PDHonline Course S151 (1 PDH)

Steel Sheet Piling

Instructor: Matthew Stuart, PE, SE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

Steel Sheet Piling

Course Content

Project Applications

Recently my involvement with three projects has highlighted some of the advantages of the use of hot-rolled, heavy gauge steel sheeting piling over other available products in the market place including concrete, vinyl and fiberglass reinforced polymers (FRP). All three projects were located in New Jersey. Two of the projects were associated with new waterfront residential redevelopment in South Amboy and Perth Amboy on the Raritan Bay and Arthur Kill, respectively. The other project was related to the remediation of an environmentally contaminated site in Newark along the Passaic River.

For the waterfront redevelopment projects, the design of the sheet pile walls was dictated by both the need to create a bulkhead along the existing shoreline and construct a seawall to change the inland flood hazard designation established by Federal Emergency Management Agency (FEMA) and the Coastal Area Facility Review Act (CAFRA) as referenced in the New Jersey Administrative Code [Reference #4]. Both of the inland areas proposed for redevelopment were originally designated as V-Zones as defined by FEMA [Reference #2]. Residential development is not allowed within a V-Zone.

A V-Zone is a flood area that is subjected to wave action greater than three feet in height during a 100-year storm event. Therefore, in order to remove the V-Zone designation from the area to be redeveloped it was necessary to extend the steel sheet piling above the inboard finished grade to an elevation at which overtopping of the wall by the storm waves did not exceed .0283 cubic meters per second (1.0 cfs), a threshold established by FEMA. In addition, FEMA also requires land use restrictions inboard of the wall of either 9.144 meters (30 feet) or 15.24 meters (50 feet), depending on whether a overtopping splash collection area is provided or not.

For the contaminated riverfront site, the design of the sheet pile walls was dictated by the anticipated dredge and remedial excavation depths, depth of contamination and longterm sealing of the interlock joints required to cutoff the flow of contaminants into the adjacent navigable body of water. The U.S. Army Corp of Engineers (USACE) established the design dredge depth based on the future plans for the Passaic River. The allowable permeability, or limit of water flow, through the interlock joints was established by the New Jersey Department of Environmental

Protection (NJDEP) as 10^{-7} centimeters per second.

The results of the analysis of the different types of materials commonly used for bulkhead construction revealed that in all cases hot-rolled steel sheet piling provided the most economical, structurally feasible solution to the design constraints of the above projects. The following provides both a general discussion of the design and analysis of steel sheet pile walls and the basis for the final solutions derived for each of the projects.

General Description

A sheet pile wall is a row of interlocking, vertical pile segments installed to form an essentially straight wall with a plan dimension sufficiently large enough for its behavior to allow for the analysis of a .3048-meter (1 foot) wide vertical segment of the wall cross-section. Sheet pile walls are typically used as earth retaining structures along shorelines to allow for higher exposed grades to occur adjacent to lower river bottoms, dredge or mud lines. Sheet piling can also be used to retain fill around open landside excavations via rectangular trenches or circular cofferdams.

There are two primary types of sheet pile walls. A cantilevered sheet pile is a wall that derives its support entirely through the interaction with the surrounding soil. An anchored sheet pile is a wall that derives its support through a combination of interaction between the surrounding soil and one or more mechanical anchors, or braces in the case of open excavations, which restrict the lateral deflection of the wall [Figure #1]. Support from the surrounding soil for both types of walls refers primarily to the passive soil pressure exerted on the embedded portion of the wall below the dredge line or bottom of excavation.

