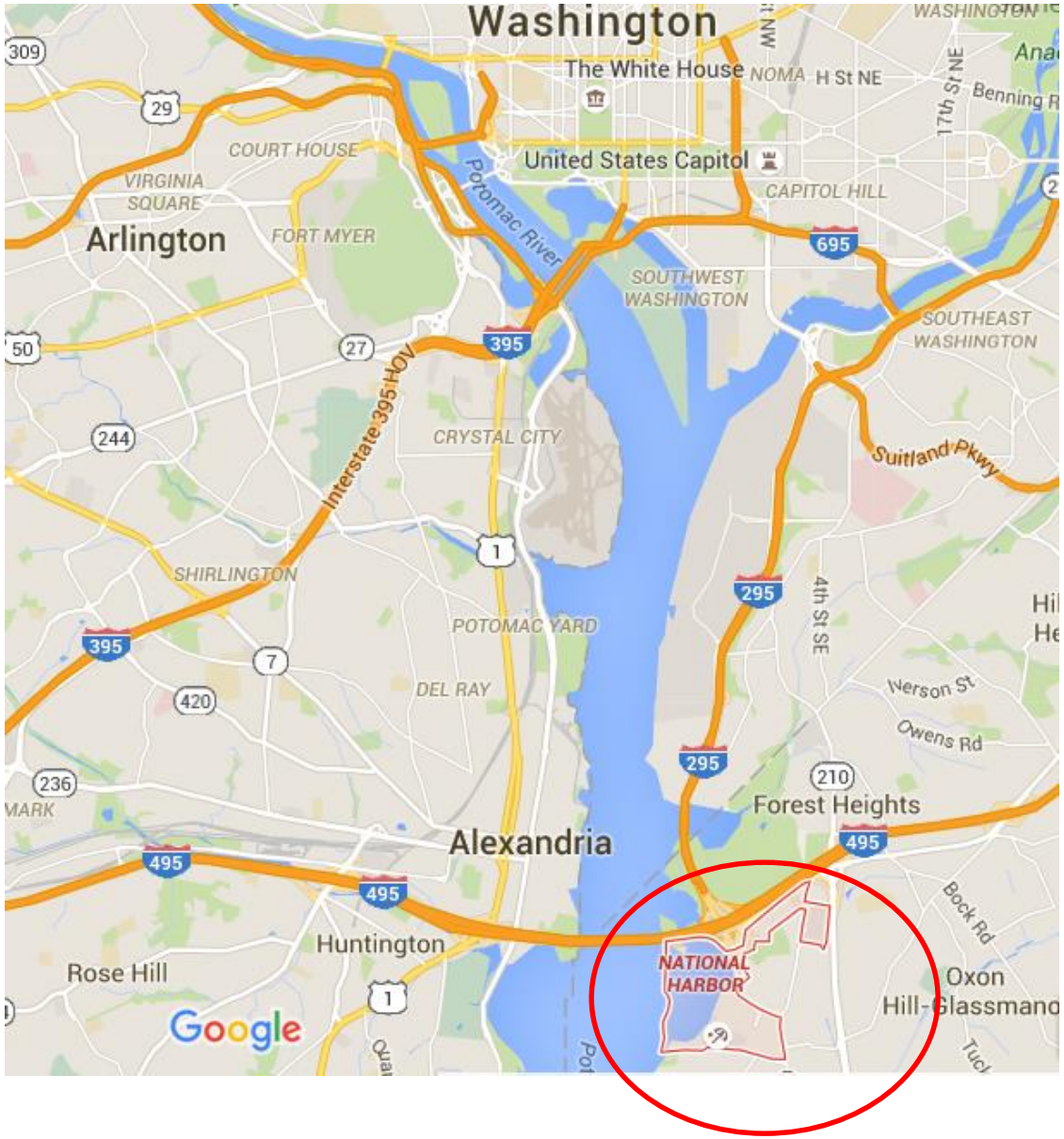
2016 building completion

OUTLINE

- Geotechnical Exploration
- Recommendations
- Foundation Decision
- Project Start
- Mid-Project Issues
- End of Project Foundation Change
- Lessons Learned/Conclusion

