An Innovative Bulk Barge Fender System

The extent, layout and connection method make the use of a fender system composed of used tires an economical as well as an inventive engineering solution.

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The Massachusetts Water Resources Authority (MWRA) is constructing a $3 billion wastewater treatment facility on Deer Island in Boston Harbor. This construction project — as well as several related construction projects in the Boston Harbor area — is known as the "Boston Harbor Project." In order to provide adequate access to the Deer Island construction site and to reduce passenger vehicle and heavy truck traffic on narrow streets on the land route through the town of Winthrop, the MWRA began construction of a marine terminal on Deer Island in June 1988 (see Figure 1). This facility has been in service since May 1990.

The terminal site is on the west side of Deer Island (which is actually a peninsula) near its southern tip. The marine terminal is comprised of a 300-foot-long passenger ferry dock, two roll-on/roll-off (RO/RO) truck barge docks and a 900-foot-long bulk barge dock that is divided into three berths to accommodate three barges at a time (see Figure 2). This marine terminal is used on a daily basis by up to 1,500 construction workers commuting to and from the island at the ferry dock, four barges at the RO/RO dock and up to six 3,000-ton bulk barges carrying large equipment, armor stone, structural fill, excavate, aggregate, cement powder, precast concrete, sanitary sludge and sodium hypochlorite at the bulk barge dock.

Prior to the start of the marine terminal, engineering studies were prepared that evaluated the natural conditions at the proposed terminal site and the various types of activities, construction equipment and marine vessels the terminal would be designed to accommodate. Boston Harbor has an average tidal range of 9.5 feet. The longest open fetch is 3 miles to the southwest. During the winter, strong winds from the northwest blowing for several days at 25 to 45 knots commonly occur once or twice a month. The region's most severe storms generally produce easterly to northeasterly winds for three or more days. These "Northeasters" occur on average once or twice a year.

The terminal site is protected by the island from direct exposure to open ocean waves generated by the Northeasters, but long period swells up to approximately 6 feet diffract

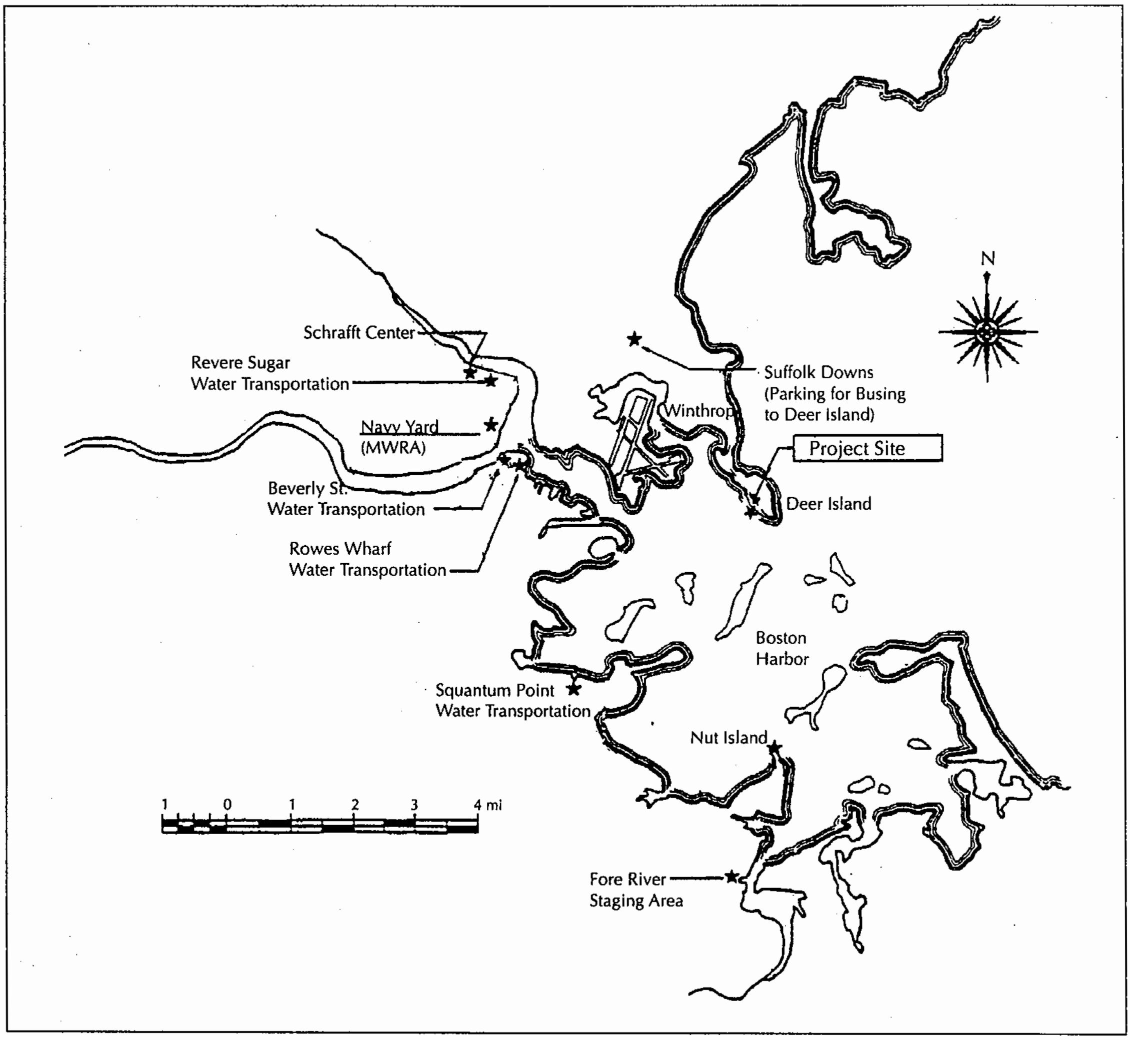

FIGURE 1. Location of the project on Deer Island.

around the southerly tip of Deer Island and travel parallel to the bulkhead barge dock. Waves of this magnitude were observed during the No-Name storm of October 1991. Winds from the northwest have been observed to generate short period waves up to approximately 4 feet. Marine terminal operations at Deer Island are cancelled when wave heights are in the vicinity of 2.5 feet or higher, which occurs approximately five days per year (based on the experience over the last six years).