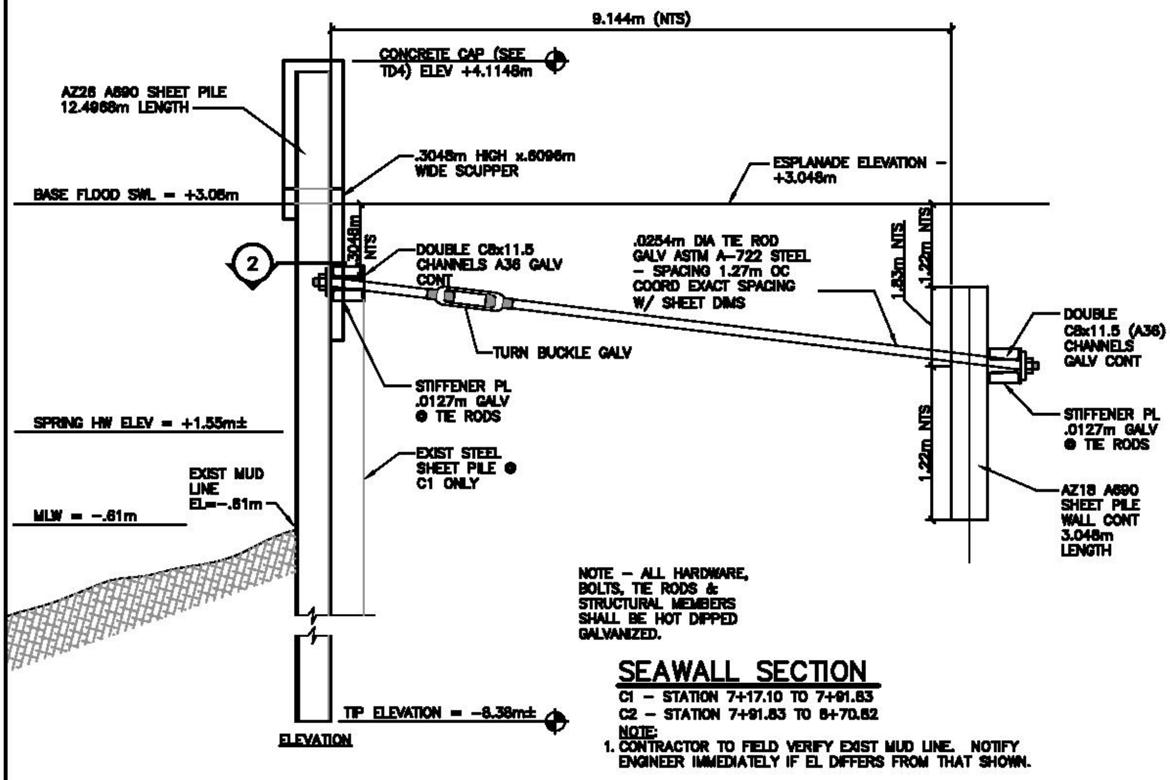
9.144m (NTS)
CONCRETE CAP (SEE TD4) ELEV +4.1148m
AZ26 A690 SHEET PILE 12.4968m LENGTH
.3048m HIGH x.6096m WIDE SCUPPER
ESPLANADE ELEVATION – +3.048m
BASE FLOOD SWL = +3.05m
.3048m NTS
2
DOUBLE C8x11.5 CHANNELS A36 GALV CONT
.0254m DIA TIE ROD GALV ASTM A-722 STEEL – SPACING 1.27m OC COORD EXACT SPACING W/ SHEET DIMS
1.83m NTS
1.22m NTS
DOUBLE C8x11.5 (A36) CHANNELS GALV CONT
TURN BUCKLE GALV
STIFFENER PL .0127m GALV @ TIE RODS
STIFFENER PL .0127m GALV @ TIE RODS
SPRING HW ELEV = +1.55m±
EXIST STEEL SHEET PILE @ C1 ONLY
1.22m NTS
AZ18 A690 SHEET PILE WALL CONT 3.048m LENGTH
EXIST MUD LINE EL=-.61m
MLW = -.61m
NOTE – ALL HARDWARE, BOLTS, TIE RODS & STRUCTURAL MEMBERS SHALL BE HOT DIPPED GALVANIZED.
SEAWALL SECTION
C1 – STATION 7+17.10 TO 7+91.83
C2 – STATION 7+91.83 TO 8+70.82
TIP ELEVATION = -8.38m±
ELEVATION
NOTE:
1. CONTRACTOR TO FIELD VERIFY EXIST MUD LINE. NOTIFY ENGINEER IMMEDIATELY IF EL DIFFERS FROM THAT SHOWN.

FIGURE 1

Cofferdams are a special form of sheet pile walls in which the primary method of resistance to horizontal soil pressures is provided through the global capacity of a circular cell to function as either a compression ring (in the case of an excavation) or via hoop stresses resisted by the interlock joints (in the case of a backfilled structure in open water). As with a cantilevered sheet pile wall the height, or depth of excavation, of a cofferdam is limited but can be increased through the introduction of compression or tension ring beams.

Cantilevered walls are usually limited to retained heights of between 3.048 meters (10 feet) and 4.572 meters (15 feet). Cantilevered walls are very susceptible to large lateral deflections and are also readily affected by scour and erosion at the outboard dredge or mud line of the wall. Anchored bulkhead walls are typically limited to 10.668 meters (35 feet) in height. However, greater heights can be achieved by the use of relieving platforms. A relieving platform is a pile supported, horizontally framed, sub-grade structure which reduces the lateral pressures imposed on the wall by supporting the gravity loads associated with the upper fill and any surface surcharge. For open landside excavations, depths of up to approximately 22.86 meters (75 feet) can be obtained through the use of internal bracing or compression rings for rectangular trenches and cofferdams, respectively.

It is common for wales to be used in conjunction with anchored or braced walls. Wales are horizontal beams attached to the bulkhead that provide a load path between the anchor force associated with the tiebacks or braces and the sheet piling. Wales are usually installed as two structural steel channels with their webs placed back-to-back with sufficient space provided in between to allow for the tie-rod or anchor to be located concentric to the adjacent members. From a load transfer stand point, the most desirable location of walers is on the outside, or exposed outboard face, of the piling. When walers are placed on the inboard, or concealed face, of a bulkhead each individual sheet pile must be bolted to the beam [Figure #2]. Internal walers associated with braced trenches and cofferdams are typically wide flange beams laid on their side so that the web of the beam is perpendicular to the sheet pile wall. Internal braces between opposing walers for open trench excavations are typically structural steel pipe sections.