GEOTECHNICAL EXPLORATION

PROXIMITY TO DC



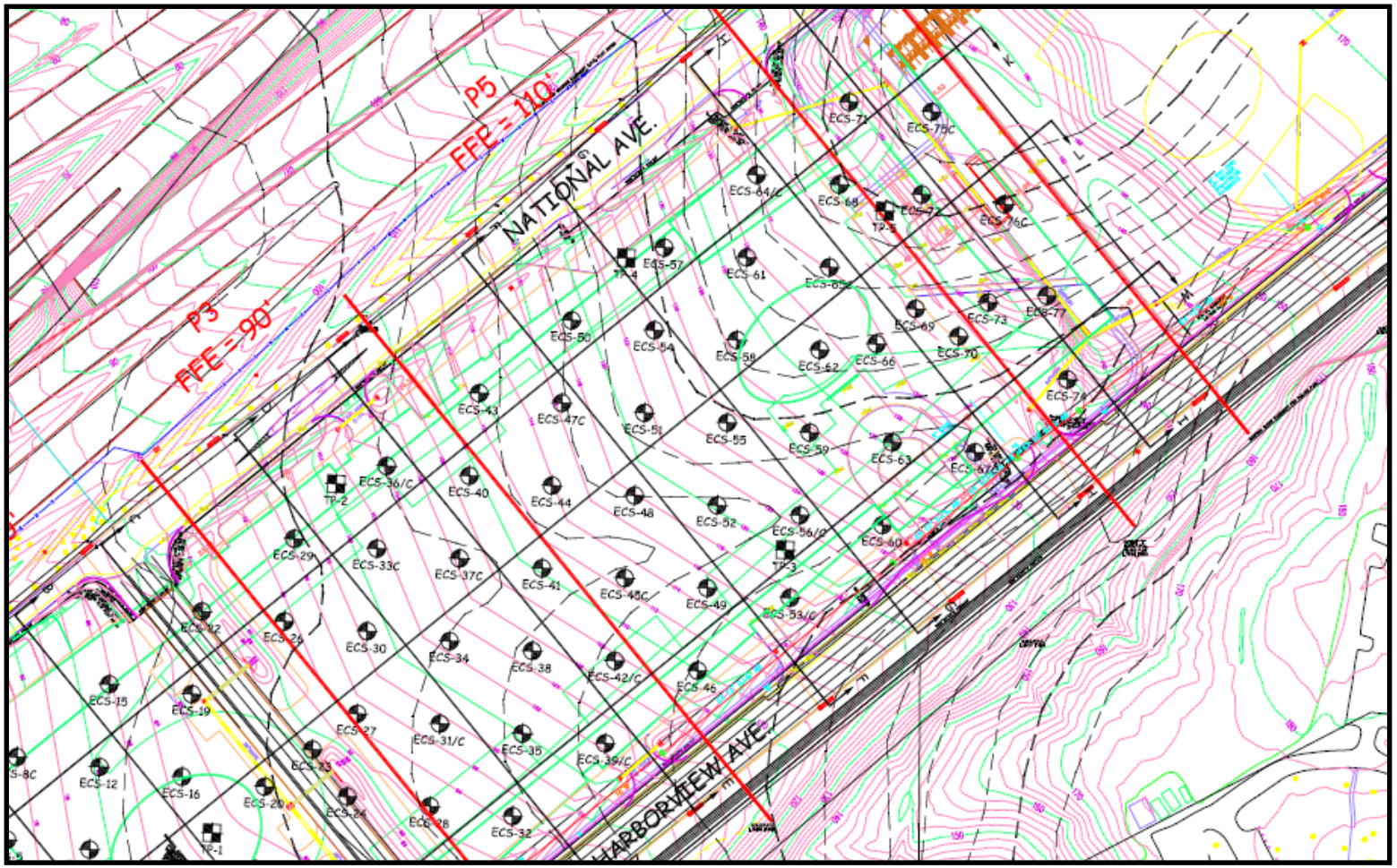
PROXIMITY TO DC

EXISTING FILL

Historic Aerials

Historic Topo from 1960's
Overlain on 2009 Aerial

EXISTING FILL

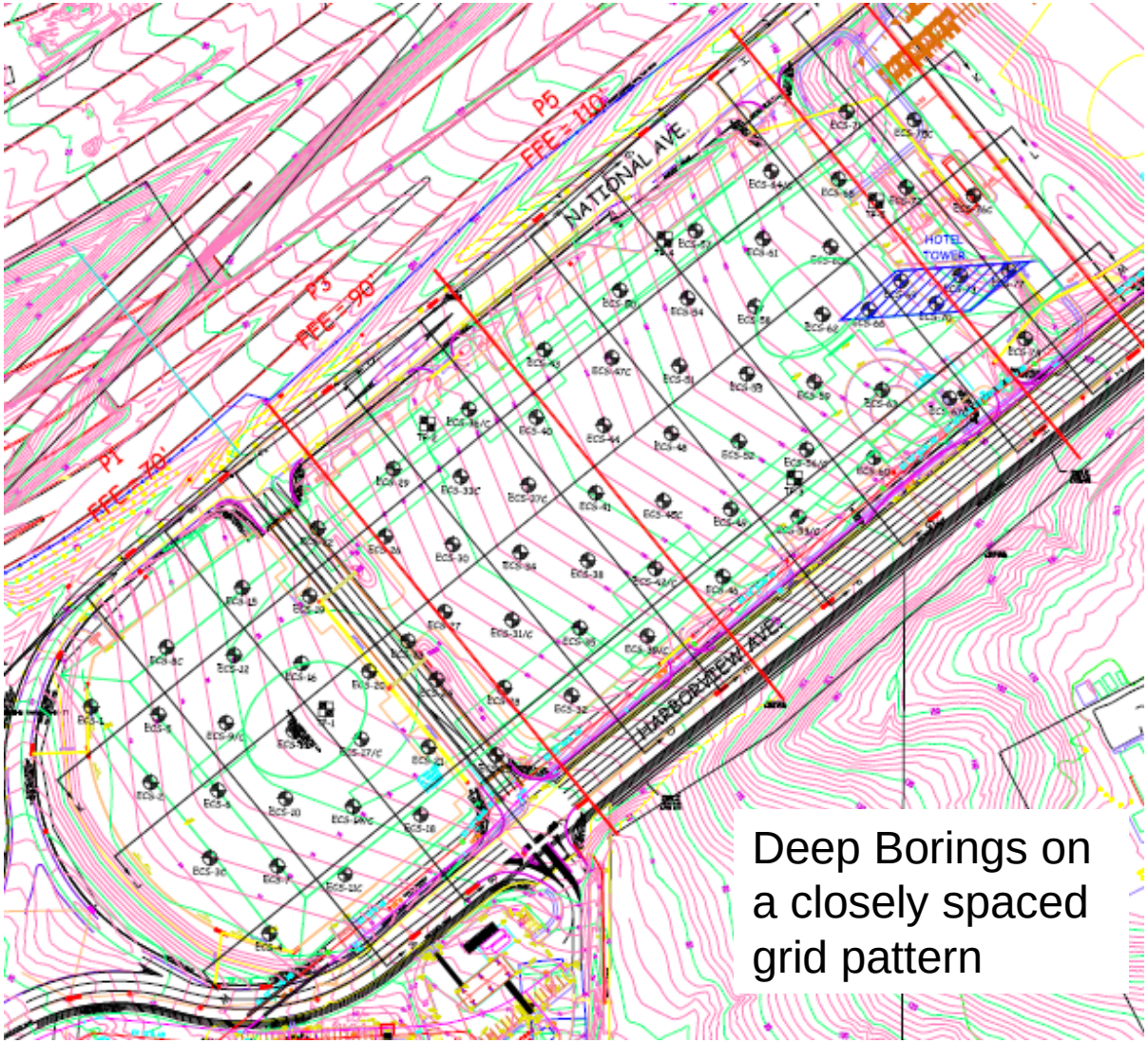


1960's Topo Overlain on 2009 Topo with Boring Locations

PORT AMERICA FOUNDATIONS

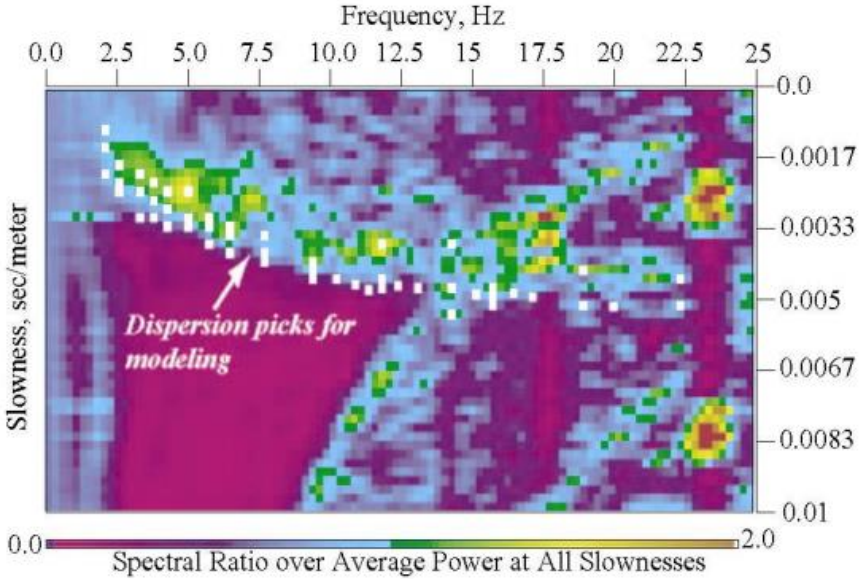
- 1987 project that was started/abandoned
- Few records available

SUBSURFACE EXPLORATION

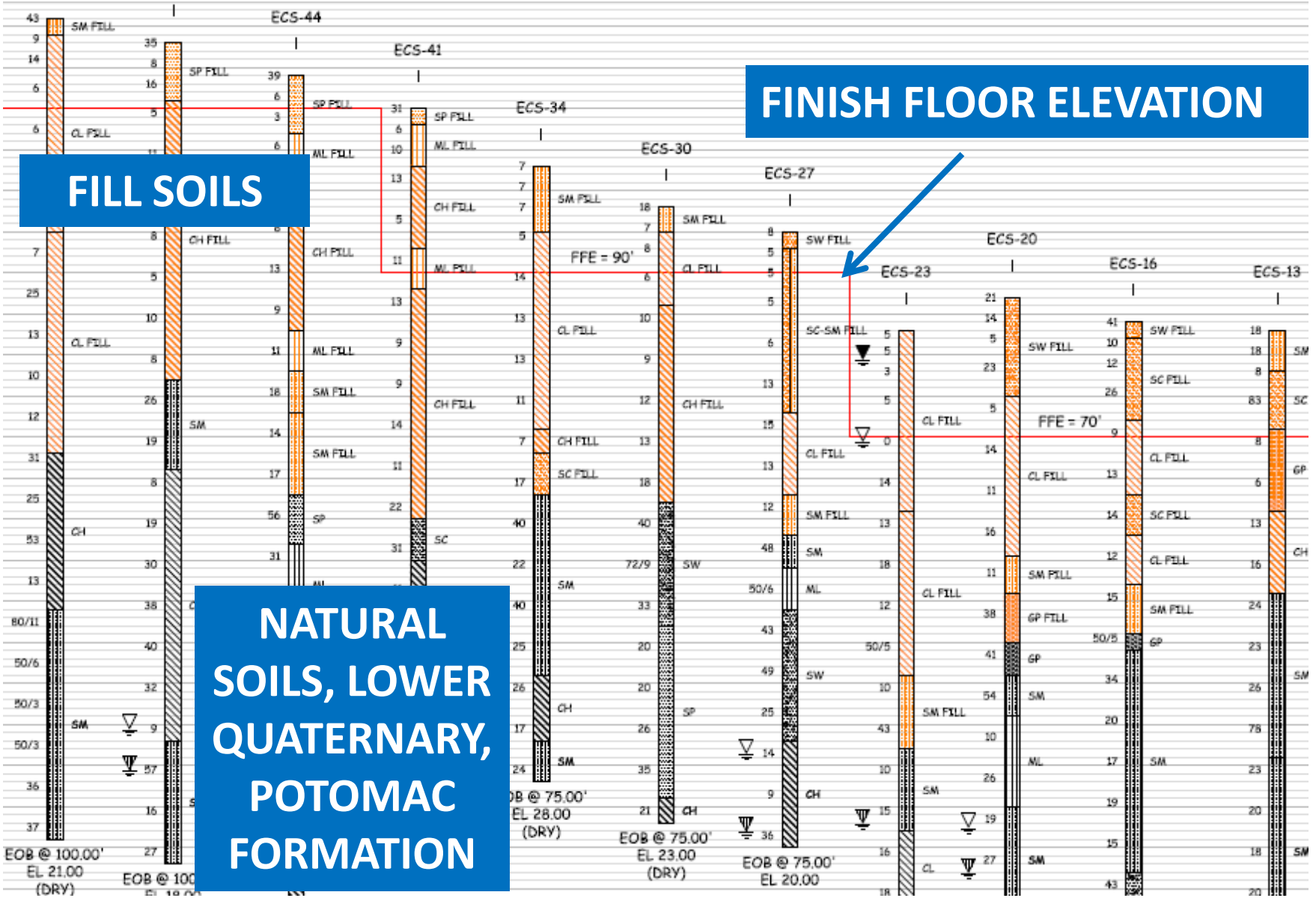


THE EXPLORATION PHASE

- **57 SPTS** – 75 to 100 feet
- **20 CPTS** – 20 to 100 feet
- **6 TEST PITS** – up to 15 feet
- **5** – Geophysical Surveys



