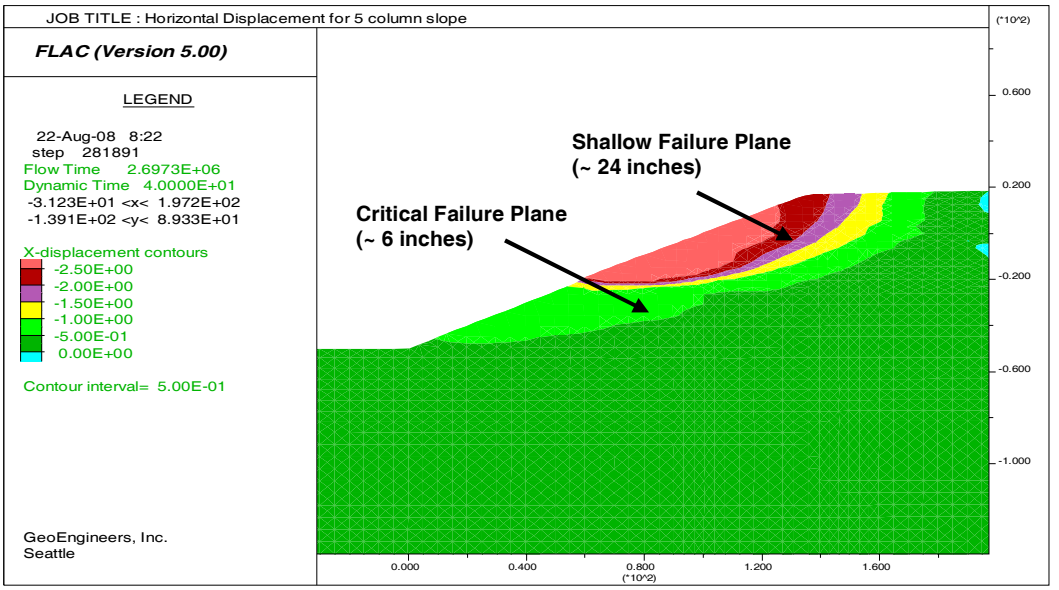

Figure 7. FLAC Results – Slope Deformation with 5 Rows of Stone Columns

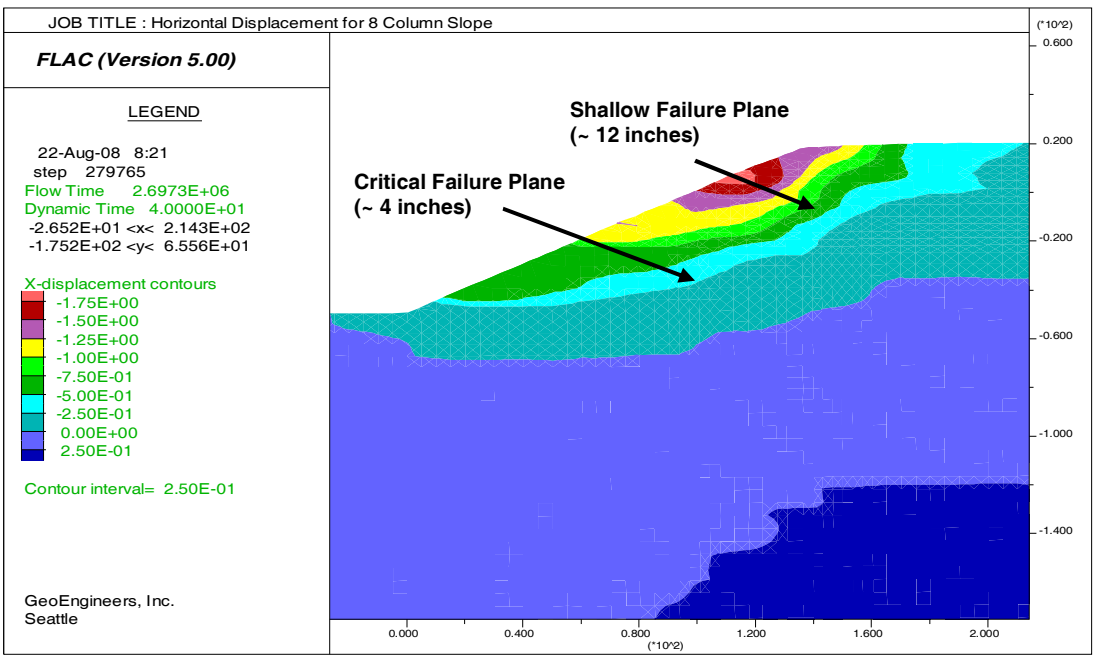

Figure 8. FLAC Results – Slope Deformation with 8 Rows of Stone Columns

Project Specific and System-Wide Considerations for Wharf Retrofit Improvements at the Port of Oakland

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ABSTRACT

The Port of Oakland (Port) was established in 1927 at which time it became a separate autonomous department of the City of Oakland. The Port inherited old timber pile-supported wharf infrastructure that was then primarily used for break-bulk operations with on-dock transit sheds. These maritime facilities have since been converted from break-bulk to container terminal operations. Although many of the original wharf structures were demolished and rebuilt, many of these rebuilt structures no longer meet today's latest design criteria. Accordingly, the Port of Oakland underwent a system-wide evaluation of its maritime wharf structures to categorize them from the most seismically vulnerable to least seismically vulnerable. Using this information, coupled with the impacts of both operational and retrofitting costs and the Port's financial capacity to perform the improvements, the Port began a series of retrofit projects.

