In 1995, the Defense Base Realignment and Closure (BRAC) Commission recommended closure of the Fleet Industrial Supply Center Oakland (FISCO), which occupied 214 ha at the center of the Port of Oakland’s marine terminals area. As a result of deed restrictions on the property and special legislation that was passed which addressed the conveyance of the Base property, the land and berth areas of the base reverted to the ownership of the Port. This conveyance gave the Port critical land and water area, creating an opportunity to develop significant improvements in the Port’s capacity and efficiency of its marine terminals and intermodal cargo transportation services. As a result the Port created a development plan called the Vision 2000 Maritime Development Program, which defined a plan to build new marine container terminals, an intermodal rail terminal, and supporting roadway and utility infrastructure.
New marine terminals were planned to be constructed with 1828 m of new wharf space to be located along the Inner Harbor Channel. This channel is used to access two existing marine container terminals located upstream from the proposed development. Owing to navigational control and safety issues, vessels entering the 152 m wide channel come in at speeds of 8-10 knots. At this speed the vessels generate hydrodynamic forces that can adversely affect ship loading and unloading operations at berths adjacent to the channel.

Therefore a hydrodynamic evaluation was performed for the proposed new berths, which indicated a need to widen the channel in order to mitigate the effects of vessel-generated pressure fields on ships at the new berths. It was determined that widening the entrance to the Inner Harbor Channel by approximately 76m and tapering back down to the existing width at the point where the new wharves will connect with the existing Port Berth 60-63; approximately 2.4 km upstream of the entrance would be necessary in order to allow for continued ship loading and unloading operations while other container vessels transit the channel. This would require the dredging and excavation of approximately 4.1 million cubic meters of miscellaneous fill soils, sand, and mud (locally referred to as Merritt Sand and Bay Mud, respectively). The plan for the new terminals incorporated this cut volume into upland and bay fill in order to address drainage problems on the existing site and to create sufficient backland area to support the new proposed container wharves. The 15 ha of bay fill created by the project were offset and mitigated by the creation of 18 ha of bay surface area.

The Port contracted with various geotechnical consulting firms to compile a tremendous amount of geotechnical information that was available and to conduct additional site specific investigations in order to generate a precise mapping of the site geology and gain an understanding of the material properties of the soils to be excavated/dredged and placed.

![Figure 2. Typical Embankment Geologic Cross Section](image)

The geotechnical investigation work revealed that the site was comprised of an approximately 3m to 6m layer of miscellaneous fill soils which had been placed by the Western Pacific Railroad, overlying 6m to 8m of Bay Mud; which in turn sat upon a layer of dense, fine-grained sand (known as the San Antonio Formation, or Merritt Sand) which extended below the depth of the required dredging. The top
layer of fill soils that were to be removed were comprised of a combination of hydraulically placed fill and fill that was imported by the Railroad from a variety of sources, which was brought to the site from the mid nineteenth century through the early part of the twentieth century. Testing of the soils indicated some minor amount of contamination. Due to the uncertainty about the extent of this contamination the Port determined that all of this soil would be used for upland fill to raise site grades and therefore be kept out of the marine environment. Approximately 994,000 cubic meters of this soil had to be removed and placed as upland fill. With the exception of a small volume of sediment along the existing embankment, the underlying Bay Mud and Merritt Sand had no contamination. This material was designated for use as the bay fill. An estimated 1.4 million cubic meters of bay mud and 1.7 million cubic meters of Merritt Sand had to be excavated and dredged to create the new channel and berth configuration.

The bay fill site was the location of former Navy piers, wharves and ship berths at the now-closed FISCO in the Oakland Middle Harbor Area. This area is located directly behind the westernmost planned new wharf. Filling this area was necessary to create the optimal configuration of contiguous terminal yard space adjacent to the wharf and provided a balanced ratio of wharf frontage and backlands depth.

![Figure 3. Cross Section Through Finger Pier Area](image)

Historically the site consisted of mudflats which were dredged and filled to create the Navy facility. The berths at the finger piers had been dredged to a depth of -12 m whereas the soil elevation under the piers was left at only -2 m. The fill plan consisted of constructing a rock containing dike perpendicular to the piers from the north shore (north marginal wharf) to the south shore (south marginal wharf) of the Middle Harbor area resulting in filling in about half of the area generally occupied by the finger piers. Since the rock containment dike crossed perpendicularly across the piers and the berths this created a discontinuity in the dike foundation that had to be
addressed. This was accomplished by keying the dike into the existing soil where the piers had stood.