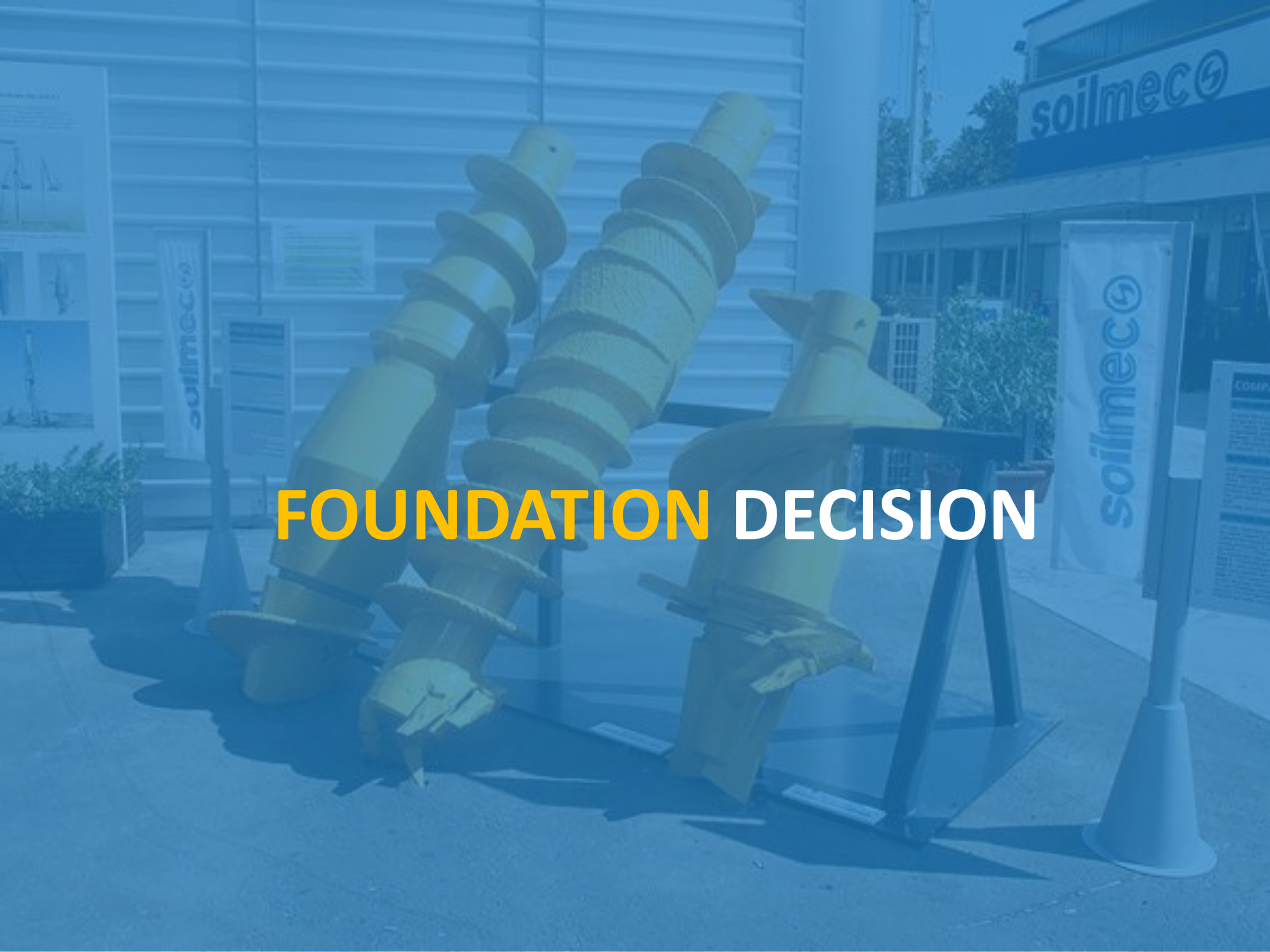
TYPICAL SOILS ENCOUNTERED



RECOMMENDATIONS

DEEP FOUNDATION RECOMMENDATIONS

Location	Foundation Type	Range of Lengths (feet)	Dimensions (inches)	Capacity (tons)
Hotel Tower	Driven PPC	54 to 64	14 Square	150
Hotel Tower	ACIP	64 to 74	16 Diameter	150
Plinth	Driven PPC	54 to 70	14 Square	150
Plinth	ACIP	64 to 80	16 Diameter	150



FOUNDATION DECISION

FOUNDATION DECISION

- A displacement, cast-in-place pile system was chosen by client.
- Early project cost estimates utilized Driven Steel H-Piles to support structure.
- ECS never recommended steel piles due to cost.

The contract between the owner and contractor was Design/Build, so where does that leave the GER?

FOUNDATION DECISION

- In Prince George's County, the Special Inspection requirements still required the GER to review and approve the Design/Build System.

- Conflicts over pile lengths ensued between the GER and Contractor.

- Total pile length basis of contract between Owner and Contractor never revealed to GER.

REVIEW OF D/B SUBMITTAL

Construction Considerations

ECS is not a foundation contractor; however, that is not to suggest that we don't have significant experience with deep foundation construction. We offer the following commentary on the DCIP pile alternative.

- Ability to reach design tip elevation. The DCIP pile type relies on torque and crowd pressure to advance the tools to the design tip. As no soil spoils are generated, there is an expected limitation on how deep DCIP piles can go into dense soils. Below is a screen shot of the soil profile beneath the hotel tower. We recommended a preliminary design tip EL. 60 ft to meet the 150 ton capacity (Driven PPC); the DCIP pile type would be presumably deeper, probably 10 feet or so (EL. 50 ft). Our research into DCIP piles indicates that these pile types are typically suited to sites with Standard Penetration Test (SPT) N-values < 25 bpf. In many instances throughout the site, the soils at the expected termination tip elevation have SPT N-values higher than 25 bpf. Will the DCIP pile be able to reach deeper tip elevations?

This concern later proved to be significant and required a pile type change

This is an excerpt from a letter ECS wrote to Owner; however, negotiations with contractor were well underway at this time

WHAT IS A DISPLACEMENT PILE?

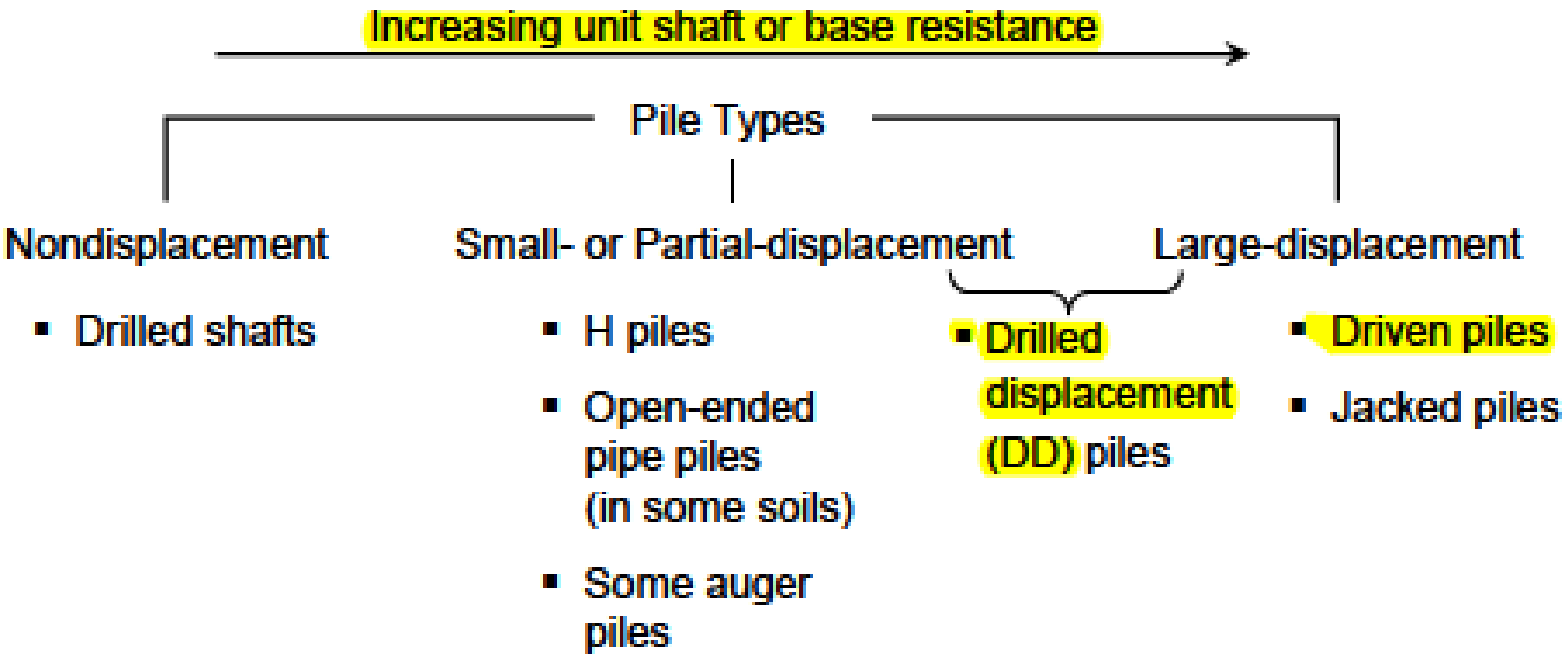


Figure 1.1 Categorization of piles based on the soil displacement produced during installation

THE RIG: IHC FUNDEX F3500

HIGH CROWD PRESSURE

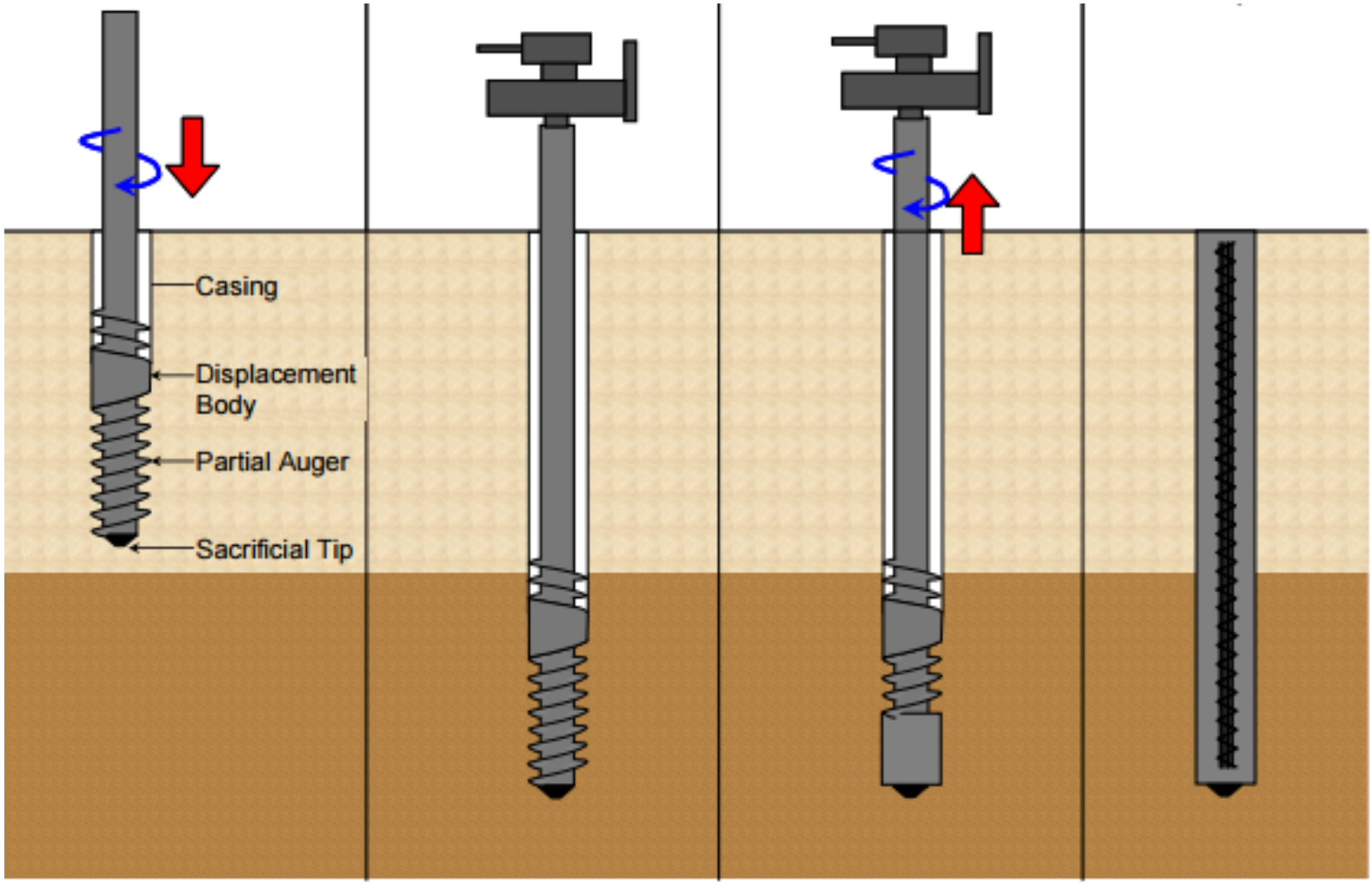
Note the lack of auger flights along mandrel and large hydraulic mechanism above mandrel for pushing