This paper will explain the numerous factors the Port of Oakland considered in determining which retrofit projects should be considered and the schedule of those proposed improvements.

INTRODUCTION

The Port of Oakland occupies 19 miles (30.6 kilometers) on the eastern shore of San Francisco Bay reaching from the Oakland-San Francisco bay bridge to the Oakland International Airport (see Figure 1). The maritime area of the Port consists of 1200 acres (486 hectares) of terminal and maritime support area, 20 deepwater berths and 31 gantry container cranes capable of accommodating Post-Panamax container ships (see Figure 2). The Port handles 98% of all containerized cargo that passes through northern California ports and is the fifth busiest port in the United States.

Figure 1. Vicinity map.

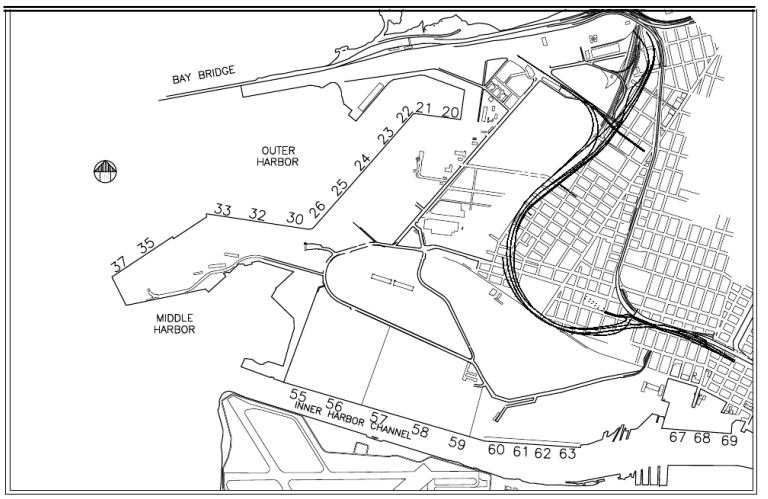

Figure 2. Port of Oakland maritime area.

The Port of Oakland was established in 1927 to promote and ensure the comprehensive and adequate development of the area within its jurisdiction. This is accomplished through continuity of control, management and operation as an autonomous department of the City of Oakland. The exclusive control and management of the Port is vested in a seven member Board of Port commissioners, nominated by the mayor and appointed by the City Council.

