THE “GREAT” GUAM AND HANSHIN EARTHQUAKES PROFILES IN PORT DISASTERS

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ABSTRACT

Two recent earthquake events, several thousand miles apart, demonstrate that even regions situated in low to moderate seismicity are not immune from catastrophic damage.

The “Great” 1993 Guam and the 1995 Hanshin earthquake are a reminder to the world that even affluent nations can be brought to their knees by the forces unleashed by Mother Nature. Whether the event is a hurricane, an earthquake or a flood, it is imperative for professional engineers to learn and improve from these events. The challenge is to reach a balance between recklessness and extravagant conservatism.

This article discusses tectonic similarities between Guam and Kobe, performance of the container terminals at the ports during the recent earthquake events, proposed repairs to the Port of Guam using a “lifeline” approach, and the lessons learned from each event.

INTRODUCTION

On August 8, 1993, a magnitude 8.1 earthquake struck the island of Guam, the largest and southernmost of the Mariana islands in the Philippine Sea. The earthquake epicentered 50 km south of Guam, causing extensive damage to the Port of Guam container terminal and producing damage to structures and lifelines throughout the island; incredibly, no fatalities were recorded.

On January 17, 1995, a magnitude 7.2 earthquake struck the Osaka bay region of Honshu, the largest island of Japan. The earthquake epicentered approximately

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12 miles southwest of the port city of Kobe, produced over a hundred billion dollars in damage, caused 5300 deaths and rendered 320,000 people homeless. This event is the deadliest earthquake to occur in Japan since the 1952 Hokkaido earthquake.

Both disasters demonstrate that even regions situated in low to moderate seismicity are not immune from catastrophic damage, and catastrophic damage, though predictable, is uncertain.

Within hours after each earthquake event, American President Lines, the terminal operators at Guam and Kobe, retained Liftech Consultants Inc. to assess the damage to the port facilities and cranes. Liftech retained Harza Consulting Engineers for geotechnical assistance. Within 48 hours of notification, the team arrived in Guam and Kobe to assess the damage and begin recovery and reconstruction activities.

SITE SEISMICITY AND GEOLOGY

The Port of Guam is located in a medium-to-high seismicity region defined by the Uniform Building Code as seismic zone 3. As a result of the August 8, 1993 earthquake, the authors believe the seismic category for Guam will be revised upwards from Seismic Zone 3 to Seismic Zone 4.

The Port of Kobe was not considered to be situated in an active seismic region. Since a Richter magnitude 6.0 or greater earthquake had not occurred in over 400 years, the region was not prepared for an event such as the January 17, 1995 earthquake. Kobe is still in the process of assessing the impact of the Great Hanshin earthquake, and no significant seismic design developments are expected for several months.

Guam is situated at the southeastern edge of the Philippine plate adjacent to the Pacific plate. The western coast of Honshu island is situated at the convergence of the Pacific plate, the Eurasian plate, and the Philippine plate, with the Pacific plate being subducted by the Eurasian plate.

The geology at the Port of Guam consists of a 1 to 12 foot layer of dense to very dense sandstone fill. Underlying the fill to a depth of 54 feet is a layer of medium to dense calcareous sand with a 15-foot lens of loose to medium dense silty sand that extends 13 to 28 feet below the ocean surface. The sand lens is potentially liquefiable. Beneath the calcareous sand is a moderately hard to hard corraline limestone formation that extends beyond the maximum explored depth of about 122 feet.

The Port of Kobe consists of three man made islands. The original geology consists of alternating deposits of marine clay and alluvial sand and gravel. The surface deposits consist of loose silty sands and soft clays. The surface deposits have been excavated to a depth of approximately 75 feet and replaced with sand and a rubble topping to seat the perimeter quay walls that contain the hydraulically placed granular fill reclamation. These materials are potentially liquefiable.

DAMAGE ASSESSMENT

PORT OF GUAM

The Port facility in Guam consists of 1900 feet of container wharf, serviced by three dockside container cranes and 750 feet of break bulk wharf serviced by self sustained vessels.

The original wharf, built in 1966, consists of sheet pile bulkhead tied back with rods to a continuous sheetpile deadman. In 1970, a 50-foot gage crane runway was added with reinforced concrete girders and vertical steel H-piles spaced 9 feet on center. The gage was held by concrete struts at 54 foot centers for the full length of the runways. The crane runway structure is independent of the sheet pile bulkhead and deadman.