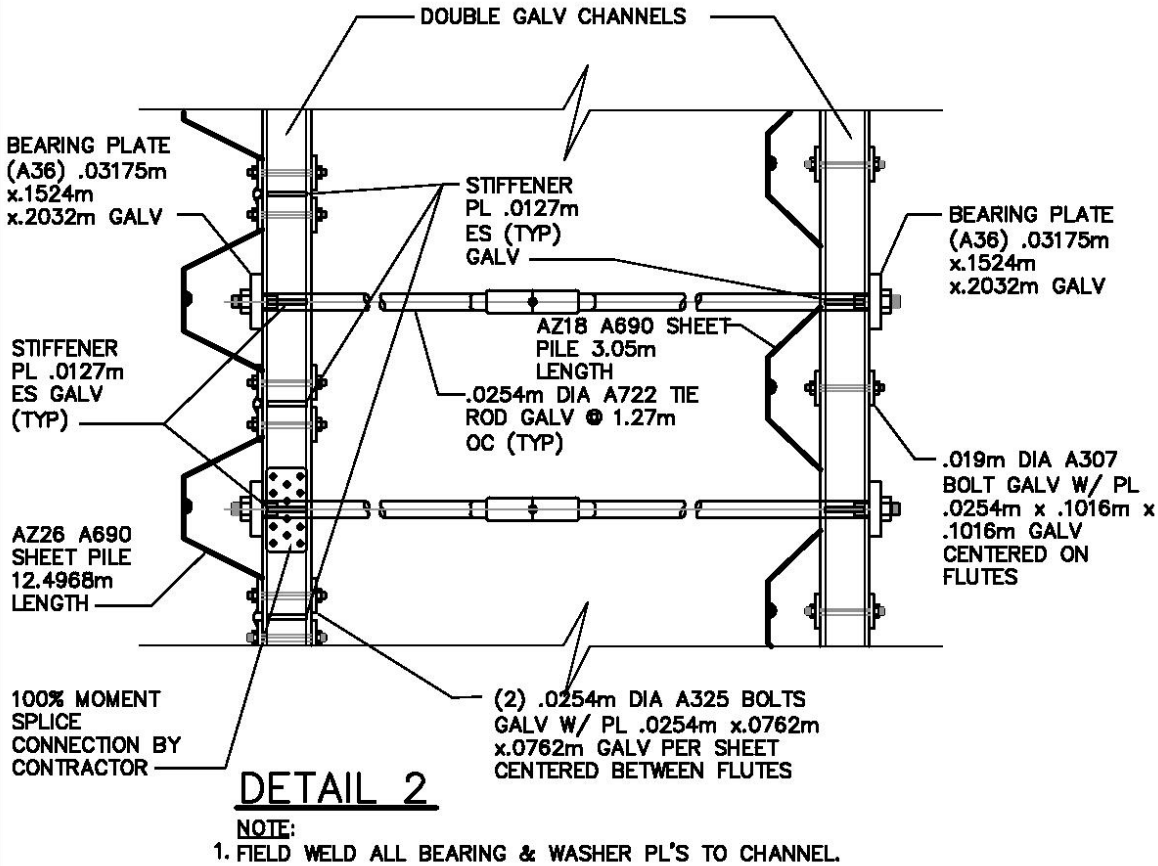
DOUBLE GALV CHANNELS
BEARING PLATE (A36) .03175m x.1524m x.2032m GALV
STIFFENER PL .0127m ES (TYP) GALV
BEARING PLATE (A36) .03175m x.1524m x.2032m GALV
AZ18 A690 SHEET PILE 3.05m LENGTH
STIFFENER PL .0127m ES GALV (TYP)
.0254m DIA A722 TIE ROD GALV @ 1.27m OC (TYP)
.019m DIA A307 BOLT GALV W/ PL .0254m x .1016m x .1016m GALV CENTERED ON FLUTES
AZ26 A690 SHEET PILE 12.4968m LENGTH
100% MOMENT SPLICE CONNECTION BY CONTRACTOR
(2) .0254m DIA A325 BOLTS GALV W/ PL .0254m x.0762m x.0762m GALV PER SHEET CENTERED BETWEEN FLUTES
DETAIL 2
NOTE:
1. FIELD WELD ALL BEARING & WASHER PL'S TO CHANNEL.

FIGURE 2

Walers are typically assumed to act as continuous flexural, simply supported members. Walers and the related tie-rod connections are typically analyzed using Allowable Stress Design with the exception that a safety factor of at least 1.2 should be used to account for additional stresses induced during installation. Walers used in braced excavations or cofferdams are typically not associated with tiebacks or ground anchors. Instead, the waler beams are usually braced internally or function as pure compression or tension rings for rectangular trenches and cofferdams, respectively.