LOW CROWD PRESSURE

Traditional Auger-Cast-In Place piles. Note continuous auger flights and small hydraulic pack on top of augers.

DISPLACEMENT
TOOLING

DCIP INSTALLATION PROCEDURE



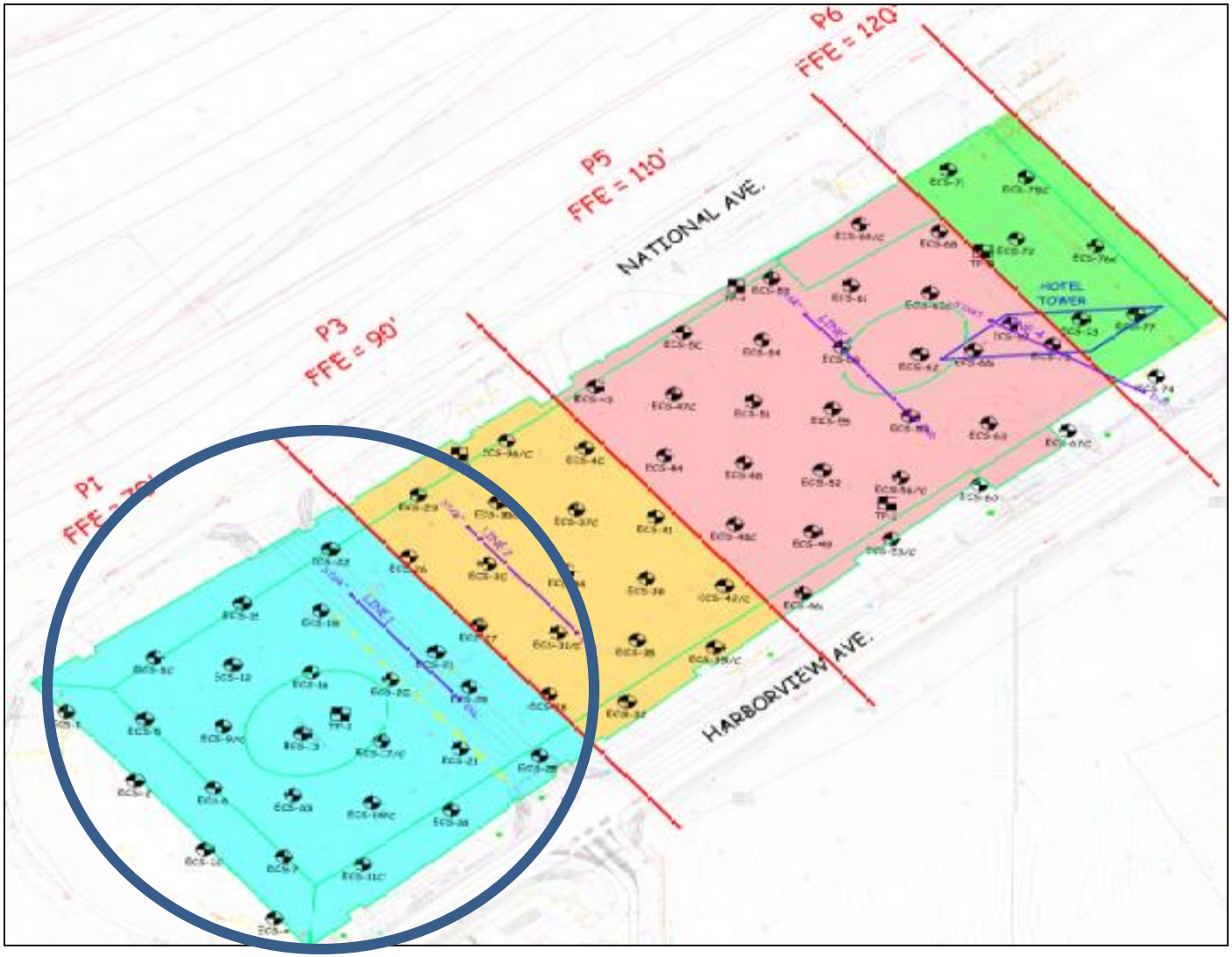
From Basu and Prezzi (2009)