The Board's power and duties include the approval or denial of permits to "…construct, extend, alter, improve, erect, remodel or repair any pier, slip, basin, wharf, dock or other harbor structure, or any building or structure within the "Port Area...". Such permits issued by the Board are in addition to any permit which may be required by law from the Building Inspector of the City of Oakland. Although the design criteria of pier and wharf structures are not specifically addressed in the local adoption of the California Building Code, 2007 edition, the City of Oakland requires the design of these structures to be based on and meet rational logical design criteria.

WHARF RETROFIT/CONSTRUCTION HISTORY - 1965 to 1995

Many of the original pier and wharf structures at the Port of Oakland consisted of a combination timber deck with timber support piles abutting a thin concrete deck slab supported by concrete piles. The timber wharf system was a narrow apron area along the berthing area. The apron area was used to temporarily store break bulk materials when off-loaded from ships using ship cranes or large lattice boom crawler cranes. These materials would then be stored in an adjacent transit shed which was supported by the concrete wharf system. As terminal operations evolved from break bulk to containerization, some of the old combination wharf systems were modified by demolishing the existing transit sheds and retrofitting the wharf system to accommodate container quay cranes. Other existing wharf systems were completely demolished and rebuilt with then state-of-the-art concrete pile, deck and embankment wharf systems.

One of the first old combination wharf systems to be retrofitted was in 1965 at Berths 20-21. Berth 22 was later retrofitted in 1977. Both of these retrofits were done strictly to accommodate 50-foot gauge container crane operations. Although these retrofits allowed the loading and unloading of a container vessel via a landside container quay crane, the timber and concrete decks were not modified and remained at their original capacity of 400psf and 600psf, respectively.

Between 1967 and 1971 the Port constructed its 7th Street peninsula. The peninsula was reclaimed from the Bay by first constructing a perimeter dike around the area and then filling behind the dike. The construction of the Berths 32-33 and Berths 35-37 wharves were part of this development. These wharves as originally built consisted of a 1-1/2-foot thick reinforced concrete deck ballasted with 2-1/2 foot of fill and an asphalt concrete pavement. The deck was supported on 16” square, pre-cast, pre-stressed concrete piles with lateral force resistance provided by a row of alternating batter piles. At Berths 32-33, the crane rails were cast within the deck with a gauge of 34 feet. The Berths 35-37 crane rails were built with a gauge of 96 feet. The landside crane rail at this facility was supported by a grade beam and not structurally connected to the deck. The embankment beneath the wharves consisted of sand fill, and young bay muds which slopes at a 1-1/2H:1V and is armored by rubble.

The Loma Prieta earthquake of 1989 caused extensive damage to the batter piles at Berths 32-33 and Berths 35-37. The Port made emergency repairs and seismically improved these wharf structures between 1990 and 1991, by constructing a new lateral force resisting system consisting of two adjacent rows of vertical, 24” octagonal pre-cast, pre-stressed concrete piles, one beneath a new landside crane girder. The existing concrete wharf decks were widened, connecting the two rows of new piles. In addition, portions of the sand fill embankment were densified by installation of stone columns.

In 1971 the wharves at Berths 60-63 were constructed. These wharves have an approximate 1-1/2-foot thick reinforced concrete deck ballasted with 2-1/2 foot of fill and an asphalt concrete pavement. The deck is supported on 16" and 18" square, pre-cast, pre-stressed concrete piles with lateral force resistance provided by a row of alternating batter piles inset from the waterside edge of the wharf. The landside crane rail at Berths 60-61 is supported by batter piles and is not structurally connected to the deck. The landside crane rail at Berths 62-63 is included in the deck. The gauge of the crane rails is 100 feet in all cases, and marked the beginning of the Port's standardization of 100-foot gauge crane rails. The embankment beneath the wharves consists of sand fill, and young bay muds which slopes at a 1-1/2H:1V and is armored by rubble.