The original wharf cross section is shown in figure 1.

A topographic survey of the crane rails and waterside bulkhead indicated the entire 1900-foot length of bulkhead and crane runway rotated clockwise about the western edge of the wharf and translated as much as 18 inches toward the water. The 810-foot long shaded portion shown in figure 2, suffered surface cracking and minor damage. A 560-foot region within the shaded area suffered serious structural damage.

The original wharf construction relies on the sheet pile deadman to hold back the bulkhead wall through passive resistance of the soil waterside of the deadman. During the earthquake, the layer of silty sands between the bulkhead wall and the deadman liquefied. This caused increased lateral forces on the bulkhead wall and reduced passive resistance in front of the deadman. The bulkhead wall and deadman moved toward the water. Liquefaction of the underlying sandy soils caused the upper gravel fill layer and asphaltic concrete to crack and settle, forming large birdbaths between the rail girders. As the deadman moved forward, a void was created behind it and the soils subsided, causing a series of cracks in the backlands.

The wharf movement and cracking due to the earthquake is shown on figure 3.

The three container cranes were undamaged.

Port of Kobe

The terminals are spread over three man-made islands: Port Island, Rokko Island and Maya Terminal. The terminals consist of approximately 30,000 feet of container wharf serviced by 57 dockside container cranes, and 30,000 feet of break bulk wharf. Port Island and Maya Terminal were constructed in the early 1960's. Rokko Island was constructed in the late 1980's. After the earthquake only eight of the 186 berths were operational. The remaining berths sustained severe damage.

The construction is similar at all three facilities. The perimeter quay wall consists of hollow concrete caissons 35 feet wide and 45 feet deep. The caissons are floated into position and seated on a 10-foot rubble topping over hydraulically placed sand. The sand replaces the natural sea bottom clay. Waterside rail girders are placed over the caisson walls. Landside rail girders for the 50 foot gage cranes are supported on 26 inch diameter steel piles. The landside rail girders for the 100 foot gage cranes are concrete grade beams supported on engineered fill. At Port Island and Maya Terminal, the hydraulically placed reclaimed sand fill does not appear to have been densified. At Rokko Island, sand drains were installed in the fill material behind the landside rail girder. The fill between the landside rail and the caissons does not appear to have been densified.

The caissons were designed for a lateral coefficient of 0.1g. This is much less than used today in active seismic regions. A seismic coefficient of 0.2g was specified for the dockside container cranes. The design criteria for the second phase of construction at Port Island, presently underway, may be different.

At all facilities, liquefaction appears to be the major contributor to the damage.

Damage at Port Island and Maya Terminal is extensive between the rails and in the backlands. The entire interior of Port Island settled as much as 3 feet due to liquefaction of the underlying fill. Rokko Island suffered extensive damage between the rails, but suffered only minor settlement in the backlands and interior. The AC paved yard between the caissons and the landside rail girders dropped 7 to 10 feet. The caissons settled approximately 3 feet, rotated between 3 to 5 degrees, and laterally shifted towards the water by as much as 12 feet.

The failure of the caisson wall foundation appears to be due to pressure from liquefaction of the fill material behind the caisson and lateral seismic forces. Until further investigations are completed, it is not clear whether liquefaction of the fill under the caisson or stress failure due to excessive bearing pressures in the underlying fill contributed to the rotation of the caisson. The lateral shifting and rotation of the caissons has resulted in the rail girders spreading by 3 to 7 feet at Port Island and Maya Terminal and 12 to 15 feet at Rokko Island.

Pile supported structures such as the 50-foot gage landside rail girder have performed well. Settlement of the 50 ft gage landside rail girder is minimal, with some minor lateral and rotational movement. The landside 100-foot gage grade beam has settled along with the backlands.

The original damaged cross-section of the wharf at Port Island is shown on figure 4.

Approximately 50 container cranes have varying degrees of structural damage. One crane at Rokko Island has collapsed, with several others in danger of imminent collapse in the event of a future strong aftershock. Damage is primarily due to rails spreading and settling and consists of buckling of legs at the portal ties. Cranes with stiff portal ties have performed much better than those with flexible or pinned struts.