Displacing/Drilling → ← **Concreting** → **Reinforcing Steel**


PROJECT START

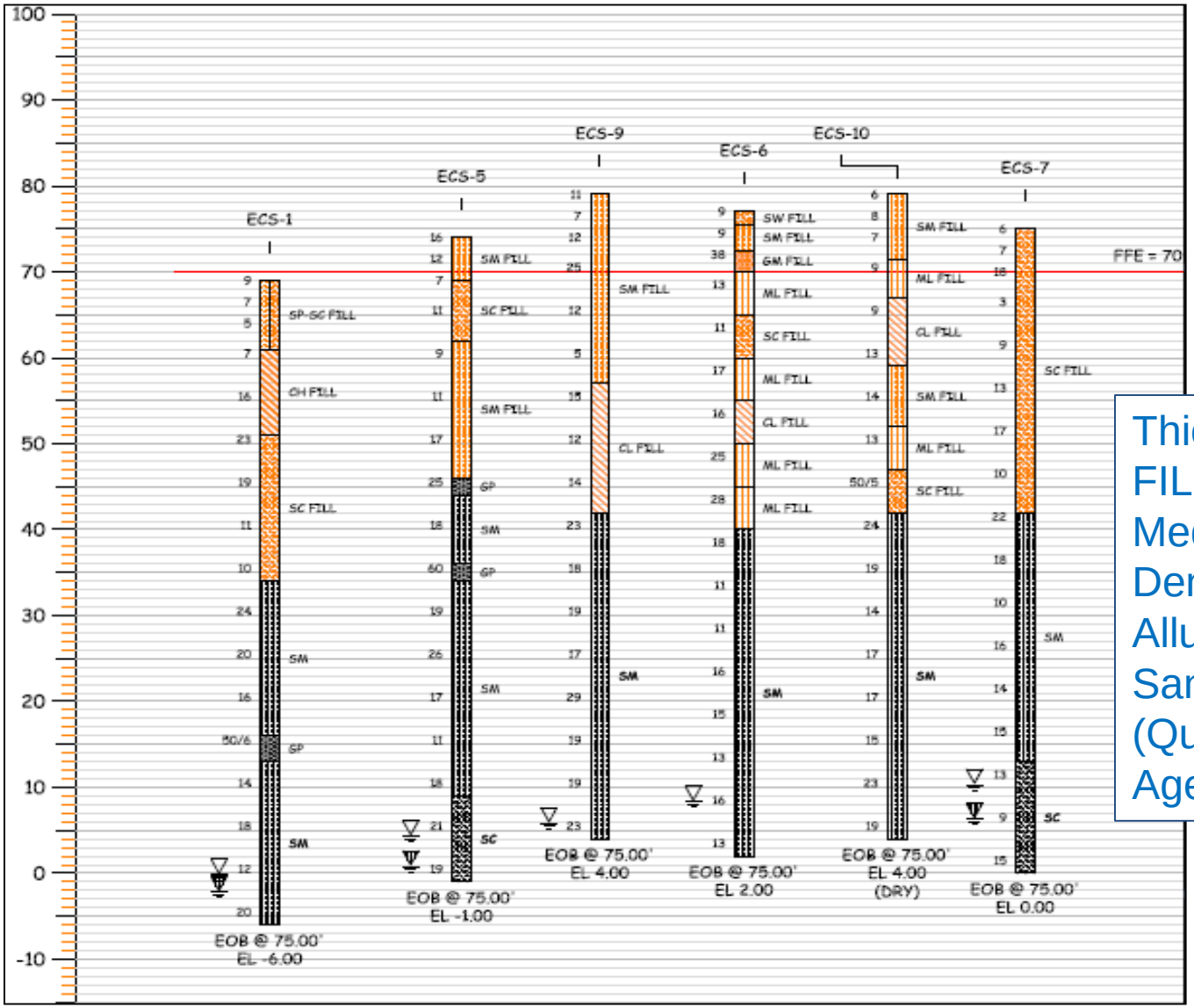
PROJECT STARTED OFF WELL

WESTERN P1 AREA



PROJECT STARTED OFF WELL

CROSS SECTION P1 AREA



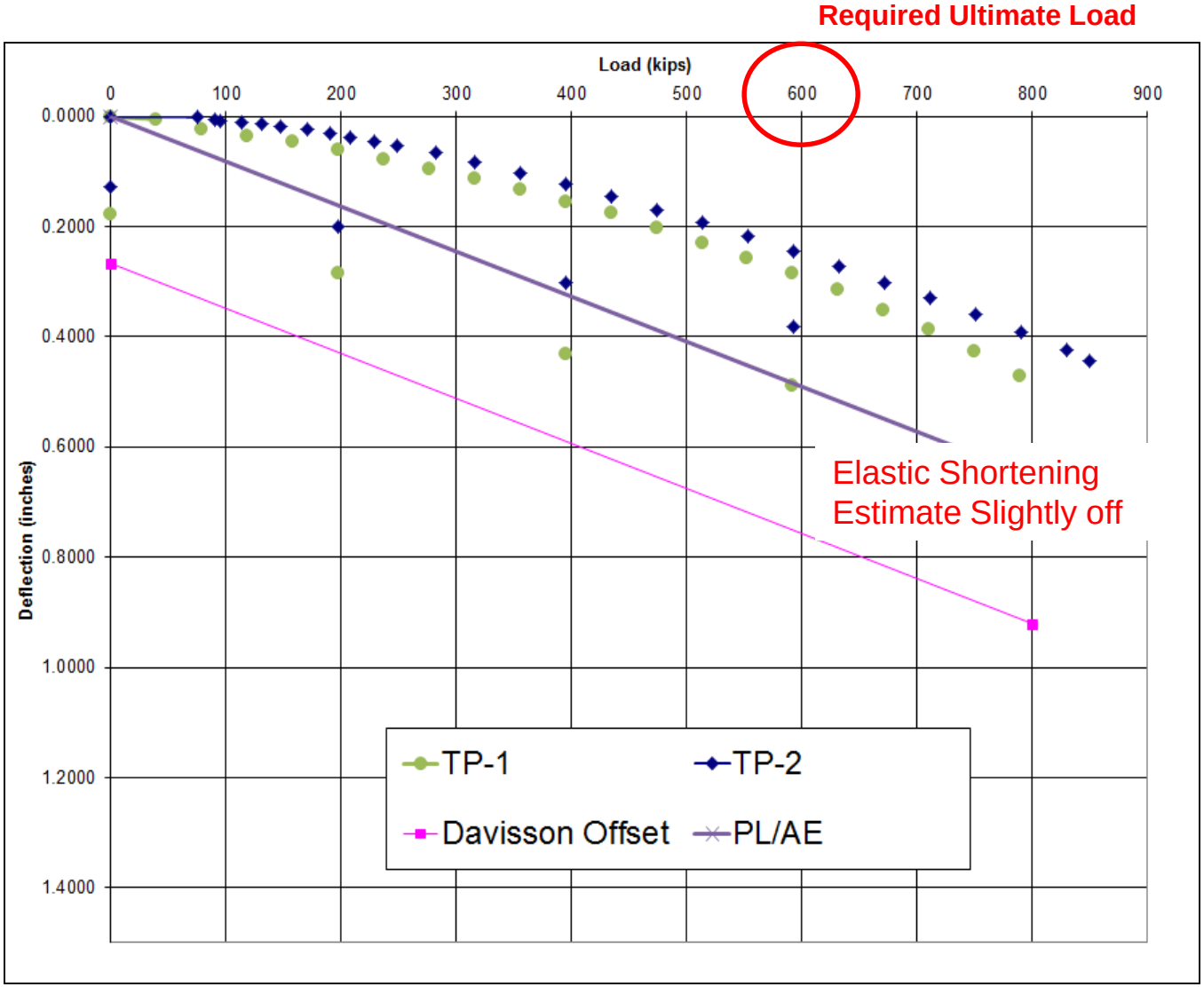
Thick sandy FILL over Medium Dense Alluvial Sands (Quaternary Aged)

PROJECT STARTED OFF WELL
LOAD TEST RESULTS P1 AREA

Conducted Two Favorable Compression Load Tests

Over 800 kips reached on load frames.

Did not learn a lot about the ultimate capacity.



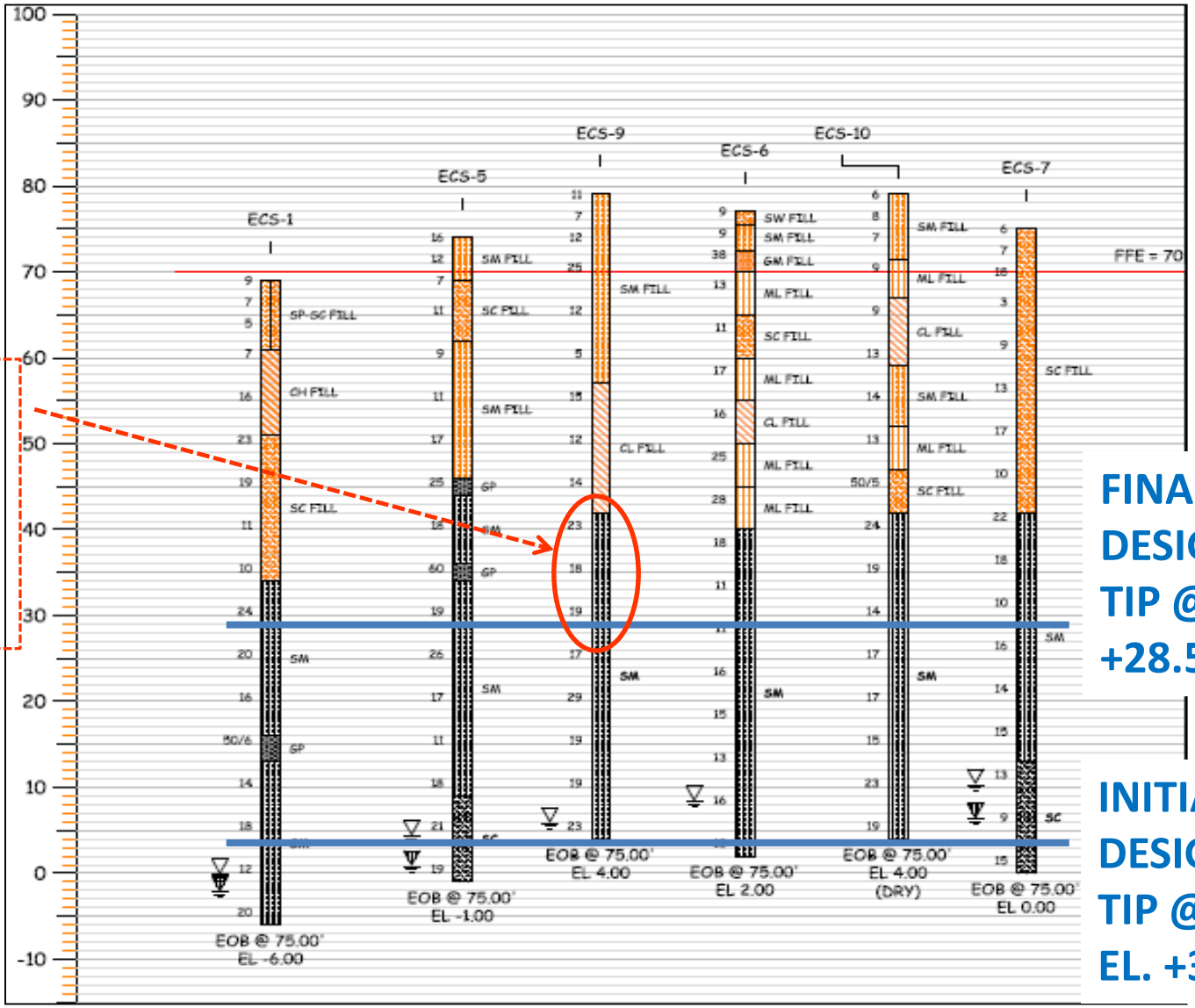
PROJECT STARTED OFF WELL
COMPARISON OF P1 LENGTHS

Location	Foundation Type	Diameter (inches)	Length Range (feet)	Bearing Stratum Embedment (feet)	Method of Analysis
P1 Level	DCIP	14	35 to 48	15 to 18	Based on Load Tests
P1 Level	Driven PPC	14	64 to 69	40 to 45	Based on Calculation
P1 Level	ACIP	16	74 to 79	50 to 55	Based on Calculation

For the P1 Area, the Drilled Displacement (DCIP) piles were considerably shorter than the Driven pile (PPC) and Auger-cast-in place (ACIP) pile estimates provided by ECS

PROJECT STARTED OFF WELL
COMPARISON ON LENGTHS

15-18 ft Embedment into Med. Ds. Sands = 150 tons (FS=2.0)



FINAL DESIGN TIP @ EL. +28.5’

INITIAL DESIGN TIP @ EL. +3.5’

PROJECT STARTED OFF WELL
DAILY PRODUCTION – P1 AREA

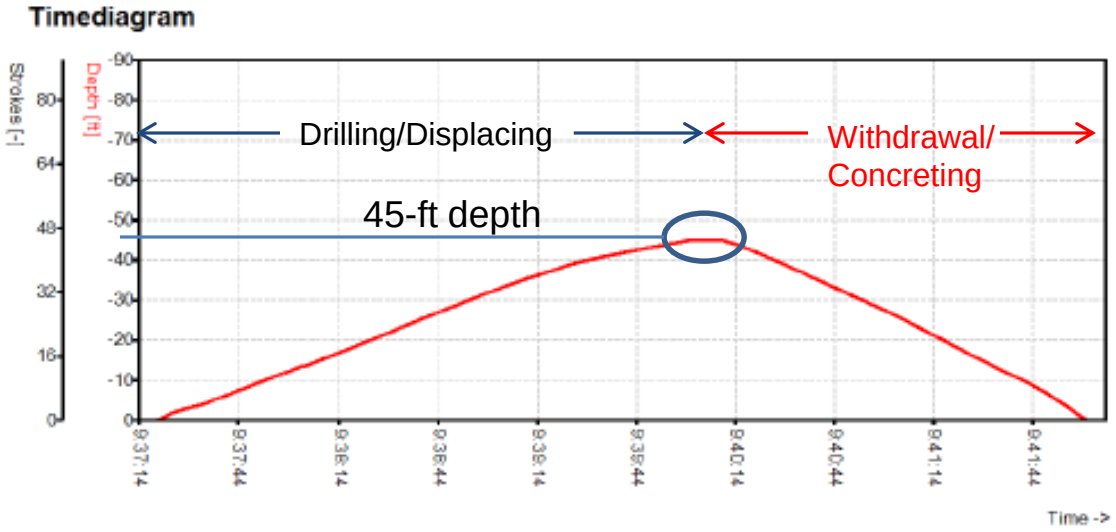
Start to Finish Times of 5 to 10 minutes per pile including concreting

