

Manhattan Cruise Terminals Geotechnical Assessment:

Analysis of Timber Piles in Soft Organic Silts

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Introduction and History

- A geotechnical assessment of conditions at Piers 88, 90, 92, and 94 was performed for as part of a full structural assessment by COWI .
- Piers 88, 90, and 92 were built in **1934** as the Manhattan Cruise Terminal (MCT) for the New York Passenger Ship Terminal (NYPST).
- Pier 94 was built in **1961** for the Cunard Steam-Ship Company.









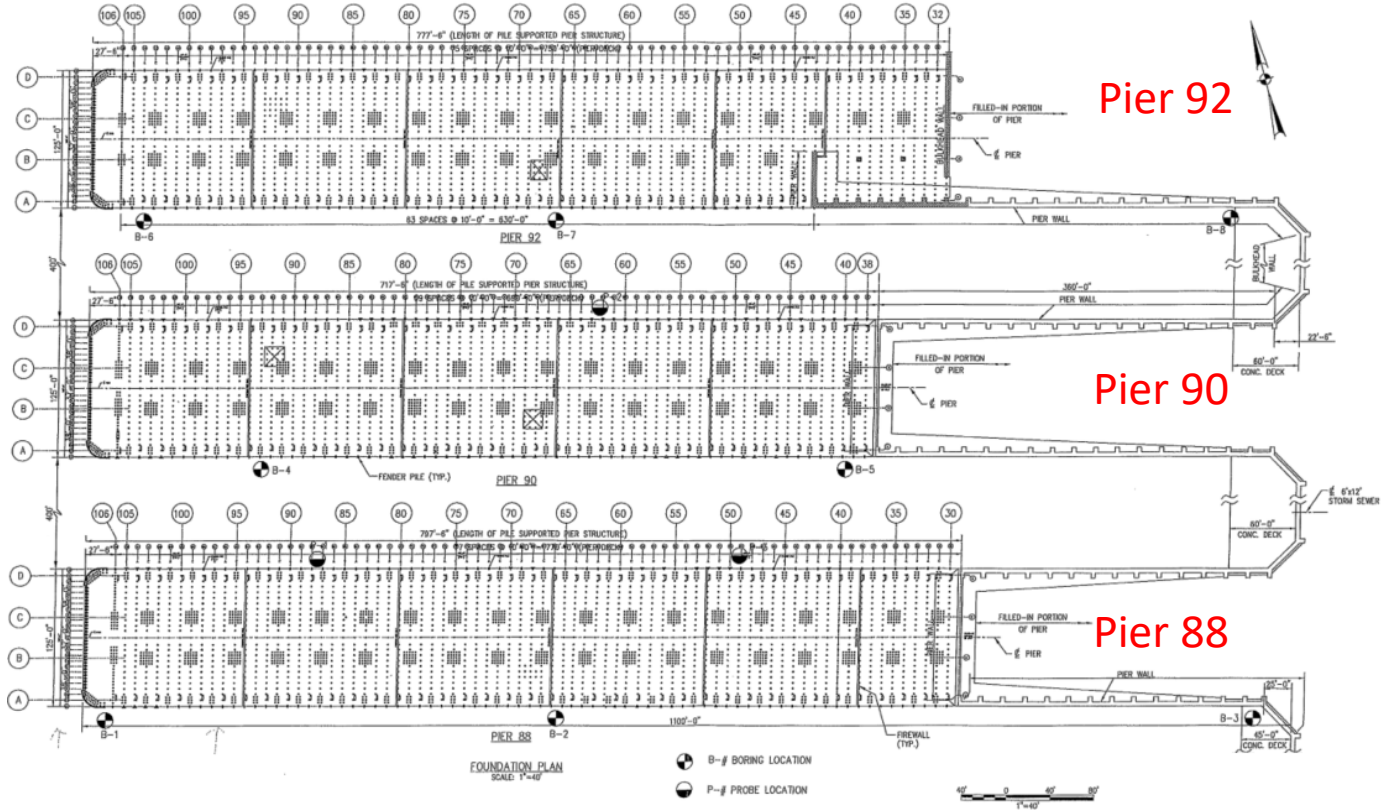
Objectives

- Assess the geotechnical conditions of the Manhattan Cruise Terminal (MCT Piers 88, 90, 92, 94).
- Perform field and laboratory testing to classify the subsurface soils within the project area.
- Evaluate bearing capacity of the existing piles.
- Conduct axial and lateral analyses to develop soil springs for structural analysis.
- Analyze the settlement of the piers.

Previous Investigations

PIERS 88, 90, 92:

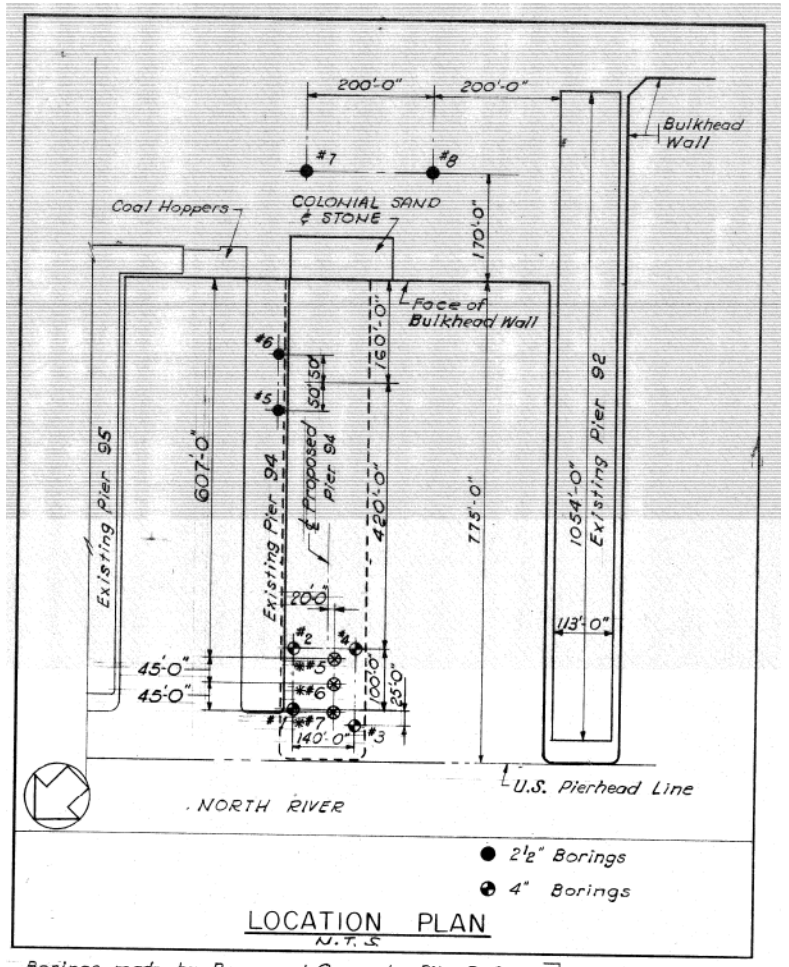
- 8 borings were drilled at Piers 88, 90, and 92 in 2002.
- All the borings extended to bedrock at a depth ranging from about **58 ft** on the **inshore side** of the pier to **200 ft** below the top of deck on the **outshore side**.
- These boring logs show that the encountered material from mudline to bedrock was **very soft organic clayey silts** except for a very soft to dense sand layer encountered at the offshore end of the pier at depths greater than 85 ft.



Previous Investigations

PIER 94:

- 11 borings were performed in **1961 and 1962** at **Pier 94**
- All the borings extended to **bedrock** at a depth ranging from about **30 ft on the inshore side** of the pier to **170 ft** below the top of deck on the **outshore side**.
- These boring logs show that the encountered material from mudline to bedrock was **very soft organic silts** except for a medium dense to dense sand layer encountered at the offshore end of the pier at depths greater than 120 ft.



Field Investigation

Standard Penetration Test (SPT) (ASTM D1586)







Field Investigation

Standard Penetration Test (SPT):