Because of the critical nature of tiebacks, the anchor forces used to design tie-rods and other similar ground anchors should include an appropriate factor of safety. This is because the real distribution of the lateral pressures on the wall may be somewhat different from that assumed by a simplified active soil pressure diagram. The anchor force may also be increased as a result of repeated application and removal of surface surcharge loads, isolated overloads or differential yielding of adjacent anchorages. Finally, settlement of the soil under the gravity weight of tiebacks can cause sagging of the rod or anchors, which can also result in an increase in the tensile stresses in the tieback. For all of the above reasons it is recommended that a safety factor of at least 1.3 be used for the design of wall anchors and a safety factor of 1.5 be used for the design of anchor splices.

In general, steel is the most common material used for sheet piling because of its inherent strength, relative light weight and potential for long service life. Although concrete sheet piling is typically capable of providing a longer service life under normal conditions than steel, it has much higher initial material and installation costs than that of steel. Light gauge steel piling is used only for small temporary and other minor installations. Light gauge sheet piling also has weaker interlock joints than hot-rolled sections and therefore has a greater tendency to “unzip” during difficult driving conditions. Hot-rolled steel is predominately used in Z-type sections for retaining and floodwall design applications where flexural bending governs the design. When interlock joint stresses control the design (such as with unbraced cellular cofferdam construction) arched or straight web piling is used.

Hot rolled sheet piling is manufactured to comply with either ASTM A572 or A690. A690 steel offers corrosion resistance superior to A572 and is typically used for either salt water or brackish exposure conditions. The rate of corrosion of exposed A572 steel is highly dependent on the environment in which the material is placed. However, in generally uncapped, exposed A572 sheet piles corrode at a rate of .0508 millimeters (2 mils) to .254 millimeters (10 mils) per year. Sheet pile driven in natural undisturbed soil will experience negligible corrosion because of the lack of oxygen below grade. The critical area of corrosion for sheet piles exposed to water is the splash zone, which occurs between the still water low tide elevation and the upper high tide elevation subject to wave action. This area will corrode at a much greater rate than those portions of the piling that remain completely submerged.

The most common method of protecting steel sheet piling from corrosion is through the use of coatings. Generally, epoxies are the most widely used coatings. For sheet piles exposed to water, the coating should cover the splash zone and extend a minimum of five feet below the point where the sheeting remains submerged. Another effective method of protecting steel sheet piling is through the use of cathodic protection. Finally, in some cases a larger sheet pile section than that required by structural analysis is provided in anticipation of loss of section over time as a result of corrosion.

The interlock joint that occurs between adjacent sheets of piling is typically very permeable. Therefore in some installations, such as a cutoff wall associated with the containment of an environmentally contaminated site, it is necessary to reduce the permeability of this vertical joint. Methods of sealing interlock joints include shop welding tandem sheets at the joints prior to installation, installing hydrophilic compounds or grouts adjacent to or within the joints and the construction of bentonite or grout slurry walls directly against the sheet pile wall [Figure #6]. The acceptability of any of these methods of sealing the interlock joints is a function of the maximum permeability permitted, the nature of the contaminants and the chemical resistant of the sealant materials to the pollutants.

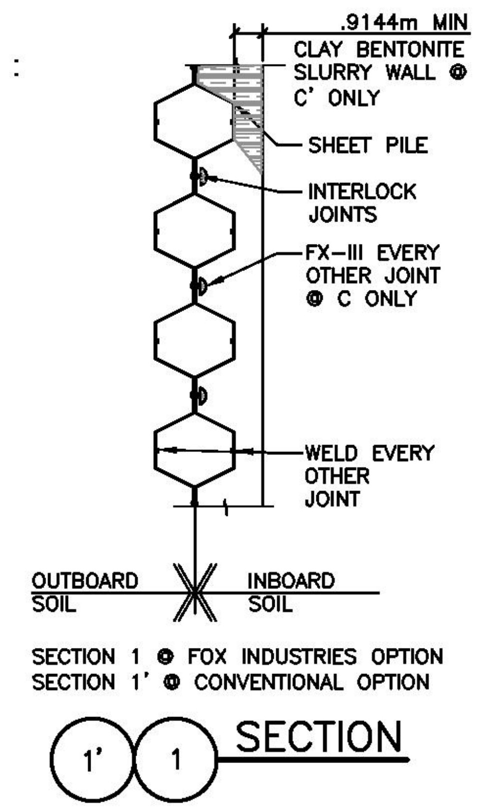
.9144m MIN
CLAY BENTONITE SLURRY WALL @ C' ONLY
SHEET PILE
INTERLOCK JOINTS
FX-III EVERY OTHER JOINT @ C ONLY
WELD EVERY OTHER JOINT
OUTBOARD SOIL
INBOARD SOIL
SECTION 1 @ FOX INDUSTRIES OPTION
SECTION 1' @ CONVENTIONAL OPTION
1'
1
SECTION

FIGURE 6

Steel sheet piling is typically installed by either driving, jetting or trenching. Steel sheet is most commonly installed with vibratory drivers and conventional hammers. Jetting of sheet piling is typically only used to penetrate strata of dense cohesionless soils. Jetting is typically performed on both sides of the piling simultaneously and is discontinued during the last 1.524 meters (5 feet) to 3.048 meters (10 feet) of penetration. Jetting involves the control, treatment and disposal of runoff water and spoils. Trenching of sheet piling is typically required when the penetration of the pile is relatively shallow and or there are mitigating circumstances that preclude driving.