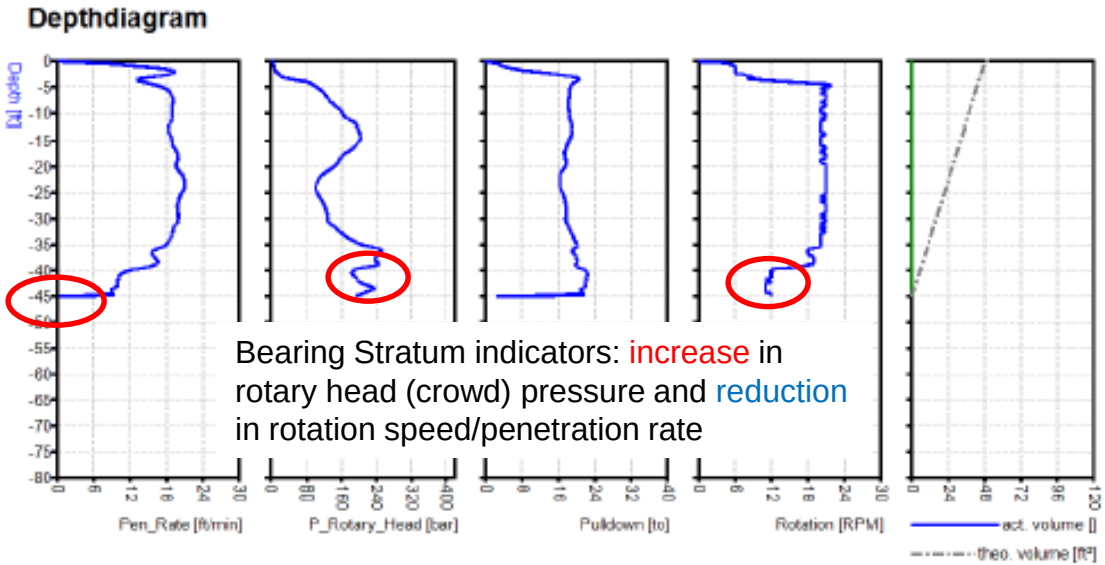
Avg. Production of 25, 40-foot long piles a day per rig

Up to 40 piles installed in any typical day

Termination Criteria was minimum tip elevation

PROJECT STARTED OFF WELL
SAMPLE LOG





- Low Head Pressures (<200 bars)
- Constant Penetration Rate (20 ft/min)
- Records did not always confirm Bearing Stratum Embedment which was a challenge during inspection.

INITIAL IMPRESSIONS

PROS

Fast Installation in Loose to Medium Dense Sands

Electronic logs recorded pertinent drilling information: rate of advancement, grout quantities, crowd pressure and tool rotation speed

CONS

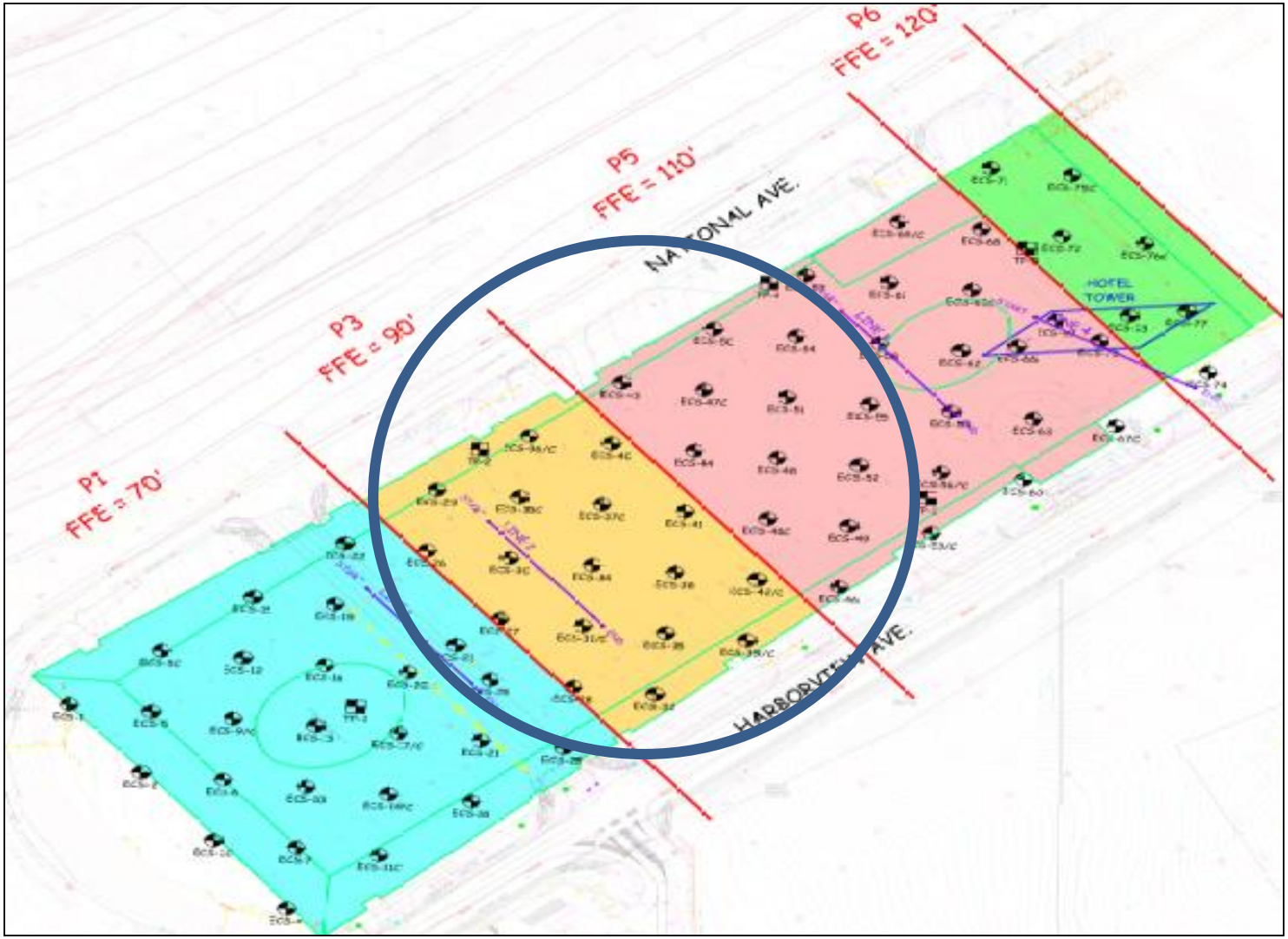
Very Large/Heavy Rig, so stable subgrade is needed. Could be expensive if subgrade is soft

Contractor chose to install piles to slab subgrade vs. pile cap bottom requiring costly later demo of pile heads

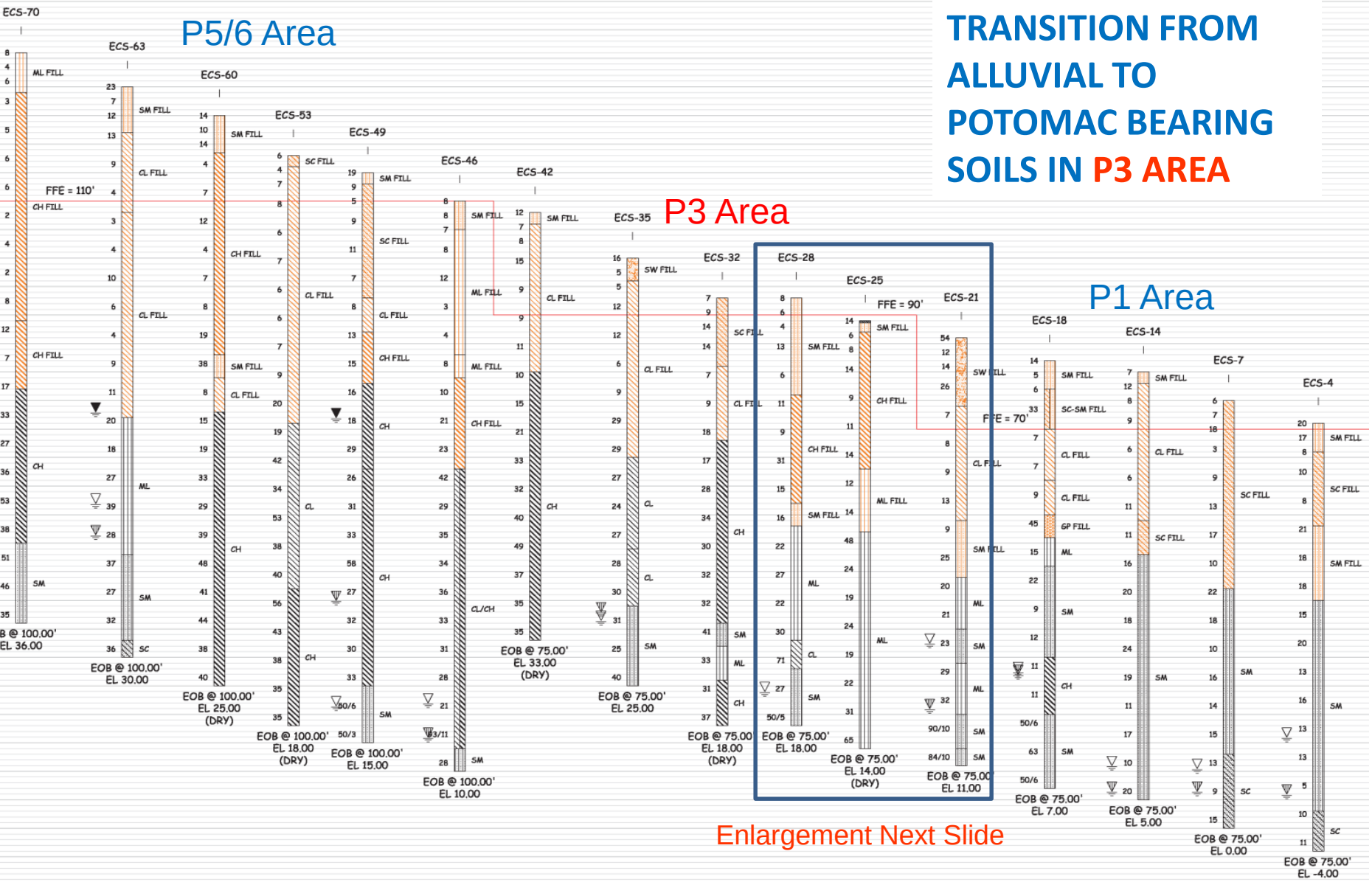
Installation records were not easily interpreted compared to a driven pile records