REPAIR AND RECONSTRUCTION AT THE PORT OF GUAM

The port is a lifeline to the Mariana islands. The liquefiable soils at Guam have been identified, and the soil improvements are designed to limit and control damage from future liquefaction. After the next significant earthquake, the 560 foot section of reconstructed wharf is designed to sustain some damage but remain operational.

Several repair schemes were investigated. Based on constructability, operational constraints, cost and schedule, a 75 foot wide concrete wharf integrated with a gantry runway was selected. The wharf is supported on 24 inch square prestressed concrete vertical piles capable of transmitting vertical and lateral loads.

The liquefiable region has been stabilized by using vibro-replacement stone columns on a 1-3/4:1 excavated slope, protected by a 5-foot layer of rip-rap.

The vibro-replacement stone columns are designed to reduce the potential for liquefaction and lateral spreading. They are compacted columns of crushed rock or stone constructed in a grid or rectangular pattern. These columns of stone densify the soils by saturating and vibrating the soils using a vibroflot hung from leads of a crane. The vibroflot is inserted in the granular soils to the depth of the column, and the annular space is filled with crushed rock which is compacted by a probe as the vibroflot is removed. A drainage blanket of filter fabric and rock is placed at the top of the columns. The system allows pore-pressure dissipation through the column during an earthquake and reduces the potential for liquefaction and lateral spreading by densifying the soils.

A cross section of the reconstructed wharf is shown in figure 5.

The seismic design criteria used for the reconstructed wharf is:

1. Compliance with UBC seismic zone 4. The seismic service lateral acceleration on the wharf is to be 0.2g as shown here:

SEISMIC DATA	MAJOR EQ (g)	MINOR EQ (g)
Peak ground acceleration(P):	0.4	0.3
Spectral ratio (SR):	2.5	3.4
Ductility Factor (Z):	5.0	5.0
Lat. EQ coeff=(P x SR / Z)	0.2	0.2
Note: SR = 2.5 is the mean value ; 3.4 is the value one standard deviation above the mean		

2. Slope to have a static factor of safety of 1.5 under vertical gravity loads.

3. Slope to have a horizontal seismic factor of safety of 1.2 under a pseudo static coefficient of 0.15g.

4. The dynamic displacement due to a peak ground acceleration of 0.3g to be limited to 6 inches.

LESSONS FROM HANSHIN AND GUAM

It is not surprising for a moderate earthquake to cause damage of the magnitude experienced at the Port of Kobe. Moderate earthquakes can cause liquefaction as experienced in Kobe. Liquefaction also occurred at the Port of Oakland after the 1989 Loma Prieta earthquake. Structures on liquefied soils are likely to be seriously damaged.

Where liquefaction is a potential problem, lateral spreading may occur. Waterside and landside rail girders should be tied to each other by a wharf slab or cross struts. In Guam, the girders are tied by cross struts at 54 foot intervals. The maximum deviation of the gage is only 1-1/4 inches. At Kobe, the rail girders are not tied to each other, and the gage has spread by as much as 15 feet, causing extensive damage to the cranes.

To reduce the potential for liquefaction for existing port facilities, liquefiable soils should be identified. If the identified areas are at, or immediately behind, the wharf, soils should be improved. If the identified areas are in the backlands, the port must decide if soil improvement is warranted. This is basically an economic decision. Improvement is costly. To completely eliminate the potential of liquefaction is impractical. At Guam, the improvements are designed to limit and control damage from liquefaction, but not eliminate it. This is also true of the improvements that were made at the Port of Oakland.

After the next significant earthquake, ports at both Guam and Oakland will sustain some damage, but they will remain operational.

For new port construction, non-liquefiable materials should be used for slopes and for fills behind the wharf section. Engineered soil compaction is critical. Other options include sand drains and stone columns.

When soil is liquefiable, pile supported structures perform better than hydraulically filled gravity structures or deadmen-supported sheetpiles. Batter piles should be avoided. During an earthquake, batter piles draw all the lateral load, resulting in concentrated damage at the batter piles. During the 1989 Loma Prieta earthquake, several of the Port of Oakland wharf structures sustained significant damage to the batter piles and their connections to the wharf. The Guam reconstruction uses 24 inch square moment-resisting vertical piles.

If caissons are used as perimeter quay walls, the crane girder system should be isolated from the perimeter support system. This avoids linking the damage to the quay wall with the crane rail system.

