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STRUCTURAL TECHNICAL REPORT NO. 035 *Rev. 1*

Date: **2021-09-16** **Document No.: 19899-30-RPT-035_1**

Project: **WTLP New Cargo Study**

Subject: **Berth 2 Foundation Retrofits - Basis of Design**

1 INTRODUCTION AND OBJECTIVE

CWA Engineers Inc. (CWA) has been retained by Westshore Terminals Limited Partnership. (WTLP) to provide engineering services for the New Cargo Project (the "Project") at their facility in Delta, BC. The project will include the construction of a new railcar dumper, product receiving infrastructure, storage shed, and product stacking/reclaiming infrastructure. The improvements will also include replacement of the existing Berth 2 shiploading infrastructure to allow the facility to handle two products, coal and potash. CWA and WTLP have discussed the seismic design criteria expectations with the Vancouver Fraser Port Authority (VFPA) from a permitting perspective, with the accepted code framework outlined in the Jensen Hughes report 1TCR00008-LTR-05 Westshore Berth 2 Retrofit – Path to Code Compliance (see Code Review Report ITCR00008-LTR-05 attached in Appendix A).

The objective of this memorandum is to show that the proposed retrofit work meets the conditions of NBCC 2015 and ASCE 41 Limited Performance Objective as accepted by VFPA and therefore meets the conclusions in the Jensen Hughes – Path to Compliance report.

2 BACKGROUND

Comprehensive geotechnical seismic assessments and corresponding soil-structure interaction analyses have been carried out for the existing Berth 2 foundations. The analyses confirmed that the existing foundations are capable of withstanding the original design seismic event of 1:100-years but would require reinforcement for any events greater than the original design event due to significant flow slides that occur at the berth under those seismic events. Figure 1 below shows the existing Berth 2 infrastructure.

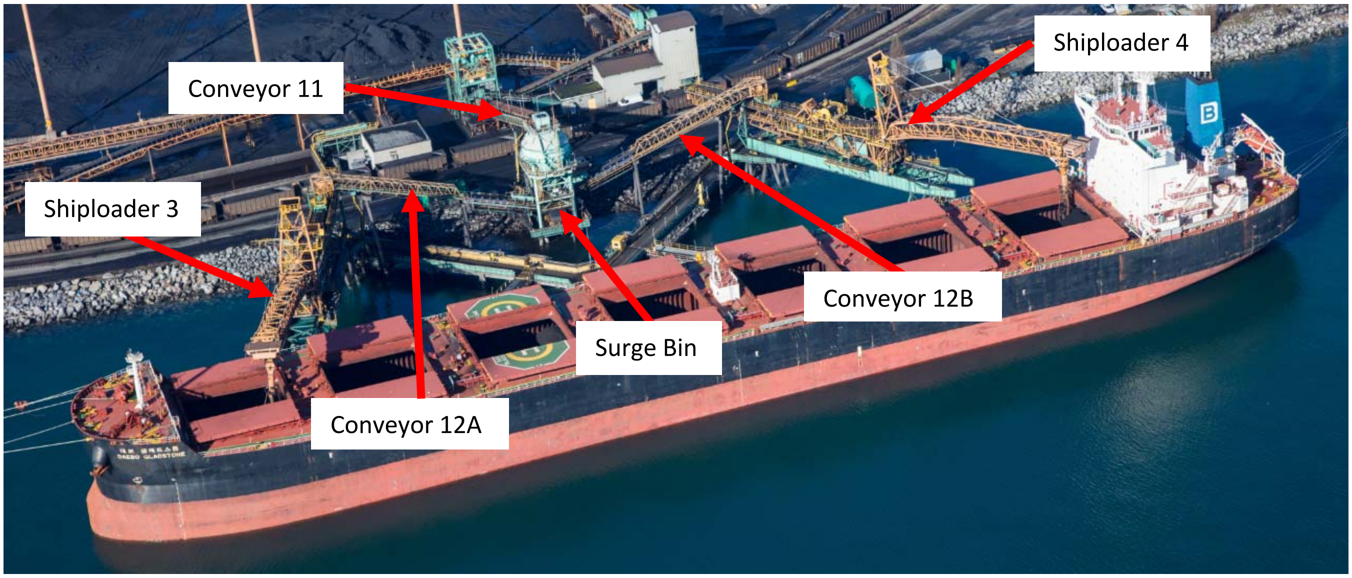

Figure 1: Existing Berth 2 Infrastructure

3 BASIS OF DESIGN

The VFPA commissioned Jensen Hughes to conduct a code review regarding the appropriate seismic performance objectives for Berth 2. The Jensen Hughes report states that the requirements of the National Building Code of Canada (NBCC 2015) can be met through the application of NBCC 2015 Commentary L which in turn refers to the use of the American Standards for Civil Engineers / Structure Engineering Institute (ASCE/SEI) 41 *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE 41) Limited Performance Objective.

Based on the above, the basis of design for the Berth 2 foundations is summarized below in Table 1.

Table 1: Berth 2 Foundations - Basis of Design

Structure	Component	Status	Life Safety Design Event	Code
Shiploaders 3 and 4	Pivot Foundations	Retrofitted	1:225	ASCE 41
	Quadrant Beam Foundations	Retrofitted	1:225	ASCE 41
Conveyor 11	Foundations	Retrofitted	1:225	ASCE 41
Conveyors 12A and 12B	Foundations	Retrofitted	1:225	ASCE 41
Tower 30 / Surge Bin	Foundation	Retrofitted	1:225	ASCE 41
Spout Tower	Foundations	New	-	NBCC 2015
Trestles and Wharf head	Foundations	Retrofitted	1:225	ASCE 41

Seismic evaluations are ongoing for each foundation to identify performance deficiencies during the design seismic events. Two modes of failure have been identified:

1. Insufficient foundation capacity
   a. Pile strains must remain within the limits specified for Life Safety performance.
   b. The capacity of each component must not be exceeded by the demands imposed by ground displacements and superstructure reactions (i.e. seismic kinematic and inertial loading).
2. Differential displacements
   a. Significant relative movement between the shiploader pivot and quadrant structures as well as along the trestle will result in collapse of the superstructures (trestle and shiploader). The ground displacements at the toe of the slope increase significantly relative to the displacements at the crest of the slope resulting in larger relative movements as the seismic return period increases.

Retrofits are being designed to meet the performance requirements.

4 DESCRIPTION OF RETROFIT WORK

The proposed retrofits include ground improvements and structural strengthening to meet the seismic performance requirements for all existing Berth 2 facilities. The retrofits address deficiencies in the structural system that are a result of the seismically-induced flow slides at Berth 2 causing increased kinematic loading on the existing foundations relative to the original design criteria. At a high level, the work includes:

- Improvements to the surge bin, Conveyors 12A & 12B, shiploader pivot & quadrant rail, trestle and wharf head foundations including additional piles at the quadrant rail, reinforcement of the pile-to-pile cap connections, and filling the existing piles with concrete.
- Densification at the top of the slope (above the HHWL).
- Temporary relocation of existing underground utilities within the densification area.

4.1 Structural Retrofits

A number of seismic retrofits are required to the existing foundations to meet the seismic performance requirements of ASCE 41 Limited Performance Objective. All of the retrofits are being done to improve the structural performance of the existing foundations and to consider seismic detailing requirements, not to increase the geotechnical capacity.

- Fill existing piles with concrete - The existing piles are hollow steel pipe piles that were filled with inhibited water once driven. Analyses indicate that the existing hollow piles do not have enough capacity to withstand the increased demands resulting from the seismically induced flow slide. Filling the piles with concrete limits the strains in the piles to below the maximum acceptable limits. The retrofits are solely required to meet the increased seimsic demands on the piles resulting from the flow slide event, not to increase the capacity for any other loading condition, and therefore, satisfy the requirements of ASCE 41 and NBCC 2015.

- Reinforcement of the pile to pilecap connection - The existing connection detail utilizes hooked dowels that are embedded into the pile cap and welded to the inside of each pile. This type of connection is permitted if the dowels are designed to remain elastic for the design earthquake event and the welds are designed to develop 1.25 times the expected nominal yield strength of the reinforcement. Given the age of the connection, it is not expected that it will satisfy these criteria. Reinforcement has been provided in the form of additional concrete encasement of the piles or stiffened steel jackets with grout-infill to provide a more rigid connection forcing plastic hinging to occur in the pile instead of at the connection. The retrofits are required to meet the increased seismic demands on the piles resulting from the flow slide event, not to increase the capacity for any other loading condition, and therefore, satisfy the requirements of ASCE 41 and NBCC 2015.
- Reinforcement of the pilecap - The existing pilecap is subjected to increased axial and flexural demands as a result of the increased inertial and kinematic loading. Retrofits are proposed to increase the capacity of the pile caps in the direction of kinematic loading application (perpendicular to slope) to maintain the preferred mode of failure for the foundation which is the ductile failure of the piles following the strong pile cap - weak pile connection concept. The retrofits are solely required to meet the detailing requirements and increased demands resulting from the seismically induced flow slide event, not to increase the capacity for any other loading condition, and therefore, satisfy the requirements of ASCE 41 and NBCC 2015.
- Additional piles – The quadrant beam experiences much larger ground displacements relative to the pivot due to its location at the toe of the slope. As such, the differential displacements between the quadrant rail and pivot become too large for the shiploader to accommodate for larger seismic events. Without the additional piles the differential displacements between the existing quadrant rail and pivot for the 225 year seismic event are anticipated to be approximately 2.5 m. To limit the movement of the quadrant rail, additional piles have been added which act as lateral bracing thereby reducing the differential displacements to less than 1m which can be accommodated by the shiploader. The additional piles are not required to increase the vertical load capacity of the quadrant rail foundations. The retrofits are solely required to reduce the lateral movement of the quadrant beam resulting from the design seismic event, not to increase the capacity for any other loading condition, and therefore, satisfy the requirements of ASCE 41 and NBCC 2015 as interpreted by Jensen Hughes (see Appendix A).
- Modifications to the wharf head deck – The trestle structure extends from the crest of the slope to the berth face beyond the toe of the slope so will experience differential displacements between pile caps. Modifications to the deck support beams and pile caps will be incorporated to allow for the anticipated differential movements. The span between supports is significantly less than the distance between the shiploader pivot and quadrant rail so the differential displacements are expected to be accommodated without the requirement for additional piles to resist movements. The retrofits are solely required to meet the increased demands resulting from the seismically induced flow slide event, not to increase the capacity for any other loading condition, and therefore, satisfy the requirements of ASCE 41 and NBCC 2015.

4.2 Ground Improvements

Densification has been included at the crest of the slope to provide slope stabilization during and after the design seismic events increasing seismic performance through a reduction in the anticipated ground displacements. Based on analyses completed to date, densification at the crest of the slope may decrease anticipated ground displacements by up to 15% for the specified design seismic events. Details of the proposed densification are shown in the drawings in Appendix B.

5 SUMMARY

The Berth 2 foundations are being designed to meet the requirements of NBCC 2015, through the use of Commentary L and ASCE 41. Due to flow slide resulting from the design seismic events, kinematic loading on the foundations, specifically the piles, increases substantially requiring retrofits to increase the seismic capacity of the foundation structures.

At a high level, the retrofits for the Berth 2 foundations include:

- Filling the existing steel piles with concrete to increase the seismic capacity.
- Reinforcing the pile to pilecap connections as a seismic detailing measure to ensure failure in the piles.
- Reinforcing of the pile caps to increase the seismic capacity.
- Additional piles at the quadrant rail to brace the foundation against seismic-induced lateral movement.

In addition to the retrofits to the foundations, densification will also be completed at the crest of the slope (above the HHWL) to help stabilize the slope and decrease anticipated seismic ground displacements by up to 15%. The decrease in ground displacements results in reduced kinematic loading on the foundations, increasing the seismic performance.

All of the proposed retrofits to the Berth 2 foundations are being proposed solely to address increased demands on the piles resulting from seismically induced flow slide, not to increase vertical load carrying capacity, and they therefore meet the requirements and intent of ASCE 41 and NBCC 2015.

Prepared by:	Reviewed by:	Approved by:
Digitally signed by Ann-Marie Giesbrecht Date: 2021.09.16 16:45:21 -07'00'	Craig Stenhouse Digitally signed by Craig Stenhouse DN: cn=Craig Stenhouse, o, ou, email=cstenhouse@cwaengineers.com, c=CA Date: 2021.09.16 17:02:57 -07'00'	Digitally signed by Steven Yee DN: cn=Steven Yee, o=CWA Engineers Inc., ou=VP, email=syee@cwaengineers.com, c=CA Date: 2021.09.16 16:55:05 -07'00'
Ann-Marie Giesbrecht, P.Eng.	Craig Stenhouse, P.Eng.	Steve Yee, P.Eng.
Project Structural Lead	Project Manager	Vice President

APPENDIX A

Code Review Report

JENSEN HUGHES
Advancing the Science of Safety

July 14, 2021
Letter 1TCR00008-LTR-05

Mr. Ken Berglund
Senior Planner
Port of Vancouver, Vancouver Fraser Port Authority
100 The Pointe, 999 Canada Place
Vancouver, B.C, Canada V6C 3T4

RE: Review of Westshore Berth 2 Retrofit – Path to Code Compliance

Dear Mr. Berglund,

Jensen Hughes is pleased to submit this letter to the Vancouver Fraser Port Authority (VFPA) to provide a review of the documentation for the Westshore Berth 2 Retrofit and related Path to Code Compliance for the proposed New Cargo Project at their facility in Delta, BC.

The following documents are the subject of the review performed herein:

Item	Document Number	Description	Document Type	File Type
1	19899-00-RPT-024	Westshore Berth 2 Seismic Retrofit – Path to Compliance	Memorandum	.pdf
2	19899-00-RPT-025	Westshore Berth 2 Occupancy Review	Memorandum	.pdf
3	19899-100-SK-1100	Berth 2 Drawing/Sketch List	Drawing	.pdf
4	40101-D0000-0000	Site Plan	Drawing	.pdf
5	19899-100-SK-1101	Berth 2 Seismic Upgrades - Full Retrofits - Plan	Drawing	.pdf
6	19899-100-SK-1102	Berth 2 Seismic Upgrades - Sections - Sheet 1	Drawing	.pdf
7	19899-100-SK-1103	Berth 2 Seismic Upgrades - Sections - Sheet 2	Drawing	.pdf
8	19899-100-SK-1104	Berth 2 Ground Improvements - General Arrangement - Plan	Drawing	.pdf
9	19899-100-SK-1105	Berth 2 Ground Improvements - General Arrangement - Section	Drawing	.pdf
10	19899-100-SK-1106	Berth 2 Retrofits - Surge Bin Concepts	Drawing	.pdf
11	19899-100-SK-1107	Berth 2 Retrofits - Conveyor 12A/B Concepts	Drawing	.pdf
12	19899-100-SK-1108	Berth 2 Retrofits - Shiploader Pivot Concepts	Drawing	.pdf
13	19899-100-SK-1109	Berth 2 Retrofits - Shiploader Quadrant Beam Concepts	Drawing	.pdf

Item	Document Number	Description	Document Type	File Type
14	19899-100-SK-1110	Berth 2 Retrofits - Trestle and Wharfhead Concepts	Drawing	.pdf
15	19899-100-SK-1112	Berth 2 - Surge Bin/Tower 30 - Isometric and Floor Plans	Drawing	.pdf
16	85690-D0300-0000	Berth 2 Shiploading Spout - Changeout System G.A. - Plan	Drawing	.pdf
17	85690-D0300-0001	Berth 2 Shiploading Spout - Changeout System G.A. - Section	Drawing	.pdf
18	85690-D0310-0120	Shiploader Spout Tower - Foundation Plan & Section	Drawing	.pdf
19	82214-D0300-0000	Coal/Potash Conveyor C11 - General Arrangement - Option 2	Drawing	.pdf
20	82215-D0300-0000	Coal/Potash Conveyor C12A - General Arrangement	Drawing	.pdf
21	82216-D0300-0000	Coal/Potash Conveyor C12B - General Arrangement	Drawing	.pdf
22	86000-D0350-6110	Berth 2 Washdown - Washdown Sequencing - Key Plan	Drawing	.pdf
23	86000-D0350-6112	Berth 2 Washdown - Washdown Sequencing - Shiploader #4	Drawing	.pdf
24	86000-D0350-6114	Berth 2 Washdown - Washdown Sequencing - Conveyor 12B	Drawing	.pdf
25	86000-D0350-6115	Berth 2 Washdown - Washdown Sequencing - Transfer Tower 30	Drawing	.pdf
26	86000-D0350-6116	Berth 2 Washdown - Washdown Sequencing - Conveyor 11	Drawing	.pdf
27	86000-D0350-6118	Berth 2 Washdown & Wastewater Collection - Washdown Sequencing - South Pivot Deck	Drawing	.pdf
28	86000-D0350-6120	Berth 2 Washdown & Wastewater Collection - Washdown Sequencing - Transfer Tower 30 Deck	Drawing	.pdf
29	86000-D0350-6121	Berth 2 Washdown & Wastewater Collection - Washdown Sequencing - South Trestle Deck	Drawing	.pdf
30	86000-D0350-6510	Berth 2 Washdown & Wastewater Collection - Modifications - General Arrangement	Drawing	.pdf
31	86000-D3750-1201	Berth 2 Washdown & Wastewater Collection - T5 Sump - General Arrangement	Drawing	.pdf
32	86000-D3750-1225	Berth 2 Washdown & Wastewater Collection - T5 Sump - Typical Sections and Details	Drawing	.pdf
33	19899-00-RPT-026	Washdown Procedure	Memorandum	.pdf
34	19899-PM-PRE-004	New Cargo Project – Berth 2 Seismic Discussion (June 22, 2021)	Presentation Slides	.pdf
35	19899-PM-PRE-005	New Cargo Project – Berth 2 Path to Code Compliance (June 23, 2021)	Presentation Slides	.pdf

The following applicable codes, standards and related documents have also been reviewed to support the key findings discussed:

- Vancouver Building By-law (2019), Division B, Part 11, Existing Buildings.
- ASCE/SEI 61-14, Seismic Design of Piers and Wharves.

- ASCE/SEI 7-16, Minimum Design Loads for Buildings and Other Structures.
- ASCE/SEI 41-17, Seismic Evaluation and Retrofit of Existing Buildings.

1.0 Reports 19899-00-RPT-024 & 19899-00-RPT-025

Jensen Hughes performed a review of Reports 19899-00-RPT-024 and 19899-00-RPT-025 as a set of mutually dependent documents. Report -RPT-025 is referenced in -RPT-024 to support the low occupancy statement, which further supports the argument for meeting the requirements of the limited performance objective delineated in the ASCE 41 standard.

The estimates provided in -RPT-025 show that there will be a proven, significant reduction on the occupancy of the Berth 2 structures which is equivalent to a direct reduction to life safety risks. The periods of time with higher occupancy rates are limited to times where maintenance work is performed, which can be defined as a temporary condition. During operating conditions, occupancy appears to be limited to no more than three (3) people for Berth 2. This value further supports the case for a system with a significantly low occupancy rate when the significant area of the Berth is factored in.

Therefore, based on the occupancy and risk assessments provided in -RPT-024 and -RPT-025, Jensen Hughes agrees on the proposal to use the limited performance objective as described in the ASCE 41 standard Tables 2-1 and C2-2. The limited performance objective will allow Westshore to meet Life Safety criteria for the seismic event with a return period of 1:225-years. Westshore will not be required to meet the Collapse Prevention Criteria for the seismic event with a return period of 1:975-years if the criteria for Life Safety is met.