MID-PROJECT ISSUES

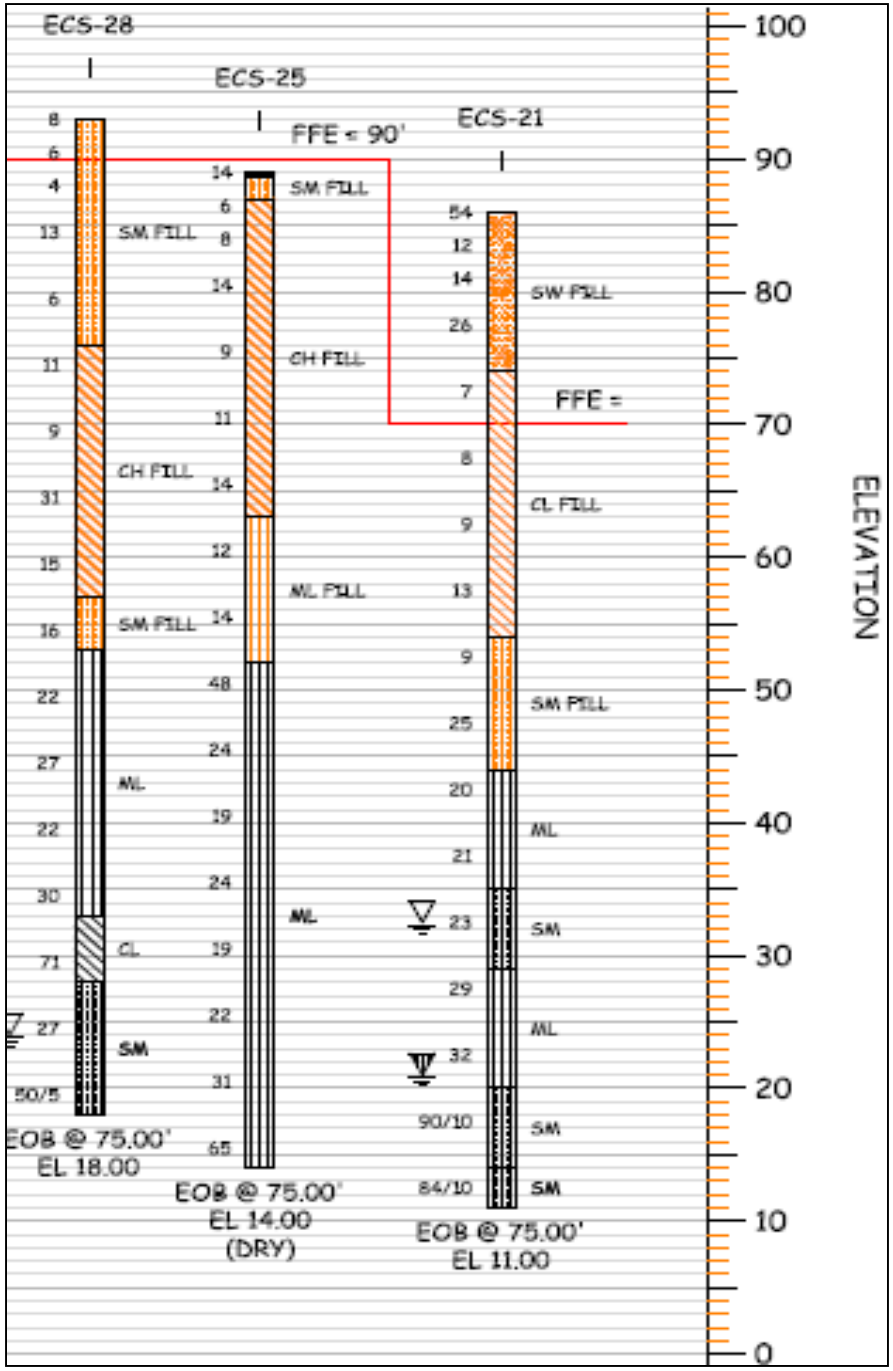
MID-PROJECT ISSUES
P3 AREA



TRANSITION FROM ALLUVIAL TO POTOMAC BEARING SOILS IN P3 AREA



Enlargement Next Slide



Enlarged Section

- 20 bpf to 48 bpf ML and CH
- Potomac soils more cohesive and denser

MID-PROJECT P3 ISSUES
HARD DRILLING

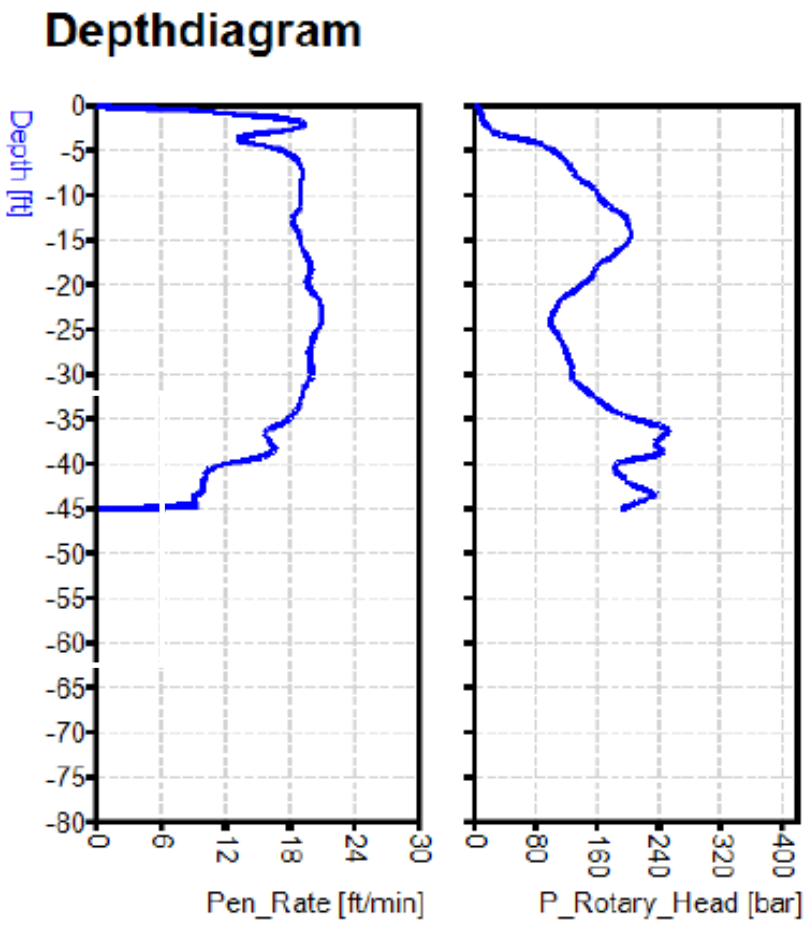
Start to Finish Times of 20 to 30 minutes per 50’ pile vs. the initial 5-10 minutes/pile

Up to 1 Hour for some piles

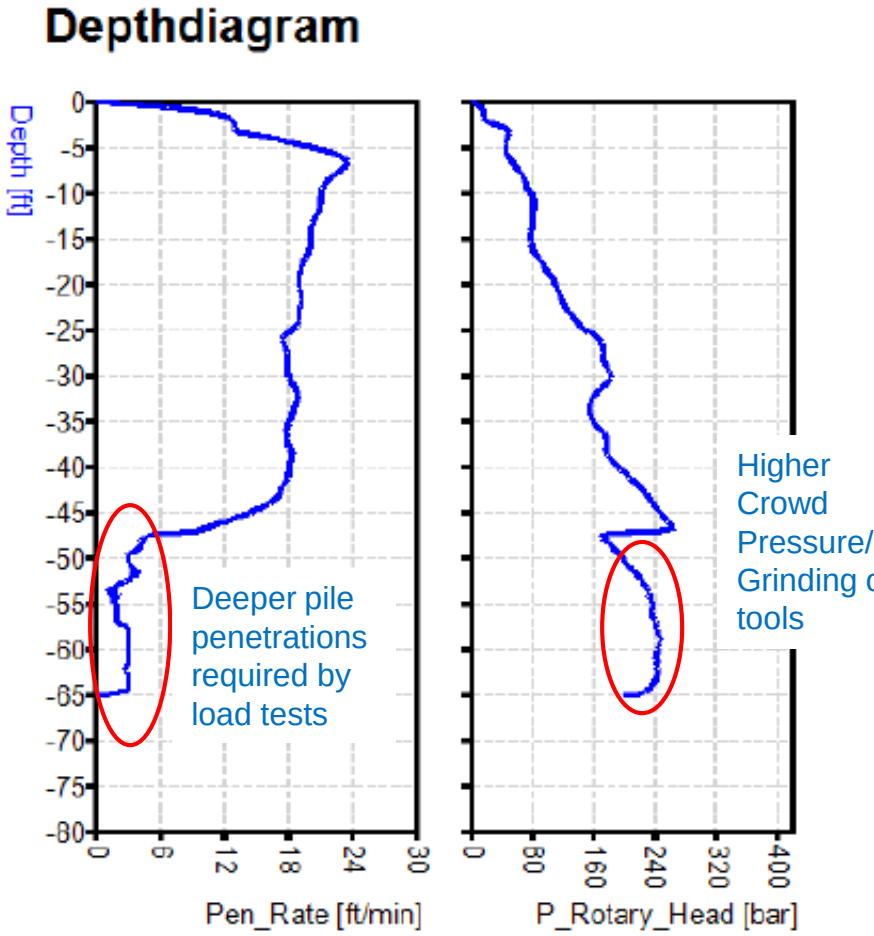
MID-PROJECT P3 ISSUES
HARD DRILLING

- Faster DCIP Tool Wear
- Predrilling Program and Early Termination Criteria
- Additional Engineering Oversight required