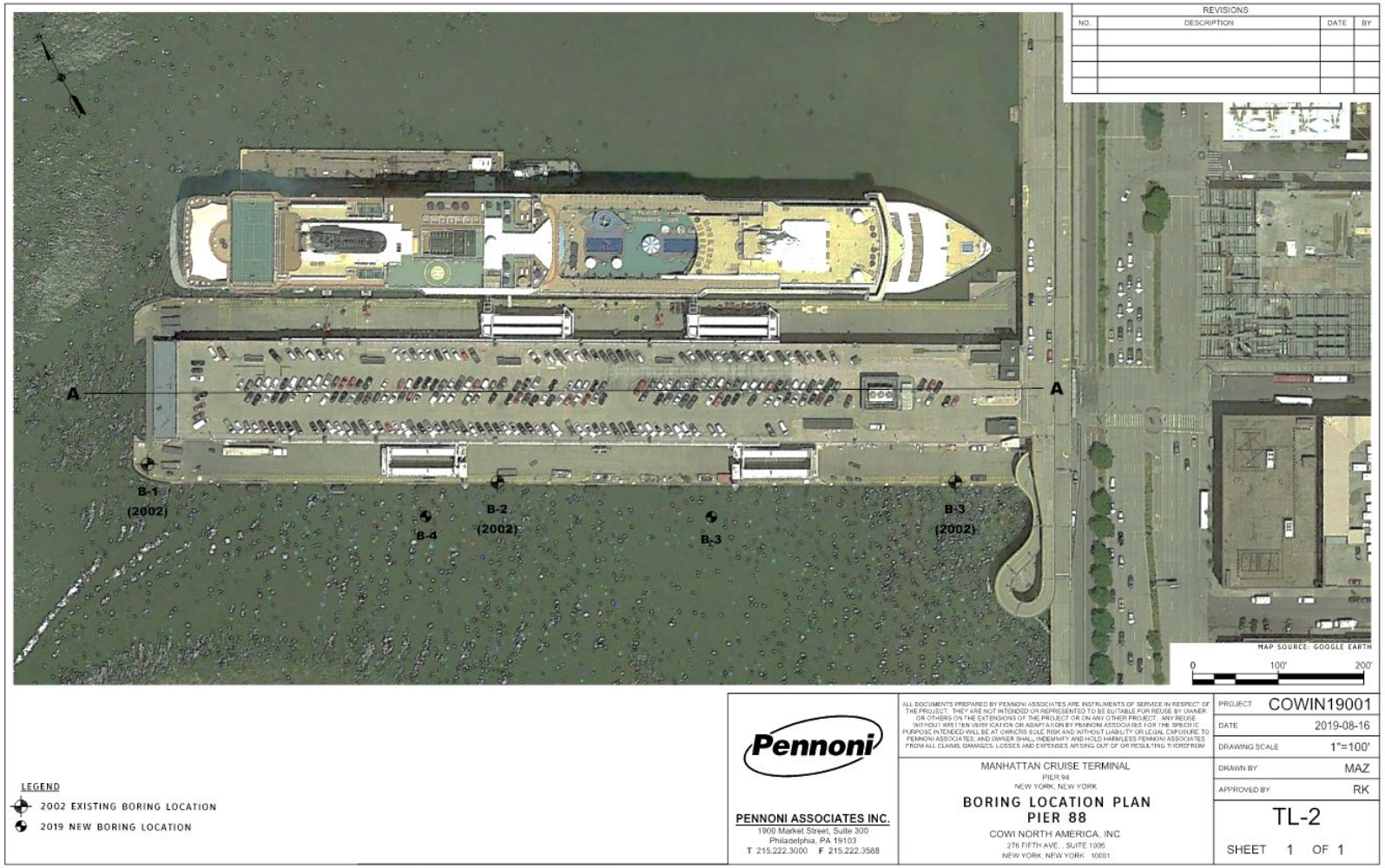
B-1 and B-2 at Pier 90



Field Investigation

Standard Penetration Test (SPT):

B-3 and B-4 at Pier 88



Field work

Standard Penetration Test (SPT):

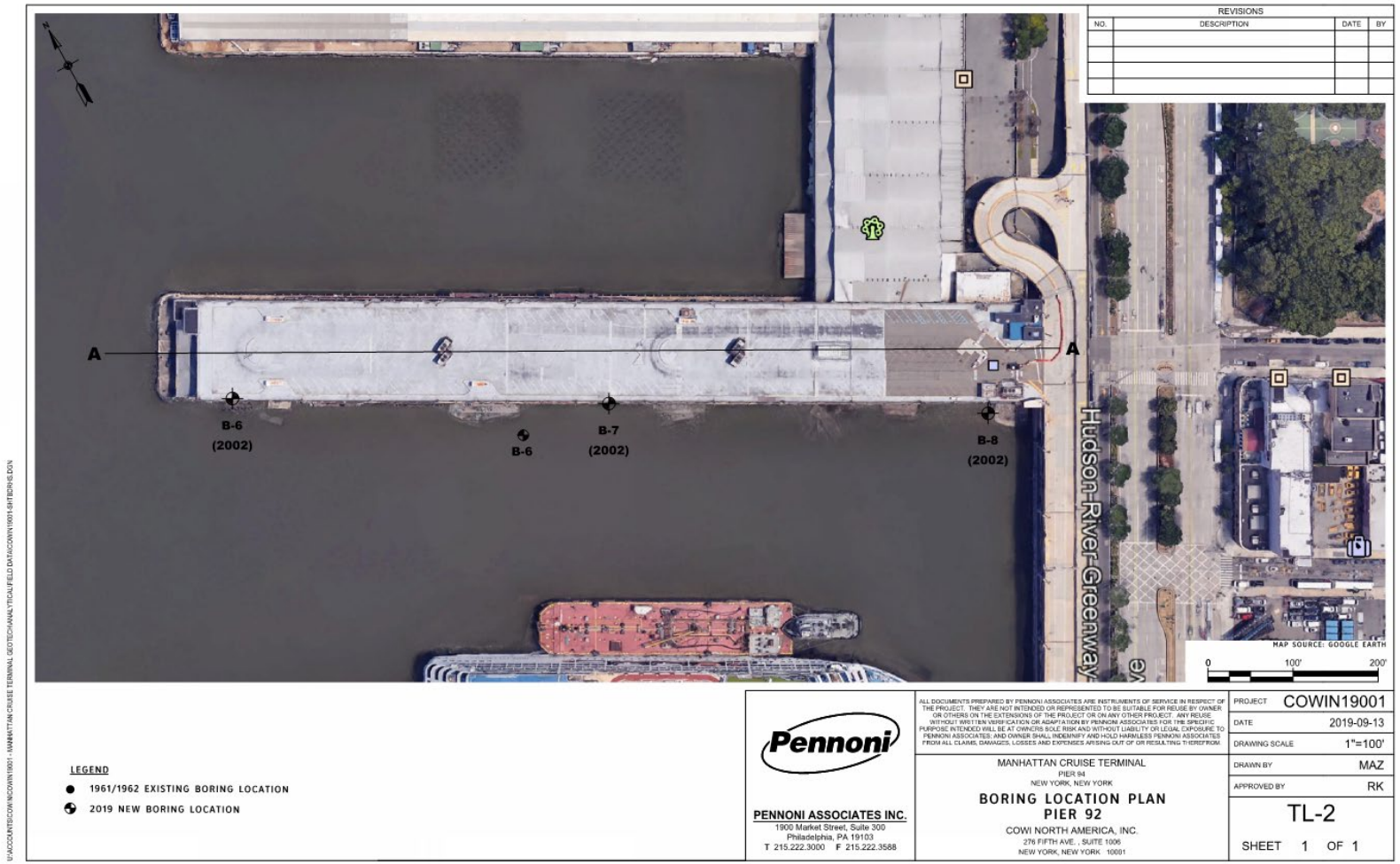
B-5 at Pier 94



Field Investigation

Standard Penetration Test (SPT):

B-6 at Pier 92



Laboratory Testing



Unconfined Compression Test (Rock)

- Natural Moisture Contents (ASTM D2216)
- Particle Size Analysis of Soils (w/o Hydrometer, ASTM D422)
- Hydrometer Test (ASTM D7928)
- Plasticity Index of Soils (ASTM D4318)
- Unit Weight of Soils (ASTM D7263)

- Organic Content, LOI (ASTM D2974)
- Consolidation Test (ASTM D2435)
- Consolidation Undrained with Pore Pressure Tests (ASTM D4767)
- Unconfined Compression Test (Rock - ASTM D7012)
- Torvane Shear Strength Test