Bulk Barge Dock

The original fender system (see Figure 3) had to be replaced since it was prone to several types of failure. The decision was made to completely remove the bulk barge dock fender system and replace it with a new system of recycled heavy rubber tires. While tires have been used for countless makeshift fenders, the extent, layout and simple but effective method of connecting the tires (and their service life) are what make this used tire fender system "innovative." The bulk barge dock provides 18 feet of water depth at mean low water and the distance from the top of the bulkhead to the design mud line is 36 feet. The bulkhead is made up of PZ-40 steel sheeting with a 7.5-foot reinforced concrete cap beam. The cap beam overhangs the sheeting by approximately 4 inches at the bulkhead face. The bulkhead has a backup wale that is tied-back by tension rods through

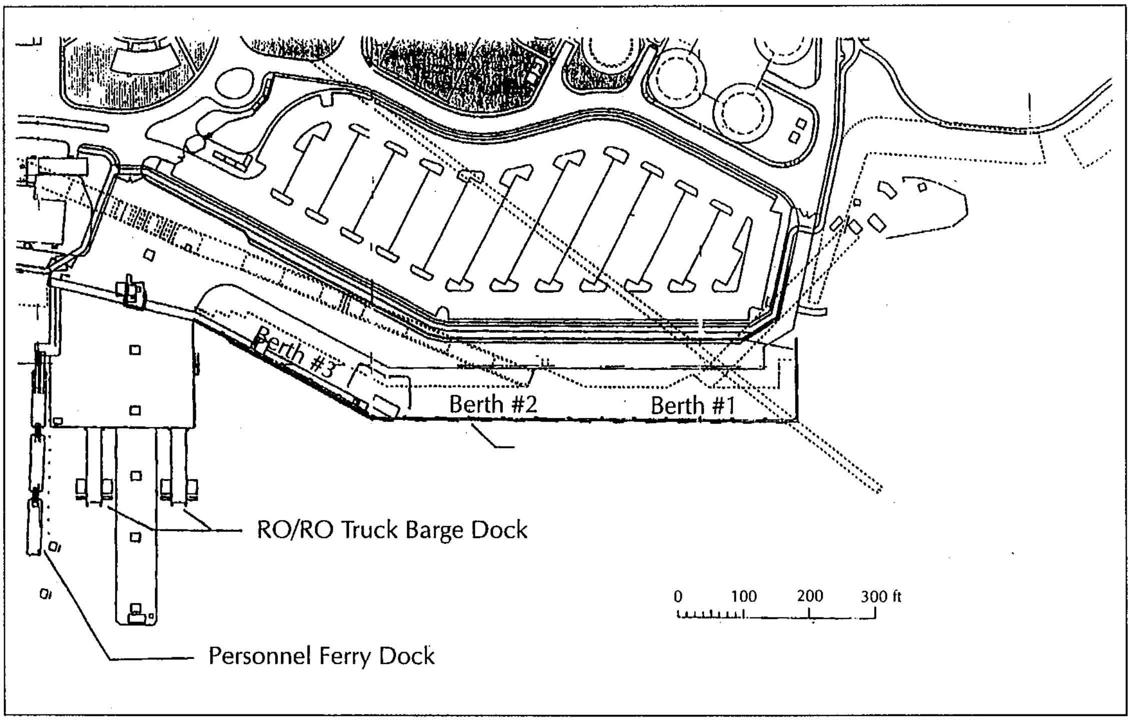

FIGURE 2. The marine terminal at Deer Island.

sleeves in a pile-supported relieving platform deck to batter piles.

The fender system was constructed as part of the original marine terminal construction

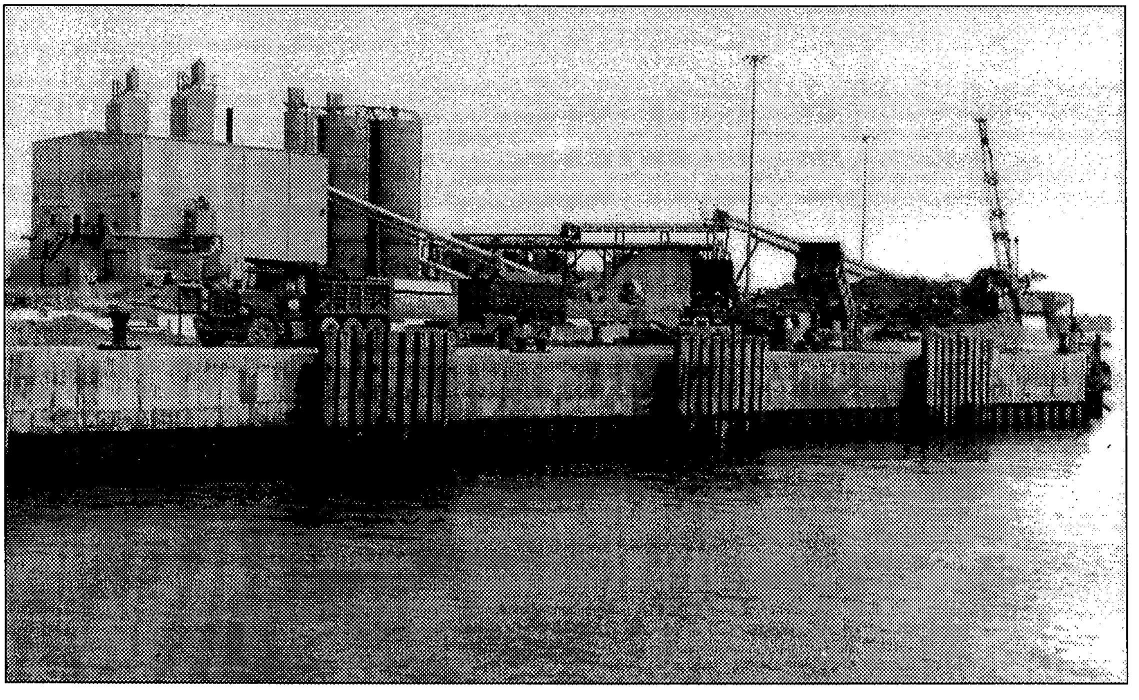

FIGURE 3. The orginal fender system installed at berth #3.