Between 1975 and 1978 the wharves at Berths 23, 24 and 25 were constructed (previously designated as Berths 2, 3, 4 & 5). These berths consist of three separate structures built at separate times. Berths 4 & 5 were constructed on each side of a 150-foot wharf structure of yet another structural design. Each structure is separated from the other with a transverse, unkeyed expansion joint. With the exception of the 150-foot extension, these wharf structures are quite similar, consisting of an approximate 2-foot thick reinforced concrete deck and an asphalt concrete pavement supported on 18" square, pre-cast, pre-stressed concrete piles. The lateral force resisting system consists of two sets of batter piles (4H:12V). The 150-foot wharf section consisted of a 1-1/2-foot thick reinforced concrete deck ballasted with a 3-foot layer of fill and an asphalt concrete pavement supported on 16" square, pre-cast, pre-stressed concrete piles. The lateral force resisting system for the 150-foot extension consists of two sets of batter piles (4H:12V), one set in the longitudinal direction and the other in the transverse direction. The landside crane rail for all berths are not structurally connected to the deck and is supported on a grade beam. The structures are located on land reclaimed from the Bay and are underlain by fill materials. The embankment beneath the wharf consists of sand fill, and young bay muds which slopes at a 1-1/2H:1V and is armored by rubble.

The wharf along Berths 67-68 was constructed in 1980. The 80' wide reinforced concrete deck is supported by five rows of vertical, 24" octagonal pre-cast, pre-stressed concrete piles. The landside crane rail is separated from the wharf structure and supported by a grade beam on batter piles. Berth 69 is a 300' extension to Berth 68 constructed in 1995. It consists of a 109' wide reinforced concrete deck supported by seven rows of vertical, 24" octagonal pre-cast, pre-stressed concrete piles. The concrete deck includes both crane rails. The embankment beneath the Berths 67-69 wharves consists of a rock dike, which slopes at a 1-1/2H:1V. The lateral force resistance is supplied by the back rows of vertical piles, which embed into the rock dike.

The wharves at Berths 26 and 30 were built in 1988 and 1992, respectively, and have a similar design as Berth 69.

The above wharf structures are listed in tabular form by berth number (see Table 1).

Table 1. Wharf retrofit/construction history - 1965 to 1995.

Berth identification #	Year	Notes
Berths 20,21	1965	Retrofit
Berth 22	1977	Retrofit
Berth 23*	1978	Original construction
Berths 24,25**	1975	Original construction
150 ' Ext. @ Berth 24	1971	Original construction
Berth 26	1988	Original construction
Berth 30	1992	Original construction
Berths 32,33	1967	Original construction
Berths 32,33	1991	Earthquake damage repair
Berths 35,37	1967	Original construction
Berths 35,37	1990	Earthquake damage repair
Berths 60-63	1971	Original construction
Berths 67,68	1980	Original construction
Berth 69	1995	Wharf extension at Berth 68

* Berth 23 was formerly designated as Berth 5
** Berths 24, 25 were formerly designated as Berths 2, 3 and 4

IMPACTS OF -50 FT CHANNEL DEEPENING PROJECT

In 1999, the Port and the Army Corps of Engineers entered into a Project Cooperation Agreement (PCA) for design of the Oakland Harbor Navigation Improvement (-50 Foot) Project, a project that would deepen the entrance channel to the Port, the channels in the Outer and Inner Harbors, as well as the turning circles at both the Outer and Inner Harbor areas. The two parties executed a PCA for construction of the project in 2001.

In conjunction with the channel deepening project, the Port began a program to deepen its berths to -50 ft Mean Lower Low Water (MLLW). The berth deepening program necessitated an overall analysis of the structural integrity of the Port's existing waterfront components (i.e. wharves and embankments) given the original designs of these components were based on a berth depth of no more than -42 ft MLLW. Unless they were structurally reinforced prior to dredging, the waterfront components would be weakened by the berth deepening project.