Design Parameters

The loads governing the design of a sheet pile wall include applied forces from soils, water, surface surcharges and impact from external objects. Horizontal forces applied by soils include at-rest pressures, active pressures and passive pressures. Water forces include hydrostatic pressures, which can occur due to differential water levels on either side of the wall and dynamic loads due to wave action. Surcharges include uniform or variable, strip or line and point loads, which rest on the soil surface in the vicinity of the wall and can increase the lateral pressures on the wall. External objects that can impact the wall include vessel breasting or moorings, debris and ice. It is recommended, however, that separate fendering systems or independent mooring bollards be provided to protect sheet pile structures from vessel docking and mooring forces, respectively.

In the case of the FEMA seawalls required at the two projects located in South Amboy and Perth Amboy the controlling design criteria was a combination of the wave forces and impact loads from floating debris, both associated with a 100-year storm event, acting on the cantilevered portion of the wall above the adjacent inboard finished grade. Static and dynamic wave pressures were developed, as recommended by FEMA, using the Hom-ma and Horikawa Method of determining wave forces on vertical walls [Reference #6]. The minimum impact load associated with floating debris was based on the requirements of Section 5.3.3.4 of ASCE 7-95 [Reference #1]. This section of the ASCE Standard requires a minimum concentrated horizontal load of 453.5924 kilograms (1,000 pounds) traveling at the same velocity of the floodwater coming to a stop in one second. This load, per the requirements of the Standard, must be applied at the most critical location of the wall or at or below the base flood elevation and is assumed to act within a .0929 square meter (1 square foot) area.

The equivalent static force used to represent the affects of the minimum ASCE impact load was calculated as follows. First the equivalent energy of the impact was calculated as;

$$[\tfrac{1}{2}\,(\text{Mass})(\text{Velocity})^2] \qquad (\text{Equation 1})$$

based on a maximum wave speed of 7.62 meters per second (25 fps) [Reference #3]. The calculated energy was then modified by a reduction factor to represent the fact that some kinetic energy is dissipated during the impact [Reference #5]. The horizontal deflection was then calculated at the top of cantilever portion of the wall for a force that would result in yielding of the section at 3515.348 kilograms per centimeters^2 (50 ksi). The modified energy was then equated to the work;

$$[(\text{Force})(\text{Deflection})] \qquad (\text{Equation 2})$$

done on the wall to solve for the equivalent static force and corresponding deflection through an iterative process.

The equivalent static force associated with the minimum impact load was of such a large magnitude that it was actually necessary to engage an inboard concrete wall (associated with the adjacent esplanade) compositely with the steel sheet pile in order to satisfy this portion of the FEMA design requirements for a seawall [Figure #3].