LOWER PLINTH VS. MIDDLE PLINTH,
CHANGES IN DRILLING RATES



Lower Plinth P1



Mid-Plinth P3

MID-PROJECT ISSUES
COMPARISON OF FOUNDATION DESIGNS

Location	Foundation Type	Diameter (inches)	Length Range (feet)	Method of Analysis
P3 Level	DCIP	14	46 to 58	Based on Load Tests
P3 Level	Driven PPC	14	54	Based on Calculation
P3 Level	ACIP	16	64	Based on Calculation

For the P3 Area, the Drilled Displacement Pile (DCIP) Lengths were much closer to our Driven pile (PPC) and auger-cast-in place (ACIP) pile estimates

MID-PROJECT ISSUES

- With GER approval, Contractor used early termination criteria (i.e., combination of min. crowd pressure and reduced penetration rate) OR minimum tip and pre-drilling for the remainder middle Plinth (P3 Level).
- Still experiencing longer installation times and excessive tool wear.
- Ultimately, the contractor asked for a pile type substitution for the upper Plinth P5/6 areas

The Displacing tools are “re-built” by welding new auger flights once they are worn down (costly and time consuming)

MID-PROJECT IMPRESSIONS

PROS

Fast Installation in Loose to Medium Dense Sands

Electronic logs record pertinent drilling information: rate of advancement, grout quantities, crowd pressure and tool rotation speed

Can sometimes be used to gauge bearing stratum embedment

Design lengths very similar to PPC lengths in Potomac Soils

CONS

Very Large/Heavy Rig, so stable subgrade is needed. Could be expensive if subgrade is soft

Contractor chose to isntall piles to slab subgrade vs. pile cap bottom requiring costly later demo

Installation records were not easily interpreted.

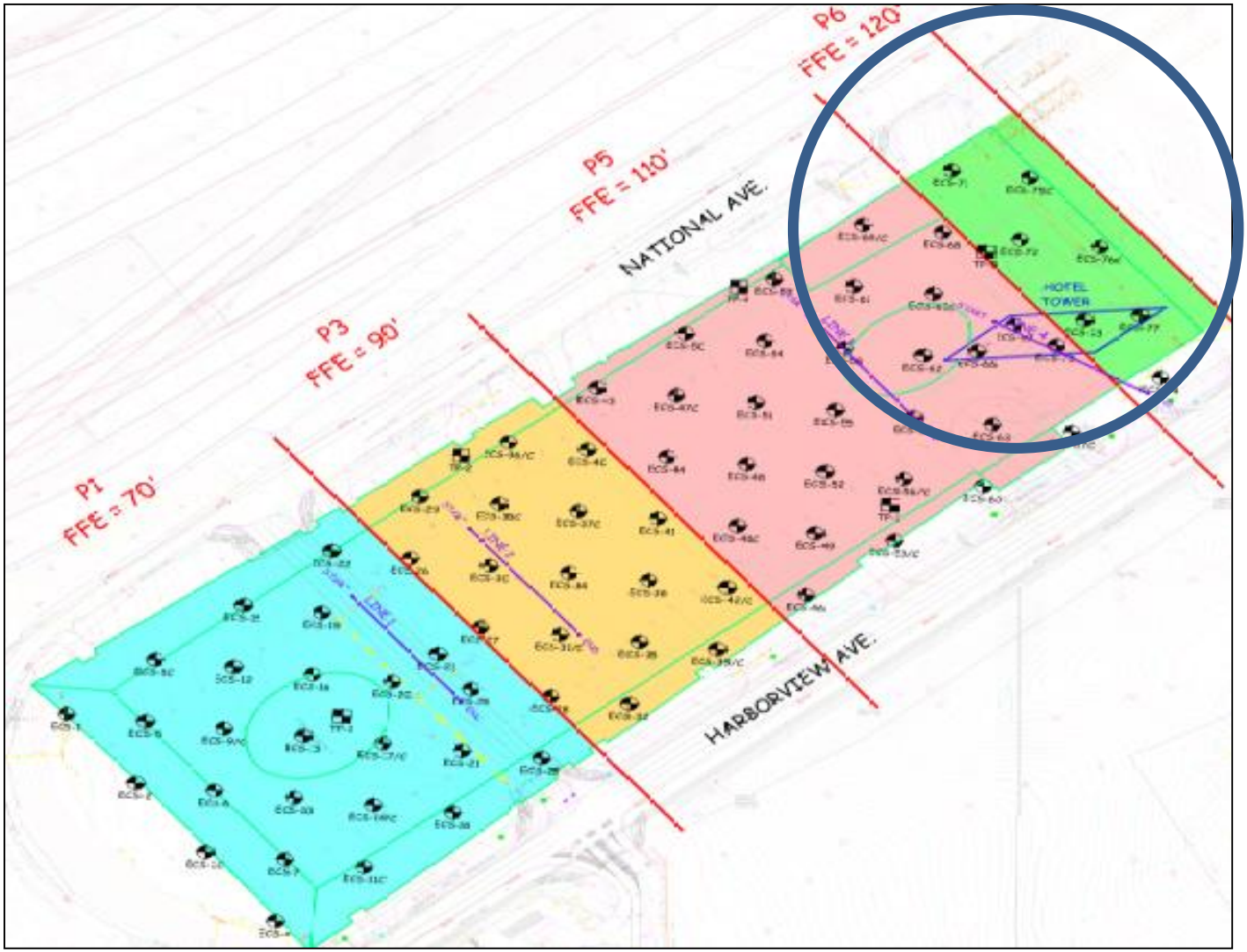
Refuses/Slow Drilling in Overconsolidated Clays and Dense Potomac Sands

Excessive tool wear and replacement


END OF PROJECT
FOUNDATION PILE CHANGE

END OF PROJECT

P5/P6 AND HOTEL



END OF PROJECT
SWITCH TO ACIP PILES

- Contractor decided to use ACIP Piles in P5/6 areas to improve installation time and get back on schedule.
- No issues achieving tip due to cutting nature of tooling and continuous augers.
- Could use the same rig, but had to switch out tooling.

END OF PROJECT P5/6
COMPARISON OF PILE TYPE

Pile Type	Test Pile (TP) Number	Embedment into Bearing Stratum (feet)	Ultimate Failure Capacity (tons)
ACIP	TP-35	27	360
	TP-42	23	375
	TP-43	27	375
DCIP	TP-30	37	400
	TP-31	27	300
	TP-32	16	285

Lower Ultimate Capacities

No obvious benefit from displacement drilling in Potomac Soils

END OF PROJECT
SWITCH TO ACIP PILES

- Little difference axial capacity between ACIP and DCIP piles of same length

- Potomac soils don't improve in strength by densification; these soils are already dense/ overconsolidated

END OF PROJECT
COMPARISON OF FOUNDATION

Location	Foundation Type	Diameter (inches)	Length Range (feet)	Method of Analysis
P5 Level	DCIP	14	51 to 61	Based on Load Tests
P6 Level	DCIP	14	43 to 55	Based on Load Tests
P5 Level	ACIP	14	60	Based on Load Tests
P6 Level	ACIP	14	62	Based on Load Tests
P5 Level	Driven PPC	14	54 to 64	Based on Calculation
P6 Level	Driven PPC	14	54	Based on Calculation
P5 Level	ACIP	16	64 to 74	Based on Calculation
P6 Level	ACIP	16	69	Based on Calculation

The DCIP piles with embedments in the Potomac Formation compared favorably with Driven concrete pile (PPC) estimates provided by ECS and reasonably well with ACIP piles

END OF PROJECT IMPRESSIONS

PROS

Fast Installation in Loose to Medium Dense Sands

Can install Augered Cast-in-Place (ACIP) Piles and Displacement Piles with the same rig

Allows the flexibility to change pile types depending on soil conditions and drilling difficulties

Electronic logs record pertinent drilling information: rate of advancement, grout quantities, crowd pressure and tool rotation speed. Can sometimes be used to gauge embedment

CONS

Very Large/Heavy Rig, so stable subgrade is needed. Could be expensive if subgrade is soft

Contractor chose to install piles to slab subgrade vs. pile cap bottom requiring costly later demo

Requires a tooling change between DCIP and ACIP piles

Excessive tool wear and replacement

Refuses/Slow Drilling in Overconsolidated Clays and Dense Sands

Installation records were not easily interpreted if you want to terminate before plan tip.

LESSONS LEARNED/CONCLUSIONS

CONCLUSIONS

- DCIP piles perform very well in loose to medium dense Quarternary sands, perhaps better than driven piles of similar length.

- DCIP piles are VERY slow in very stiff/hard Clays and Dense Sands.

- In Potomac soils, the displacing nature does not result in additional soil strength improvement or pile capacity.

- Depths are comparable to driven piles & ACIP Piles (when in Dense Sands/Clays).

- Was this project a good candidate for a Design/Build Contract?

QUESTIONS?

Karl A. Higgins, III, P.E., D. GE
Senior Vice President/Chief Engineer
703.471.8400 • khiggins@ecslimited.com

James P. Racine, P.E.
Senior Project Engineer
301.645.6472 • jracine@ecslimited.com