Accordingly, in 2000, the Port commenced the Wharf and Embankment Strengthening Program (WESP), a structural and seismic risk reduction analysis program involving approximately 12,000 linear feet of pile-supported, marginal wharf structures. WESP was a three-phase program that consisted of 1) seismic analyses of the WESP berths to determine the then current seismic capacities of waterfront components, 2) conceptual design of seismic upgrade improvements together with economic and risk analyses for consideration of the seismic upgrades,

beginning with the improvements necessary to maintain the existing seismic capacities after the berth deepening, and 3) the implementation of the WESP, which would be a separate series of projects under their own contract to construct the selected structural modifications necessary to mitigate the effects of the proposed -50ft MLLW berth deepening program. The timing of the WESP projects are based on priority and funding availability.

WHARF AND EMBANKMENT STRENGTHENING PROGRAM ANALYSIS

The berths included in the WESP were Berths 23-26, 30, 35-37, 60-63, and 67-69. Not included in this analysis were Berths 20-21 because this area was not to be deepened, Berth 22 because this wharf was in conceptual design for replacement, Berths 32-33 because this wharf was in conceptual design for retrofit, and Berths 55-59 because these wharves were under construction. Berths 22, 32-33 and 55-59 were each designed to accommodate the deeper berths.

The first phase of the WESP was a seismic analysis of the WESP berths to determine the then current seismic capacities of the waterfront components. This exercise back-calculates the peak horizontal ground accelerations that would result based on the performance of the wharf components using a multi-level performance-based design approach. The controlling accelerations were then converted to a corresponding percentage probability of exceedance in 50 years. The performance levels were as follows:

- Level I - The wharf and embankment system experiences only minor, repairable damage and operations would not be interrupted. The Port's current design criteria are based on ground motions having a 50% probability of exceedance in 50 years at this performance level.

- Level II - The wharf and embankment system experiences controlled, economically repairable damage and operations may be limited and/or interrupted. In addition, collapse shall be prevented and damage shall be observable and accessible for repair. The Port's current design criteria are based on ground motions having a 10% probability of exceedance in 50 years at this performance level.

- Post Level II - The wharf and embankment system may experience significant uneconomically repairable damage, but will not be sufficient to endanger the life-safety of the users of the structure. Collapse shall be prevented.

The culmination of the first phase of the WESP was a relative ranking of seismic vulnerability of the selected WESP berths. Table 2 presents this relative ranking (Lobedan, et al., 2001).

Table 2. Relative ranking of seismic vulnerability for the WESP berths.

Berth identification #	Probability of exceedance in 50 years (%)		
	Level I	Level II	Post Level II
Berth 23	60	40	30
Berths 24,25	60	35	25
150' Ext. @ Berth 24	95	95	35 to 45
Berth 26	20	5	5
Berth 30	26	26	13
Berths 35,37	60	20	10
Berths 60,61	Unavailable	Unavailable	Unavailable
Berth 62	65	62	62
Berth 63	70	67	67
Berths 67,68	50	20	15
Berth 69	30	30	15

The new wharf structure at Berth 22, the wharf extension east of Berth 32 (part of the Berths 32-33 retrofit project), and the wharves at Berths 55-59 were all designed to the Level I and Level II performance levels. The existing wharf structure at Berths 32-33 was retrofitted, such that, the existing seismic capacity would be maintained after the berth was deepened.

The existing wharf at Berth 22 was demolished and rebuilt in 2003 with a reinforced concrete deck supported by seven rows of vertical, 24" octagonal pre-cast, pre-stressed concrete piles. The concrete deck includes both crane rails at a gauge of 100 feet. The embankment beneath the wharves consists of rock fill, which slopes at a 1-1/2H:1V. The lateral force resistance is provided by the back rows of vertical piles, which embed into the rock fill.

The Berth 32 wharf extension and retrofit was constructed in 2004. The design of the extension was similar to Berth 22. The Berths 32-33 retrofit included an 8'-6" widening of the wharf structure so its wharf face would align with the face of the adjacent Berth 30 wharf. The wharf widening and the construction of the new waterside crane rail piles and girder provided an opportunity to increase the waterside crane rail capacity to a factored load of 65klf. The new waterside crane rail construction, coupled with construction of the landside girder on the pre-existing piles driven under the 1991 seismic retrofit project, also provided an opportunity to accommodate 100-foot gauge cranes.