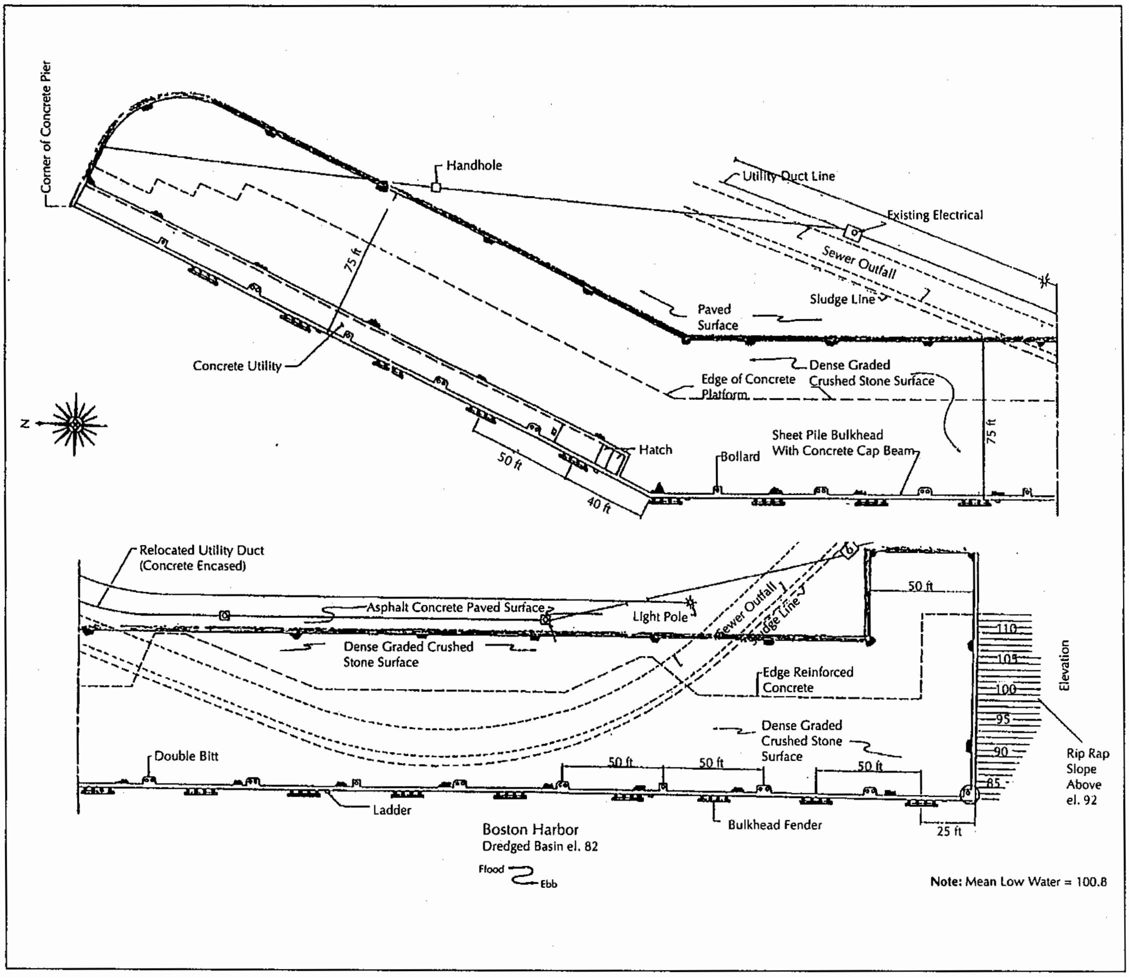

FIGURE 4. The original fender design.

project. The original fender design was an arrangement of steel framed panels with oak studs facing on 50-foot centers with 35 feet between panels (see Figures 3 and 4). Each panel measured approximately 18 feet vertically and 15 feet laterally and was supported by four slotted hinges (see Figure 5). Monel hinge pins (each 12 inches long by 1.875 inches in diameter) slid in the slots. These hinge pins were held in place by the pin flange at one end and a monel washer and cotter pin at the other end. The slots allowed each panel to move up to 7 inches along the bulkhead against the resistance of sixteen rubber fender blocks, each 12 by 12 by 12 inches with a 5-inch cylindrical hollow core held in position between the fender panels and the bulkhead by clips. The design basis of the panels provided for direct load and assumed that while barges were docking they would move very little laterally along the bulkhead. The design also assumed that the fore and aft axes of the barge would be less than 10 degrees from parallel to the bulkhead. The hinges were, therefore, not designed to tolerate significant lateral loads.

After the marine terminal construction had been completed, bulk barge berth #3, which is 300 feet in length at the northernmost end of the bulk barge dock (see Figure 2), was designated by the MWRA's Sewerage Division for use in exporting liquid sludge and importing liquid sodium hypochlorite. Because of the very low freeboard of these bulk liquid barges, there was concern that a barge might hang up under the fender panels at extreme low water. Therefore, in 1991, treated wood fender piles