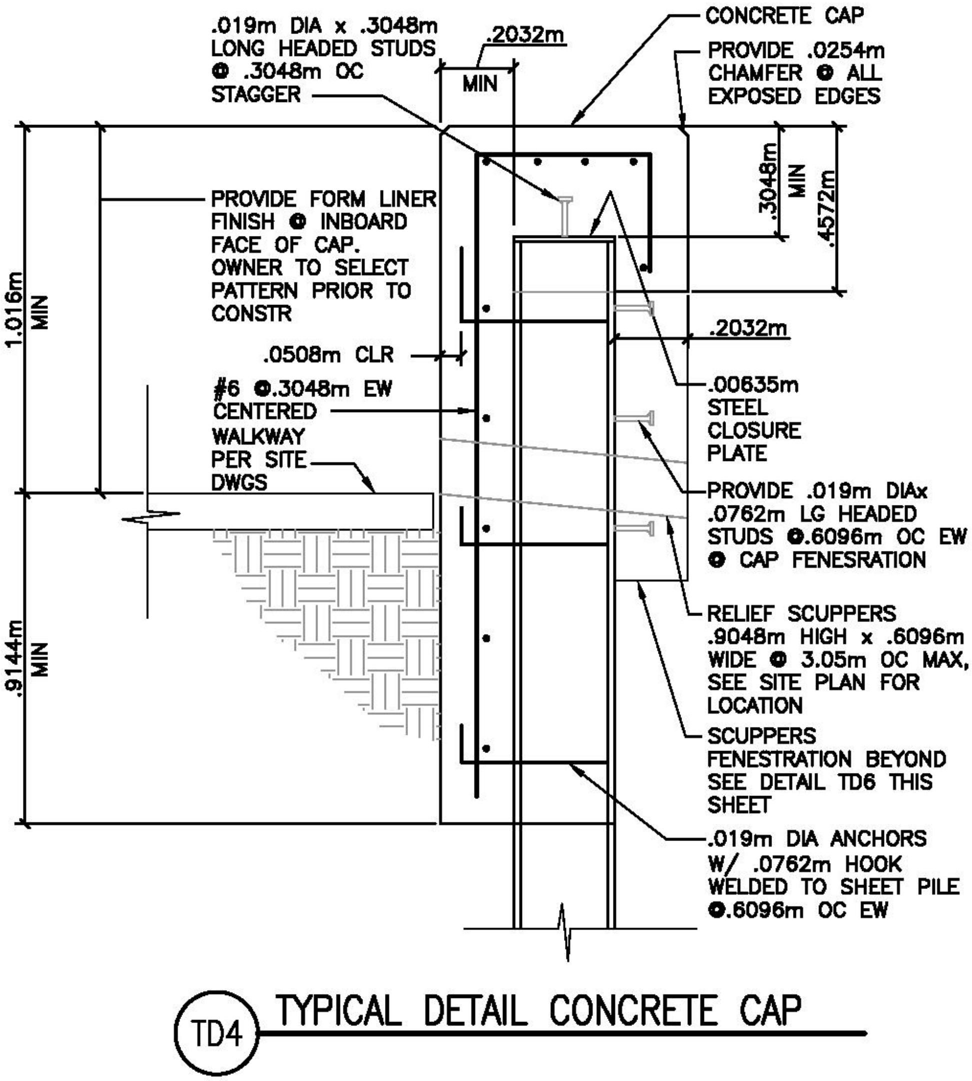
.019m DIA x .3048m LONG HEADED STUDS @ .3048m OC STAGGER
.2032m MIN
CONCRETE CAP
PROVIDE .0254m CHAMFER @ ALL EXPOSED EDGES
.3048m MIN
.4572m
PROVIDE FORM LINER FINISH @ INBOARD FACE OF CAP. OWNER TO SELECT PATTERN PRIOR TO CONSTR
1.016m MIN
.2032m
.0508m CLR
#6 @.3048m EW CENTERED
.00635m STEEL CLOSURE PLATE
WALKWAY PER SITE DWGS
PROVIDE .019m DIAx .0762m LG HEADED STUDS @.6096m OC EW @ CAP FENESRATION
RELIEF SCUPPERS .9048m HIGH x .6096m WIDE @ 3.05m OC MAX, SEE SITE PLAN FOR LOCATION
.9144m MIN
SCUPPERS FENESTRATION BEYOND SEE DETAIL TD6 THIS SHEET
.019m DIA ANCHORS W/ .0762m HOOK WELDED TO SHEET PILE @.6096m OC EW
TD4
TYPICAL DETAIL CONCRETE CAP

FIGURE 3

This same magnitude of load eliminated both vinyl and FRP sheet pile products as viable alternatives because of the inability of these materials to resist the extreme level of imposed stresses. Although precast, prestressed concrete sheet piling would have been capable of resisting the magnitude of load involved, this product was not considered for either of the projects because of higher material and installation costs when compared to steel.

In the case of the environmental remediation project, the controlling design criteria for the steel sheet piling was the soil pressures associated with the retained fill. For this project there were actually two options considered for the remediation of the contaminated site. The first option involved the construction of a bulkhead cutoff wall that would simply prevent the landside contaminants from migrating into and polluting the adjacent river [Figure #5]. The second option involved the construction of either a braced rectangular trench or series of circular cofferdams that would allow for the removal and replacement of the contaminated soil along a 15.24 meters (50 feet) wide by 15.24 meters (50 feet) deep strip parallel to the riverfront [Figure #4].