With respect to the methods used to upgrade the Berth 2 structures and components, shown below, Jensen Hughes agrees that the proposed retrofit strategy will meet the intended objective of achieving the life safety performance level discussed above. However, the next reasonable step in the design process would be to perform the required structural calculations to demonstrate the effectiveness of the retrofit strategy:

- Soil densification using stone columns at the top of the slope accessible from shore.

  JH Comment: Using stone columns as means to improve the soil that support the foundations of the Berth 2 structures is a reasonable and widely recognized method for soil improvement as discussed in “Principles of Foundation Engineering” by Braja M. Das (included as Exhibit A).

- Soil densification using either stone columns or timber compaction piles at the toe of the slope directly under the berth area and accessible by a construction vessel.

  JH Comment: As discussed in the previous bullet point, using stone columns or timber piles as means to improve the soil through compaction is a reasonable and widely recognized method for soil improvement.

- Structural strengthening of piles and pile caps - concrete fill of piles; jackets at the tops of piles; added structural members to pile caps.

  JH Comment: Concrete fill of the steel piles will increase the load-carrying capacity of the pile cross section, which will lead to a higher resistance of the entire group of piles/foundations. Jacketing is a commonly used method to improve the strength and deformation capacity of structural components.

2.0 Drawings by Westshore

Jensen Hughes has performed a high-level review of all the drawings, i.e., design concepts, provided by Westshore, which are listed above. The intent of the review is to verify that the design concepts provided are consistent with the proposed retrofit in Section 3 of Westshore Report -RPT-024.

The details provided in the drawings show a comprehensive concept design that involves increasing cross sectional capacities and the addition of new concrete to increase the capacity of existing concrete sections. The details provided also show concept designs for the connections of piles to pile caps. The upgraded connections between the piles and the pile caps will further increase the strength and deformation capacity of these components through the addition of pile jackets.

Details for the soil improvement strategy were not included in the submittal. However, this is not a requirement during the development of design concepts since the strategy is clearly defined and the method, i.e., soil improvement with stone columns and timber piles, has been proven to increase the structural performance of foundations for applications like those described in the reports by Westshore. It is likely that a contractor for the soil improvement will be engaged and a detailed description of the stone columns and/or timber piles will be provided at a later stage.

3.0 Presentation Slides

The presentation slides provided in file 19899-PM-PRE-004.pdf are the focus of the review in this section of the letter/report since there is new information provided that has not been previously reviewed. The content of the slides provided in file 19899-PM-PRE-005 is essentially discussed in Westshore report -RPT-025 which is addressed in Section 1.0 of this letter/report.

File 19899-PM-PRE-004.pdf provides additional descriptions and detail on the loadings and configurations of the replaced structures. The write up further supports the concept of a “replacement in kind” since changes in loads are less than 10%, which is one of the requirements that must be met to use this concept.

Figure 1 below shows the options that have been reviewed by Westshore for the soil/ground improvement of Berth 2. Ultimately, Westshore proposal will be limited to densification at the top and the toe of the slope due to valid concerns about the effects of densification around existing structures within the slope.

JH Comment: This is a reasonable approach, especially when the seismic event for which the structural performance is targeted, has a return period of 1:225-years.

Overall, Jensen Hughes agrees with the “Full Retrofit” solution as being the most suitable approach for meeting the requirements of the NBCC and all other applicable standards. The “Full Retrofit” concept is further supported by performance-based approach that is followed which in the end will provide assurance that life safety performance level is achieved in the process.

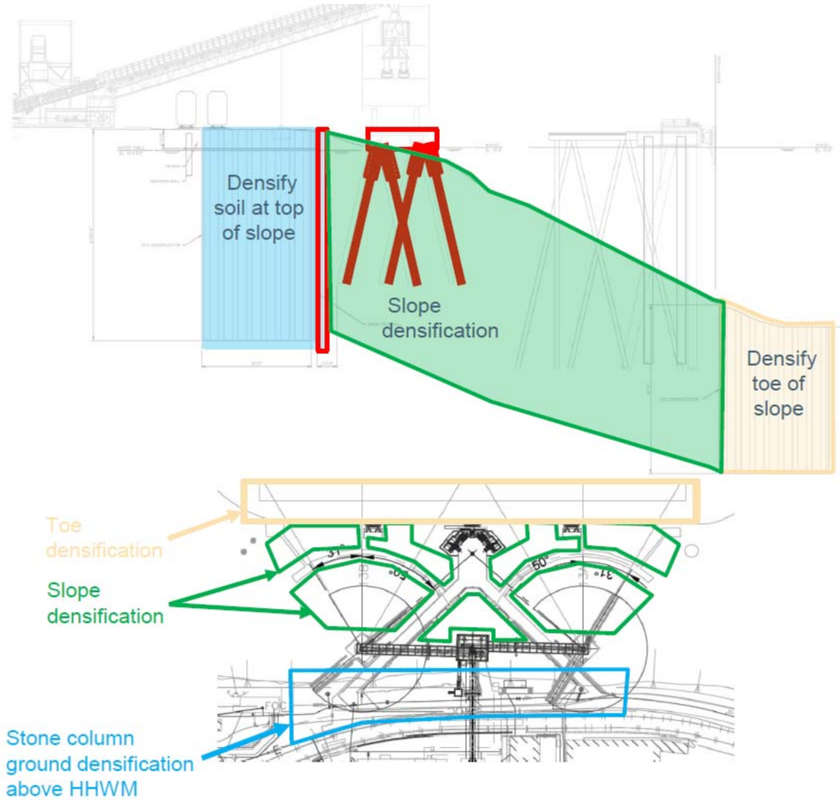

Figure 1. Diagram showing the options for soil densification

In Summary, Jensen Hughes agrees that the path to code compliance provided by Westshore meets the intent of maintaining the performance level of life safety per the requirements of the NBCC by meeting the requirements of the performance-based approach of the American Standard ASCE 41 for existing structures. Jensen Hughes is also in agreement that the proposed retrofit design concept will likely meet the requirements of the life safety performance level.

Jensen Hughes appreciates the opportunity to assist Vancouver Fraser Port Authority. If you have any questions, please contact me at 781-471-5019 or dmoreno@jensenhughes.com.

Respectfully submitted,

Jensen Hughes

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Exhibit A: Pages from “Principles of Foundation Engineering” by Braja M. Das

Principles of

FOUNDATION ENGINEERING

Eighth Edition

Braja M. Das

hydrated lime to produce cementitious products. For that reason, lime–fly-ash mixtures can be used to stabilize highway bases and subbases. Effective mixes can be prepared with 10 to 35% fly ash and 2 to 10% lime. Soil–lime–fly-ash mixes are compacted under controlled conditions, with proper amounts of moisture to obtain stabilized soil layers.

A certain type of fly ash, referred to as "Type C" fly ash, is obtained from the burning of coal primarily from the western United States. This type of fly ash contains a fairly large proportion (up to about 25%) of free lime that, with the addition of water, will react with other fly-ash compounds to form cementitious products. Its use may eliminate the need to add manufactured lime.

16.14 Stone Columns

A method now being used to increase the load-bearing capacity of shallow foundations on soft clay layers is the construction of stone columns. This generally consists of water-jetting a vibroflot (see Section 16.6) into the soft clay layer to make a circular hole that extends through the clay to firmer soil. The hole is then filled with an imported gravel. The gravel in the hole is gradually compacted as the vibrator is withdrawn. The gravel used for the stone column has a size range of 6 to 40 mm (0.25 to 1.6 in.). Stone columns usually have diameters of 0.5 to 0.75 m (1.6 to 2.5 ft) and are spaced at about 1.5 to 3 m (5 to 10 ft) center to center. Figure 16.32 shows the construction of a stone column.

After stone columns are constructed, a fill material should always be placed over the ground surface and compacted before the foundation is constructed. The stone columns

Figure 16.32 Construction of a stone column [*DGI-Menard* (*USA*).]

tend to reduce the settlement of foundations at allowable loads. Several case histories of construction projects using stone columns are presented in Hughes and Withers (1974), Hughes et al. (1975), Mitchell and Huber (1985), and other works.

Stone columns work more effectively when they are used to stabilize a large area where the undrained shear strength of the subsoil is in the range of 10 to 50 kN/m^2 (200 to 1000 lb/ft^2) than to improve the bearing capacity of structural foundations (Bachus and Barksdale, 1989). Subsoils weaker than that may not provide sufficient lateral support for the columns. For large-site improvement, stone columns are most effective to a depth of 6 to 10 m (20 to 30 ft). However, they have been constructed to a depth of 31 m (100 ft). Bachus and Barksdale provided the following general guidelines for the design of stone columns to stabilize large areas.

Figure 16.33a shows the plan view of several stone columns. The area replacement ratio for the stone columns may be expressed as

$$a_s = \frac{A_s}{A} \tag{16.49}$$

where

A_s = area of the stone column
A = total area within the unit cell

For an *equilateral triangular pattern* of stone columns,

$$a_s = 0.907\left(\frac{D}{s}\right)^2 \tag{16.50}$$

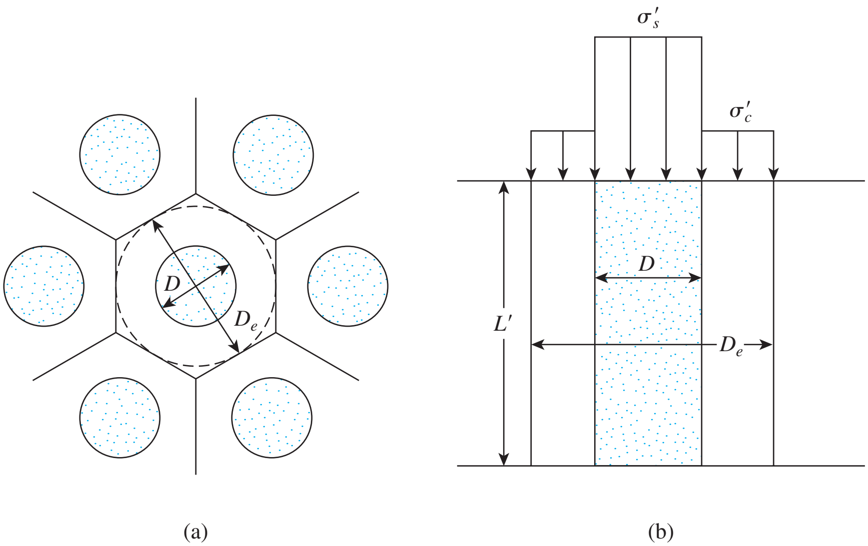


Figure 16.33 (a) Stone columns in a triangular pattern; (b) stress concentration due to change in stiffness

where

D = diameter of the stone column
s = spacing between the columns

Combining Eqs. (16.49) and (16.50),

$$\frac{A_s}{A} = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}D_e^2} = a_s = 0.907\left(\frac{D}{s}\right)^2$$

or

$$D_e = 1.05s \tag{16.51}$$

Similarly, it can be shown that, for square pattern of stone columns,

$$D_e = 1.13s \tag{16.52}$$

When a uniform stress by means of a fill operation is applied to an area with stone columns to induce consolidation, a stress concentration occurs due to the change in the stiffness between the stone columns and the surrounding soil. (See Figure 16.33b.) The stress concentration factor is defined as

$$n' = \frac{\sigma'_s}{\sigma'_c} \tag{16.53}$$

where

σ'_s = effective stress in the stone column
σ'_c = effective stress in the subgrade soil

The relationships for σ'_s and σ'_c are

$$\sigma'_s = \sigma'\left[\frac{n'}{1 + (n' - 1)a_s}\right] = \mu_s\sigma' \tag{16.54}$$

and

$$\sigma'_c = \sigma'\left[\frac{1}{1 + (n' - 1)a_s}\right] = \mu_c\sigma' \tag{16.55}$$

where

σ' = average effective vertical stress
μ_s, μ_c = stress concentration coefficients

The improvement in the soil owing to the stone columns may be expressed as

$$\frac{S_{e(t)}}{S_e} = \mu_c \tag{16.56}$$

where

$S_{e(t)}$ = settlement of the treated soil
S_e = total settlement of the untreated soil

Load-Bearing Capacity of Stone Columns

When the length L' of the stone column is less than about $3D$ and a foundation is constructed over it, failure occurs by plunging similar to short piles in soft to medium-stiff clays. For longer columns sufficient to prevent plunging, the load carrying capacity is governed by the ultimate radial confining pressure and the shear strength of the surrounding matrix soil. In those cases, failure at ultimate load occurs by bulging, as shown in Figure 16.34. Mitchell (1981) proposed that the ultimate bearing capacity (q_u) of a stone column can be given as

$$q_u = c_u N_p \tag{16.57}$$

where c_u = undrained shear strength of clay
N_p = bearing capacity factor

Mitchell (1981) recommended that

$$N_p \approx 25 \tag{16.58}$$

Based on several field case studies, Stuedlein and Holtz (2013) recommended that

$$N_p = \exp(-0.0096c_u + 3.5) \tag{16.59}$$

where c_u is in kN/m^2.

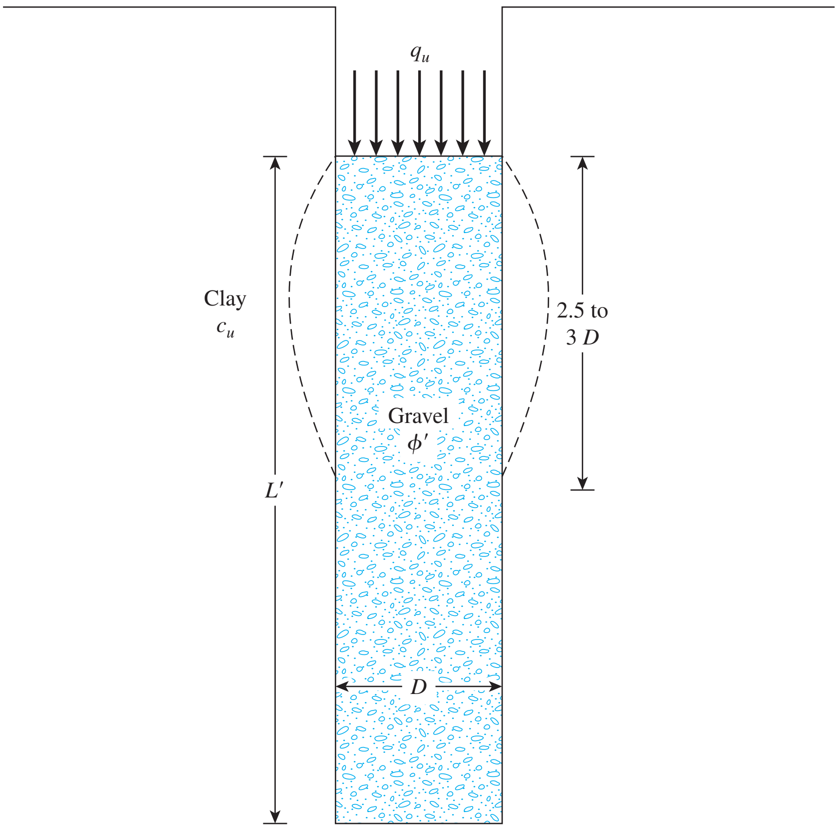


Figure 16.34 Bearing capacity of stone column

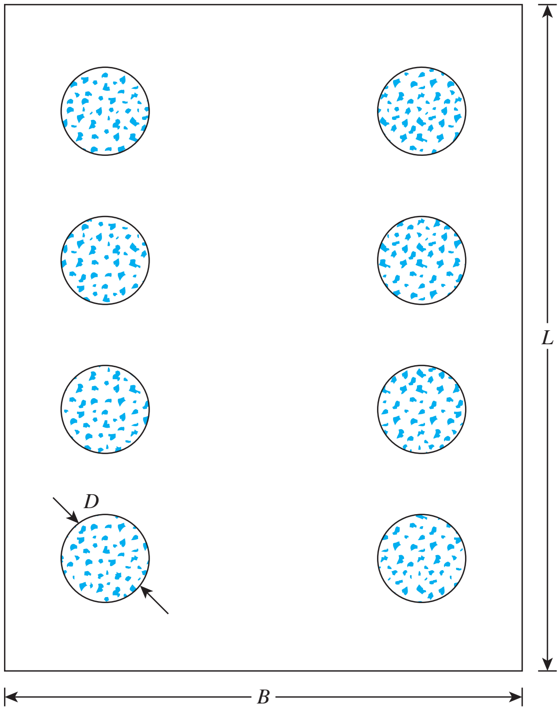


Figure 16.35 Shallow foundation over a group of stone columns

If a foundation is constructed measuring $B \times L$ in plan over a group of stone columns, as shown in Figure 16.35, the ultimate bearing capacity q_u can be expressed as (Stuedlein and Holtz, 2013)

$$q_u = N_p c_u a_s + N_c c_u (1 - a_s) F_{cs} F_{cd} \tag{16.60}$$

where N_p is expressed by Eq. (16.59)

$N_c = 5.14$

F_{cs} and F_{cd} = shape and depth factors (see Table 4.6)

Then

$$F_{cs} = 1 + 0.2\frac{B}{L} \tag{16.61}$$

and

$$F_{cd} = 1 + 0.2\frac{D_f}{B} \tag{16.62}$$

where D_f = depth of the foundation.

Example 16.7

Consider a foundation 4 m × 2 m in plan constructed over a group of stone columns in a square pattern in soft clay. Given

Stone columns: $D = 0.4$ m
Area ratio, $a_s = 0.3$
$L' = 4.8$ m
Clay: $c_u = 36$ KN/m^2
Foundation: $D_f = 0.75$ m

Estimate the ultimate load Q_u for the foundation.