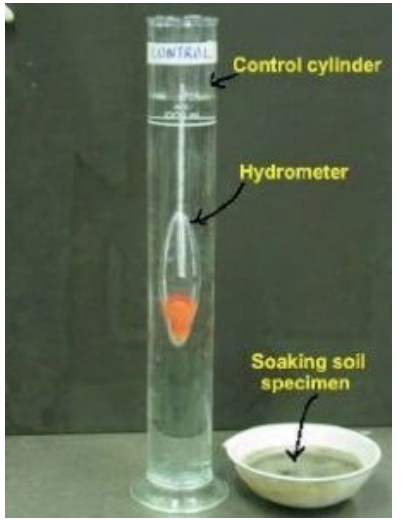
Consolidation Test



Plasticity Index of Soils



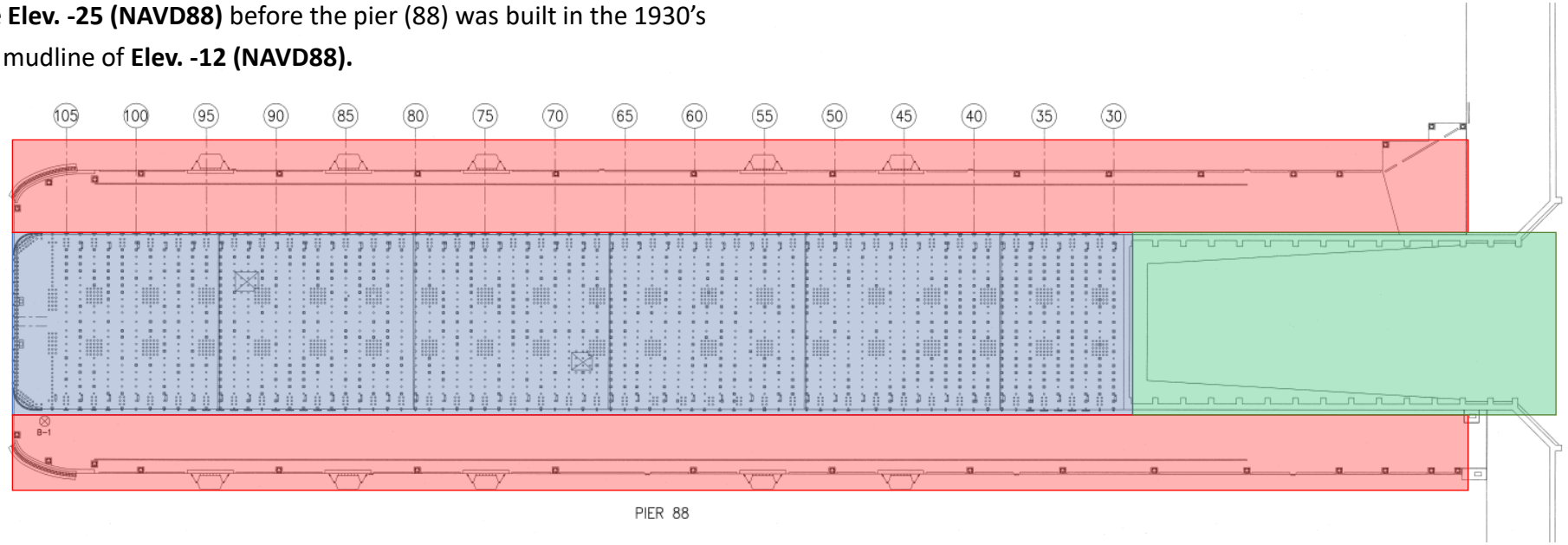
Particle Size Analysis of Soils



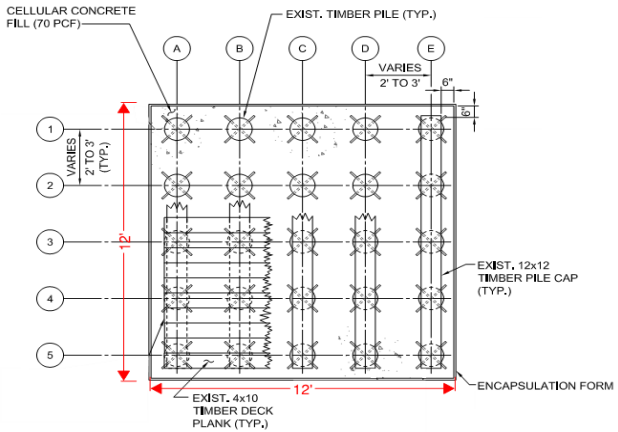
Hydrometer Test

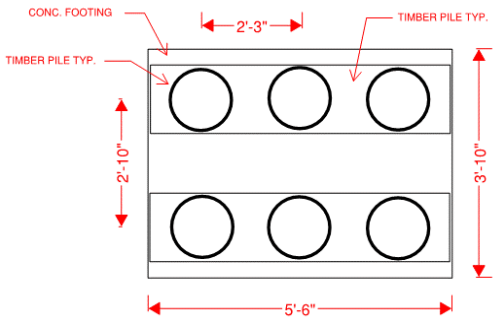
PIER 88: Existing Conditions

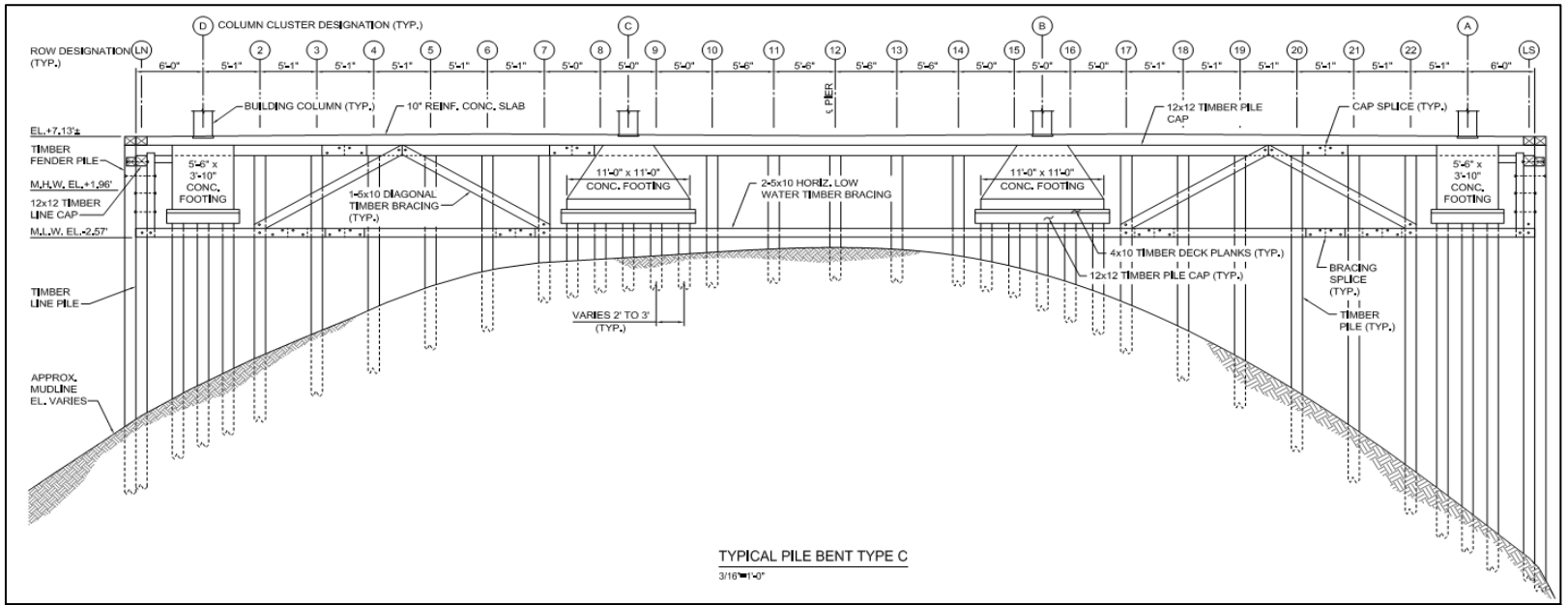
- The following presentation will focus on the investigation and analysis performed at Pier 88.
- Pier 88 was originally constructed: **1,040 ft long** x **125 ft wide**.
- Between 2006 and 2010, two 46-ft wide **aprons** added on the north and south sides.
- The pier consists of **three distinct** structural parts:
  - **Timber High-Level Platform**: The main concrete deck slab is supported on a timber substructure at the offshore end. The shed columns are supported on timber piles arranged in 6-, 18- and 25-pile clusters.
  - **Earth-filled inshore portion of the pier:** The fill is retained by a concrete gravity wall founded on bedrock, which runs along the north, south, and east faces of the pier.
  - **North and South Aprons:** these aprons consist of a precast and cast-in-place concrete deck that is supported by cast-in-place concrete pile caps and steel pipe piles.
- Mudline elevation:
  - Historic mudline **Elev. -25 (NAVD88)** before the pier (88) was built in the 1930's
  - Current average mudline of **Elev. -12 (NAVD88).**