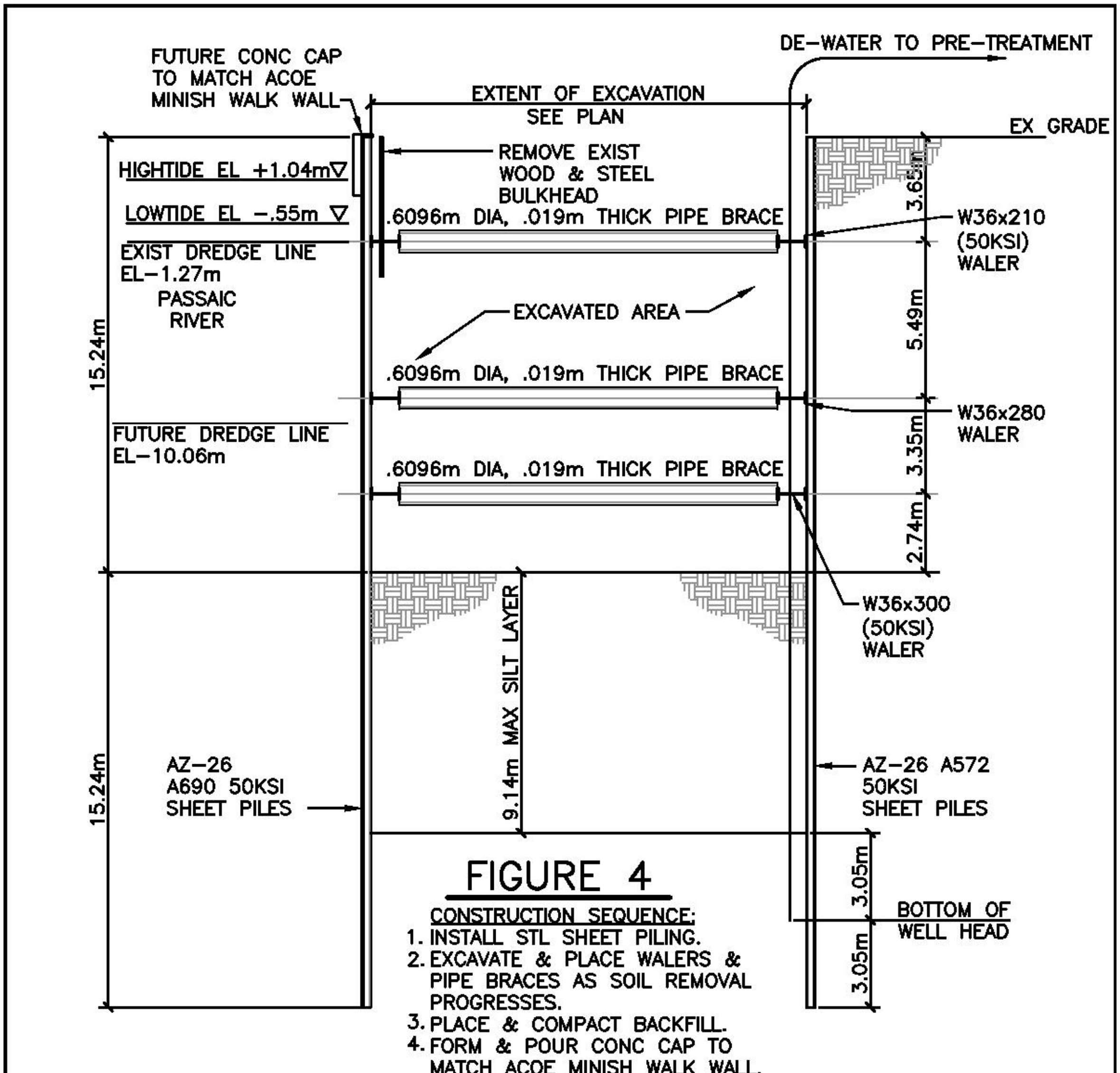
FUTURE CONC CAP
TO MATCH ACOE
MINISH WALK WALL
EXTENT OF EXCAVATION
SEE PLAN
DE-WATER TO PRE-TREATMENT
EX GRADE
HIGHTIDE EL +1.04m
LOWTIDE EL -.55m
REMOVE EXIST
WOOD & STEEL
BULKHEAD
.6096m DIA, .019m THICK PIPE BRACE
EXIST DREDGE LINE
EL-1.27m
PASSAIC
RIVER
3.65m
W36x210
(50KSI)
WALER
EXCAVATED AREA
5.49m
15.24m
.6096m DIA, .019m THICK PIPE BRACE
W36x280
WALER
FUTURE DREDGE LINE
EL-10.06m
3.35m
.6096m DIA, .019m THICK PIPE BRACE
2.74m
W36x300
(50KSI)
WALER
9.14m MAX SILT LAYER
15.24m
AZ-26
A690 50KSI
SHEET PILES
AZ-26 A572
50KSI
SHEET PILES
3.05m
BOTTOM OF
WELL HEAD
3.05m
FIGURE 4
CONSTRUCTION SEQUENCE:
1. INSTALL STL SHEET PILING.
2. EXCAVATE & PLACE WALERS & PIPE BRACES AS SOIL REMOVAL PROGRESSES.
3. PLACE & COMPACT BACKFILL.
4. FORM & POUR CONC CAP TO MATCH ACOE MINISH WALK WALL.