Solution

From Eq. (16.60),

$$Q_u = N_p c_u a_s + N_c c_u (1 - a_s) F_{cs} F_{cd}$$

From Eq. (16.59),

$$N_p = \exp(-0.0096 c_u + 3.5) = \exp[(-0.0096)(36) + 3.5] = 23.44$$

$$F_{cs} = 1 + 0.2\left(\frac{B}{L}\right) = 1 + 0.2\left(\frac{2}{4}\right) = 1.1$$

$$F_{cd} = 1 + 0.2\left(\frac{D_f}{B}\right) = 1 + 0.2\left(\frac{0.75}{2}\right) = 1.075$$

and

$$q_u = (23.44)(36)(0.3) + (5.14)(36)(1 - 0.3)(1.1)(1.075) = 406.31 \text{ kN/m}^2$$

Thus, the ultimate load is

$$Q_u = q_u BL = (406.31)(2)(4) = \mathbf{3250.48\ kN}$$ ■

16.15 Sand Compaction Piles

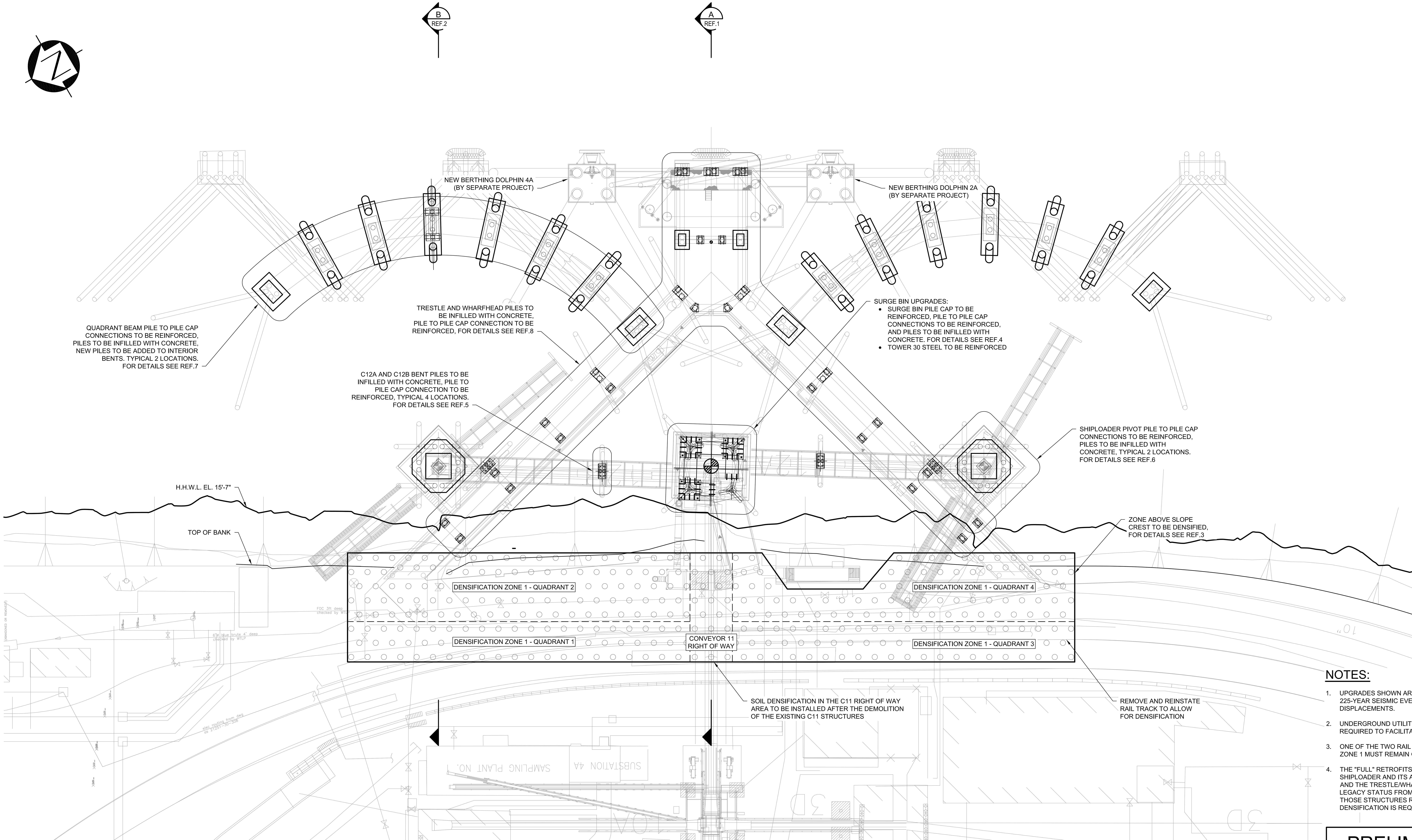
Sand compaction piles are similar to stone columns, and they can be used in marginal sites to improve stability, control liquefaction, and reduce the settlement of various structures. Built in soft clay, these piles can significantly accelerate the pore water pressure-dissipation process and hence the time for consolidation.

Sand piles were first constructed in Japan between 1930 and 1950 (Ichimoto, 1981). Large-diameter compacted sand columns were constructed in 1955, using the Compozer technique (Aboshi et al., 1979). The Vibro-Compozer method of sand pile construction was developed by Murayama in Japan in 1958 (Murayama, 1962).

Sand compaction piles are constructed by driving a hollow mandrel with its bottom closed during driving. On partial withdrawal of the mandrel, the bottom doors open. Sand is poured from the top of the mandrel and is compacted in steps by applying air pressure as the mandrel is withdrawn. The piles are usually 0.46 to 0.76 m (1.5 to 2.5 ft) in diameter and are placed at about 1.5 to 3 m (5 to 10 ft) center to center. The pattern of layout of sand

APPENDIX B

Retrofit Drawings



PLAN
1" = 25'-0"

NOTES:

1. UPGRADES SHOWN ARE TO ACCOMMODATE A 225-YEAR SEISMIC EVENT AND ONSET KINEMATIC DISPLACEMENTS.
2. UNDERGROUND UTILITIES TO BE RELOCATED AS REQUIRED TO FACILITATE DENSIFICATION WORK.
3. ONE OF THE TWO RAIL TRACKS IN DENSIFICATION ZONE 1 MUST REMAIN OPERATIONAL AT ALL TIMES.
4. THE "FULL" RETROFITS PLAN ASSUMES THAT THE SHIPLOADER AND ITS ASSOCIATED FOUNDATIONS AND THE TRESTLE/WHARFHEAD ARE NOT AWARDED LEGACY STATUS FROM THE VFPA, THEREFORE THOSE STRUCTURES REQUIRE UPGRADING AND DENSIFICATION IS REQUIRED AT THE SLOPE CREST.

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
8	19899-100-SK-1110	BERTH 2 RETROFITS - TRESTLE AND WHARFHEAD CONCEPTS									
7	19899-100-SK-1109	BERTH 2 RETROFITS - SHIPLOADER QUADRANT BEAM CONCEPTS									
6	19899-100-SK-1108	BERTH 2 RETROFITS - SHIPLOADER PIVOT CONCEPTS									
5	19899-100-SK-1107	BERTH 2 RETROFITS - CONVEYOR 12A/B CONCEPTS									
4	19899-100-SK-1106	BERTH 2 RETROFITS - SURGE BIN CONCEPTS									
3	19899-100-SK-1104	BERTH 2 GROUND IMPROVEMENTS - PLAN - GENERAL ARRANGEMENT									
2	19899-100-SK-1103	BERTH 2 SEISMIC UPGRADES - FULL RETROFITS - SECTIONS - SHEET 2	P2	2021-08-31	ISSUED FOR INFORMATION	DJC		DJC		AMG	AJK
1	19899-100-SK-1102	BERTH 2 SEISMIC UPGRADES - FULL RETROFITS - SECTIONS - SHEET 1	P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

REFERENCE DRAWINGS / DESIGN STANDARDS | ISSUES / REVISIONS | * HAND INITIALS ON FILE

DRAWN BY: DJC | SCALE: AS NOTED | ACAD FILENAME: 19899-100-SK-1101

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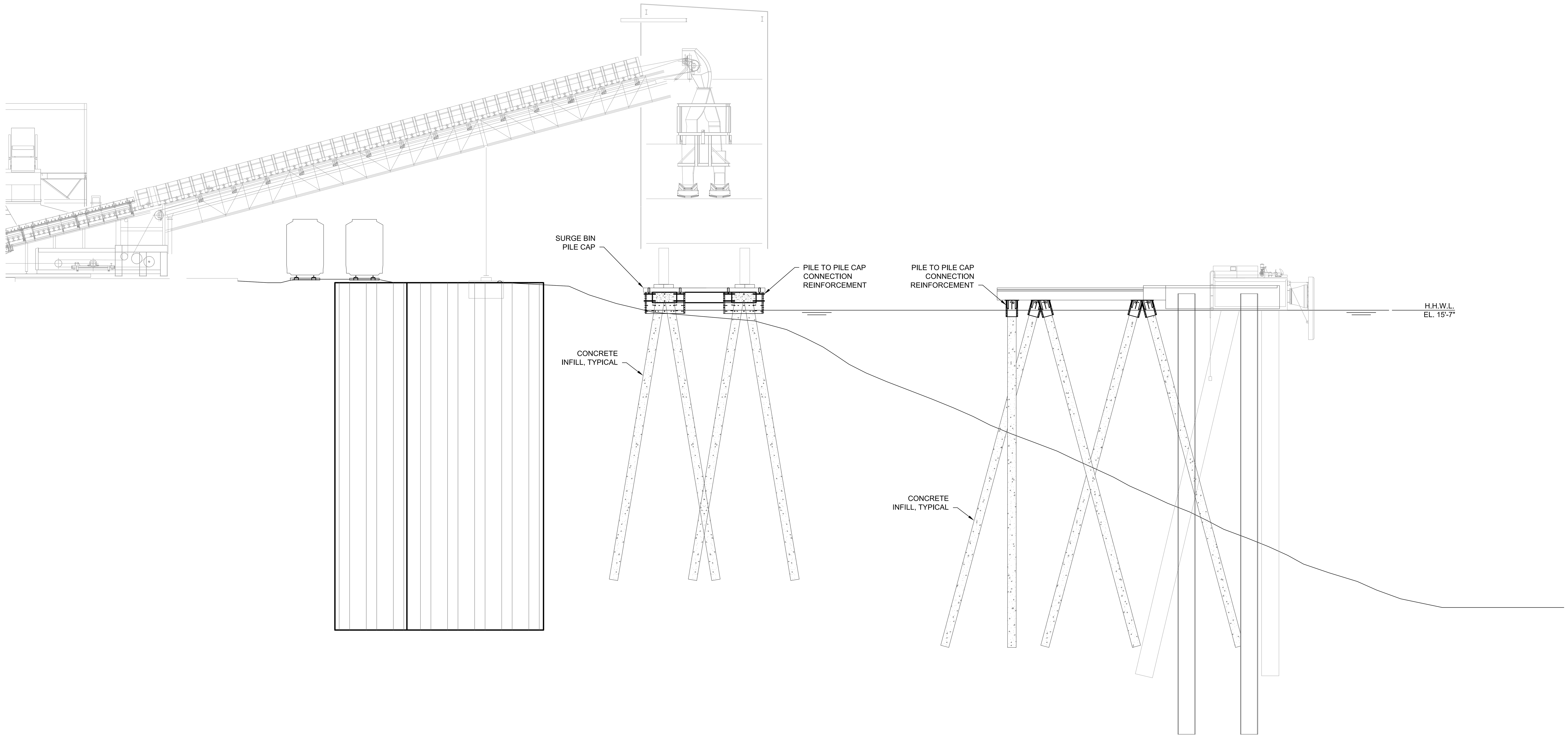
WestshoreTerminals

CWA PROJECT NUMBER: 19899

NEW CARGO STUDY
BERTH 2 SEISMIC UPGRADES
FULL RETROFITS - PLAN

19899-100-SK-1101 | P2
REV.



SECTION A / REF.1
1" = 15'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION
1	19899-100-SK-1101	BERTH 2 SEISMIC UPGRADES - FULL RETROFITS - PLAN

REFERENCE DRAWINGS / DESIGN STANDARDS

No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
P2	2021-08-31	ISSUED FOR INFORMATION	DJC		DJC		AMG	AJK
P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

ISSUES / REVISIONS

∗ HAND INITIALS ON FILE

CWA

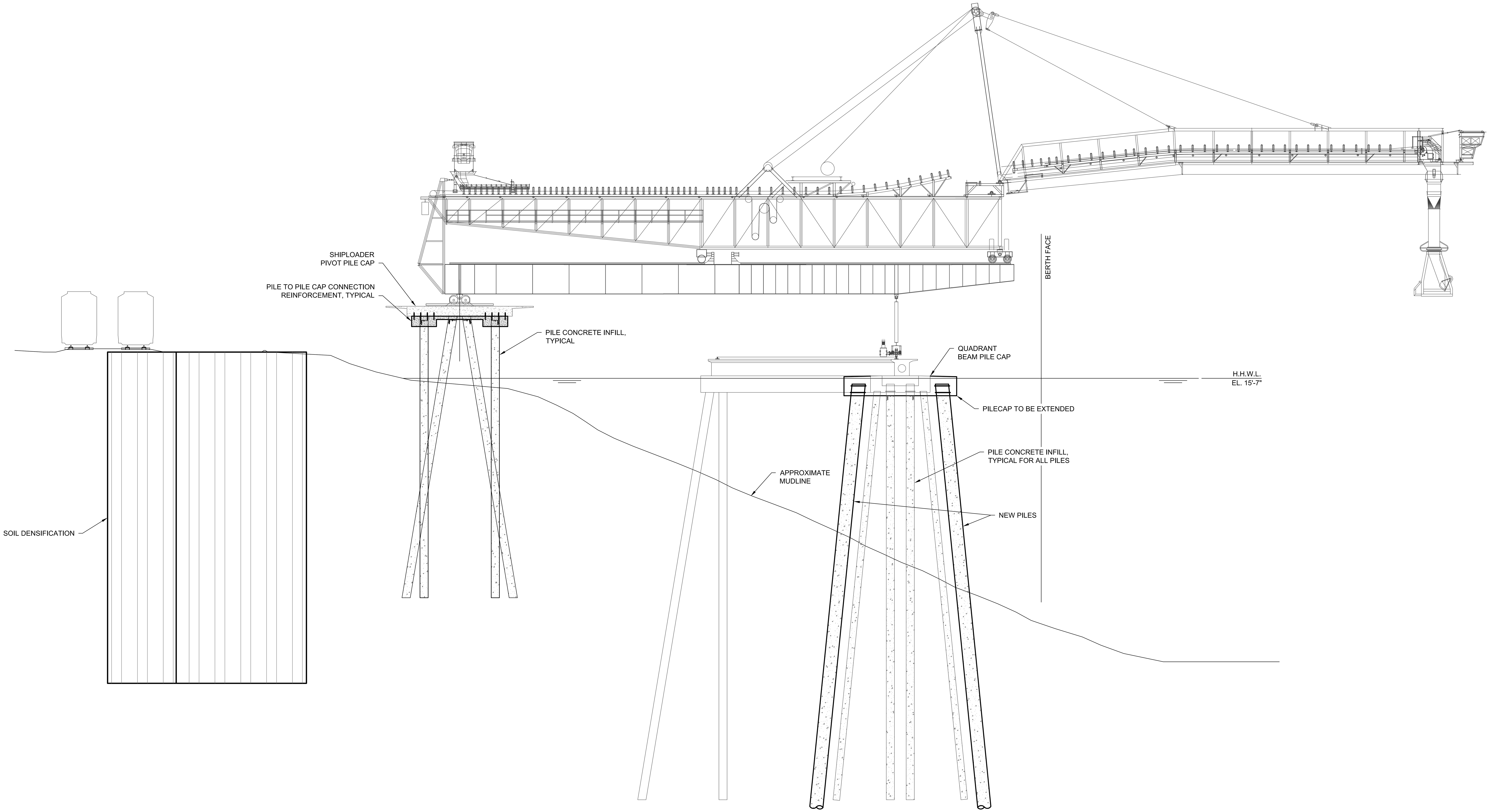
Westshore Terminals

CWA PROJECT NUMBER: 19899

NEW CARGO STUDY
BERTH 2 SEISMIC UPGRADES
FULL RETROFITS - SECTIONS - SHEET 1

19899-100-SK-1102 | P2

DRAWN BY: DJC | SCALE: AS NOTED | ACAD FILENAME: 19899-100-SK-1102 | REV.



SECTION B
1" = 15'-0"
REF.1

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION
1	19899-100-SK-1101	BERTH 2 SEISMIC UPGRADES - FULL RETROFITS - PLAN

REFERENCE DRAWINGS / DESIGN STANDARDS

No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
P2	2021-08-31	ISSUED FOR INFORMATION	DJC		DJC		AMG	AJK
P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

ISSUES / REVISIONS

∗ HAND INITIALS ON FILE

DRAWN BY: CPL

SCALE: AS NOTED

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ACAD FILENAME: 19899-100-SK-1103

WestshoreTerminals

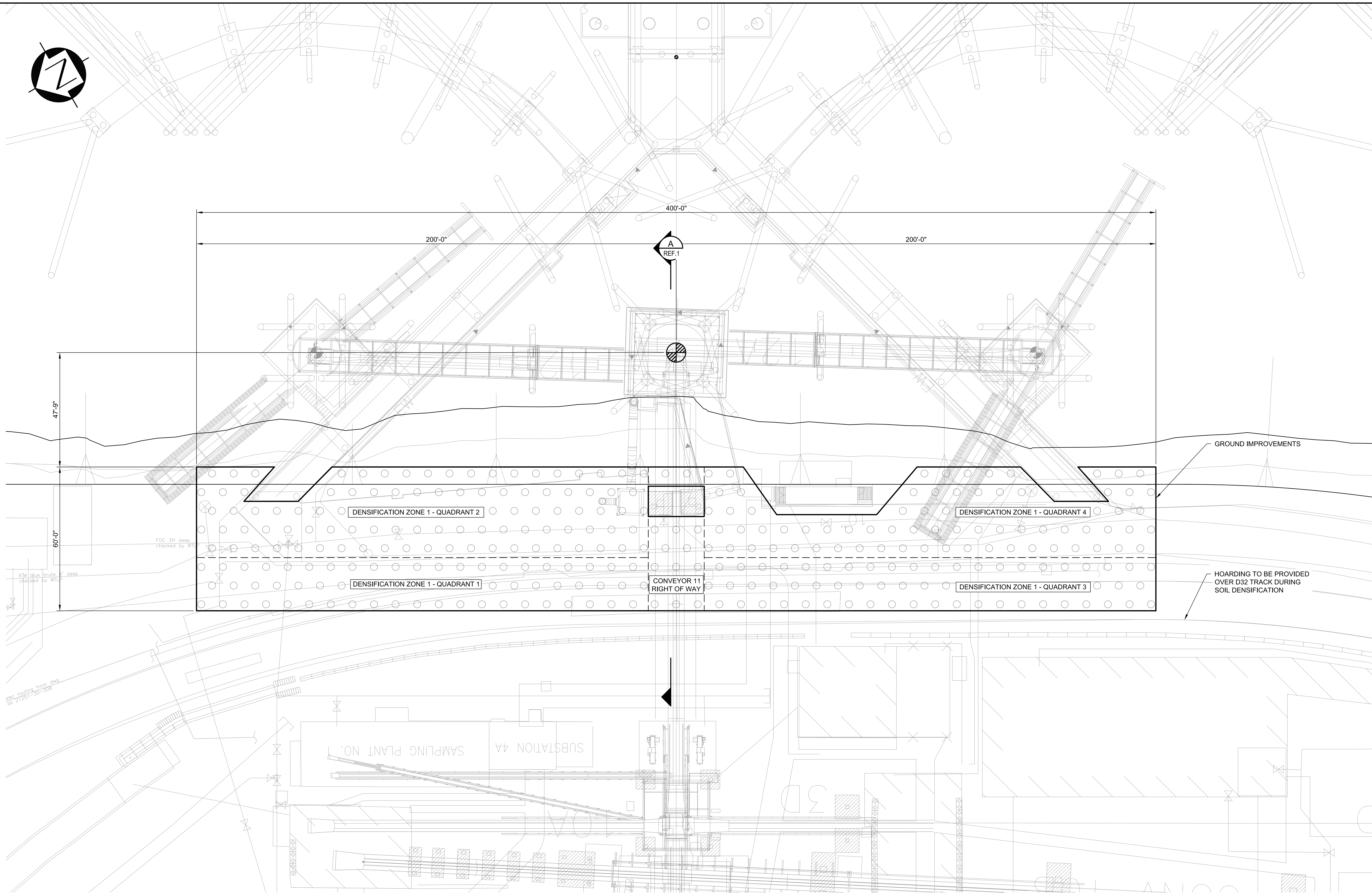
CWA PROJECT NUMBER: 19899

NEW CARGO STUDY
BERTH 2 SEISMIC UPGRADES
FULL RETROFITS - SECTIONS - SHEET 2

19899-100-SK-1103

P2

REV.