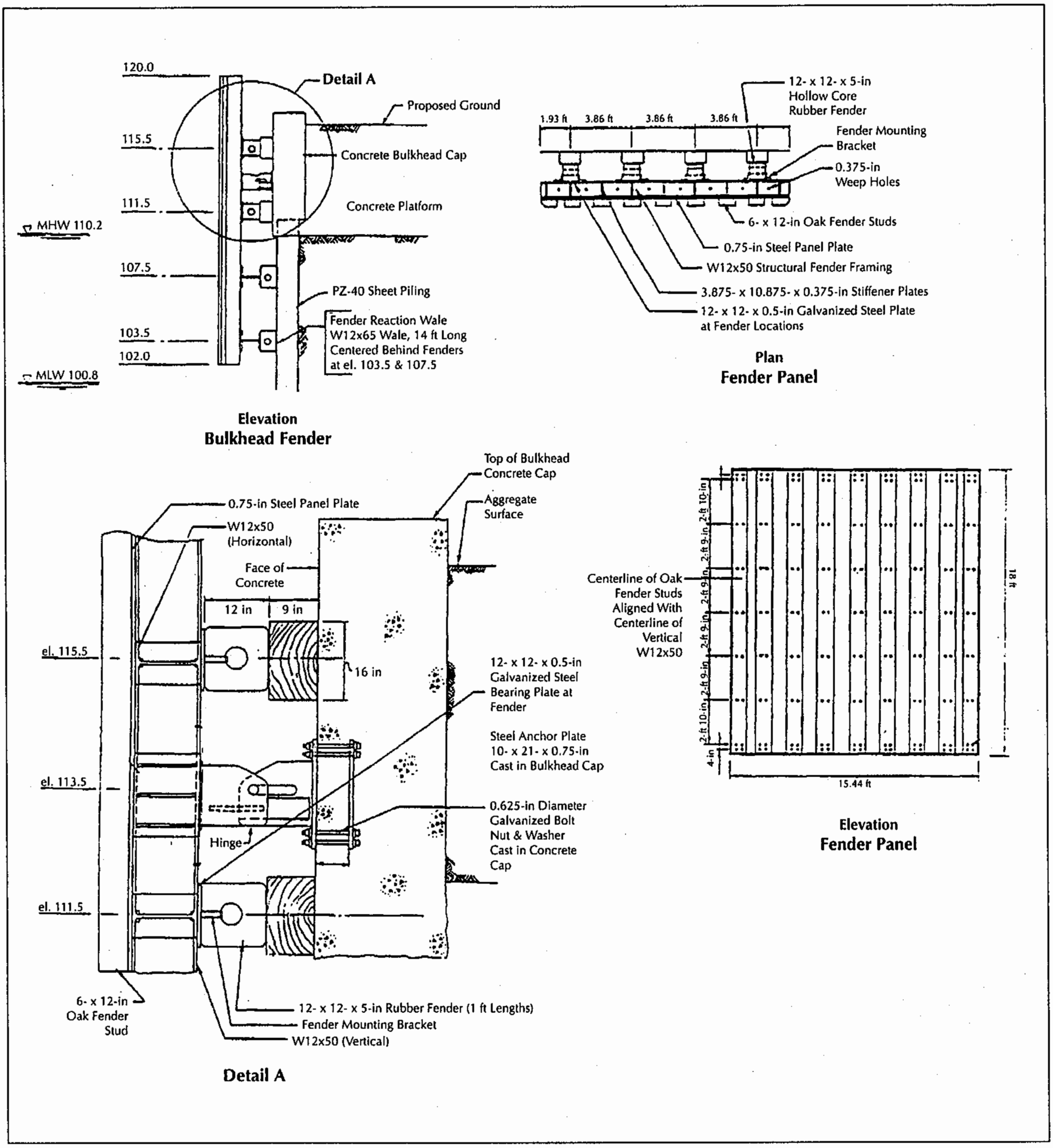

FIGURE 5. A view of a fender panel showing the hinge set-up.

with walers backed up by rubber fender blocks against the concrete cap beam were installed at a cost of $1,600 per linear foot.

After several months of operation of the bulk barge dock berths #1 and #2, two problems became apparent. The monel cotter pins were being sheared off and the monel pins began backing out, causing several panels to fall off. Serious concerns were raised regarding potential injury to barge workers being struck by a falling fender panel. The problem was believed to result from the vertical and horizontal barge action against the fender panels due to wave action. A second problem was that lateral impact loads from the barges were striking the vertical edge of the panels and knocking the panels off (which occurred on at least three occasions).

Considerable discussions on these problems among the project management led to the decision to immediately remove the fender panels to prevent a serious injury caused by a falling panel. Without any fender protection, damage to both the bulkhead and to the barges was, as could be expected, intolerable. Temporary fenders of large used tires were hung at berths #1 and #2 in order to prevent further damage to the dock's cap beam and to the vessels using the facility. The temporary tire fenders were hung with steel cable to existing bollards that were set back from the edge of the dock.

While the temporary fenders provided some protection to the dock, there were not enough bollards to hang tires from and the multiple cables strung along the cap beam posed a tripping hazard to personnel working near the edge of the dock. The cables also caused damage to the bulkhead by cutting into the concrete cap beam and gaps in the temporary fendering arrangement also exposed the bulkhead and vessels to damage.

For additional fender protection, a floating foam-filled steel cylindrical camel onto which tires were threaded was used. The camel prevented direct barge impact to the steel sheeting, especially at low tide, but there was concern that the rubbing of the camel against the sheeting would accelerate the corrosion rate of the sheeting by continually wearing off the oxide layer that formed on this uncoated surface.

In late 1992, Boston Harbor Project management became very concerned about the effects that the problems at the bulkhead pier were having on the Deer Island treatment plant construction. It was decided that "in-house" engineers would study the problem and make recommendations to management on resolution of the problem. The "in-house" engineers went on to provide the detailed design and specifications for the recommended fix.

A number of alternatives were considered to provide adequate long-term protection to the bulk barge dock:

- Reinstall the original fender panels and add additional fender panels of the same design to reduce the spacing between panels.
- Install a wood pile system similar to what had been installed at the northerly end of the barge dock.
- Install a system of commercially available hollow rubber cylinders.
- Install a system composed of used heavy rubber tires.

Several criteria were established to evaluate these alternatives. The chosen system should:

- Provide adequate protection to both the bulkhead and the vessels under reasonable docking maneuvers;
- Resist damage to fenders from normal, lateral and vertical loads to the bulkhead that were presently being applied by the barges and vessels that use the facility;
- Have an estimated life expectancy of at least 10 years (the Boston Harbor clean-up project is expected to be completed by approximately the year 2000);
- Have a minimal maintenance cost;
- Have a low capital cost; and,
- Be relatively easy to repair.

Engineering & Evaluation of the Design Alternatives

Reinstall the Original Fender Panels. The alternative to reinstall the original fender panels and to add more panels focused on issues of the spacing between the piles and proper use of the facility by the tug boat operators. On several occasions, it was considered that poor docking maneuvers may have contributed to some of the damage to the fender panels and to the cap beam. Since any fender system has operational limits beyond which damage to the fenders and/or to the dock can be expected, project management recognized that better control of the usage of the facility had to be achieved regardless of the fender system selected. However, the fender system design must not place unreasonable operating limits on the usage of the facility in order to prevent damage.

After a number of discussions over a lengthy period, it was decided that the problem with the shearing of the cotter pins could be solved by welding the washers to the monel pins but that adding an additional panel between each of the original panels would still leave gaps that would subject the panels to side impact loads even when the facility was used in a reasonably controlled manner. The decision was