The footprint of the containment dike was underlain by an approximately 2 m layer of highly compressible sediment that had accumulated within the last five years. This created a potential stability and settlement problem for the dike that had to be addressed. Typically the soft sediment would have been removed from beneath the dike allowing the rock to found on the firm underlying Merritt Sand formation. However this would have resulted in a significant amount of dredging in sediment that was suspected of containing sufficient levels of contamination to preclude open water disposal, and so would have to be placed behind the containing dike in order to be contained within the overall fill. Therefore, in order to minimize the amount of dredge material that would have to be incorporated into the fill a keyway trench was dredged within only a portion of the dike footprint. The keyway was located under the outboard toe of the dike such that the remaining soft foundation material would be consolidated as a result of the fill surcharge placement. In order to mitigate the risk of dike failure during a seismic event, a shelf of dredge material from the terminal development was placed outboard of the dike to further buttress it.

Bay Mud is highly compressible and can experience significant settlement. If not stabilized it is generally unsuitable for use as a construction fill. Merritt Sand, however, can provide a high quality sub-base foundation with a very high strength. When compacted, R-values in excess of 75 are typical. Therefore if Bay Mud and Merritt Sand are to be used to construct a deep fill, the Bay mud would ideally be placed deep beneath a layer of Merritt Sand which would initially serve as a surcharge to consolidate the mud and then function as the sub-base or foundation.
layer for the development. Coincidently with the Bay Mud overlaying the Merritt Sand, the order of dredging was consistent with placing the Bay Mud in the fill site before dredging and placing the Merritt Sand.

The amount of Bay Mud to be placed in the fill site would result in an approximately 11 m thick layer of mud, which could result in significant settlement. The geotechnical analysis of the Bay Mud to be dredged indicated that it had experienced consolidation as a result of the fill placed over it as well as the ongoing operations of the Navy and the Union Pacific Railroad. Assuming no preconsolidation pressure for the mud, total settlement was estimated to be in the range of 3 m to 5 m. Settlement for the mud with an assumed preconsolidation pressure of 794 MPa resulted in an estimated settlement of 1.4 m to 2.0 m. Clearly the consolidation state of the dredged mud as placed in the fill site has a profound affect on the amount of expected settlement. This indicated a real benefit of minimizing the disturbance of the Bay Mud during dredging and placement in order to retain as much of the preconsolidation pressure as possible.

Figure 5. Bay Mud Placement at Southern Cell and Hydraulic Dredging of Merritt Sand at Berth 55/56

Hydraulic dredging of the bay mud was rejected. Although significantly cheaper than mechanical dredging, hydraulic dredging would severely disturb the structure of the Bay Mud, resulting in a semi-fluid fill with no residual preconsolidation pressure. Hydraulic dredging of the mud would likely have also resulted in a more turbid discharge from the fill site which would have been difficult to manage within the constraints of Waste Discharge Requirements issued by the Regional Water Quality Control Board. The Port decided that the material would be best dredged mechanically with a bucket dredge, and bottom-dumped directly into the fill site, and re-handled out of the dredge scows when water depth precluded bottom-dumping. This kept the mud as close to its preconsolidated state as possible and avoided potential water quality problems associated with hydraulic placement of mud. The slightly contaminated sediment, as well as some mildly contaminated material from an adjacent navigation improvement project, was also placed at the bottom of the mud fill. This effectively encapsulated it, allowing the fill to double as a Confined Disposal Facility for this material.
The underlying Merritt Sand was then dredged and placed with a hydraulic cutterhead dredge to both complete the fill and to create a surcharge for the now underlying Bay Mud. Although the sand was able to provide for a surcharge of nearly 9 m, the rate of consolidation and settlement was controlled by the thickness of the Bay Mud fill. In order to compensate for the thickness of the Bay Mud layer and to accelerate the consolidation, a wick drain and pore water collection system was designed to provide pathways for the excess pore water to be squeezed out of the mud fill by the surcharge.