PLAN
1" = 20'-0"

NOTES:

1. DENSIFICATION ZONE 1 IS TO BE VIBRO STONE COLUMNS.
2. DENSIFICATION ZONE 1 TO BE INSTALLED PER A PERFORMANCE-BASED SPECIFICATION (TBD); STONE COLUMN SPACING TO BE DETERMINED BY CONTRACTOR TO ACHIEVE DENSIFICATION TARGETS.

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P2	2021-08-31	ISSUED FOR INFORMATION	DJC		-		AMG	AJK
1	19899-100-SK-1105	BERTH 2 GROUND IMPROVEMENTS - SECTION - GENERAL ARRANGEMENT	P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		-		AMG	AJK
REFERENCE DRAWINGS / DESIGN STANDARDS			ISSUES / REVISIONS			* HAND INITIALS ON FILE					

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CWA

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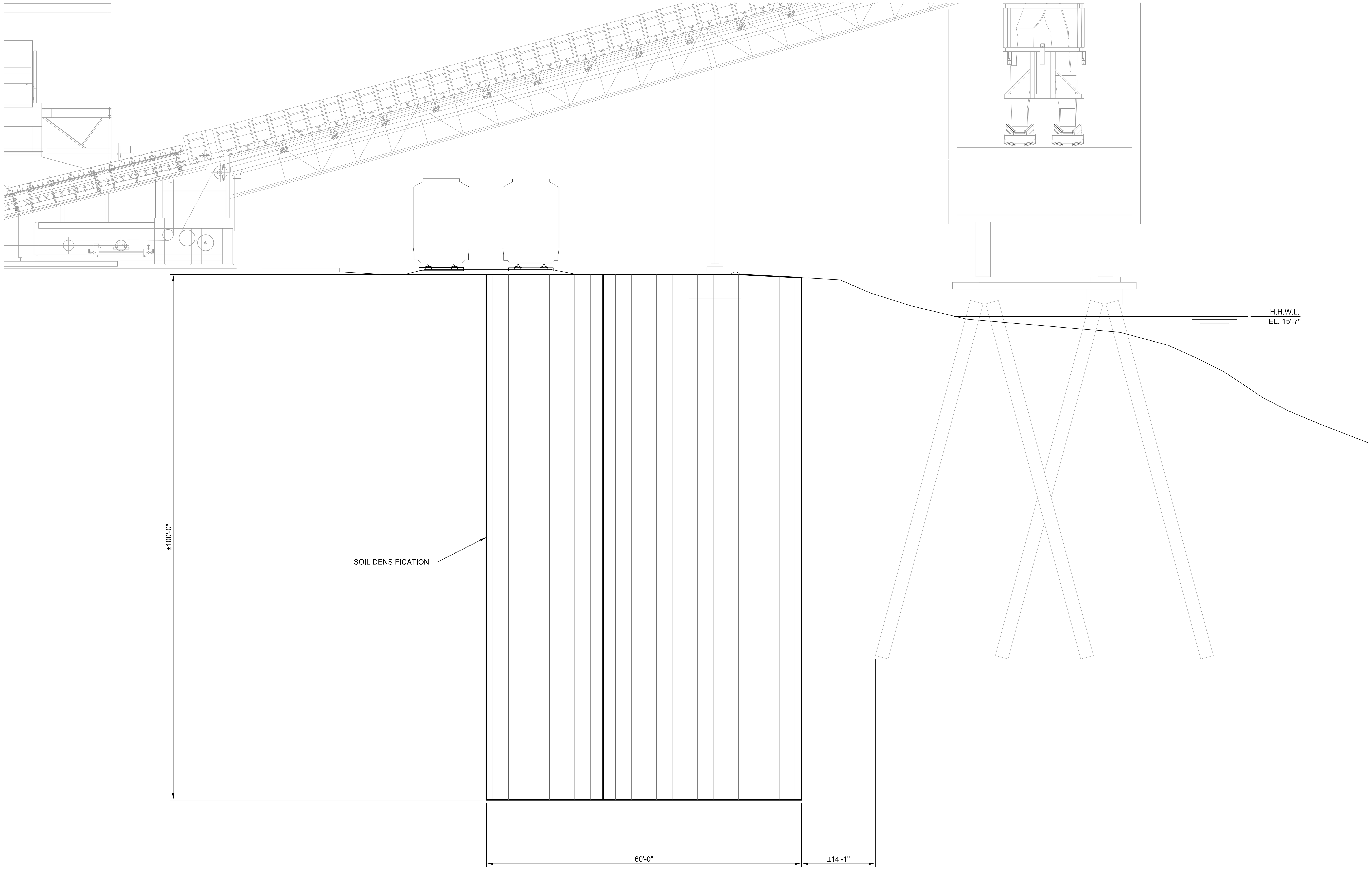
CWA PROJECT NUMBER: 19899

NEW CARGO STUDY
BERTH 2 GROUND IMPROVEMENTS
PLAN - GENERAL ARRANGEMENT

19899-100-SK-1104 | REV. P2



SECTION A
1" = 10'-0"
REF.1

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P2	2021-08-31	ISSUED FOR INFORMATION	DJC		-		AMG	AJK
1	19899-100-SK-1104	BERTH 2 GROUND IMPROVEMENTS - PLAN - GENERAL ARRANGEMENT	P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		-		AMG	AJK

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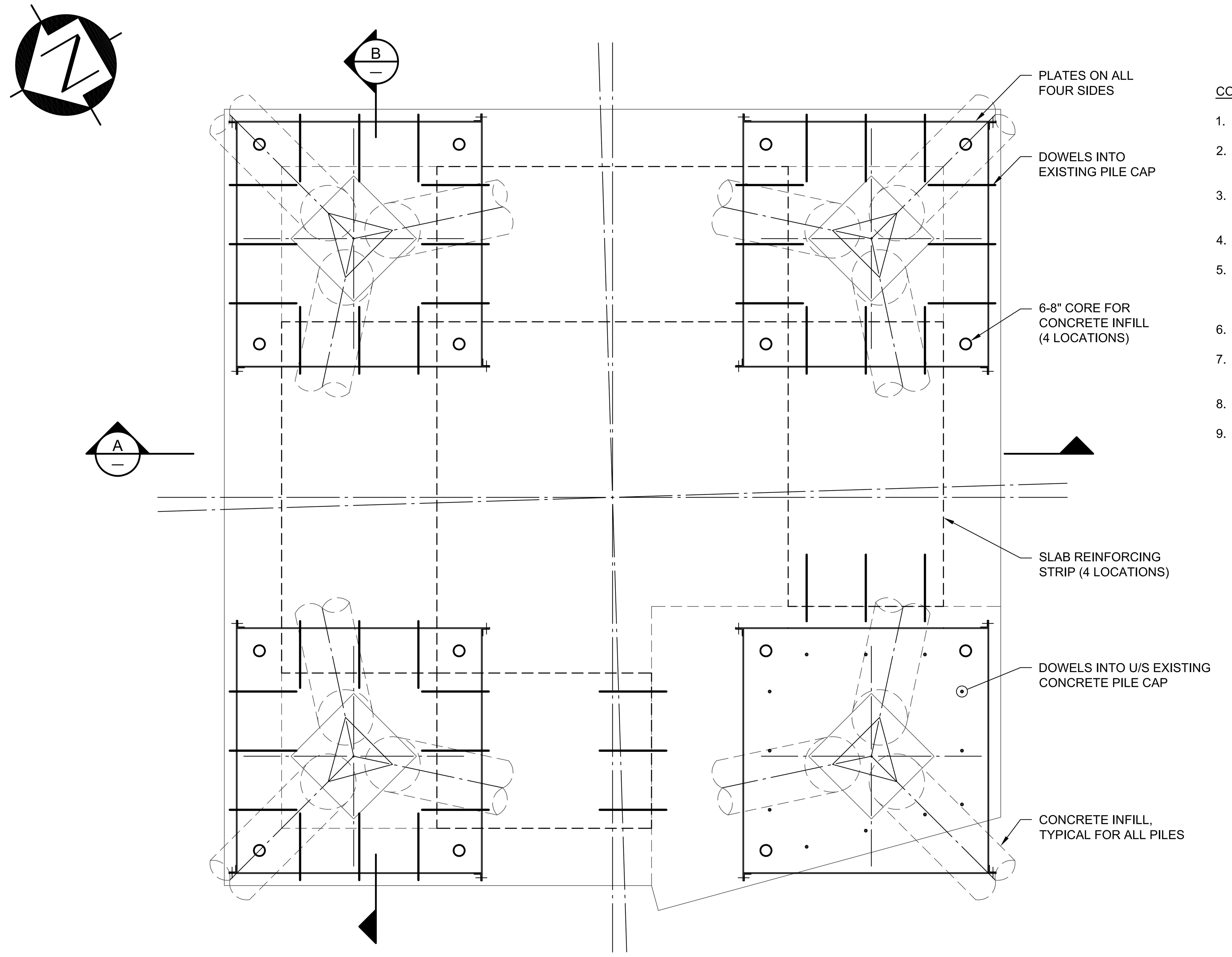
NEW CARGO STUDY
BERTH 2 GROUND IMPROVEMENTS
SECTION - GENERAL ARRANGEMENT

19899-100-SK-1105 | P2
REV.



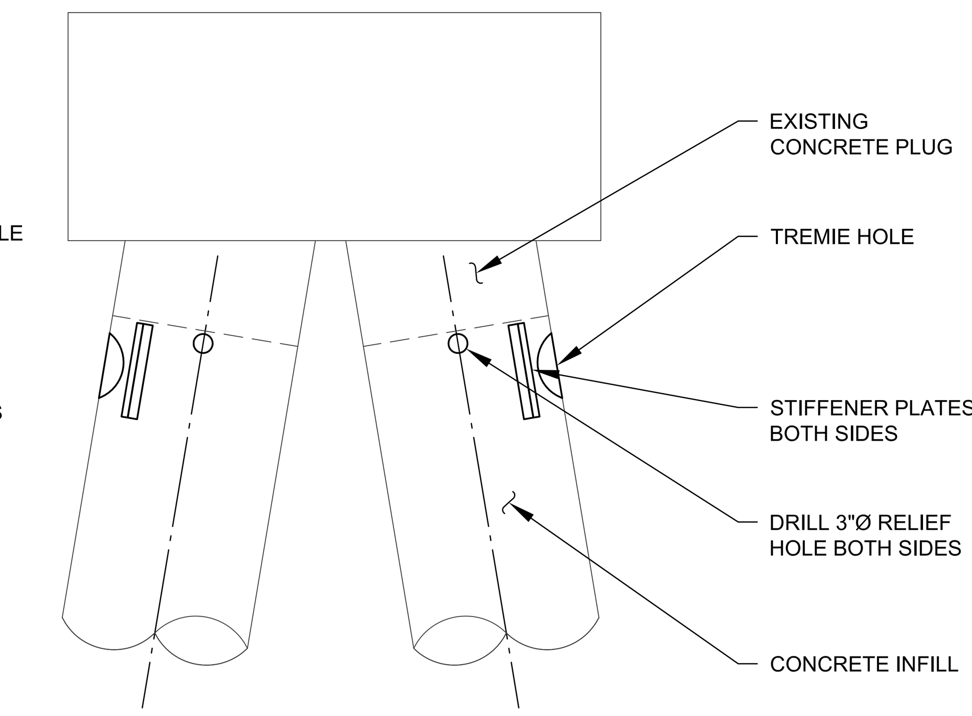
PLAN - SURGE BIN PILE CAP
1/4" = 1'-0"

CONSTRUCTION SEQUENCE

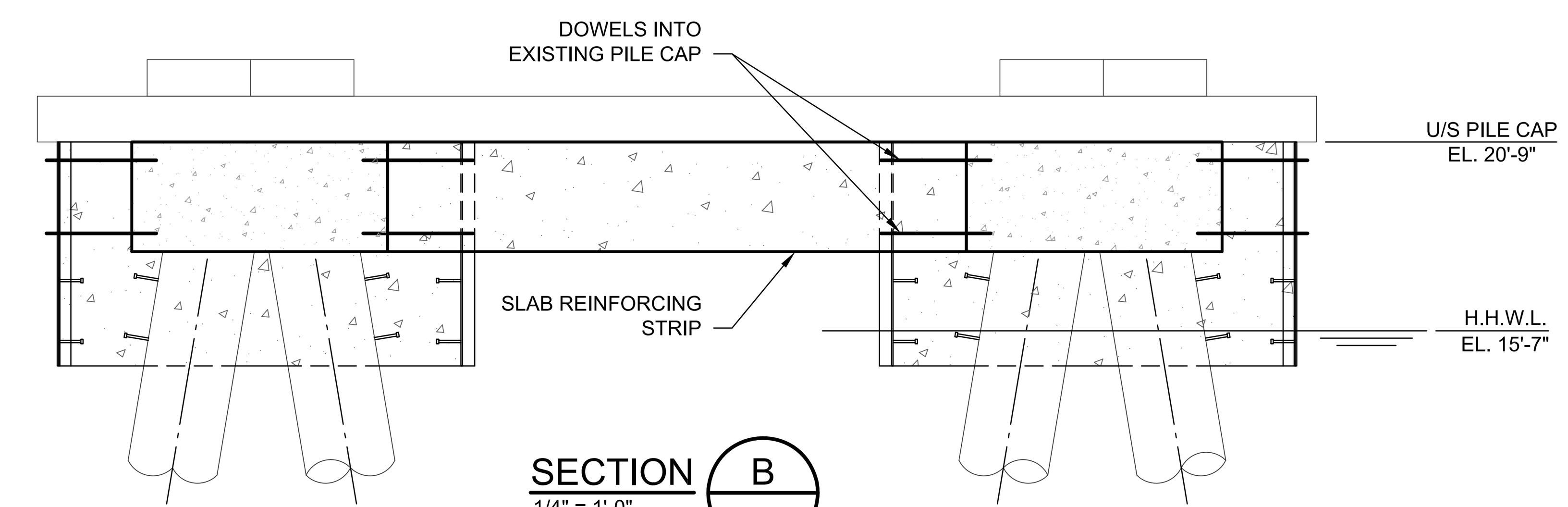
1. WELD NELSON STUDS TO PILES.
2. SCAN SURFACE FOR REINFORCEMENT. CORE 6-8" DIA HOLES IN BETWEEN REINFORCEMENT.
3. INSTALL DOWELS INTO SIDE FACES OF EXISTING PILE CAP AND U/S OF SLAB.
4. HANG REBAR CAGE FROM UNDERSIDE OF SLAB.
5. ERECT PLATEWORK BOX AND PROVIDE TEMPORARY SUPPORT. (DOWELS WILL NOT TAKE LOAD UNTIL CONCRETE HAS SET)
6. FORM UP UNDERSIDE OF BOX.
7. PUMP SELF CONSOLIDATING CONCRETE THROUGH CORED HOLES IN SLAB.
8. SEAL VENT HOLES ONCE BOX IS FULL.
9. FILL REMAINDER OF CORE HOLES AND FINISH FLUSH WITH SLAB SURFACE.

CONSTRUCTION SEQUENCE

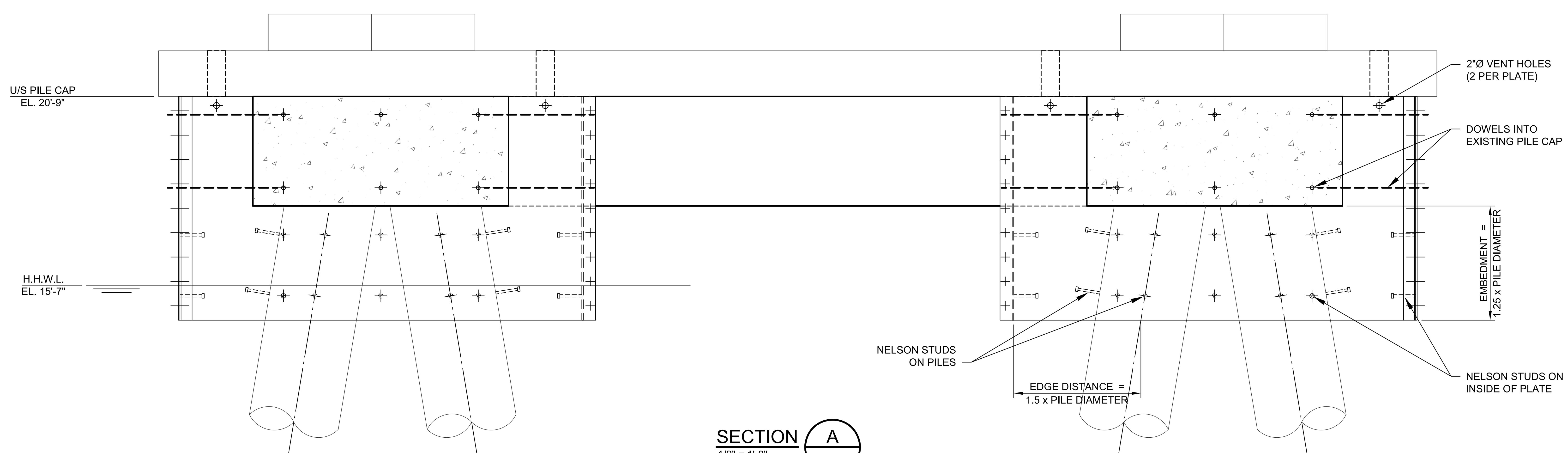
1. TAP/SCAN PILE TO DETERMINE EXTENT OF CONCRETE PLUG.
2. ADD STIFFENERS TO PILE ADJACENT TO HOLE LOCATIONS.
3. CUT 6"-8"Ø HOLE FOR TREMIE PUMP BELOW CONCRETE PLUG. DRILL 3"Ø RELIEF HOLES NEAR TOP OF PILE.
4. PUMP CONCRETE INTO PILE UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.