Earthquakes will come again. After any catastrophic event, there is a public outcry for foolproof structures. The challenge to the professional engineer is to learn from the event, improve designs, and always work for a balance between recklessness and extravagant conservatism.

Guam’s reconstructed wharf, as well as Port of Oakland’s repairs, strike such a balance. The wharves will remain operational and provide a lifeline during the traumatic days immediately following a significant earthquake. As we continue to assess the impact of the Great Hanshin earthquake on Kobe, and begin to think of design improvements, we must keep in mind our challenge: recklesness vs. extravagant conservatism.

ACKNOWLEDGMENTS

The authors credit the success of their operation in Guam and Kobe to the prompt actions taken by American President Lines immediately following the 1993 Guam earthquake and the 1995 Hanshin earthquake.

Seven days after the earthquake at Guam, the wharf was back in operation and container traffic had resumed.

Ten days after the earthquake at the Port of Kobe, American President Lines was the first major shipping company to service self-sustaining container vessels. During that time, temporary ramps were designed and built, and APL’s three container cranes were secured from further damage in a future aftershock.

In both instances, early recovery efforts were successful because of the Port's rapid response, a prompt initial investigation and assessment of the damage, and the design team's previous experience with repairs of similar structures following the 1989 Loma Prieta earthquake and the 1994 Northridge earthquake.