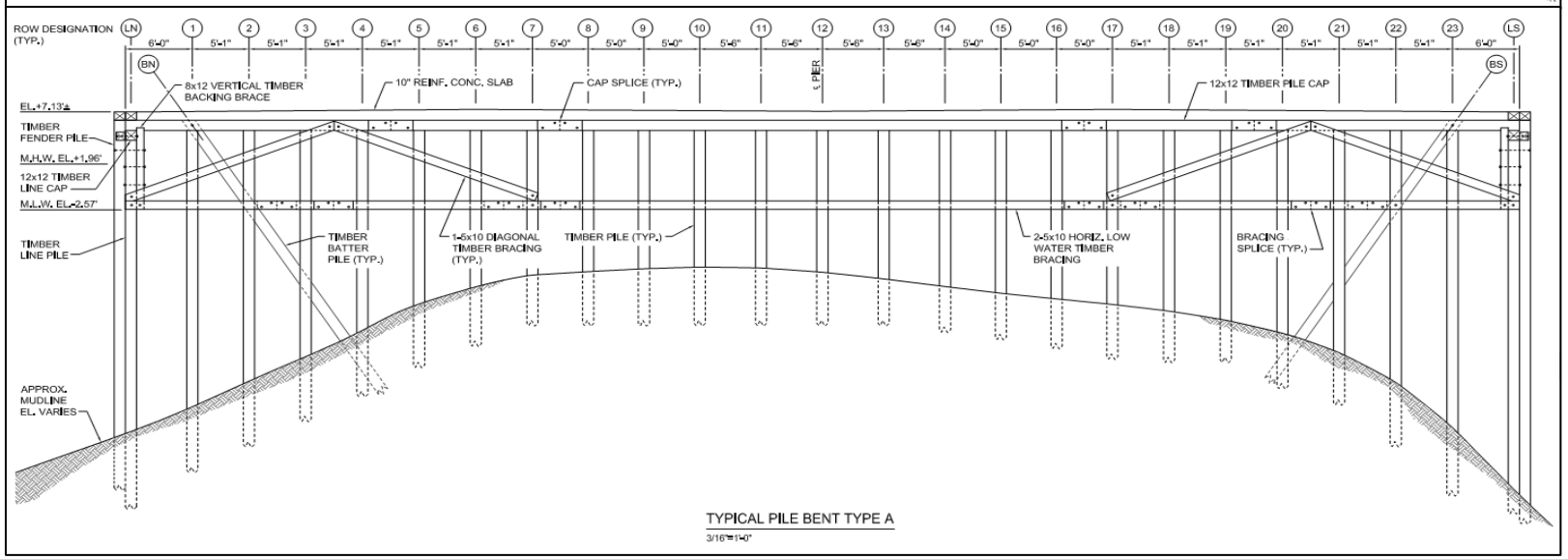


PIER 88: Existing Conditions





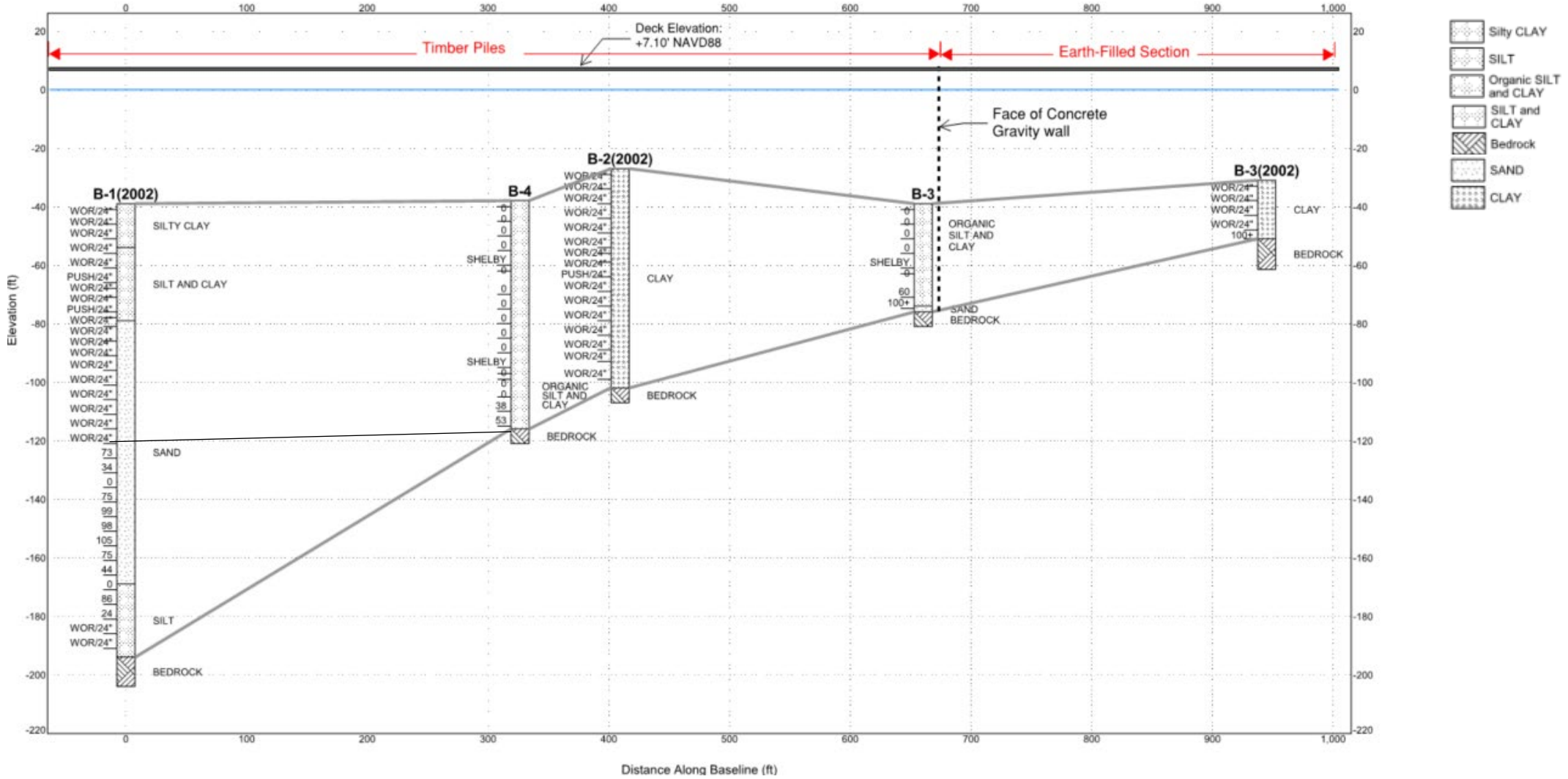




Subsurface Stratigraphy

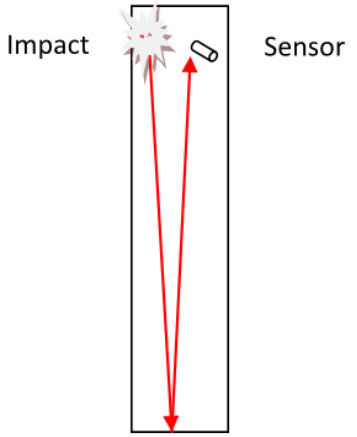
Stratum	Description
1	**Organic Silt:** Very soft dark grey to black organic silt with varying amounts of clay. This stratum generally extends to bedrock.
2	**Silty Sand:** Loose to medium dense grey fine to medium silty sand with trace amounts of course gravel and shell fragments encountered at offshore end of pier between the organic silt and bedrock.
R	**Bedrock**: Dark grey mica schist encountered at depths ranging from 30 ft to 200 ft.

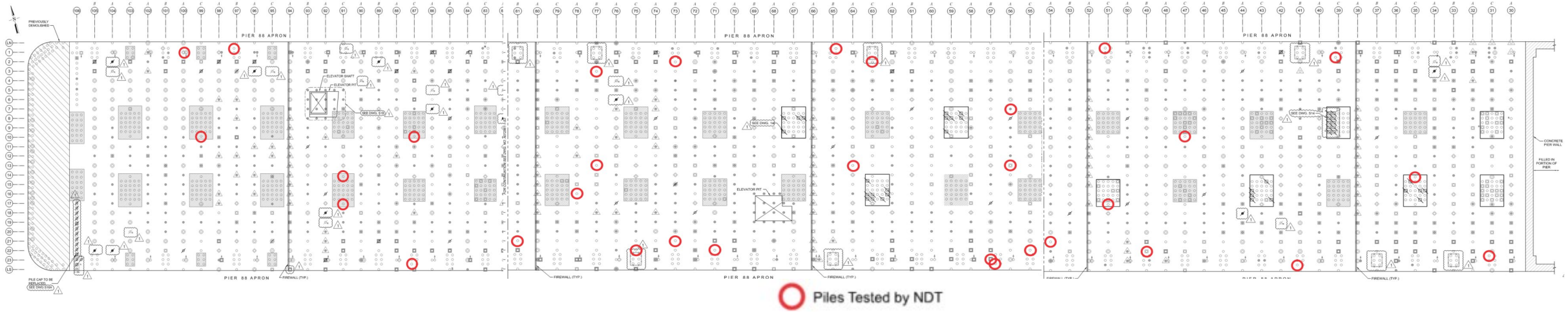
Subsurface Profile



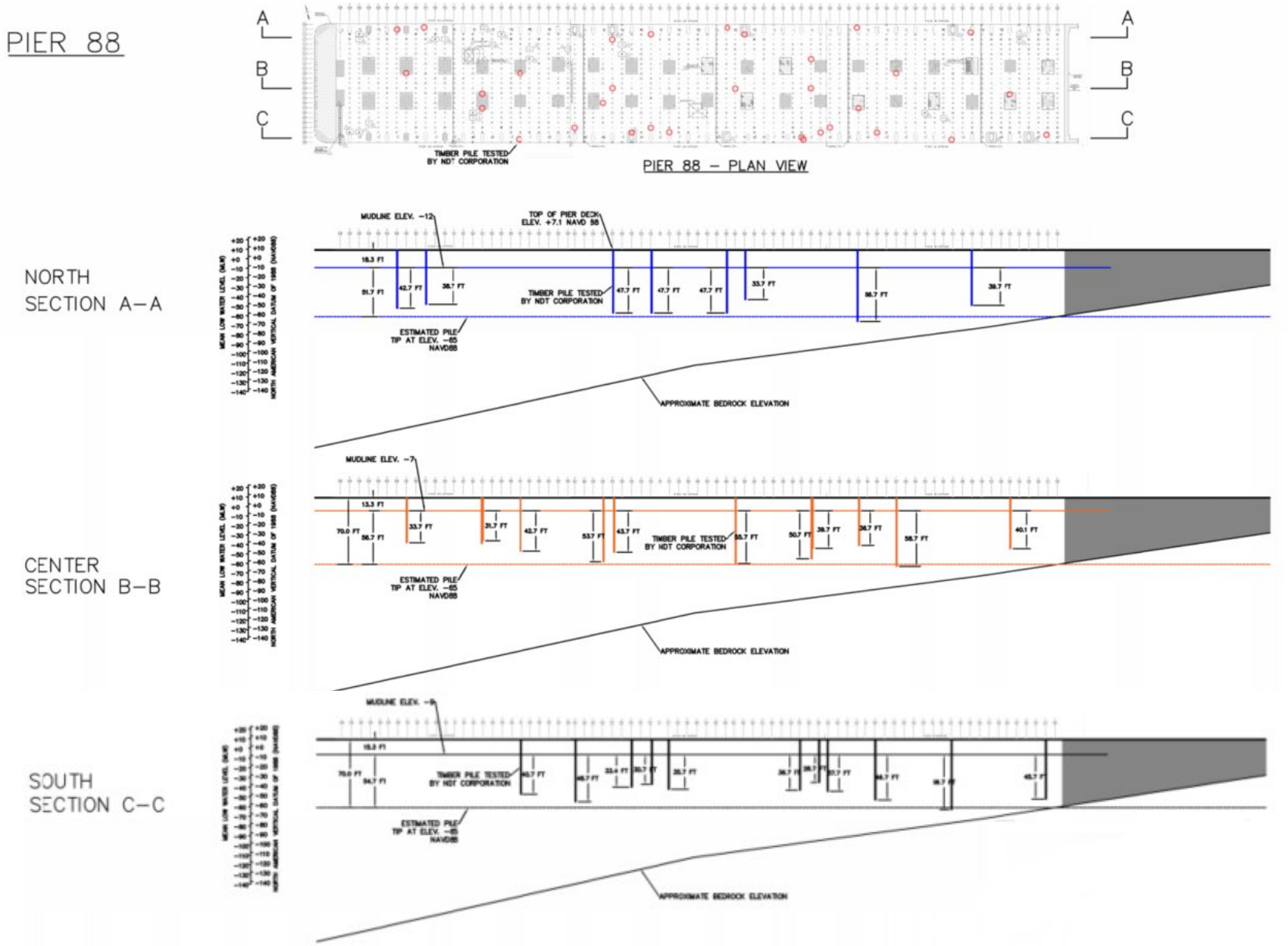
Non-Destructive Testing (NDT)