TYPICAL CONCRETE INFILL FOR EXISTING PILES
1/2" = 1'-0"



SECTION B
1/4" = 1'-0"



SECTION A
1/2" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

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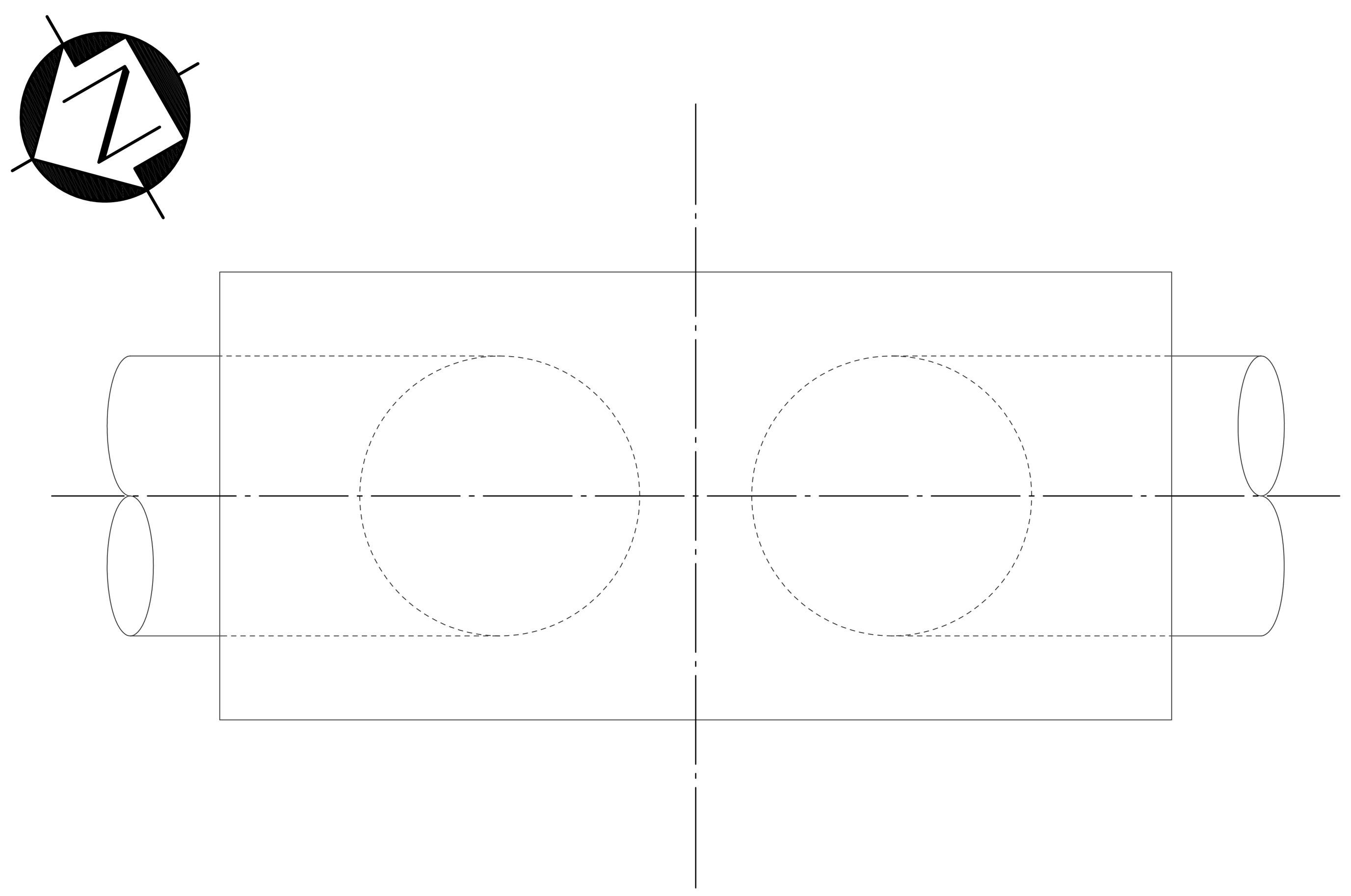
CWA

Westshore Terminals

CWA PROJECT NUMBER: 19899

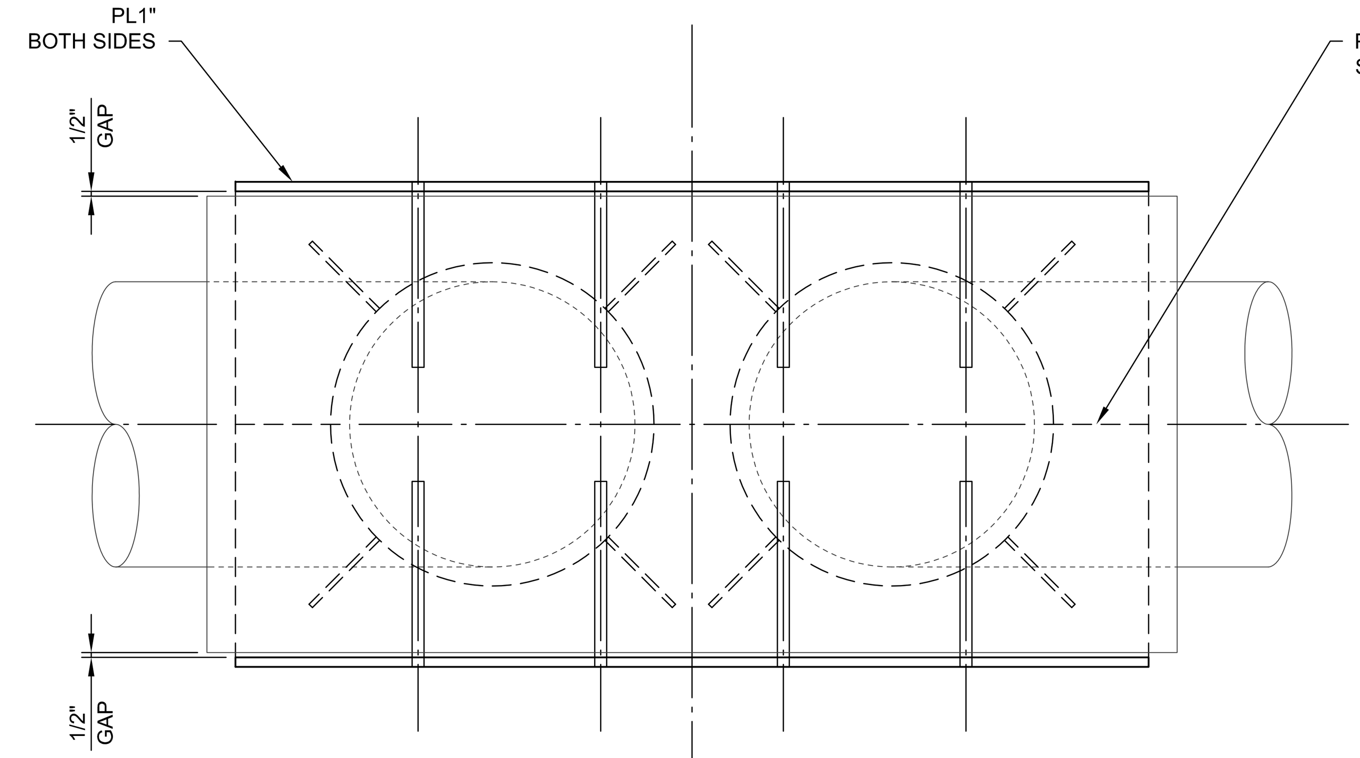
NEW CARGO STUDY
BERTH 2 RETROFITS
SURGE BIN CONCEPTS

19899-100-SK-1106 | REV. P1



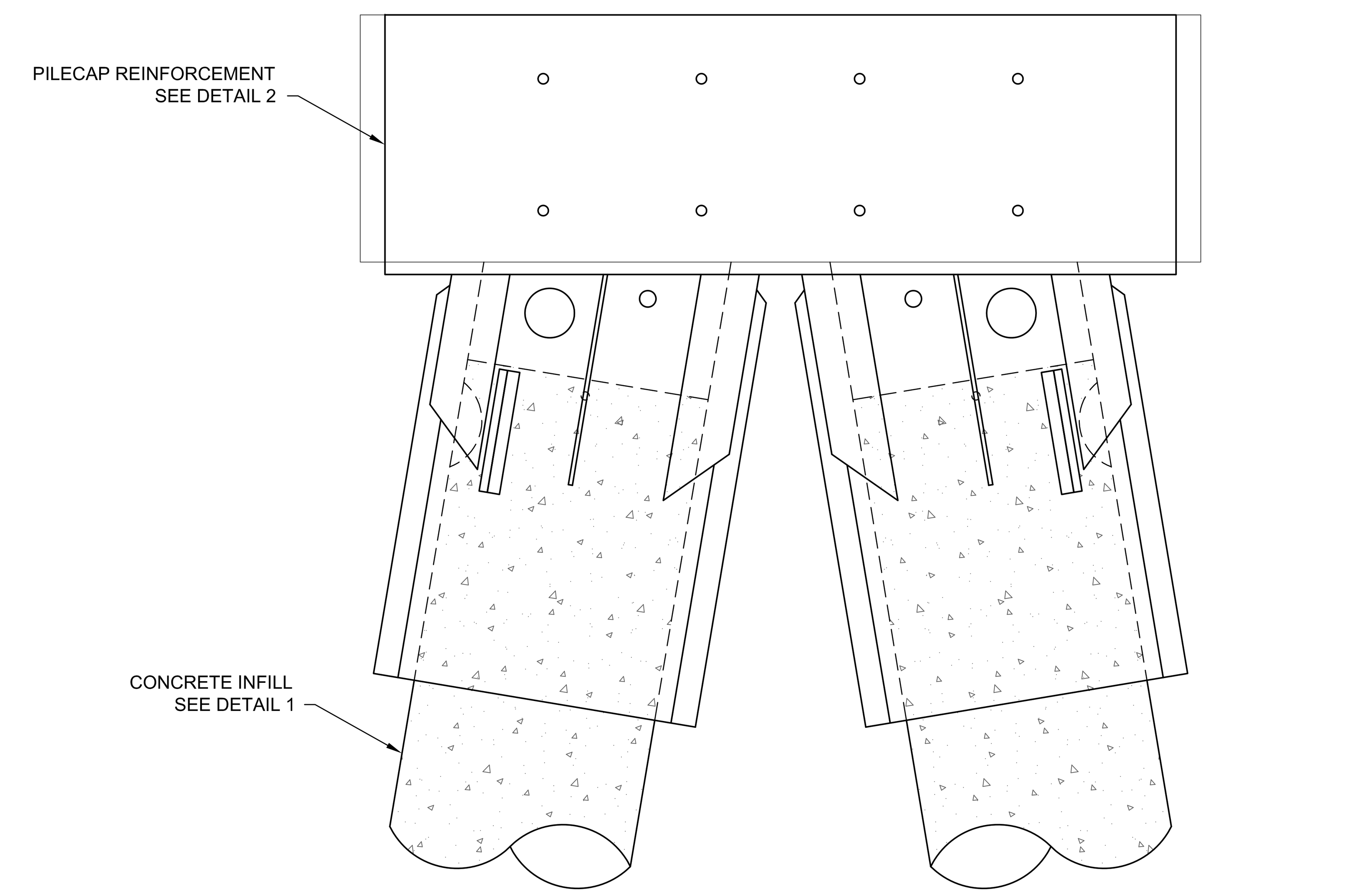
PLAN

3/4" = 1'-0"



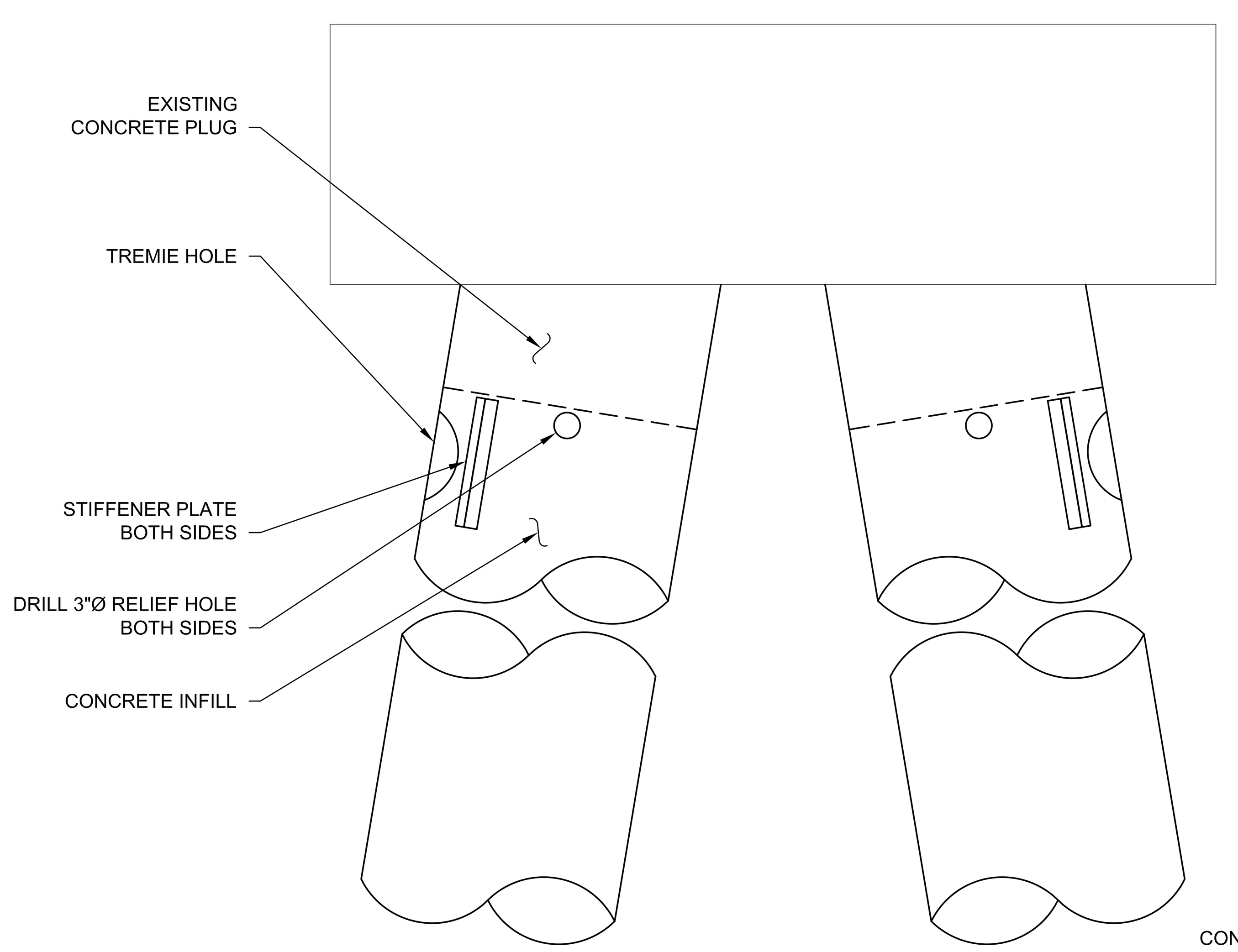
PLAN

3/4" = 1'-0"



ELEVATION
CONVEYOR 12A/B PILECAP TYPE A

3/4" = 1'-0"

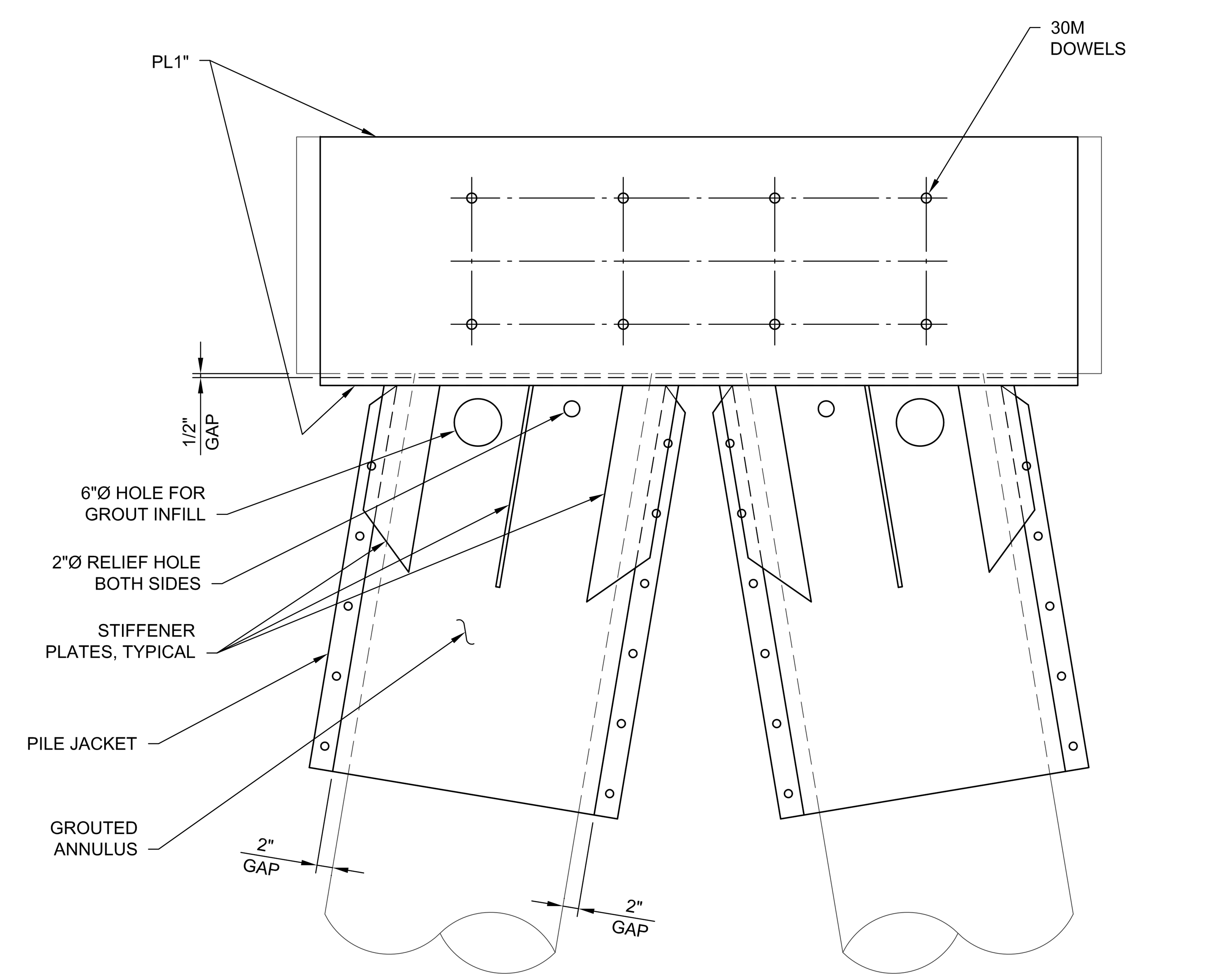


ELEVATION
DETAIL 1 - PILE CONCRETE INFILL

3/4" = 1'-0"

CONSTRUCTION SEQUENCE:

1. TAP/SCAN PILE TO DETERMINE EXTENT OF CONCRETE PLUG.
2. ADD STIFFENERS TO PILE ADJACENT TO HOLE LOCATIONS.
3. CUT 6"-8"Ø HOLE FOR TREMIE PUMP BELOW CONCRETE PLUG. DRILL 3"Ø RELIEF HOLES NEAR TOP OF PILE.
4. PUMP CONCRETE INTO PILE UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.