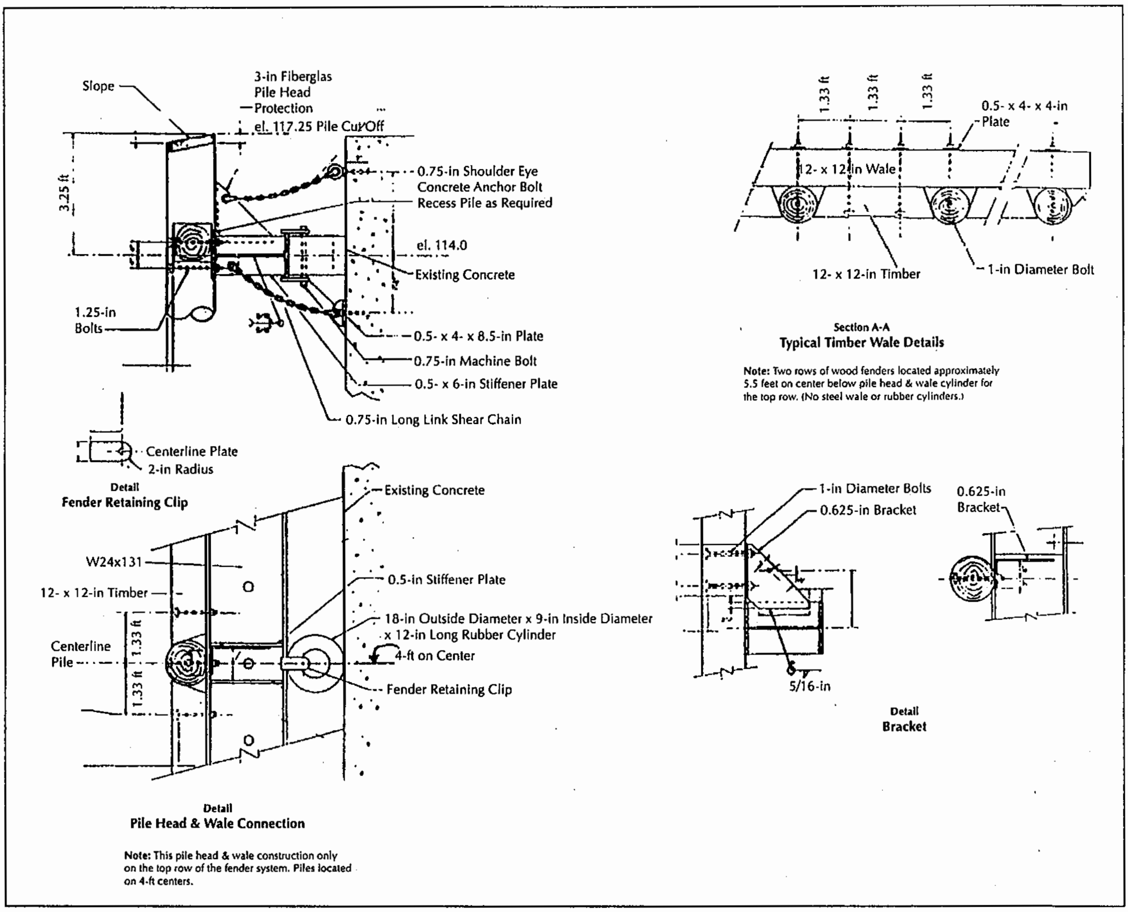

FIGURE 6. The wood pile fender system.

made, therefore, not to reinstall the panels and eliminate this alternative from further consideration.

Install a Wood Pile System. The use of wood fender piles is a common method of providing protection to both dock facilities and vessels. This method of bulkhead protection was selected as a replacement fender system for barge berth #3 shortly after work on the Boston Harbor Project started (see Figure 6). After the completion of the terminal facility construction, berth #3 was designated to be used solely by sludge and sodium hypochlorite barges. Because of the very low barge freeboard of these loaded barges, there was concern that at low tides these barges would hang-up underneath the originally designed fender panels. The decision to replace the fenders at berth #3 was made before the lateral impact load problem became readily apparent.

The advantage of the wood pile system was that it was a proven design that worked reasonably well. A major disadvantage was that the pilings would be somewhat susceptible to damage by impact loads (several piles were broken during the first several months after construction). Additional permits were also required prior to installation, and the system proved to be more expensive to install and repair than other evaluated alternatives. After approximately three years of operation, berth #3 continues to provide good service but at a much lower level of activity and under much less severe docking conditions than at berths #1 and #2, which are used for construction support barges.

The cost evaluation of the wood pile fender system was very straightforward since recent detailed cost information for a similar design was available for berth #3. On a proportionate

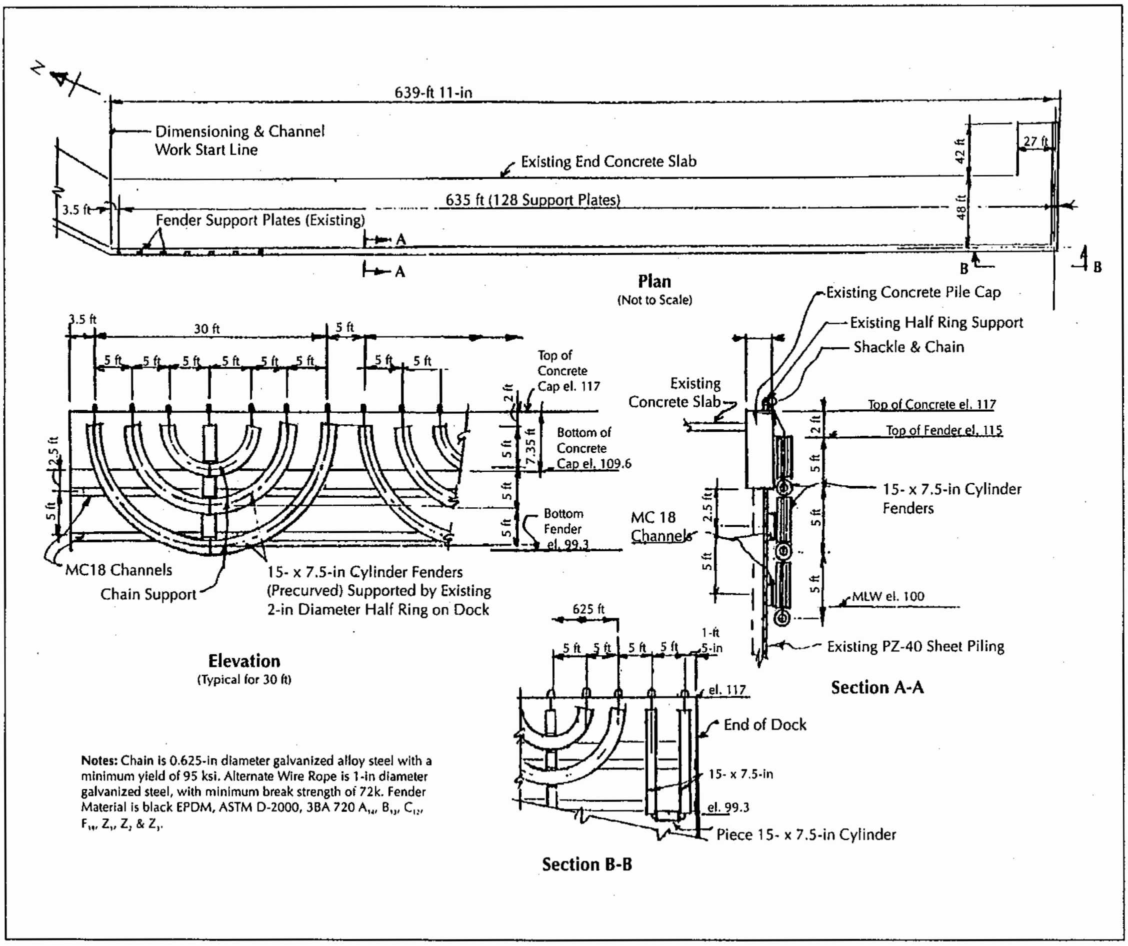

FIGURE 7. The hollow rubber cylinder fender system.

basis, the evaluated cost to construct 639 feet of treated wood fender pile system for berths #1 and #2 was estimated at $1,022,400.