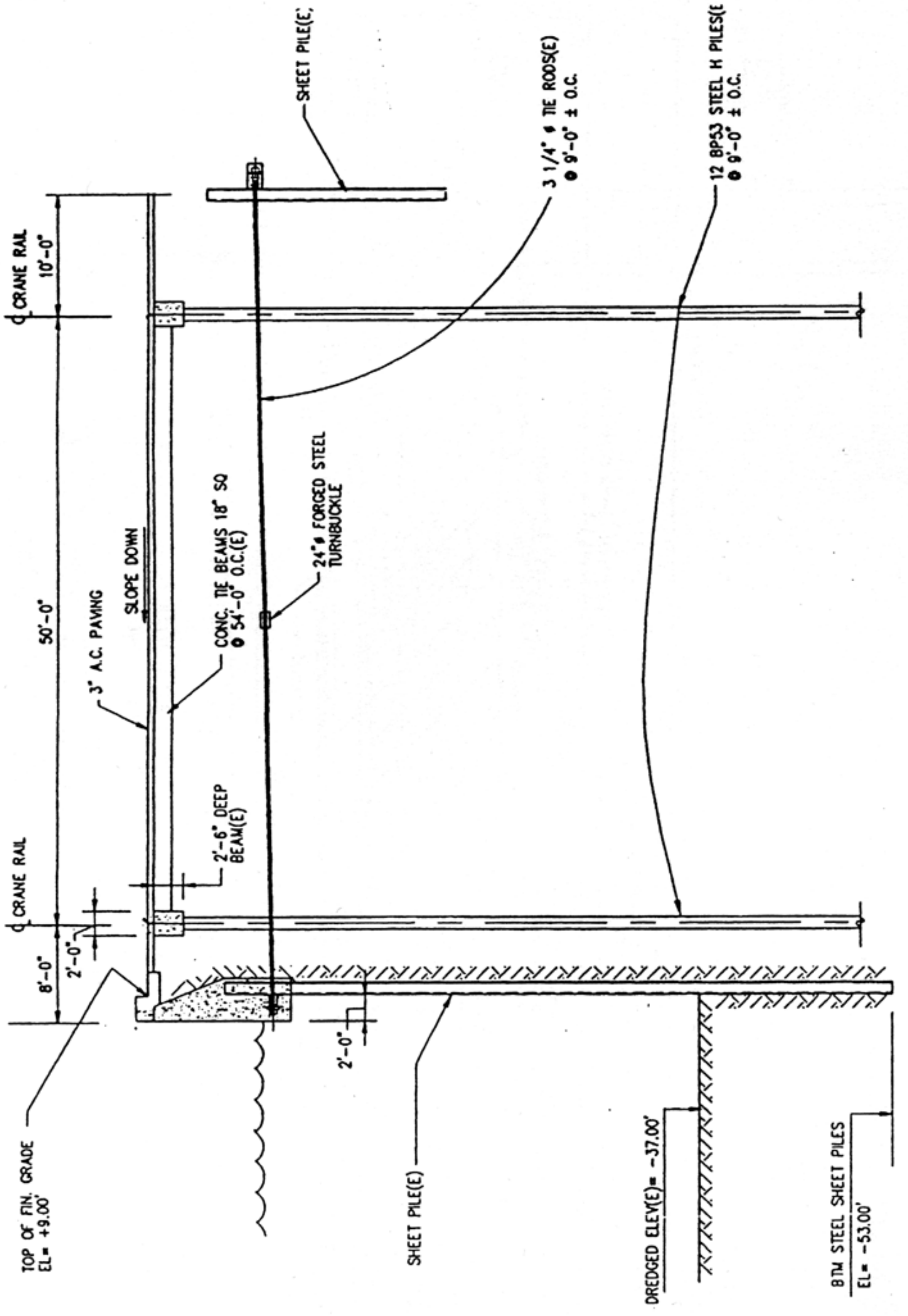


Figure 1 - Original Wharf, Port Authority of Guam