FIGURE 4

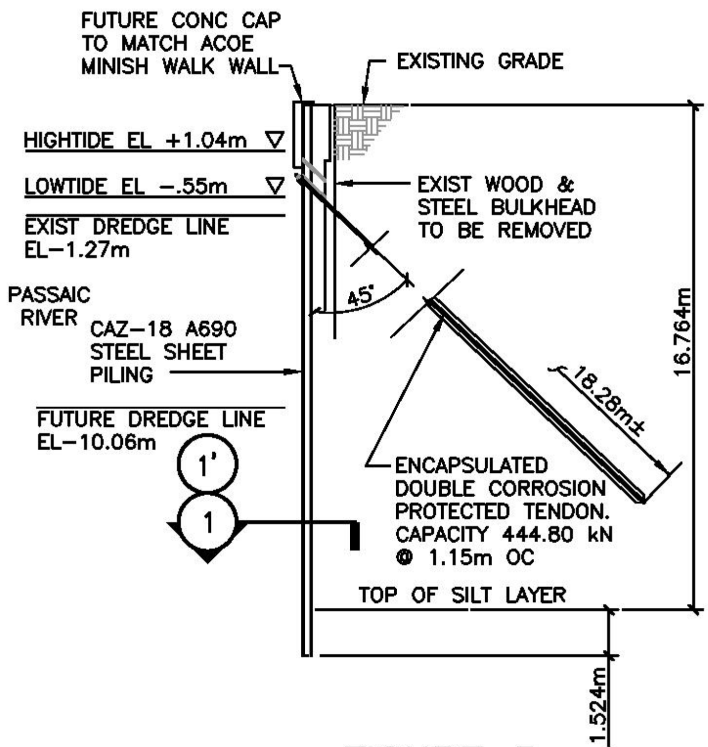

FIGURE 5

CONSTRUCTION SEQUENCE:
1. INSTALL STL SHEETING.
2. INSTALL CLAY BENTONITE SLURRY WALL OR FX-111.
3. FORM AND POUR CONCRETE CAP TO MATCH ACOE MINISH WALK.
4. INTSTALL TIEBACKS.

FIGURE 5

A cantilevered sheet pile wall would have sufficed for the cutoff bulkhead wall because of the shallow existing dredge depth and excessive embed as required to penetrate below the depth of existing contamination. However, because of the future plans to dredge the river to a depth of 10.0584 meters (33 feet) below the top of the existing grade, it was necessary to ultimately design the wall as an anchored or tied back structure. The design of a reinforced concrete slurry cutoff wall to satisfy the same design criteria as that provided by the sheet piling indicated that the cost of the steel was less than that of concrete.

Steel piling was selected as the preferred material of choice for both the rectangular braced trench and the cofferdam remediation options because of the familiarity of the local contractors with sheet piles for use in open landside excavations. In both cases the sheet piling was designed as vertically spanning elements subjected to varying levels of horizontal soil, hydrostatic and surcharge pressures supported by intermittently spaced braced or compression ring walers. Both options were also analyzed separately for a situation in which the subgrade structures would have to provide their own lateral stability in a backfilled condition in the presence of a future deeper dredge depth on the riverside and a 15.24 meters (50 feet) deep future excavation on the landside. Both the steel sheet pile braced trench and cofferdam structures provided an ideal solution to both the initial excavated and subsequent future conditions.

Structural Analysis

The design of a sheet pile retaining wall involves the following tasks; evaluation of forces and lateral pressures acting on the wall, determination of required depth of penetration, design of anchorage and waling system (if applicable), calculation of maximum bending moments and selection of the appropriate piling section based on allowable stresses and or serviceability requirements.

Lateral forces and pressures are typically established by the governing agency (FEMA, USACE, etc.) and the project geotechnical engineer, respectively. Lateral pressures assumed for cantilevered and anchored walls depend on whether the soil is granular or cohesive and the degree of differential hydrostatic head between opposing sides of the sheet piling.

Methods of design of cantilevered walls include the conventional and simplified methods. The analysis of cantilever sheet pile assumes that the wall rotates as a rigid body about some point in its embedded length. The equilibrium of the wall requires that the sum of the horizontal forces and moments about any point must be equal to zero. The equilibrium equations are used to solve for the required embedment depth of the wall. Typically the calculated embedment is increased by 20% to 40% to provide an additional safety factor. However, some designers chose not to include this safety factor because the soil strength and pressures provided by the Geotechnical engineer for the purposes of designing a wall already include a similar factor of safety.

The primary methods of analysis for anchored walls include free earth support, Rowe's moment reduction method and fixed earth support. As with cantilevered walls, it is common to increase the embedment length by 20% to 40% to provide an additional safety factor.

Recommended sources for guidance in the design and analysis of steel sheet pile walls includes the Design of Sheet Pile Walls published by ASCE (an adaptation of the USACE Engineering Manual EM 1110-2-2504) and the Steel Sheet Piling Design Manual published by United States Steel. There is also software that is available for the design and analysis of sheet piling. This includes SPW911 developed by Pile Buck, Inc. and Prosheet distributed by ARBED. The SPW911 program is capable of handing more than one line of walers and also provides the magnitude of deflection at the top of the wall. The Prosheet program is only capable of assuming one line of walers and does not provide deflection information.

References

Reference #1: Standard

ASCE Minimum Design Loads for Buildings and Other Structures, ANSI/ASCE 7-95; June 1996

Reference #2: Code

FEMA Guidelines and Specifications for Wave Elevation Determination and V-Zone Mapping; March 1995

Reference #3: Unpublished Report

Lynch, Giulliano & Associates, Inc. South Amboy Redevelopment V-Zone Elimination Feasibility Study; July 2002

Reference #4: Code

New Jersey Administrative Code Chapter 7E Coastal Zone Management Rules; February 23, 2003

Reference #5: Book

Roark and Young (1982). Formulas for Stress and Strain, 5th Edition, 580-581

Reference #6: Document

USACE Criteria for Evaluating Coastal Flood-Protection Structures; December 1989