Hollow Rubber Cylinders. A fender system composed of commercially available hollow rubber cylinders was evaluated. The conceptual design for the cylinders was a repeating pattern of three concentric arcs arranged with 5-foot spacing between the arcs. The arcs were formed by hanging the rubber cylinders from galvanized chains fixed at both ends of each cylinder arc at the top of the cap beam (see Figure 7). The outside arc was designed to extend down to the mean low water line.

This type of hollow rubber cylinder fender system limited the engineering and design required since adequate technical properties and information were readily available from the manufacturers of the cylinder fenders. The method used to select the kinetic energy (KE) to be absorbed by this fender system (and also the used tire system) was based on a 3,000-ton barge docking at a 10-degree angle while travelling at 1.5 knots. The results indicated that a 15- by 7.5-inch core rubber cylinder would absorb the calculated energy along a 15- to 20-foot pier contact length while deflecting between 6 to 7.5 inches. The chain selected to support the cylinders was 0.625-inch diameter hot-dipped galvanized chain. The link dimensions for this chain were approximately 2.125 inches wide by 4.5 inches long. This chain was selected for both rubber cylinder and the used tire systems.

To prevent accelerated corrosion of the sheeting with this alternative, and to allow the barges to slide along against the fenders parallel to the sheeting, it was decided that heavy channels should be welded to the sheeting at two elevations across the entire 600-foot length of berths #1 and #2. These channels were not expected to provide total protection to the sheeting from contact with the compressed fender but would significantly lessen the contact. The channels were also selected to spread barge impact loads to the sheeting and prevent direct sudden impact loads to the flute recess especially during docking at low tidal levels.

Because of the relatively low bearing area of the rubber cylinders with respect to the channel (especially with a low freeboard barge at low tide), the wear of the cylinders was a concern. However, a more economical substitute method was not identified.

With the large tidal range in Boston Harbor, the problem of welding of the channels to the sheeting was considered. Because the sheeting is not in a perfect straight line along the bulkhead, shim plates would have to be welded to the sheeting before the channels could be attached. The cost of installing these parallel channels was, therefore, a major cost factor for this system and the tire fender system alternative. Despite the cost, it was important that this protection be provided to the sheeting. The estimated cost for this alternative was $483,640.

Heavy Rubber Tires. The idea to construct a fender system from used tires (which would provide protection similar to commercial rubber cylinder fenders) was derived from the makeshift use of tires to provide temporary protection to the bulkhead and vessels. The temporary fenders were made from very large construction equipment tires. These tires were found to work well but were not extensive enough, especially at low tidal elevations, to provide adequate protection to the bulkhead and barges. In addition, the cables used to support the tires caused a personnel tripping hazard and created excessive damage to the cap beam. The cables cut deep gashes in the concrete cap beam, exposing the reinforcing steel in several places. If used construction tires were to be used for the permanent fenders, the design would have to provide adequate protection for both berths #1 and #2 at all tidal elevations and the support design would have to eliminate cap beam damage and the tripping hazard. There were also questions regarding being able to obtain a large number of suitable used tires that have nearly the same diameter and tread width. Having geometric similarity would allow the fender design to be a regular array. The conceptual design would have to be assured to resist damage and be relatively easy to repair and also provide capital cost benefits over the alternative fender systems.

The availability issue was the first question to be answered in the determination of the feasibility of the used tire fender system. An initial estimate of number of tires that would be needed for the fender system was three hundred tires, each 5 feet in diameter. This estimate was based on a conceptual fender design that would cover the entire bulkhead of berths #1 and #2 with tires from the cap beam to the low water elevation. Such a layout would provide adequate protection to the bulkhead and the unloaded or loaded barges, with low freeboard for the full tidal range. The arrangement would be a single layer of tires laying flat against the bulkhead in a continuous array with each tire in contact at the tread with adjoining tires (see Figures 8 and 9).

A number of calls were made to local contractors and tire dealers to determine if it would be possible to obtain enough suitable used tires. While some tires were available from these sources, it quickly became apparent that this close-to-the-source approach would not provide the number of tires this concept would require. The contacts did, however, identify a regional tire recycler that could possibly provide the tires. Discussions with the recycler confirmed that required 5-foot diameter tires with tread widths from 20 to 24 inches were common and could be provided at reasonable cost in the quantity required.

The tripping hazard and cable damage to the cap beam problems were addressed in this concept by heavy steel mounting plates. The mounting plates would be bent in the middle at right angles and mounted on the edge of the cap beam with half the plate on top of the cap beam and the other half extending down the face of the cap beam (see Figure 10). Specially designed anchors grouted in the top and face of the cap beam would secure the plate to the cap beam. A steel half ring welded to the top of the plate near the bend line would provide the attachment point for the fenders. A mounting