- The available historical data did not include any information regarding the timber piles (driving logs, driving criteria, embedment depth, etc.) which are important parameters required in order to estimate the capacity of these piles.
- Sonic/ultrasonic nondestructive pulse-echo reflection measurements were conducted on thirty-two (32) timber piles under Manhattan cruise terminal Pier 88 to determine representative pile lengths.
- The location of the tested piles is shown in the figure below.
- The length is determined by the time required for a stress wave to travel from top to bottom and be reflected.
- $\text{Time of Reflection} = \frac{2 \times \text{Length}}{\text{Velocity}}$





Non-Destructive Testing (NDT)



- The results of the Non-Destructive testing indicated that the timber piles had an average estimated total length of about **70 ft** throughout the pier.
- Historical as-built drawings showed that these piles may have been driven to an **18 tons** capacity
- Based on the pile capacity calculations, this is not achievable with a 70 ft long piles.
- However, based on the review of available historical data, drawings, documents and photographs, it is believed that other construction techniques (such as, splicing and/or adding timber fins at the pile tip) may have been used to increase the capacity of these timber piles in order to reach the desired design allowable pile capacity.
- In this analysis, a 100 ft equivalent total pile length was back calculated based on the subsurface characteristics and the original pile design capacity (18 tons) found in historical data.
- It is assumed that a 30 ft pile section may have been spliced at the tip of the 70 ft piles measured by the NDT. As a result, the signal from the NDT could have reflected at the splice location, not reaching the bottom portions of the piles.

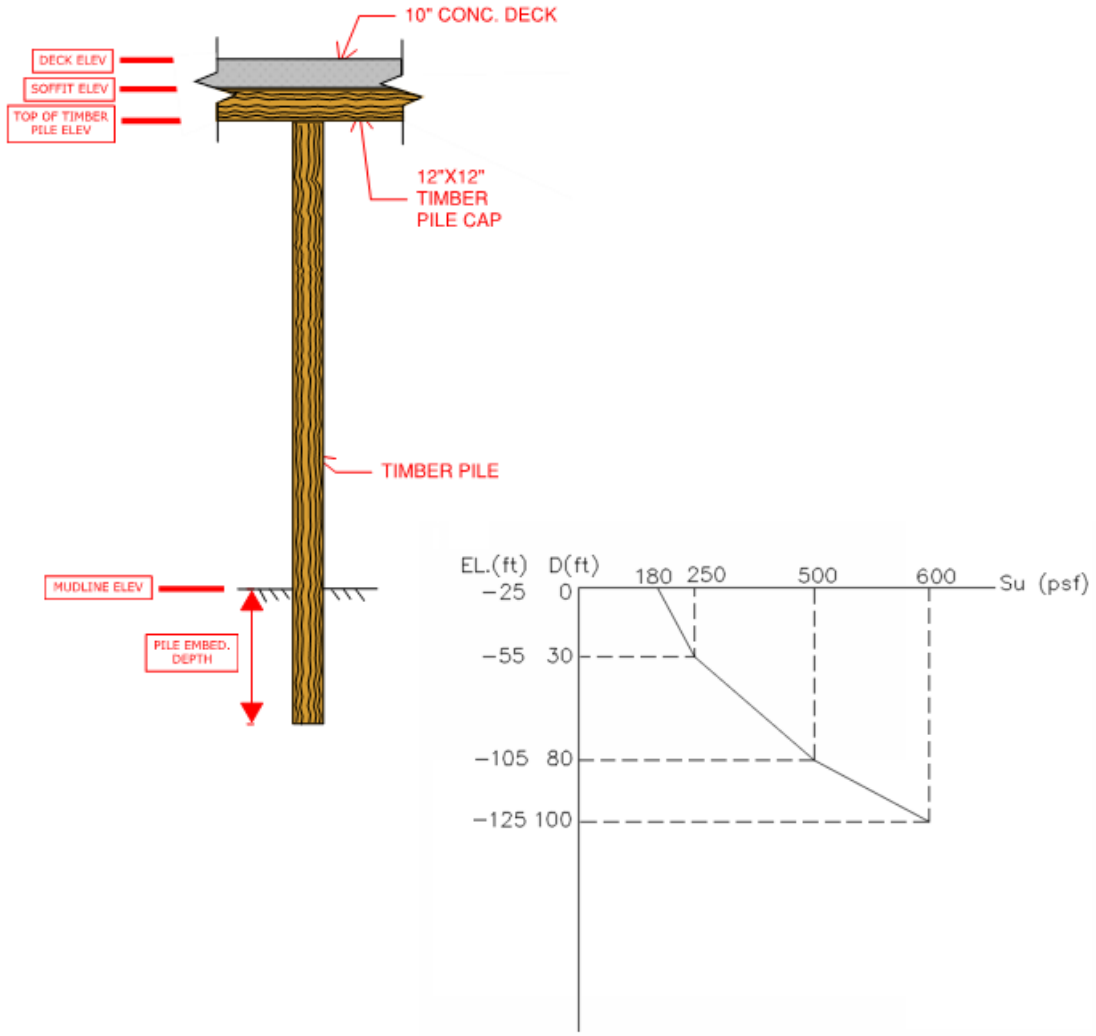
Geotechnical Analysis

Four Components:

- Bearing Capacity Analysis
- Lateral Analysis
- Axial Analysis
- Settlement Analysis

Assumptions:

- L = **100 FT total length**, 14” diameter
- The **original mudline (Elev. -25 NAVD 88)** was used and additional soil deposits were not considered during calculation.
- Embedment length = 70 FT , Stickup = 30 FT
- Embedded in **Soft Organic Silts and Clays**
- Bearing capacity being achieved through **side bearing** rather then end bearing.
- The laboratory testing showed that the pile skin friction or **adhesion** increases with depth. Values of **180 psf** and **500 psf** were used at the mudline and pile tip respectively.



Bearing Capacity Analysis

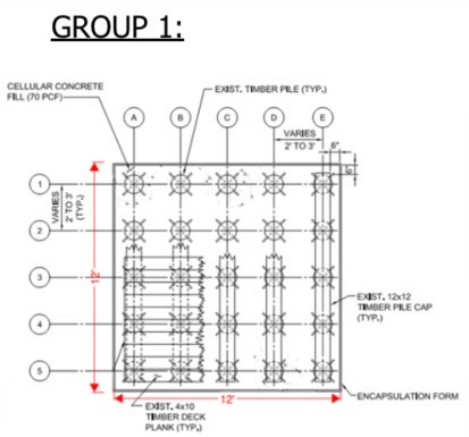
For a single 100 ft long individual pile with a 70 ft embedment into soft organic silt:

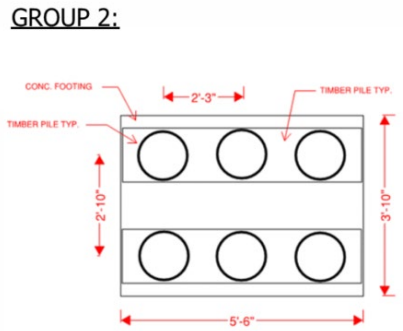
- Qu= **36 tons** (72 kips).
- Qall= **18 tons** (36 kips) for a factor of safety of 2,

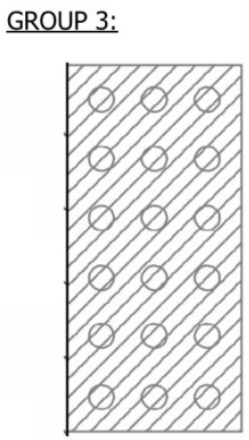
Group Effects:

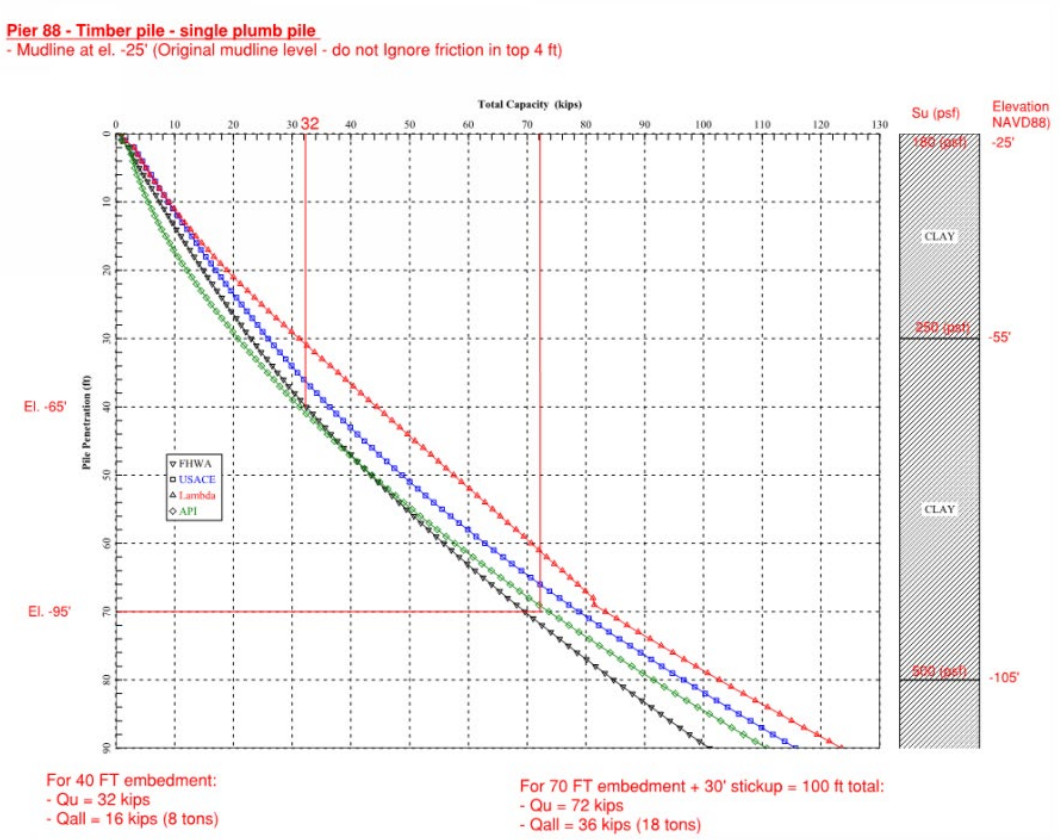
Reduction Factor = 0.65 (FHWA's recommendation based on pile layout, spacing and diameter)

- Qu= **23.5 tons**.
- Qall= **11.75 tons**.

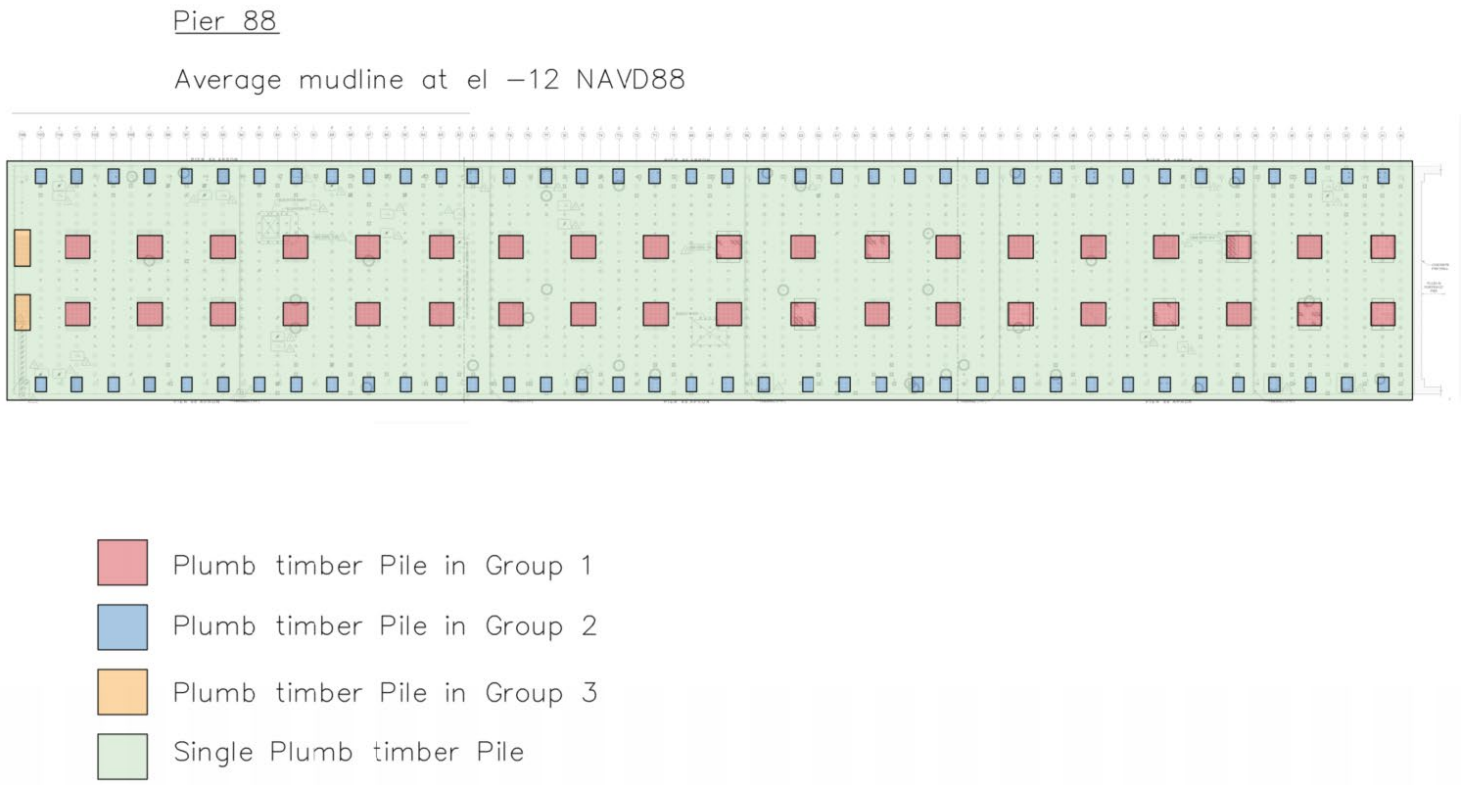








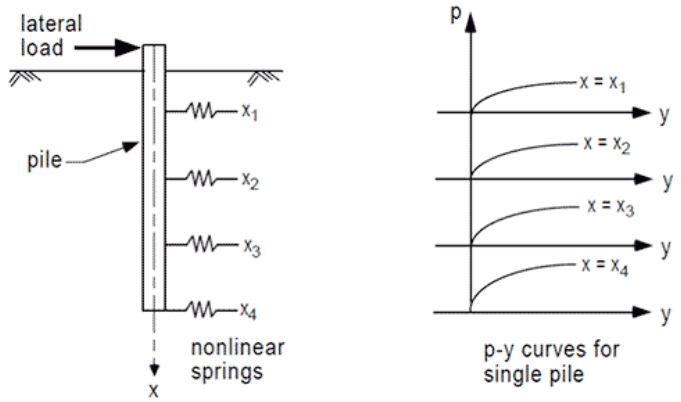
Lateral Analysis



- The following categories of timber piles were analyzed:
  - Type A: 14-inch diameter single plumb pile.
  - Type B: 14-inch diameter **plumb** pile in an interior column cluster pile **group 1** containing a total of 25 piles.
  - Type C: 14-inch diameter **plumb** pile in an exterior column cluster pile **group 2** containing a total of 6 piles.
  - Type D: 14-inch diameter **plumb** pile in an exterior column cluster pile **group 3** containing a total of 18 piles.
  - Type E: 14-inch diameter **battered** pile with 3V to 2H batter angle.

Lateral Analysis

- LPILE 2019 software was used to generate the p-y curves along the shaft of the timber piles. The piles were modeled as having a pinned connection at the top.
- The p-y analysis is a numerical model that simulates the **soil resistance** as predefined **nonlinear springs**, where **p is the soil pressure** per unit length of the pile and **y is the pile deflection**.
- The soil is represented by a series of nonlinear p-y curves that vary with depth and soil type.