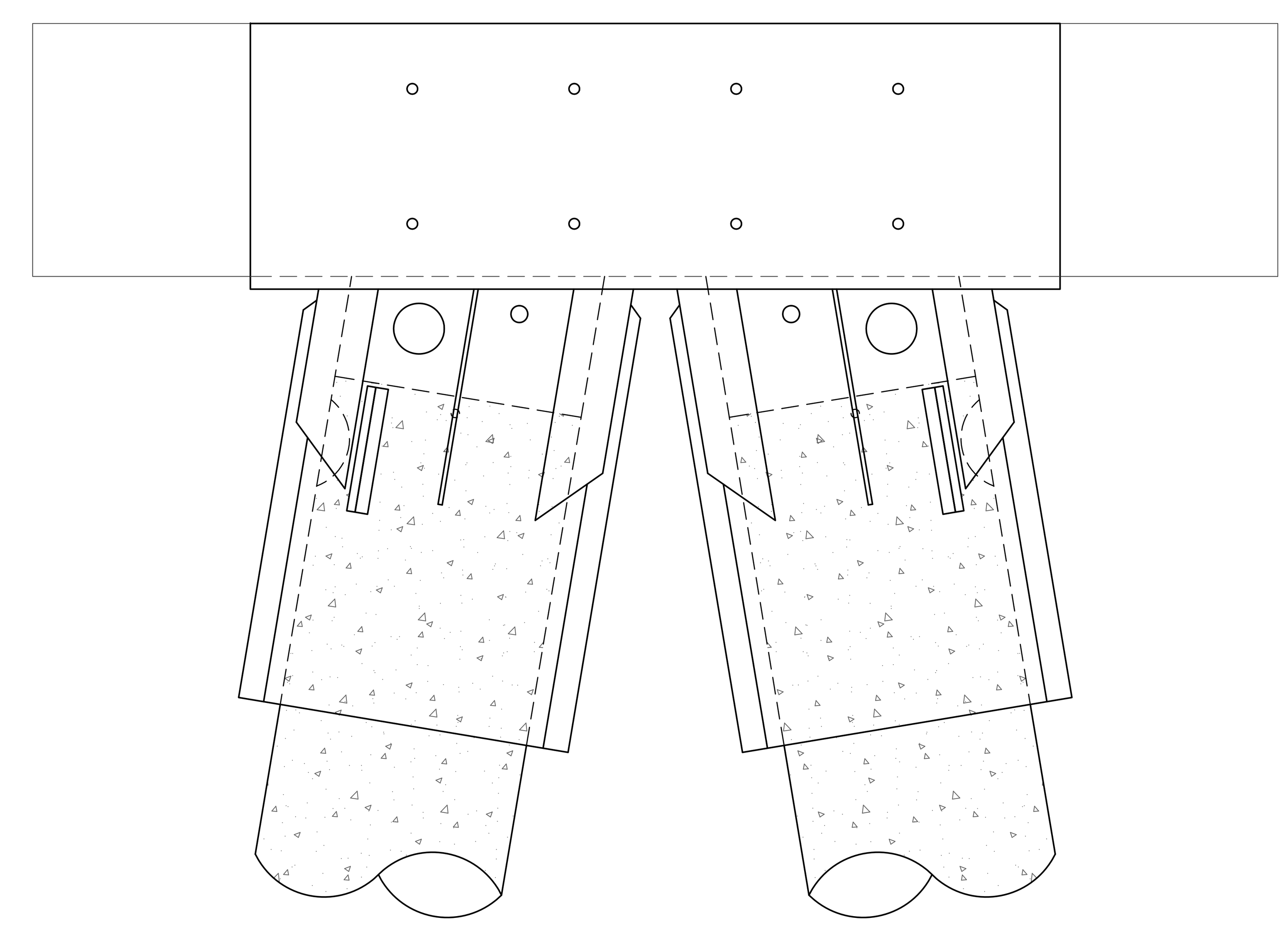


ELEVATION
DETAIL 2 - PILECAP REINFORCEMENT

3/4" = 1'-0"

CONSTRUCTION SEQUENCE:

1. INSTALL DOWELS USING REINFORCING PLATES AS TEMPLATE.
2. INSTALL PILE JACKET AND PLATE HALVES (EACH PILE JACKET HALF SHOP WELDED TO L-SHAPED PLATES).
3. BOLT UP PILE JACKET.
4. PUMP GROUT THROUGH OPENING TO FILL VOID BETWEEN PILE AND PILE JACKET (ANNULUS) UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.



ELEVATION
CONVEYOR 12A/B PILECAP TYPE B

3/4" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

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Westshore Terminals

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NEW CARGO STUDY
BERTH 2 RETROFITS
CONVEYOR 12A/B CONCEPTS

19899-100-SK-1107 | P1

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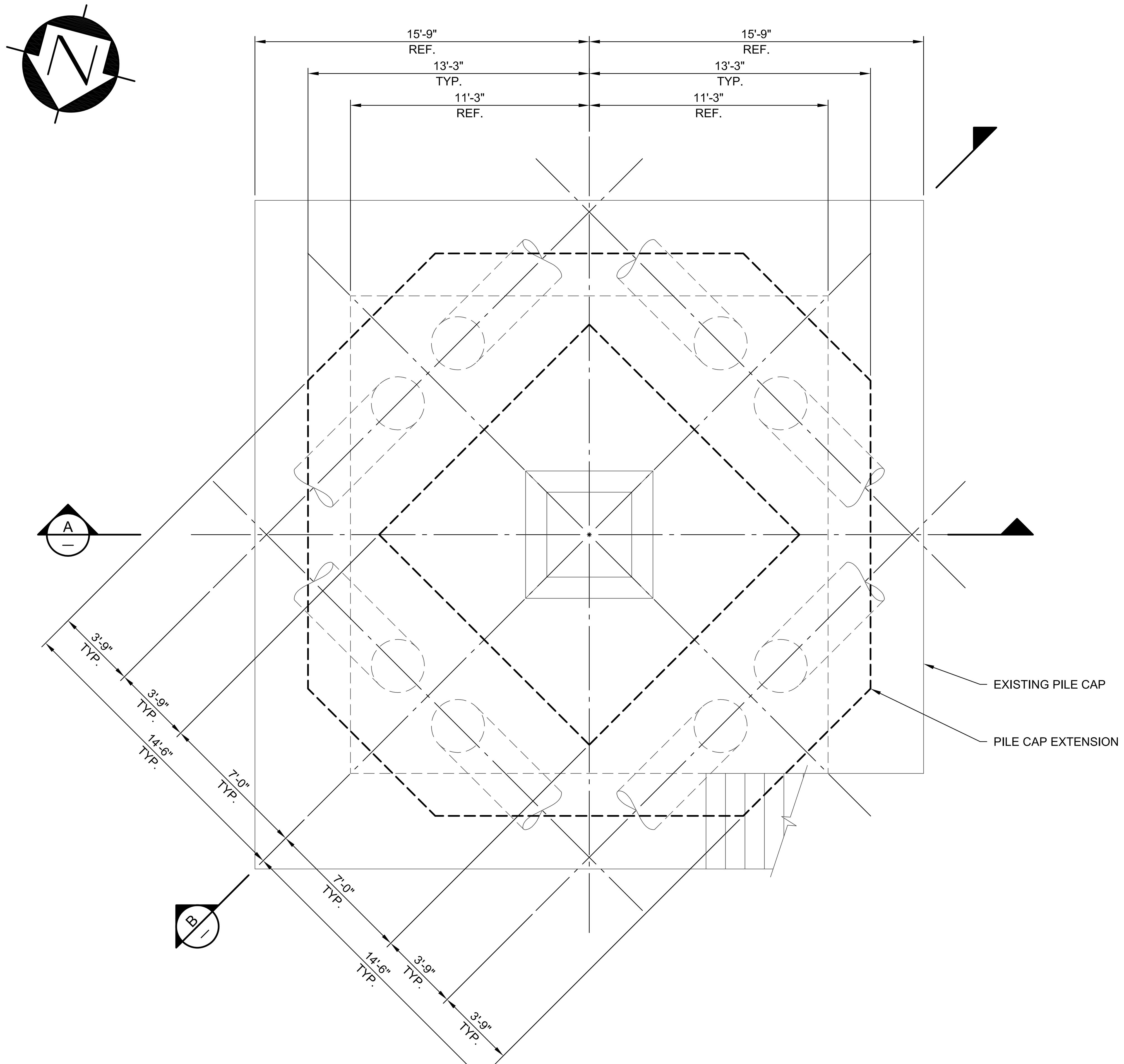
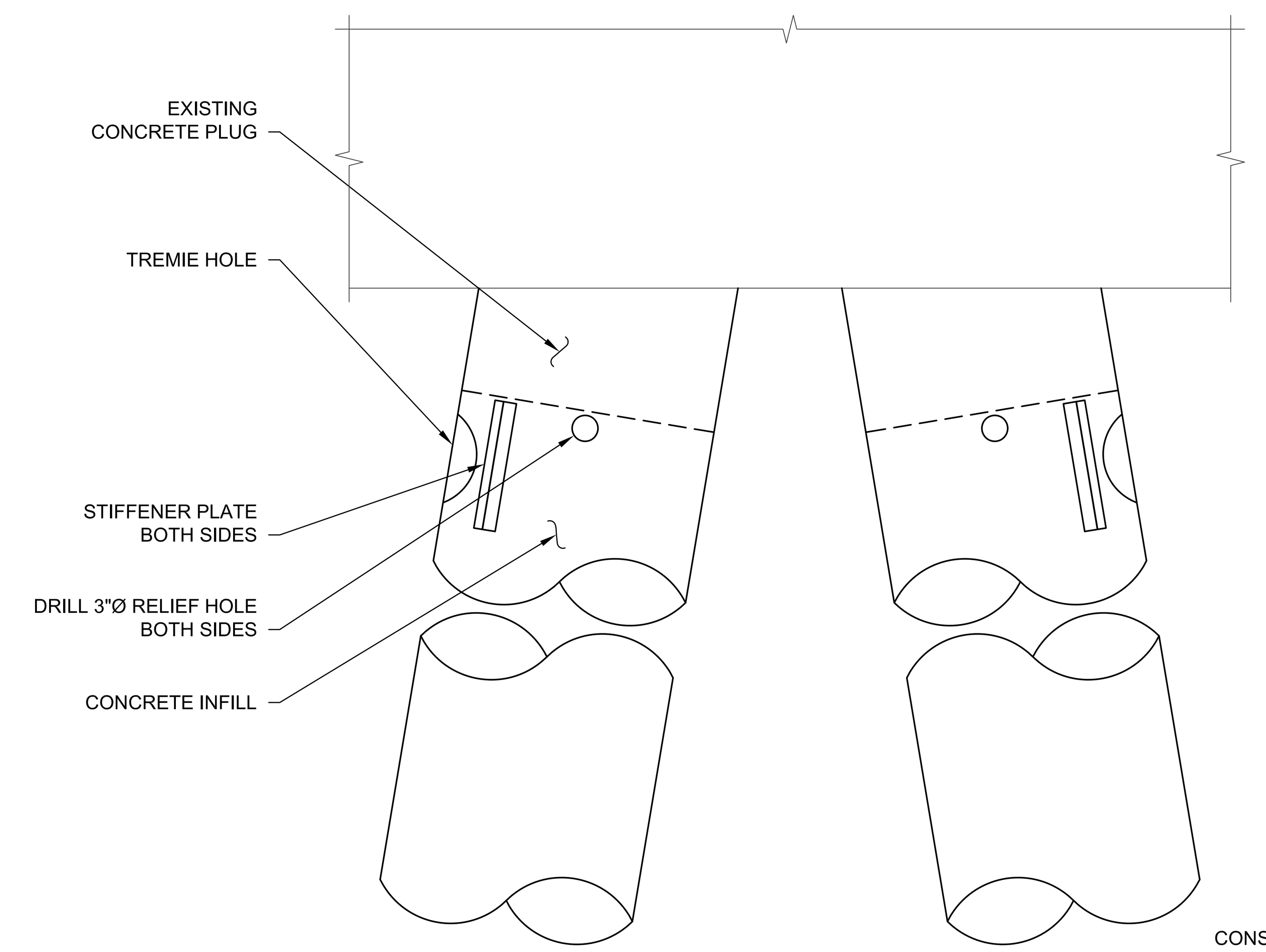


PLAN - SHIPLOADER PIVOT No.2 PILE CAP

1/4" = 1'-0"

(SHIPLOADER PIVOT No.1 PILE CAP IS MIRRORED)

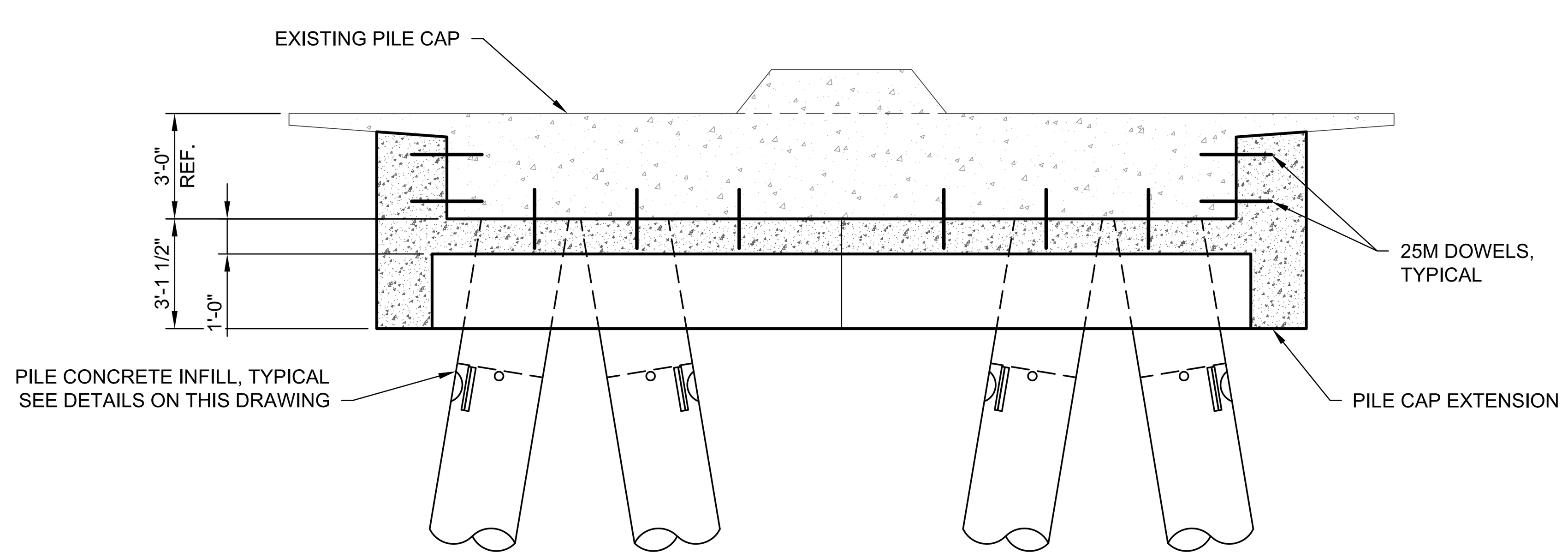


ELEVATION
DETAIL 1 - PILE CONCRETE INFILL

3/4" = 1'-0"

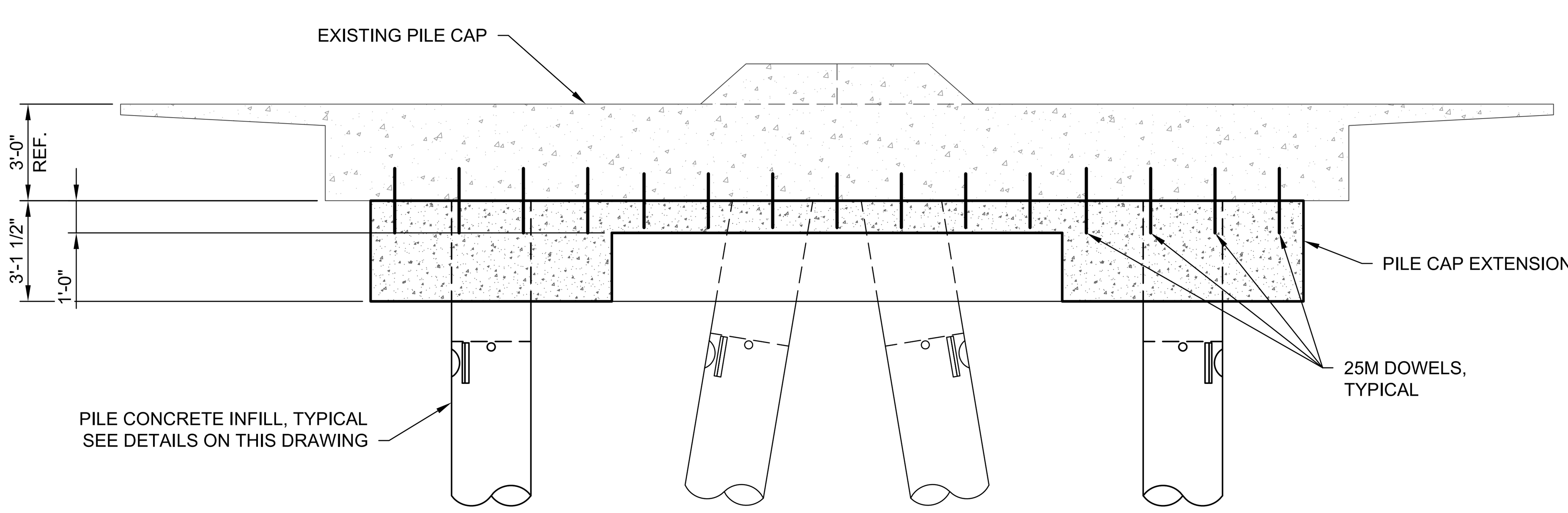
CONSTRUCTION SEQUENCE:

1. TAP/SCAN PILE TO DETERMINE EXTENT OF CONCRETE PLUG.
2. ADD STIFFENERS TO PILE ADJACENT TO HOLE LOCATIONS.
3. CUT 6"-8"Ø HOLE FOR TREMIE PUMP BELOW CONCRETE PLUG. DRILL 3"Ø RELIEF HOLES NEAR TOP OF PILE.
4. PUMP CONCRETE INTO PILE UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.