The wharves at Berths 55-59 were part of the Port's Vision 2000 Program; a program that converted over 400 acres of the Navy's former Fleet and Industrial Supply Center, Oakland - FISCO (part of the Base Realignment and Closure - BRAC process), into container terminal, rail, and public access facilities. These wharves consist of a 124' wide reinforced concrete deck supported by eight rows of vertical, 24" octagonal pre-cast, pre-stressed concrete piles at Berths 55 and 56. At Berths 57-59 the deck is supported by seven rows of 24" octagonal and one row of 48"

cylindrical pre-cast, pre-stressed concrete piles. The concrete deck at all berths includes both crane rails, with a driving lane on the waterside of the waterside crane rail. The embankment beneath the wharves consists of rock fill, which slopes at a 1-1/2H:1V. The lateral force resistance is supplied by the back rows of vertical piles, which embed into a cement deep soil mixed (CDSM) wall.

As part of the WESP, seismic risk reduction concepts were conducted at the selected facilities. Strengthening concepts and associated construction cost estimates for up to 4 increasing levels of design associated with increasing levels of seismically induced forces were developed. The seismic performance and expected damage that would result at these berths from a range of plausible earthquake events for the region were evaluated for each strengthening concept. Corresponding repair costs and business interruption costs (i.e. operational costs) for the range of plausible earthquake events were prepared for comparison purposes.

A system-wide evaluation (multiple terminal berths) of the wharf components was also performed recognizing the Port's authority to relocate tenants and have them share facilities in emergency situations. As provided for in the typical Port/tenant lease agreements, "The Port reserves the right for itself or through its designated Secondary Users and upon written notice to Assignee to use all or any part of the Premises and any of the Port Cranes or Assignee Cranes, for the berthing of Vessels and loading or discharging of cargoes and operations incidental thereto, including right of access to and through the Premises over access routes available to and used by the Assignee…" Of course, this use cannot unreasonably interfere with the Assignee's operations. Given this right of use, especially for emergency situations, the Port evaluated the performance of its wharves on a system-wide basis in an effort to minimize the upgrade, repair, and business interruption cost impacts. This system-wide evaluation also considered the impacts of Berths 32-33 and Berths 55-59. It is important to note that the Port limited its analysis to only berth structures, and did not include other infrastructure within or outside the terminal areas.

WHARF RETROFITS - POST WESP ANALYSIS

The Port began construction of selected WESP upgrades in 2005, beginning with Berths 23-26 and 30, and continuing in 2006 with WESP upgrades to Berths 35/37. The selection of these upgrades was based primarily on the Port's available funds to perform the work, as well as the seismic vulnerability of the structures. For these structures, the minimum seismic improvements were selected, such that, the same seismic capacity was maintained after the berth deepening work as existed prior to the deepening work.

The work at Berths 23-26 and 30 included a sheet pile wall driven along the face of the wharf structures. The wall was designed to maintain the existing seismic capacity over the expected remaining life of each wharf structure. Accordingly, the size of the sheet pile varied between structures to match the estimated remaining lives of these structures. Construction was phased to ensure large portions of the berths

remained available for operations and to account for different fender systems with varying wharf-face offsets. Recognizing the need for phased construction and planned berth closures, this allowed the opportunity for other required operational improvements to the wharves to be constructed under the same contract. Higher capacity unit fenders and bollards and additional waterside crane rail pile/girder supports, increasing the crane rail capacity to the established retrofit standard factored load of 51klf, were also part of the improvement project (see Figures 3 and 4).