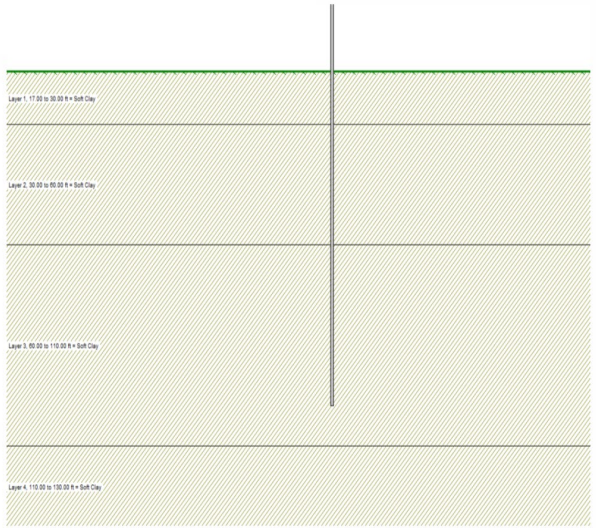


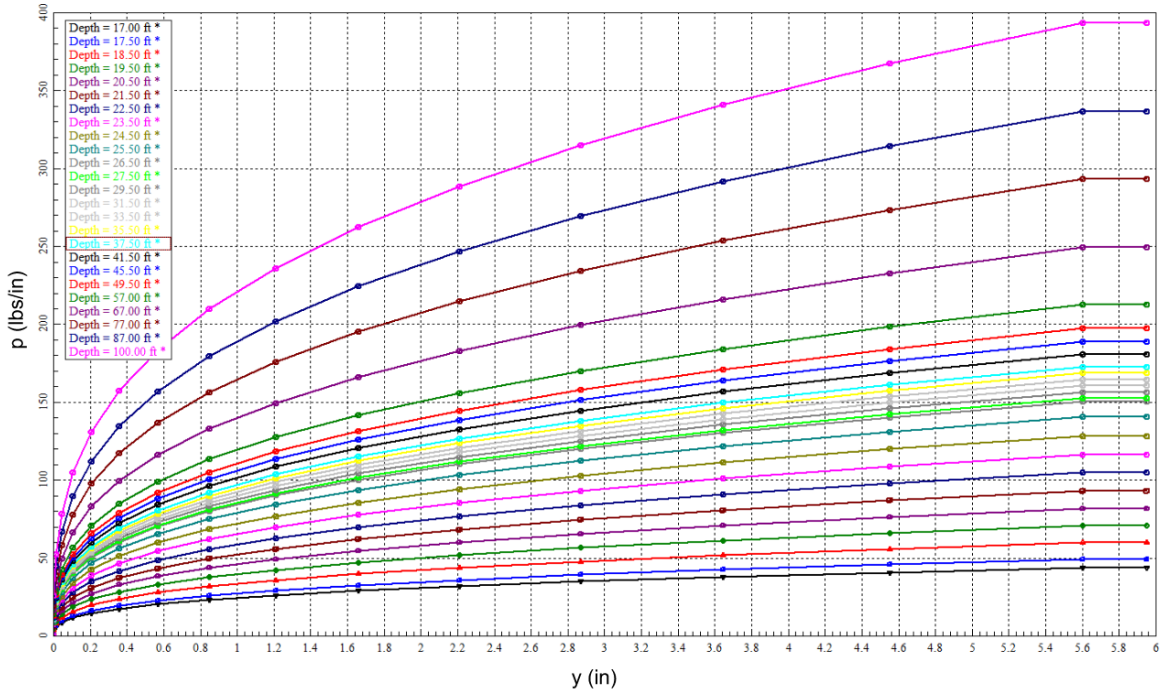
(a) Single pile model.

Lateral Capacity Analysis:

Single Pile Anaylsis:

Pile A: Plumb Timber pile - pile length = 100' , embedment = 83', stickup= 17'

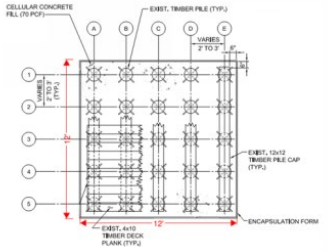




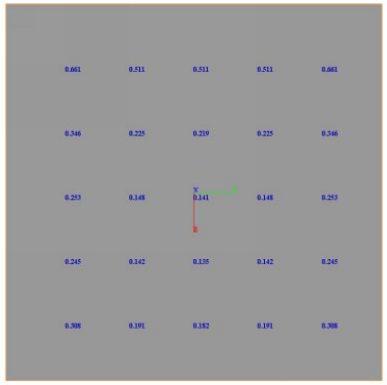
Lateral Analysis

- Lateral group effects were studied using GROUP-2016 software to determine the appropriate reduction factors for each type of cluster. Reduction factors were applied to piles in groups as shown in fig. 10. Multiple cases were modeled to generate corresponding p-y curves based on the pile type, layout and location.

GROUP 1:

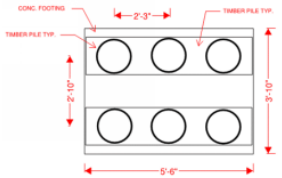


Load direction (-+z)

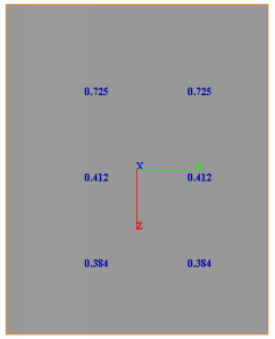


$p_{ave} := 0.298$

GROUP 2:

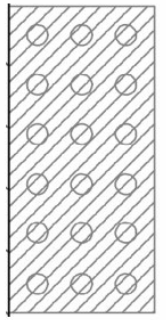


Load direction (-+z)

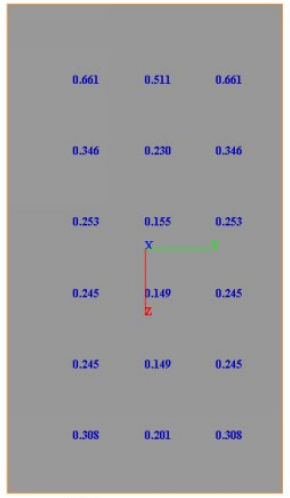


$p_{ave} := 0.50$

GROUP 3:



Load direction (-+z)