SECTION A

1/4" = 1'-0"



SECTION B

1/4" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P2	2021-08-31	ISSUED FOR INFORMATION	CPL		DJC		AMG	AJK
			P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

REFERENCE DRAWINGS / DESIGN STANDARDS — ISSUES / REVISIONS — ∗ HAND INITIALS ON FILE

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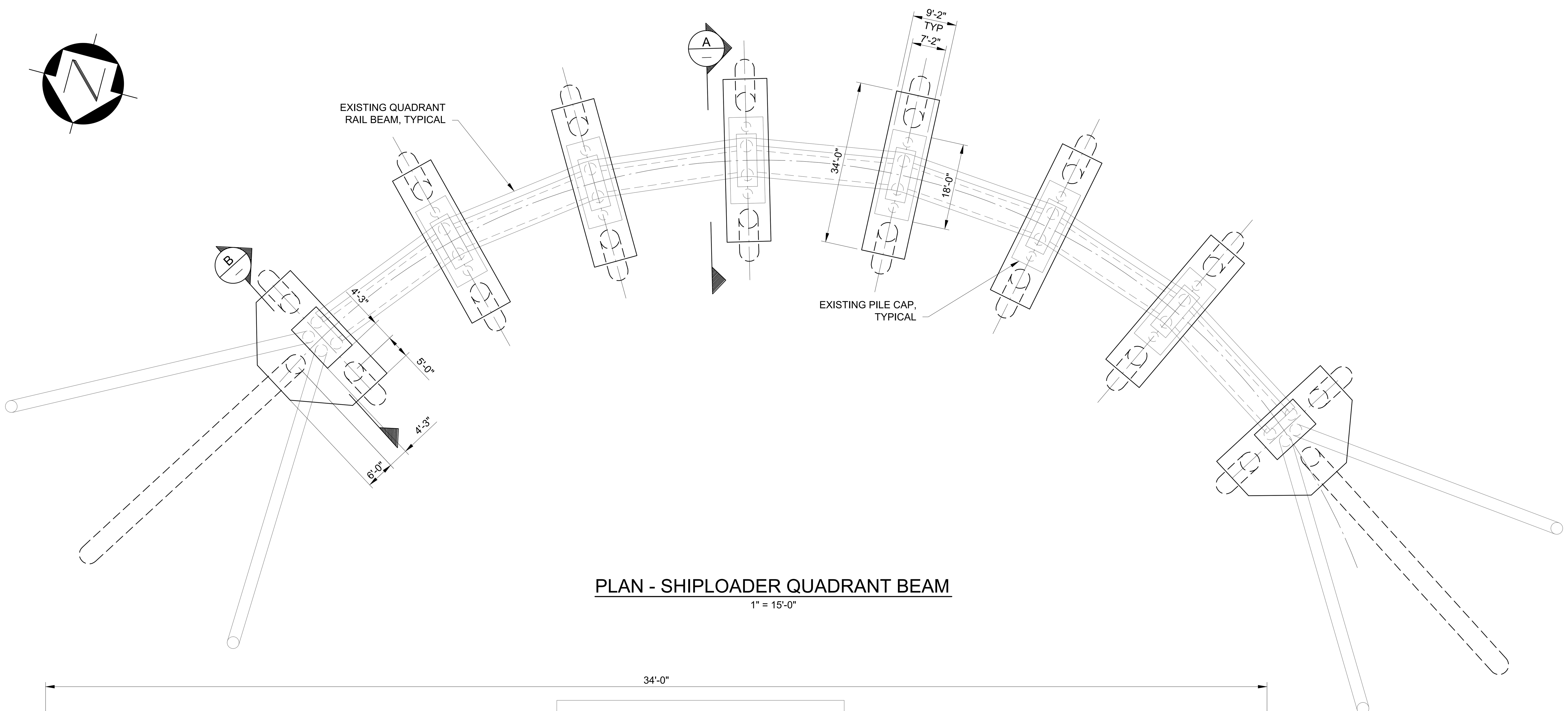
Westshore Terminals

CWA PROJECT NUMBER: 19899

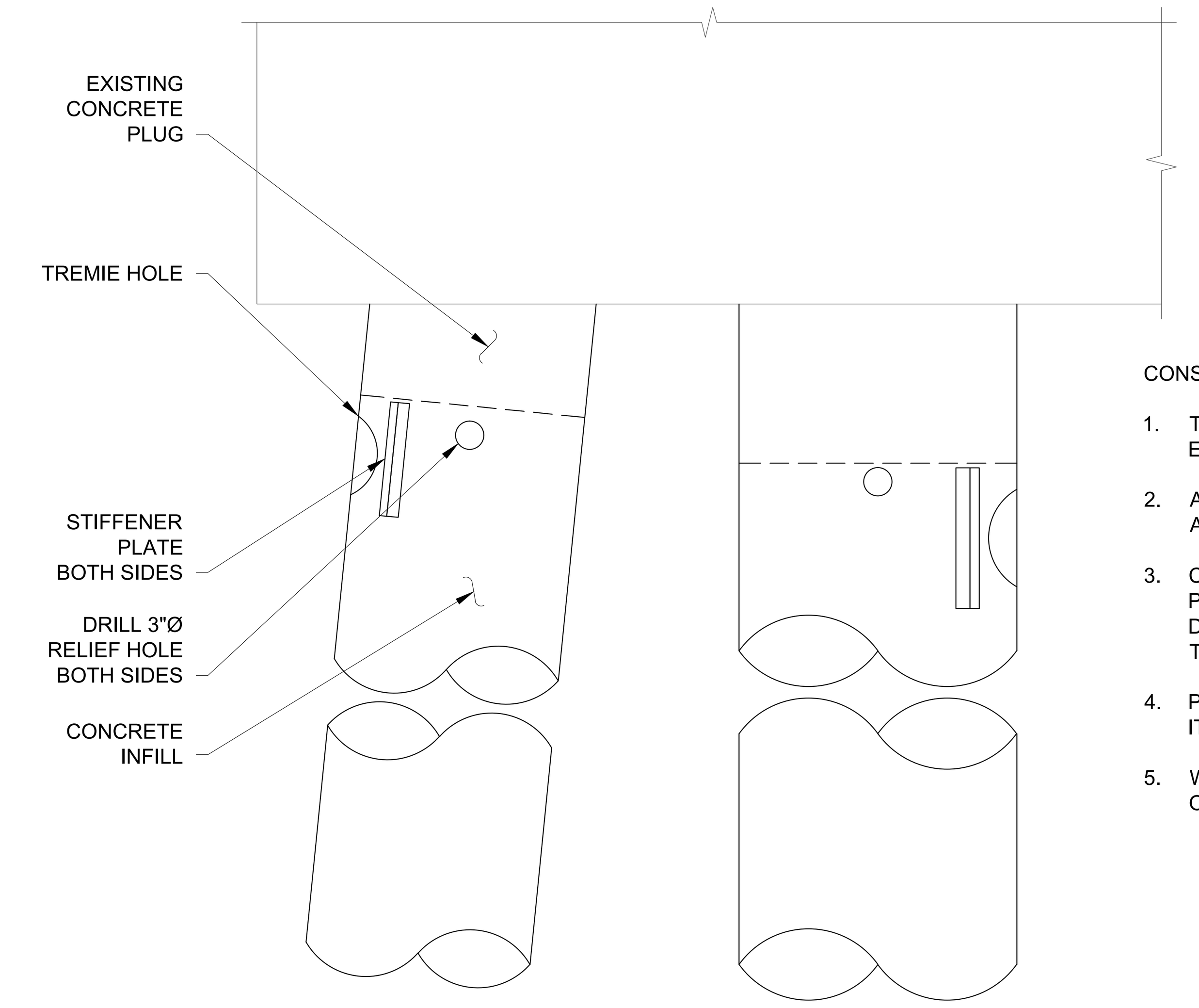
NEW CARGO STUDY
BERTH 2 RETROFITS
SHIPLOADER PIVOT CONCEPTS

19899-100-SK-1108 — REV. P2



PLAN - SHIPLOADER QUADRANT BEAM

1" = 15'-0"



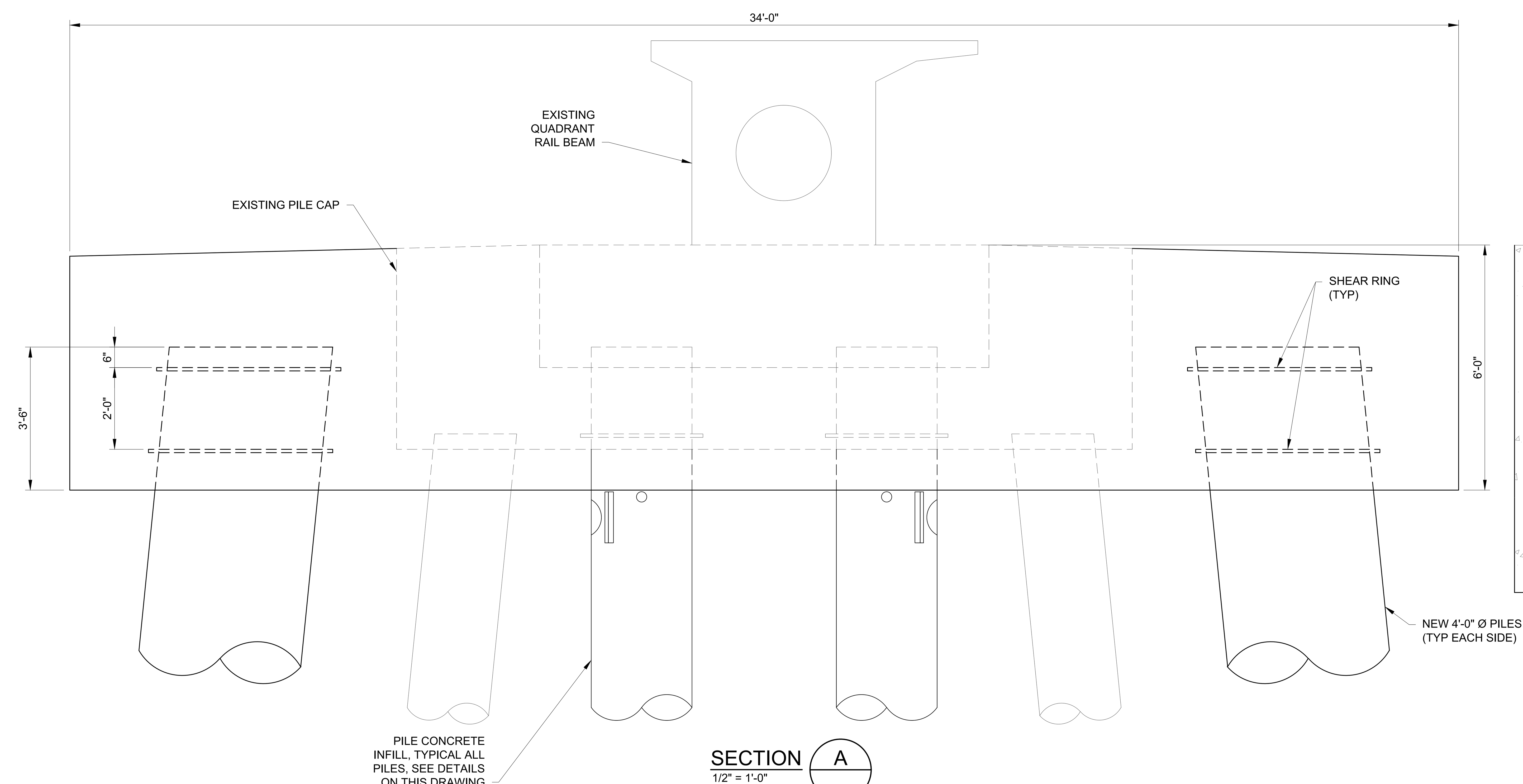
CONSTRUCTION SEQUENCE:

1. TAP/SCAN PILE TO DETERMINE EXTENT OF CONCRETE PLUG.
2. ADD STIFFENERS TO PILE ADJACENT TO HOLE LOCATIONS.
3. CUT 6"-8"Ø HOLE FOR TREMIE PUMP BELOW CONCRETE PLUG. DRILL 3"Ø RELIEF HOLES NEAR TOP OF PILE.
4. PUMP CONCRETE INTO PILE UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.

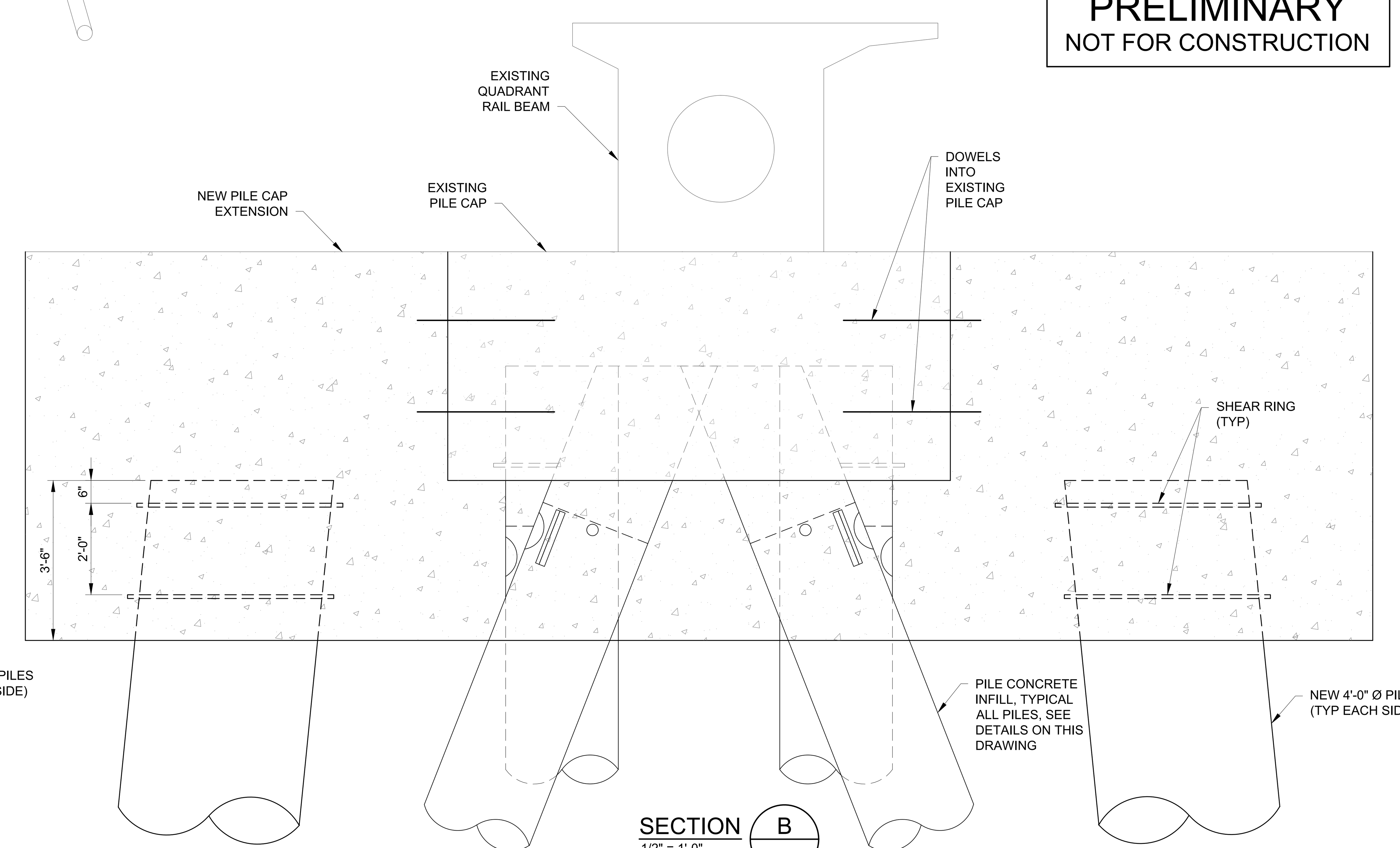
ELEVATION
PILE CONCRETE INFILL DETAIL

3/4" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION



SECTION A
1/2" = 1'-0"



SECTION B
1/2" = 1'-0"

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

REFERENCE DRAWINGS / DESIGN STANDARDS | ISSUES / REVISIONS | * HAND INITIALS ON FILE

CWA

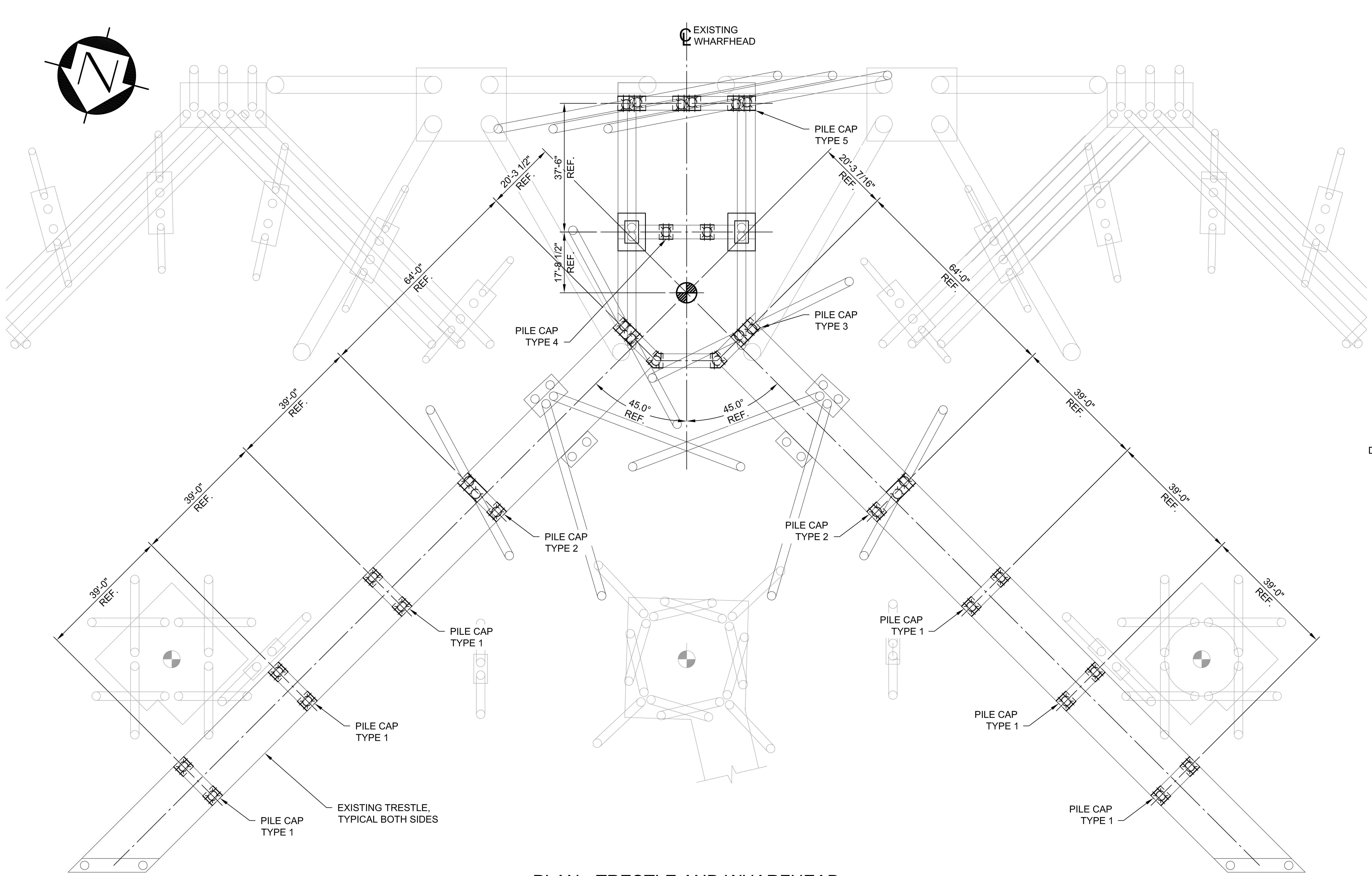
Westshore Terminals

CWA PROJECT NUMBER: 19899

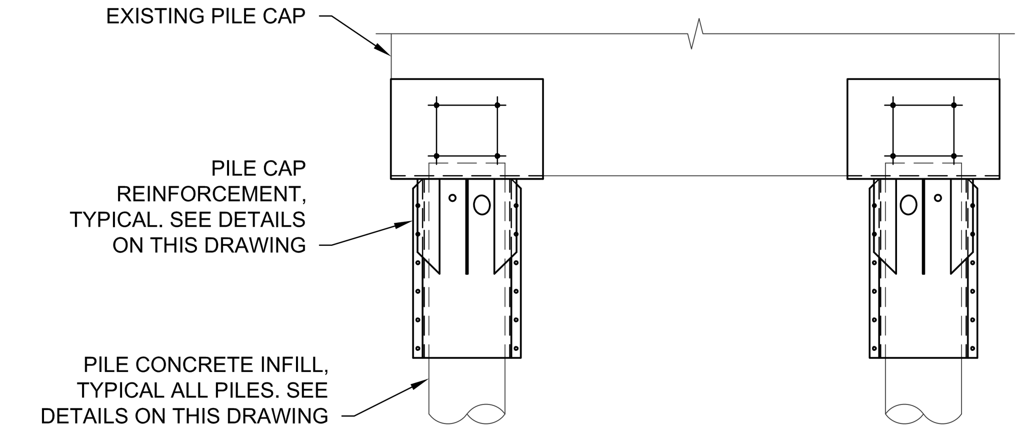
NEW CARGO STUDY
BERTH 2 RETROFITS
SHIPLOADER QUADRANT RAIL CONCEPTS

19899-100-SK-1109 | P1

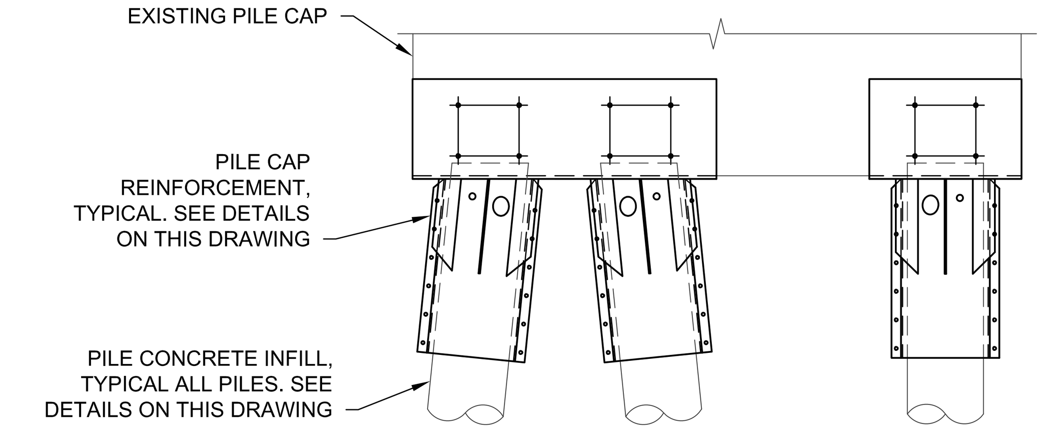
DRAWN BY: CPL | SCALE: AS NOTED | ACAD FILENAME: 19899-100-SK-1109 | REV.