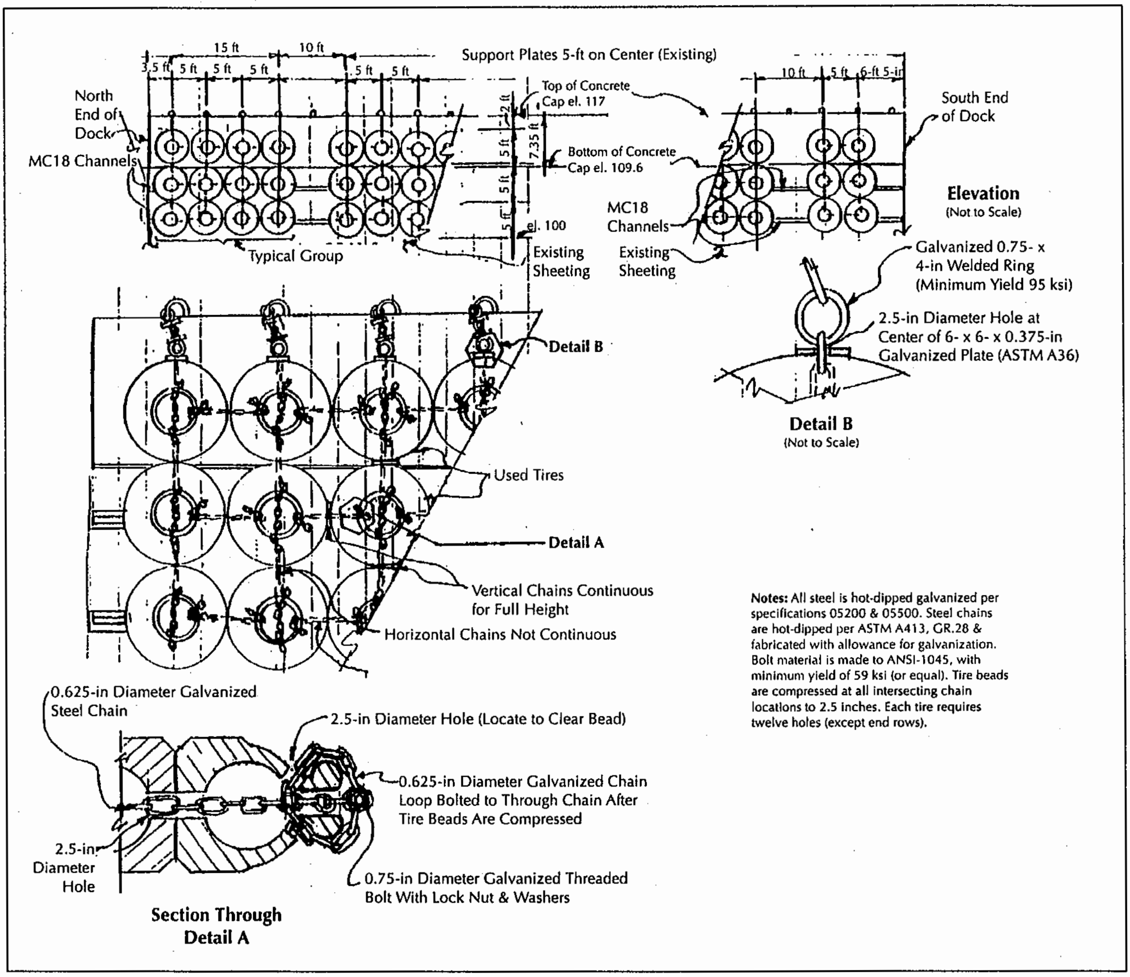

FIGURE 8. The used tire fender system.

plate would be provided for each vertical row of tires. This arrangement would eliminate the problem of the cap beam being damaged by the fender support since the mounting plates would protect the edge of the cap beam. The mounting ring would be positioned at the edge of the cap beam to eliminate the tripping hazard.

The conceptual design for the used tire system assumed the same barge weight, velocity, pier contact length, docking angle and deflection range as was used for the hollow rubber tube system. Since no energy absorption characteristics are available for used construction tires, a typical tire was analyzed to provide this information. The analysis indicated that this size and type of tire would provide suitable energy absorption characteristics.

The problem of tires wearing-off the protective oxide layer from the sheeting would be the same as described above for the cylindrical fender system. Two horizontal steel channels with 4-inch flanges were designed to prevent this problem and to provide a flat contact surface and flush bearing face with the concrete cap beam against which the tires could slide under barge lateral loads.

On the basis of the conceptual design, a cost estimate was prepared. It was estimated that the total installed cost for this system would be $412,840.

System Selection

The decision to select one of the alternative systems was made primarily on the basis of cost since all three alternatives were considered

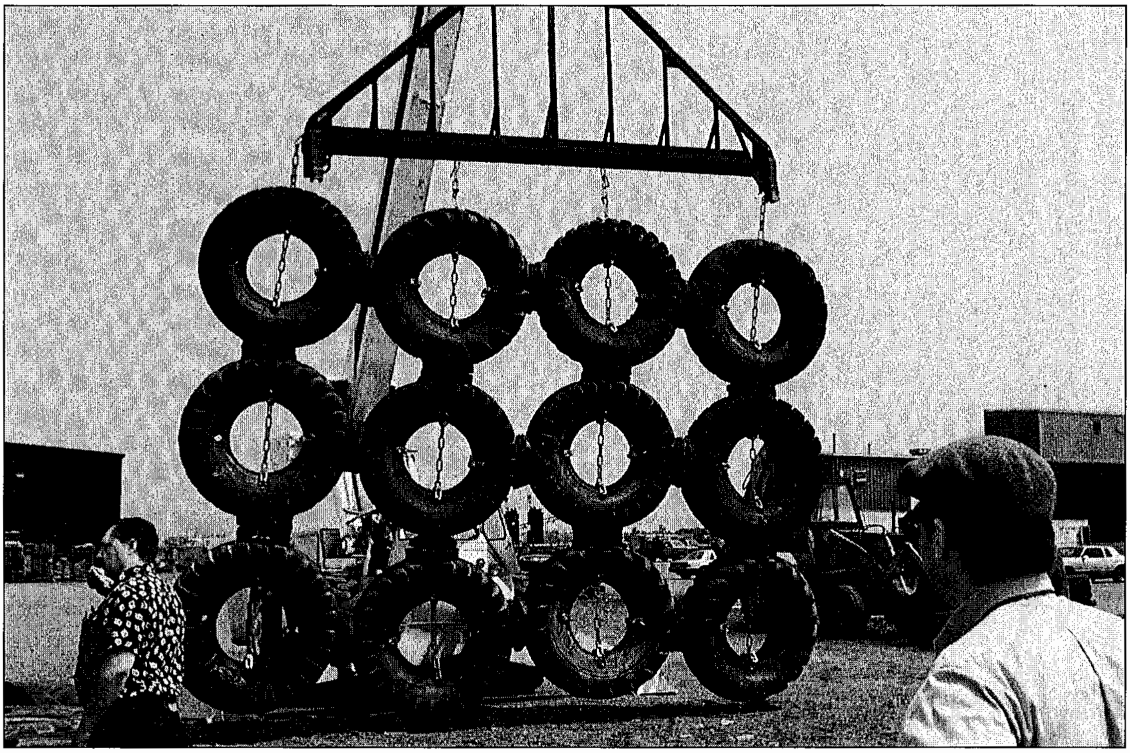

FIGURE 9. A used tire fender mat.

technically acceptable. It was, however, thought that the used tire alternative would be less likely to be damaged by construction usage than the wood pile system. It was also believed that the used tire system would provide more complete protection of the bulkhead than the cylindrical fenders. It was also apparent that since the used tires were constructed with reinforced rubber, longer life could be expected compared to the non-reinforced commercial cylinders. However, there was some technical opposition to this alternative because no experience could be provided for this design concept.