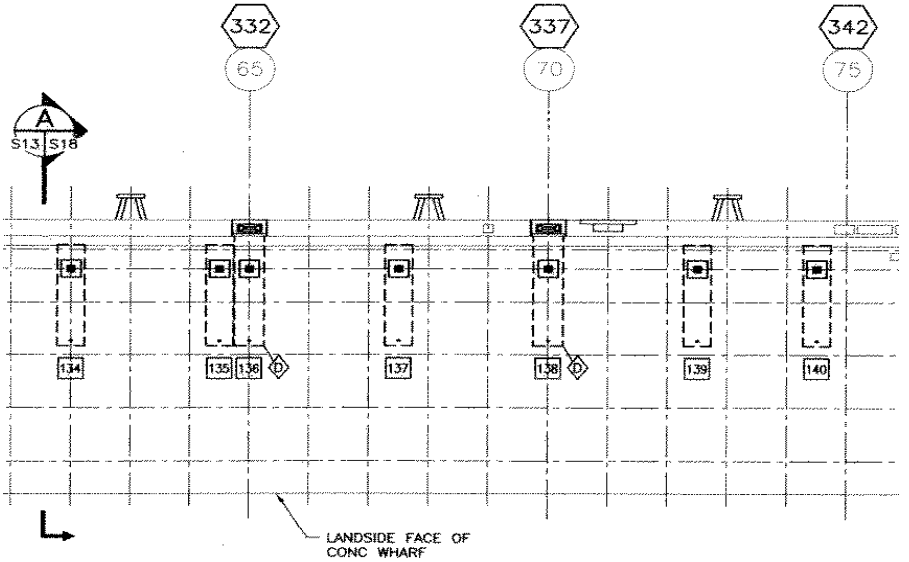

Figure 3. Berth 5 (25) WESP plan.

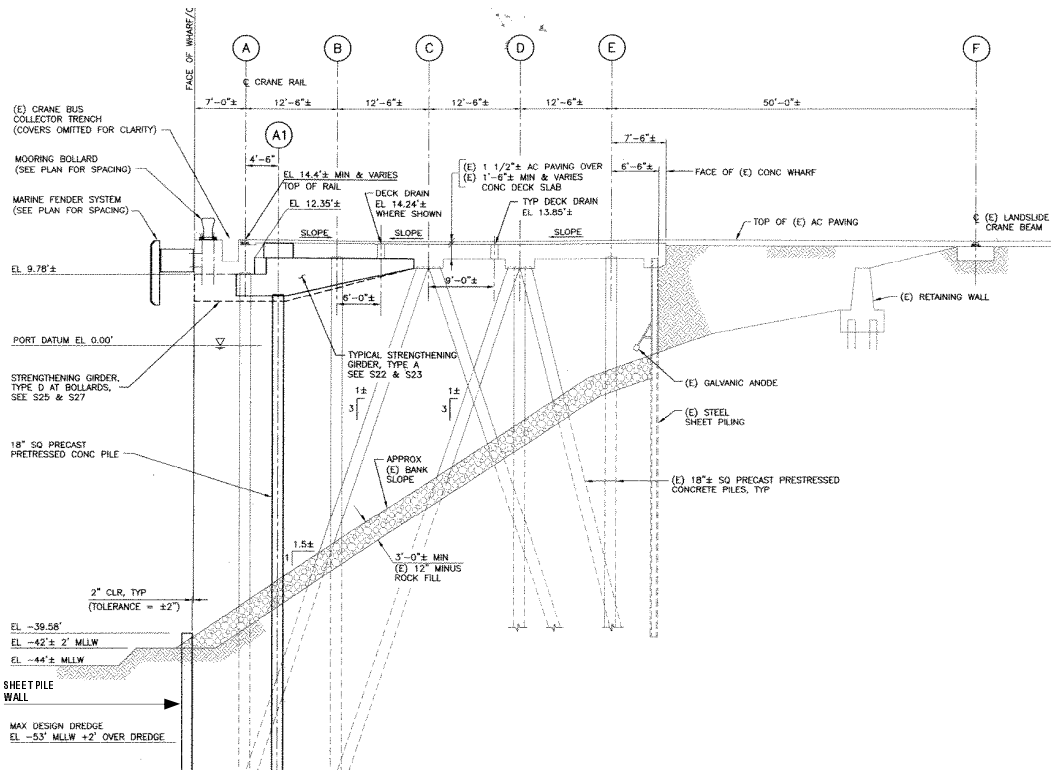

Figure 4. Berth 5 (25) WESP section.