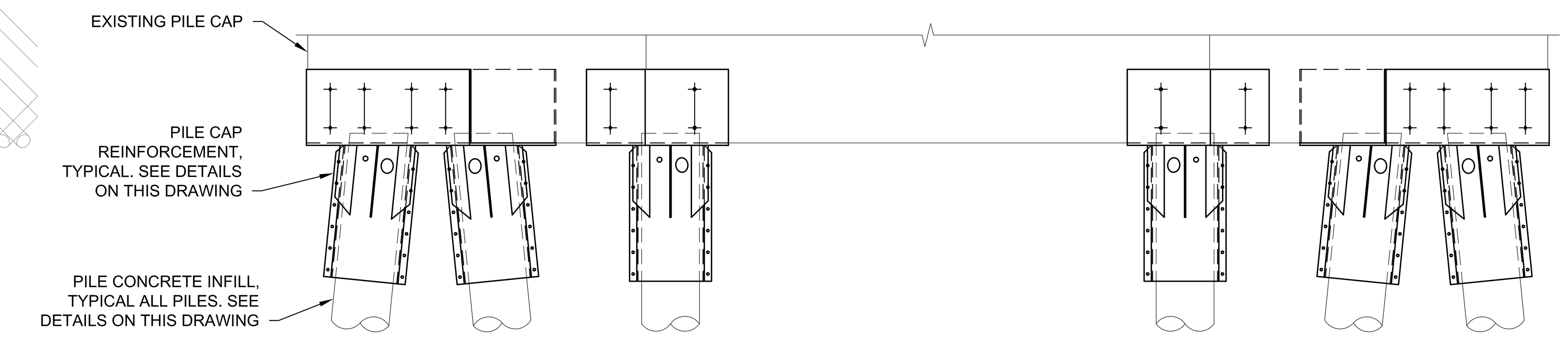
PLAN - TRESTLE AND WHARFHEAD
1" = 20'-0"



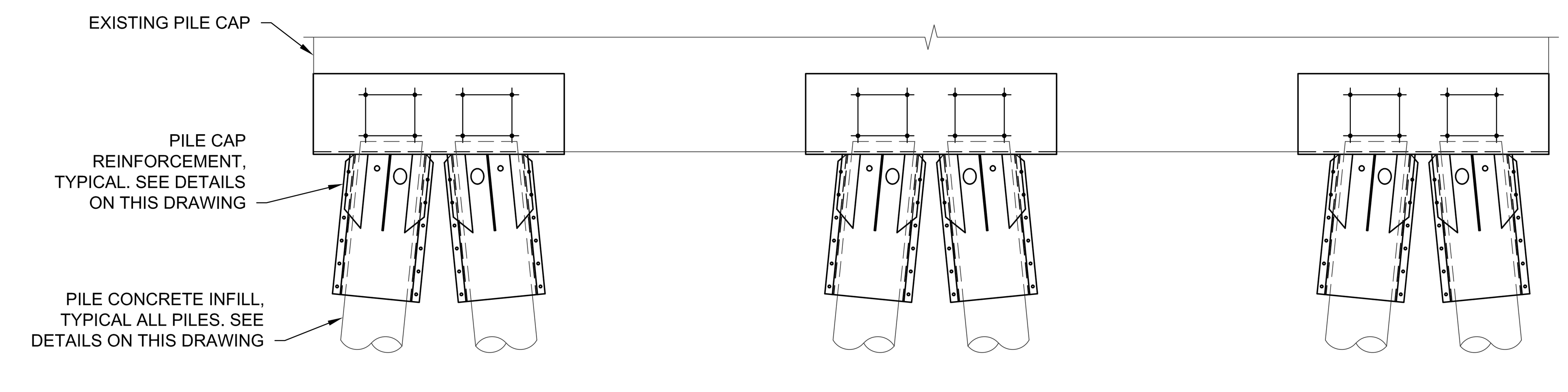
ELEVATION - PILE CAP TYPE 1
1/4" = 1'-0"



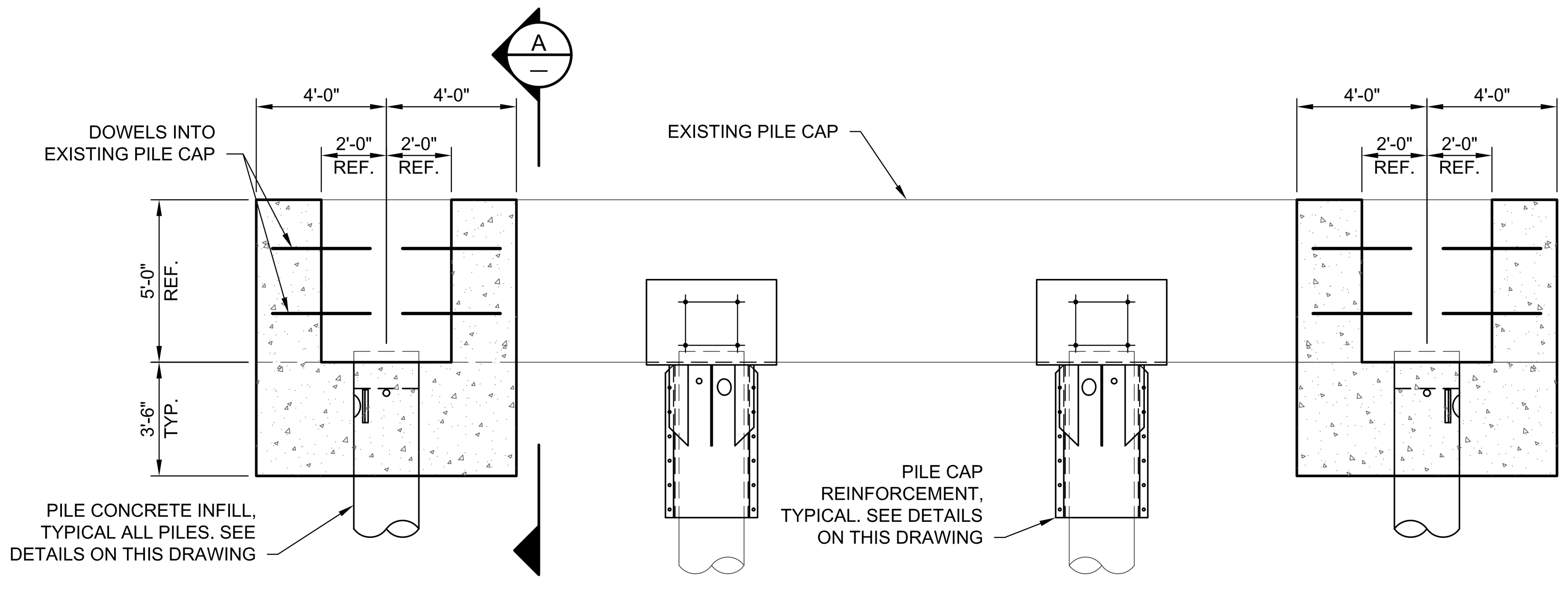
ELEVATION - PILE CAP TYPE 2
1/4" = 1'-0"



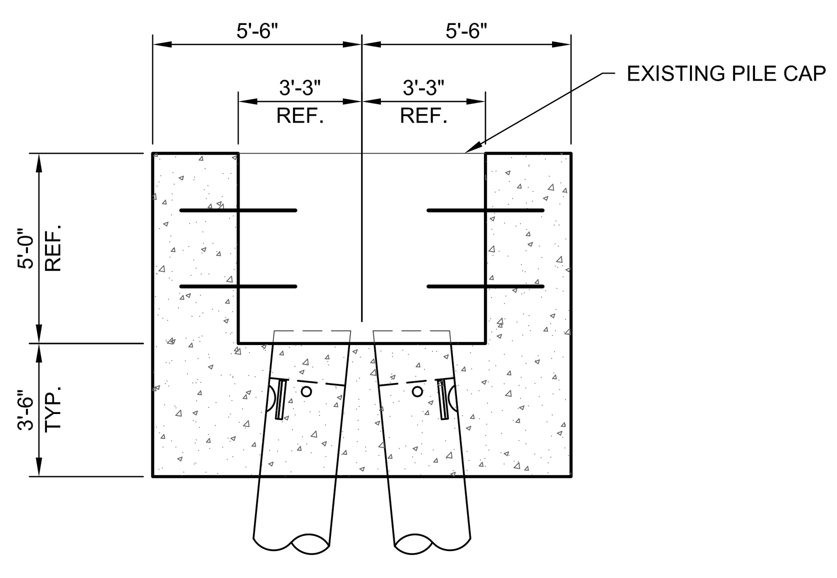
ELEVATION - PILE CAP TYPE 3
1/4" = 1'-0"



ELEVATION - PILE CAP TYPE 5
1/4" = 1'-0"

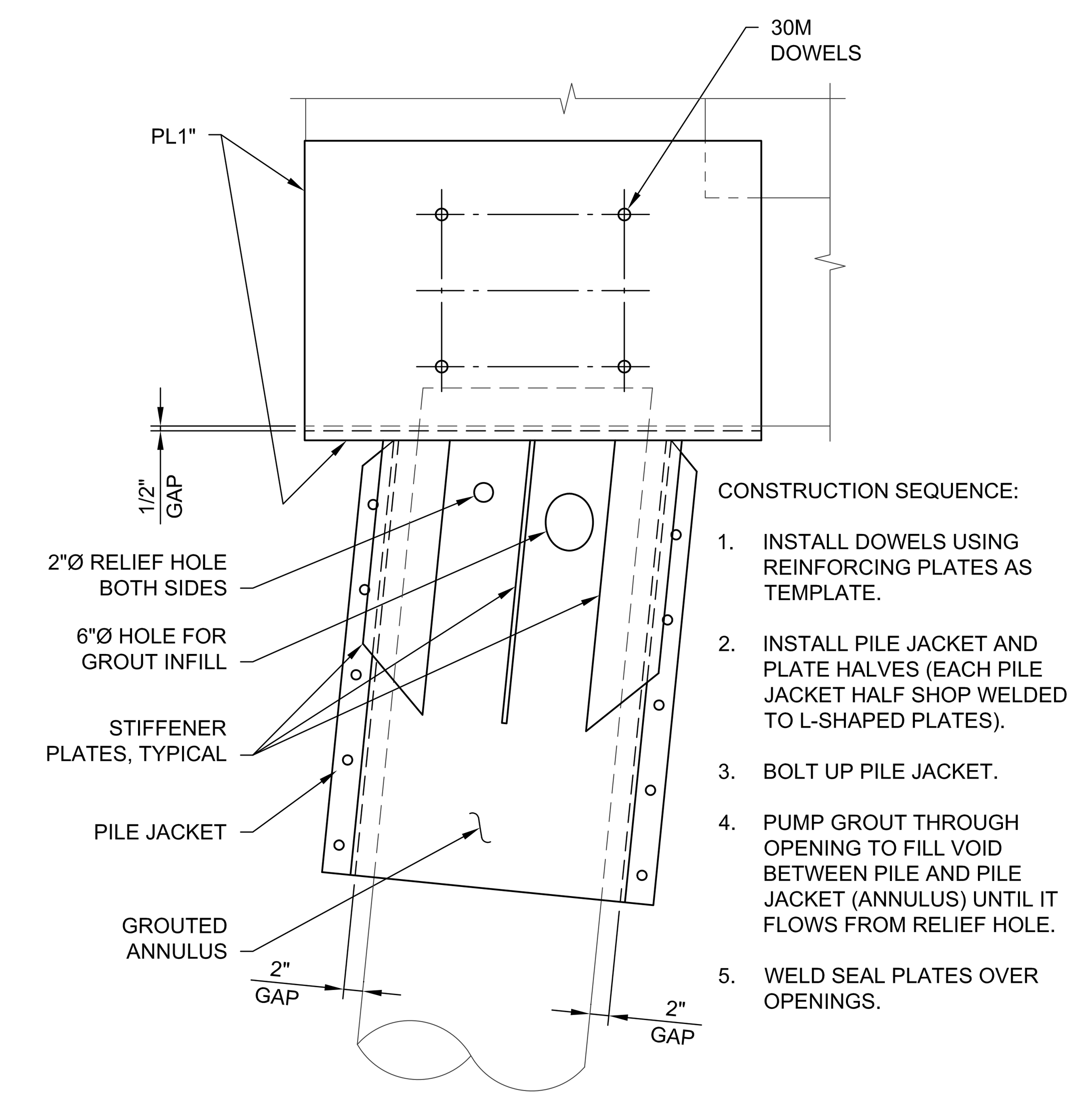


ELEVATION - PILE CAP TYPE 4
1/4" = 1'-0"



SECTION A
1/4" = 1'-0"

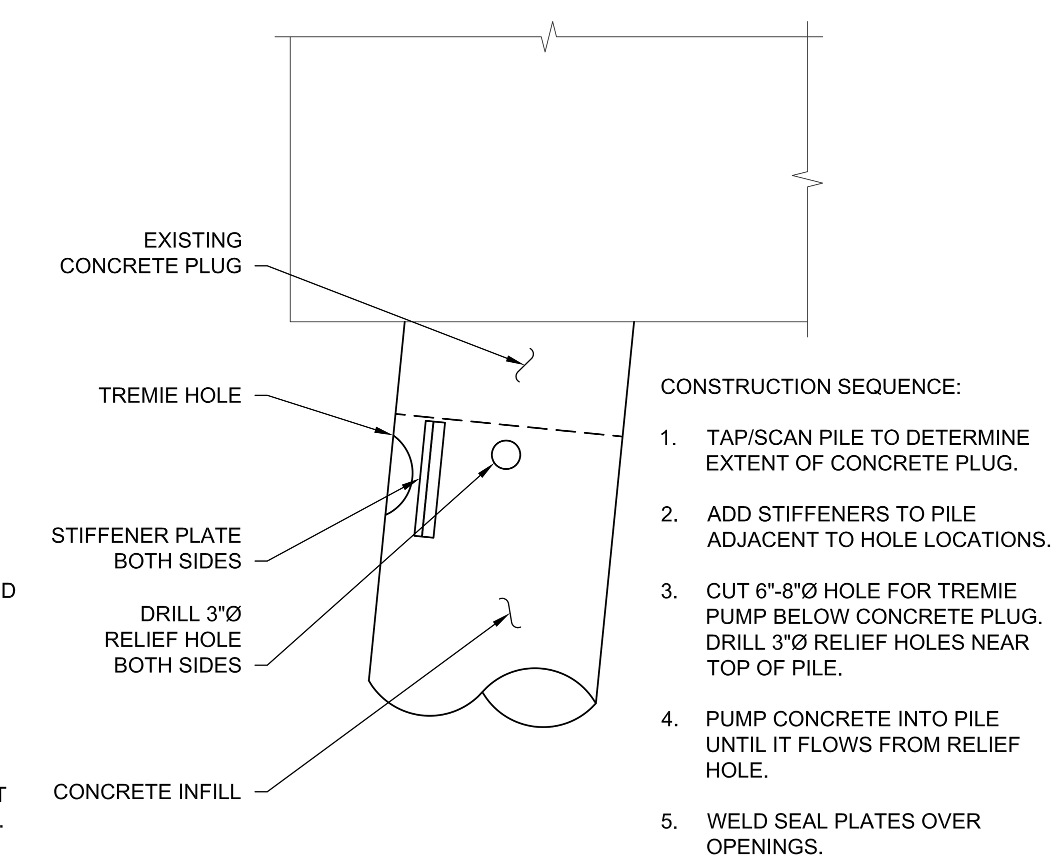
PRELIMINARY
NOT FOR CONSTRUCTION



CONSTRUCTION SEQUENCE:

1. INSTALL DOWELS USING REINFORCING PLATES AS TEMPLATE.
2. INSTALL PILE JACKET AND PLATE HALVES (EACH PILE JACKET HALF SHOP WELDED TO L-SHAPED PLATES).
3. BOLT UP PILE JACKET.
4. PUMP GROUT THROUGH OPENING TO FILL VOID BETWEEN PILE AND PILE JACKET (ANNULUS) UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.

ELEVATION
DETAIL 1 - PILECAP REINFORCEMENT
3/4" = 1'-0"



CONSTRUCTION SEQUENCE:

1. TAP/SCAN PILE TO DETERMINE EXTENT OF CONCRETE PLUG.
2. ADD STIFFENERS TO PILE ADJACENT TO HOLE LOCATIONS.
3. CUT 6"-8"Ø HOLE FOR TREMIE PUMP BELOW CONCRETE PLUG. DRILL 3"Ø RELIEF HOLES NEAR TOP OF PILE.
4. PUMP CONCRETE INTO PILE UNTIL IT FLOWS FROM RELIEF HOLE.
5. WELD SEAL PLATES OVER OPENINGS.

ELEVATION
DETAIL 2 - PILE CONCRETE INFILL
3/4" = 1'-0"

REF.	DWG. NUMBER	DESCRIPTION	No.	YYYY-MM-DD	DESCRIPTION	DRAWN	DWG. CHECK	DESIGN	DESIGN CHECK	DISC. APPROVAL	PROJ. APPROVAL
			P1	2021-06-28	ISSUED FOR VFPA REVIEW	CPL		DJC		AMG	AJK

REFERENCE DRAWINGS / DESIGN STANDARDS — ISSUES / REVISIONS — ∗ HAND INITIALS ON FILE

DRAWN BY: CPL — SCALE: AS NOTED — ACAD FILENAME: 19899-100-SK-1110

CWA

WestshoreTerminals

CWA PROJECT NUMBER: 19899

NEW CARGO STUDY
BERTH 2 RETROFITS
TRESTLE AND WHARFHEAD CONCEPTS

19899-100-SK-1110 — P1 — REV.