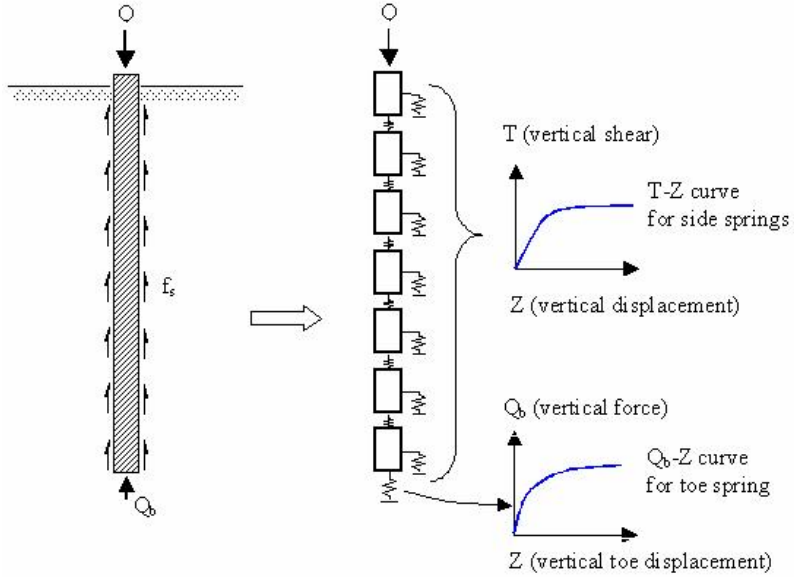


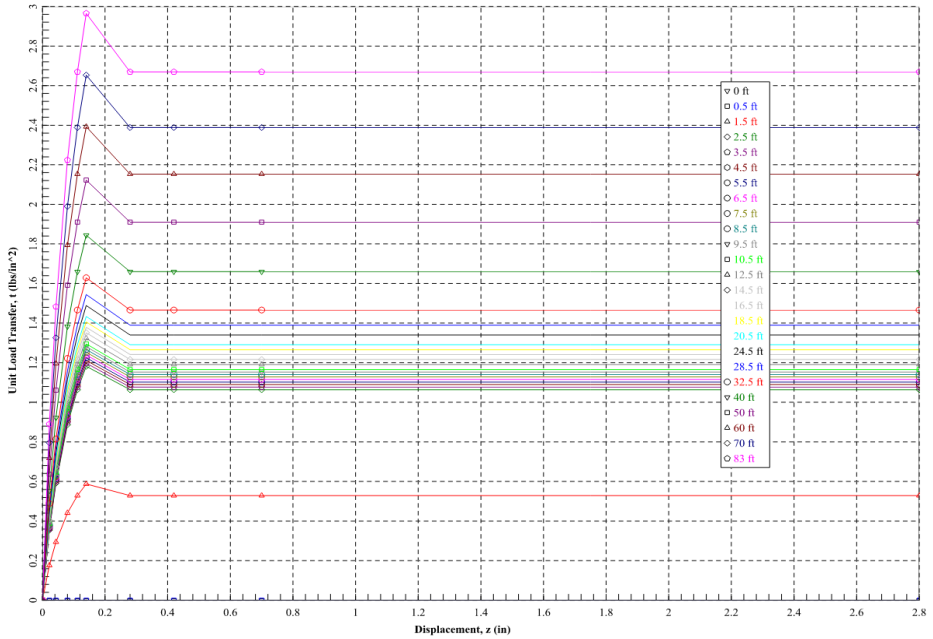
$p_{ave} := 0.3$

Axial Analysis

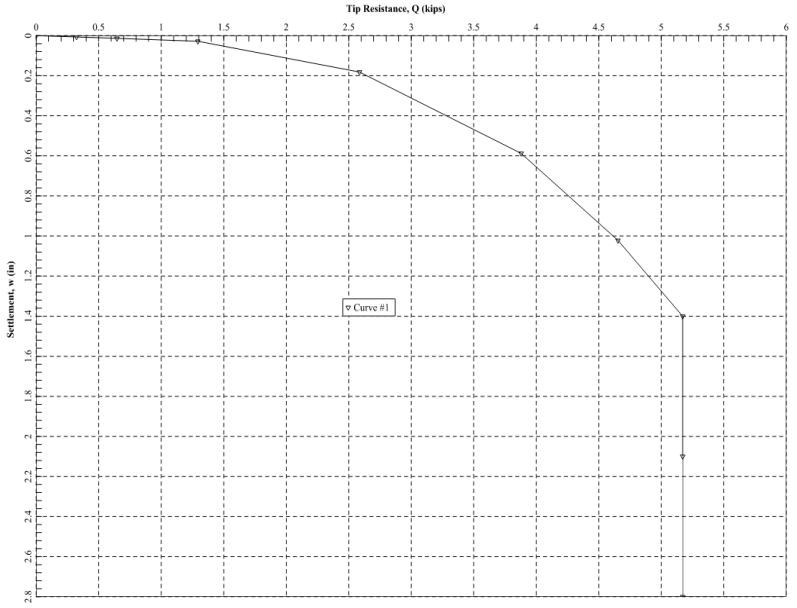
T-z and Q-w Curves

- Axial analysis along the shaft of the piles.
- Similarly, for the axial analysis, APILE 2018 software was used to generate the t-z curves along the shaft of the piles and q-w at the pile tips.
- The same 5 cases were modeled to generate corresponding axial springs based on the pile type, layout and location. Sample results of the axial analysis and the generated t-z and q-w curves are shown in the figures below.





Axial soil springs (t-z curves) for a Type A pile at Pier 88



Axial soil springs (q-w curves) for a Type A pile at Pier 88

Settlement Analysis

- Based on the subsurface profile, the pile tips are expected to be very close to or on top of the bedrock to the east of Bent 55 (inshore side of the pier). No major soil consolidation settlement is anticipated at this inshore end of the pier.

- To the west of Bent 55, (offshore side of the pier), the average thickness of the organic silt layer between the pile tips and the bedrock ranges from 0 to about 25 ft thick at the offshore side of the pier.

- From Lab Consolidation tests:

Organic Silt

γ= 100 pcf
e0= 1.6

Cc= 0.55
Cr= 0.08

- Using a typical "**Group 1**" column cluster:

  (25 piles x 23.5 kips = 587.5 kips)

- Total primary consolidation settlement = **15 inch**
- Consolidation time of **180 years**.
- Pier was constructed in 1935 (84 years ago)

  → **95%** consolidation

  → **14.4 in** current settlement for a 100 ft pile.

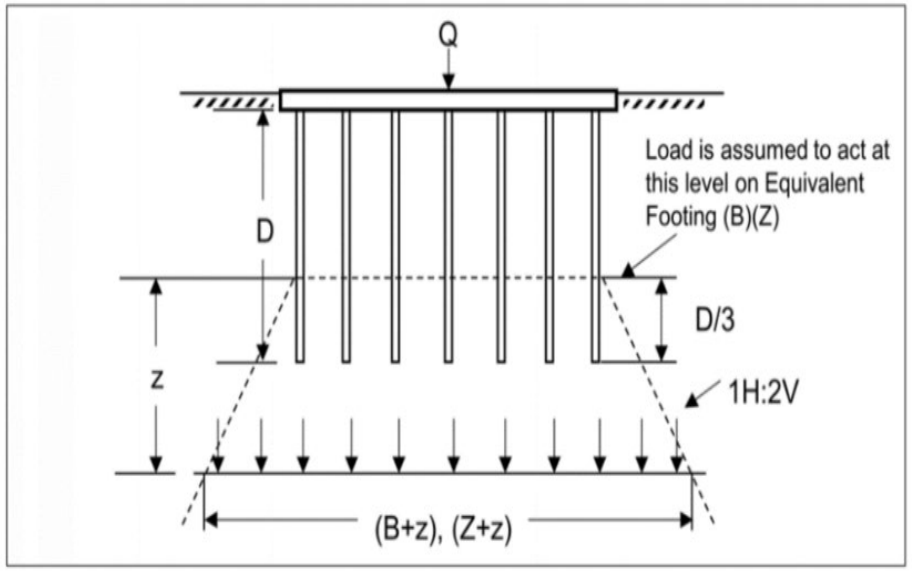
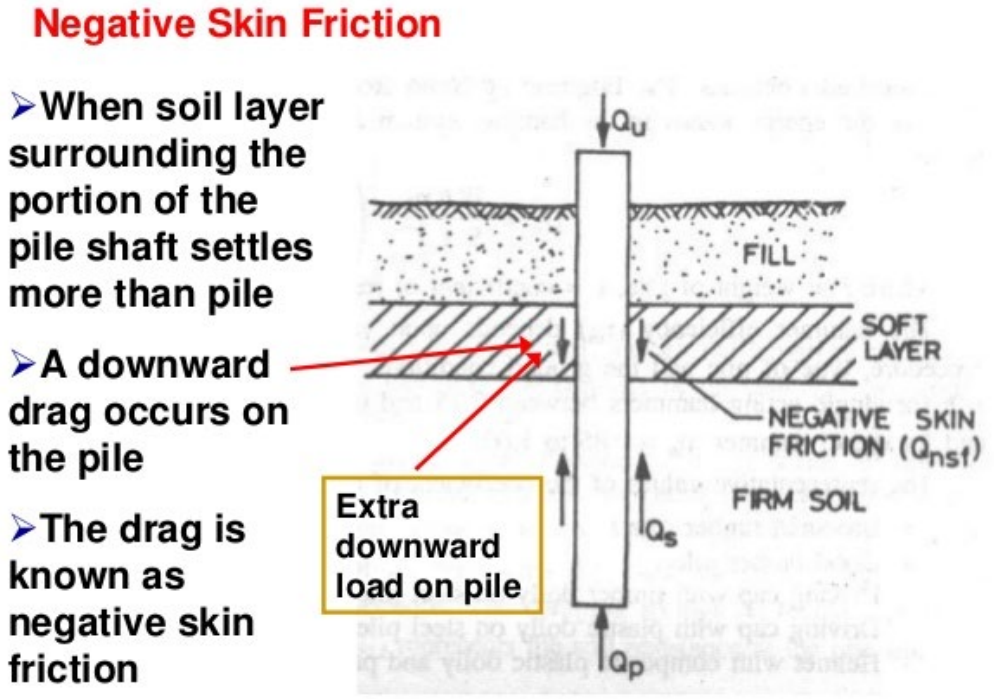


Figure 7-44 Equivalent footing concept.

Negative Skin Friction

- Initial mudline at Elev. -25
- Current mudline at Elev. -12
- It is estimated that a total of about 13 ft of silty soils have been deposited on top of the original mudline since the construction of the pier.
- These loose deposits may be contributing towards a negative skin friction or downdrag applied on the piles.
- For a 100 ft pile the down drag settlement is estimated to be **6 in** of settlement on the pile groups increasing the total anticipated settlement of the pile under both pier loading and down drag to **21 in**.



Summary and Conclusions

- The assessment of the geotechnical conditions at the MCT (Pier 88 specifically) showed that the pier is supported by approximately 2,500 timber piles bearing on soft organic silts and clays.
- The results of the NDT testing showed an approximate pile length of 70 ft. However, our geotechnical capacity calculations indicate that an equivalent 100 ft total pile length is necessary to achieve the original design capacity of 18 tons.
- Therefore, it is believed that other construction techniques (such as, splicing and/or adding timber fins at the pile tip) may have been used to increase the geotechnical capacity of these timber piles in order to reach the desired design allowable pile capacity. Such methods could not be detected by the non-destructive testing.
- One of the most important lessons learned from this project was that non-destructive sonic testing was not an effective tool to estimate the bearing capacity of the existing timber piles. Other techniques such as parallel seismic testing or a full axial load text could have provided better estimates.

Summary and Conclusions

- Based on the settlement analysis, the total settlement from consolidation and negative skin friction combined was estimated around 21 inches under a typical pile cluster allowable design loading.
- Considering that the pier was constructed in 1935 (85 years ago), it is estimated that the organic silt layer is at about 95% consolidation.
- These estimations were found to be in conformance with the uniform settlements observed on site across the pier.
- Axial and lateral analyses were also performed to develop the soil springs (p-y, t-z, and q-w curves). These springs were used as an input in the structural model to depict a more accurate behavior of the piles and the structure under the actual current loading conditions.
- The results from the structural model were in conformance with the estimated settlements based on our calculations, except for some locations across the pier, where the actual current loading has exceeded the design capacity of the piles, leading to excessive settlements.
- The additional loading is attributed to the multiple additions and renovations and maintenance activities that took place over the years at these locations since the pier was originally constructed.

Questions?

Thank You