Initially a ten foot thick layer of sand was placed over the mud fill to support construction equipment. Wick drains were then installed on five-foot spacing and connected to corrugated plastic drain pipes laid horizontally to collect the pore water and discharge it into the bay at the containment dike. Settlement plates and piezometers were installed to monitor the settlement and pore pressure of the fill in order to identify when enough consolidation had occurred to allow for the construction of the container terminal to proceed. The sand was then placed to the full surcharge height at an elevation of approximately +9 m. Bulldozers were used to control the placement of the sand by moving sand mounds as they formed at the discharge pipe. The sand was used to build up a confining dike around the perimeter of the fill site to contain the significant quantity of carrier/decant water which was then discharged to the bay via a weir and pipe outlet system at the rock containing dike. The mechanical reworking of the sand and the vibrations induced by the operations of the dozers also served to compact the sand as a means to mitigate liquefaction potential.

![Figure 6. Fill Sequence at Southern Fill Cell](image)

The dredging and filling operation occurred in two phases corresponding with the phased construction of the Vision 2000 wharfs. The fill site was divided into two separate ‘cells’, with the mound area beneath the northernmost finger pier providing a separation between them. A rock containment dike was constructed around the southernmost cell and the material dredged from the first phase of terminal wharf development (Port Berths 55/56) placed there. The northernmost cell was then designated to receive dredge material from the second phase of terminal wharf development (Port Berths 57-59). The land fill created by these cells was then developed as Phases 2 and 3 of the adjacent Berth 55/56 (Hanjin) container terminal.
yard. The dredging of the Berth 57-59 area and associated filling of the northern fill cell was completed before the Bay Mud in the southern cell had reached the target consolidation. Based on the monitoring program, once the Bay Mud had reached target total settlement and settlement rates which indicated future settlement under the container terminal would be at acceptable levels, the excess surcharge was made available for site fill and trench backfill at the Berths 57-59 container terminal yard site. Approximately 76,000 cubic meters was ultimately incorporated into site fill and used for trench backfill. The remaining excess surcharge was then removed as a part of the construction of the second phase of the Hanjin terminal container yard development, with the material being placed as additional surcharge for the northernmost cell area.

As with the southern cell, monitoring of settlement and pore pressure was then conducted. Following consolidation of the mud, removal of the excess surcharge was then incorporated into the construction contract for development of the third phase of the Hanjin terminal container yard development. That construction contract also included construction of an adjacent shoreline park with a beach to be built under the westernmost portion of the fill footprint. A substantial portion of the surcharge excess was therefore used as submarine fill offshore from the beach to attenuate wave energy and stabilize the beach. In addition, approximately 31,000 cubic meters was stockpiled at the site of a future rail terminal development within the Port area, less than a mile from the fill area. Approximately 76,000 cubic meters was also used to negotiate a change order with the contractor; with a commitment to a one month acceleration of the contract given by the contractor in exchange for his ability to use the sand for an off-site (non-Port) project.

Figure 7. Fill Sequence at Northern Cell

The initial settlement analysis indicated that even with the installation of wick drains and the use of a surcharge, post-surcharge settlement (9 to 18 months of surcharge) could likely be nearly 0.6 m and could range as high as 2 m if the Bay Mud had no preconsolidation pressure. Mechanical dredging and placement was therefore chosen in order to preserve as much of the preconsolidation pressure as possible.

The post-surcharge settlement was also found to be very sensitive to the spacing of the wick drains. Anticipated post-surcharge settlement nearly doubled when the wick
drain spacing was increased from 1.5 m to 2 m. The closer spacing was therefore chosen.

These two decisions proved their worth, as both fill sites were available to commence construction of the final phases of the terminal yard development within less than six months of final placement of the dredged material with likely settlement of less than 8 cm.

The overall plan also proved to be a success in terms of balancing earthwork cut and fill for the project. Aside from solid estimating of the volume of excavation and dredging, this proved possible as a result of careful planning of the sequence of construction. Significant capacity for accommodating the dredge material was gained from the volumetric reduction in the Bay Mud during consolidation and the Merritt Sand proved to be a very useful and valuable resource. The value of the sand was both realized through its use in the terminal and rail development projects, but also proved to be a high quality fill material that was marketable for off-site projects. The Port therefore incurred no costs for either importing or exporting fill to or from the site.