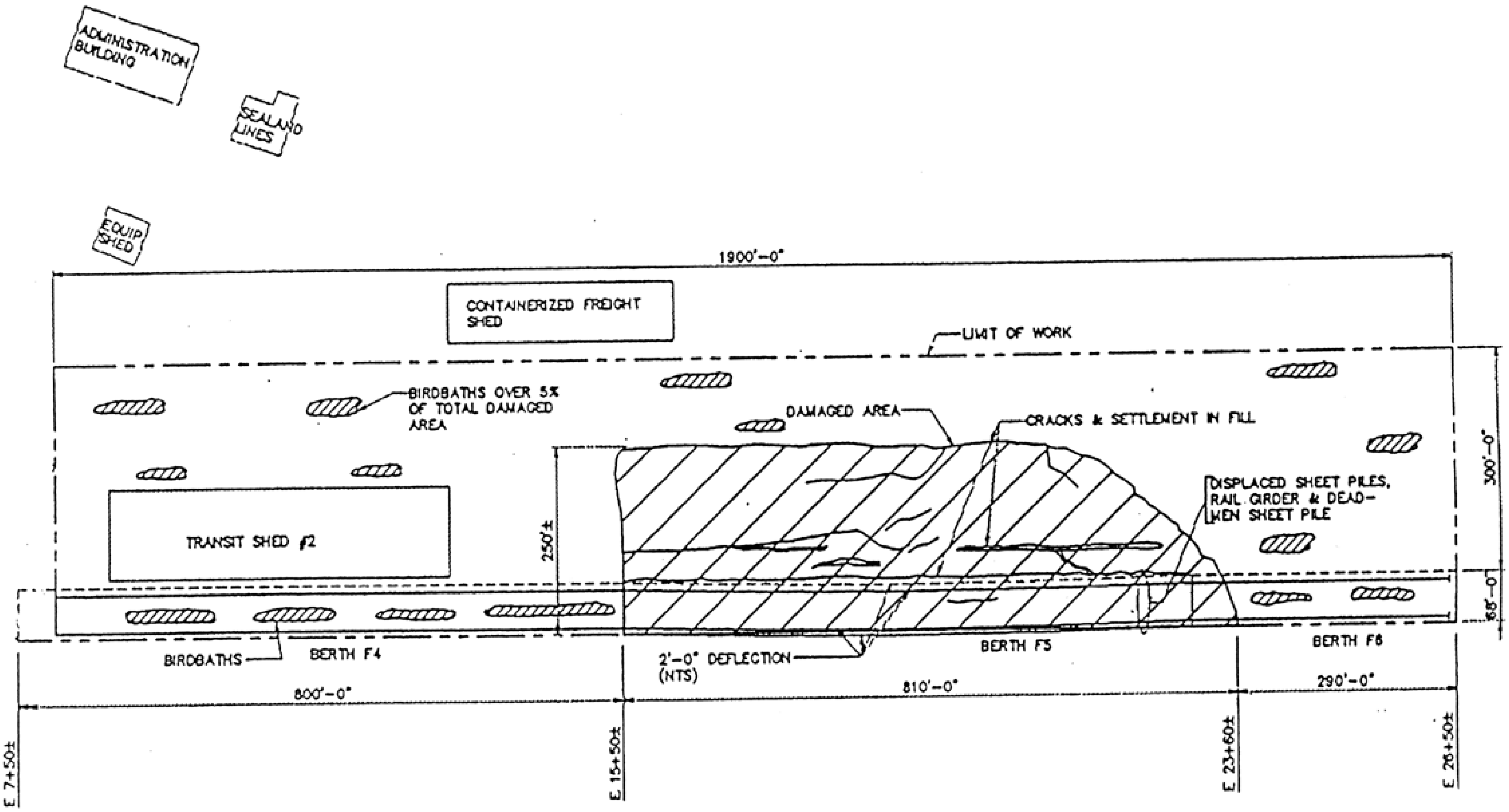
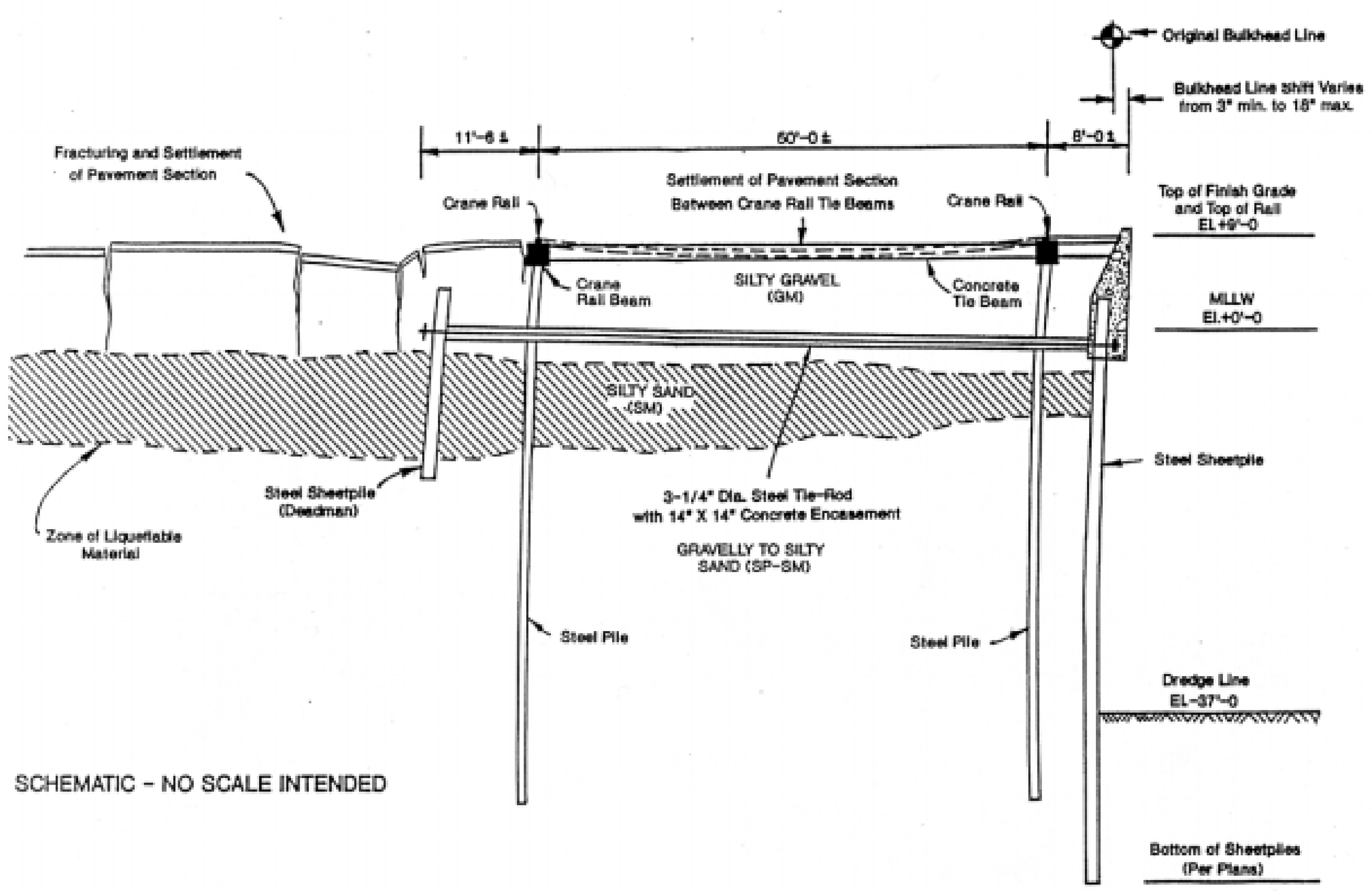


FIGURE 2 - WHARF BACKLANDS DAMAGE
PORT AUTHORITY OF GUAM



SCHEMATIC – NO SCALE INTENDED

FIGURE 3 - WHARF MOVEMENT AND CRACKING DUE TO EARTHQUAKE
PORT OF GUAM

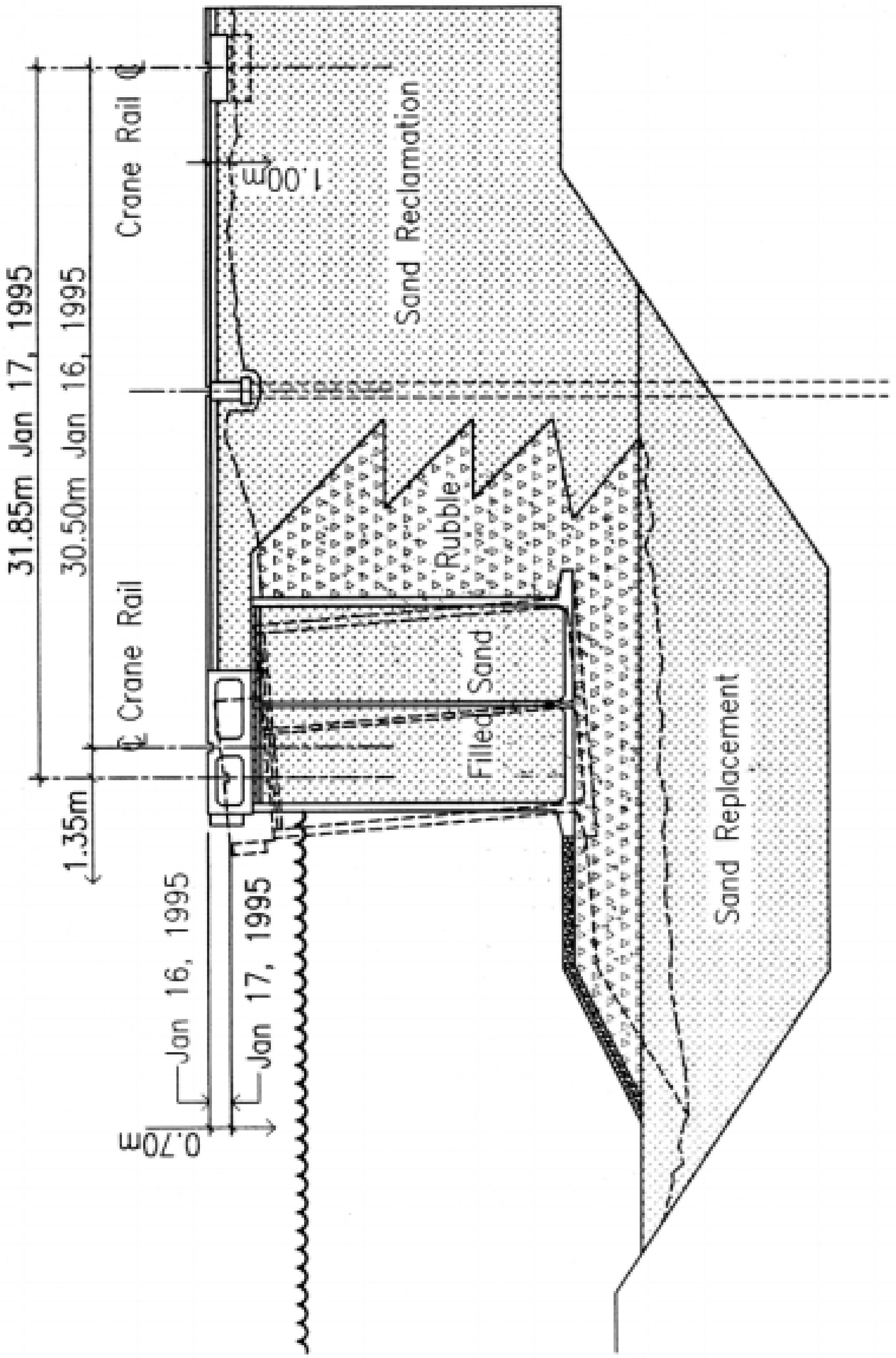


Figure 4: Wharf Construction and Damage – Port of Kobe

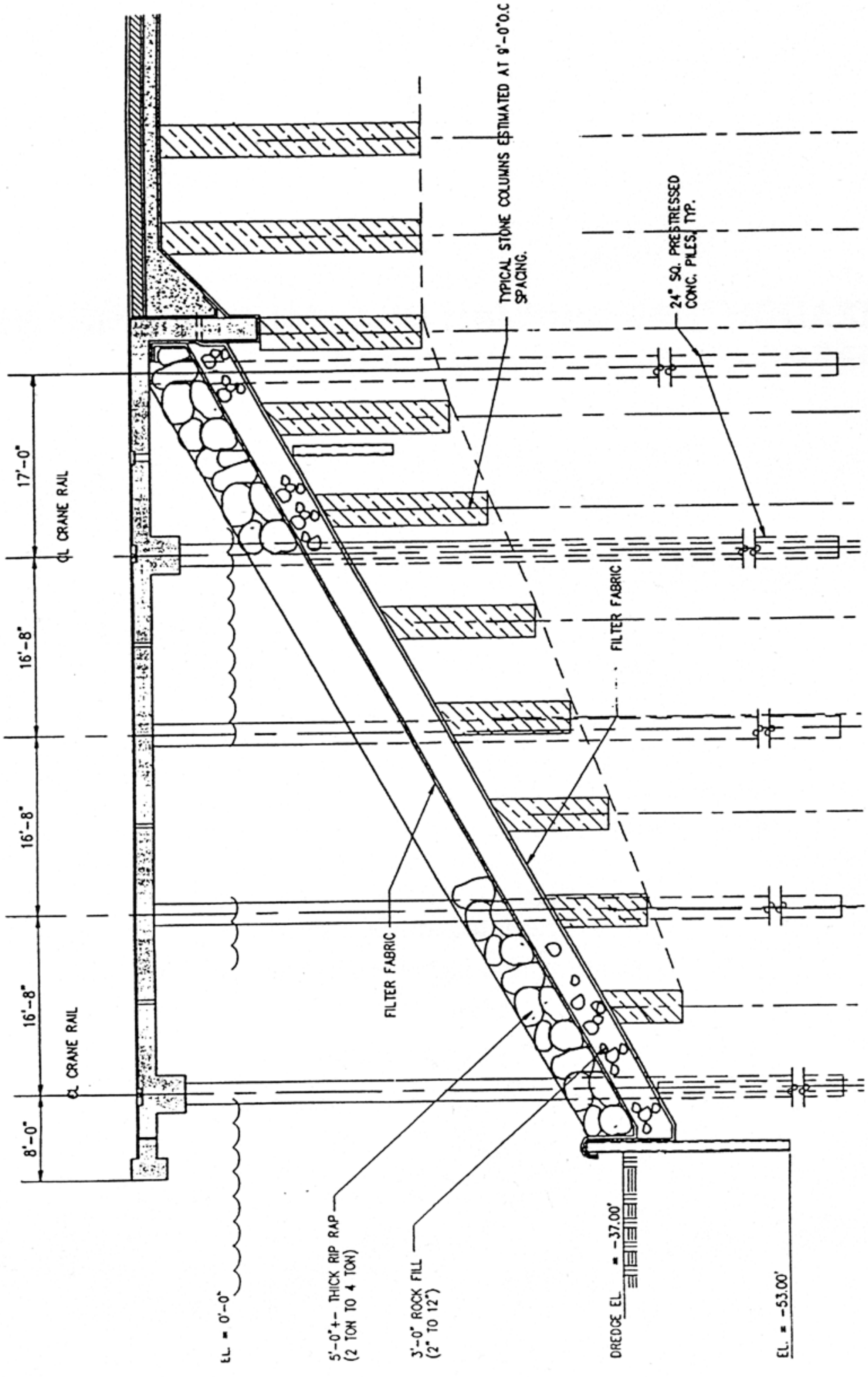


Figure 5 - Wharf Reconstruction, Port Authority of Guam