The cost estimates were developed for the hollow cylinder and used tire alternatives and were compared with the adjusted bid cost for the wood pile alternative, which was based on the bid price for the timber pile fender system used for berth #3. The costs are provided for comparison purposes since construction access to Deer Island is limited to scheduled barge and personnel transportation service (which tends to increase construction costs). The result was that the estimated cost for the used tire option was $70,800 less than the cylindrical fenders and $600,000 less than the wood pile fenders. This cost advantage was substantial enough to overcome the objections concerning the lack of experience for this design approach. (It should be noted that much of the design for the used tire and cylinical fenders is the same and that the cost savings in favor of the recycled tire fenders is due to the cost difference in the purchase cost of the fenders.)

Engineering & Design of the Selected System

The design of the used tire fender system can be broken down into the following components:

- Used tire specifications and arrangement;
- Anchor plates;
- Vertical chain supports;
- Horizontal chain tire ties; and,
- Horizontal steel channels.

A good arrangement of the tire fenders was needed to protect both berths #1 and #2 from the top of the cap beam down to approximately

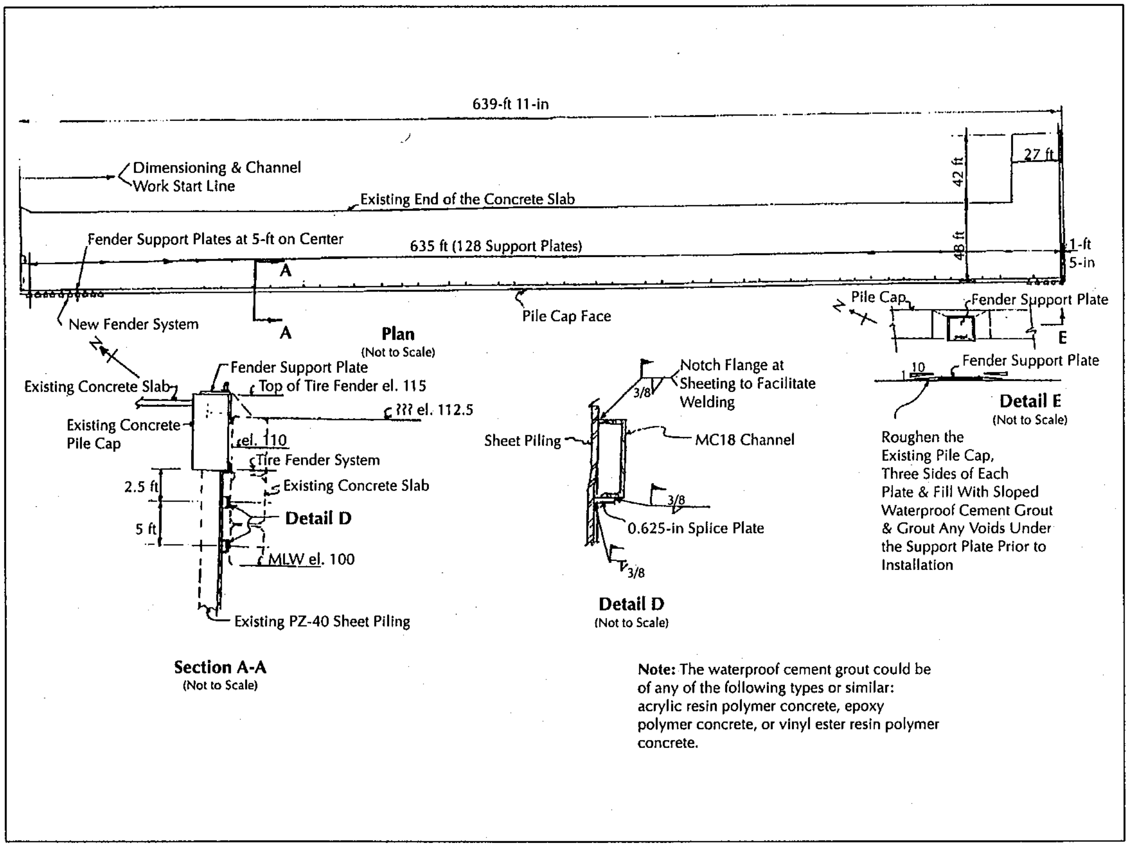

FIGURE 10. The anchor plate design for the used tire fender system.

mean low water. A second requirement was that the fenders be easily installed and maintained. In the conceptual design, the tires were assumed to be arranged in three parallel continuous horizontal rows extending the length of berths #1 and #2. This arrangement was modified slightly during detailed design into fender "mats" with each mat comprised of an array of four tires in each horizontal row and three rows vertically (see Figure 9). The specification required 5-foot diameter tires but slightly smaller tires were also allowed with the addition of heavy rubber spacers to make-up the difference. The mat dimensions were controlled by these adjustments to a uniform 20 feet horizontally by 15 feet vertically.

The used tires weighed approximately 350 pounds each and the fender mats totalled about 2.25 tons. A 5-foot horizontal space between mats was left to allow ladders to be placed as needed (required by OSHA) and to provide room for the horizontal movement of each mat. The 5-foot gaps between mats were not thought to significantly expose the bulkhead to barge impacts. If experience did, however, show that the gaps needed to be protected, it would be possible to add tires into the gaps and support them from the anchor plates on the cap beam and also secure them to the adjacent mats. The arrangement of the tires into mats allowed preassembly at the manufacturer's shop.

Since the rubber in the used tires varied, requirements were controlled by specifying a minimum of 0.25-inch depth of remaining tread for the selected tires. This criterion would provide approximately 1.5 inches minimum total rubber thickness through the tire at the tread. Tires specified were 20.5 by 25 inches minimum to 23.5 by 25 inches maximum. No material property or load energy data were available for the used tires. All values were calculated. The analyzed load/energy deflection values were close per linear foot to those for the

15- by 7.5-inch core cylindrical fender system for the spacing arrangement selected. In order to calculate the KE on the dock, the barge tonnage was increased to reflect the displacement (dead weight) tonnage. Using a barge forward velocity of 1.5 knots, the velocity normal to the dock was calculated using a 15-degree angle. Also, the hydraulic effect of the water mass moving with the barge (which increases the energy of the barge) was included in the calculations. This approach is a common method used by the manufacturers of marine fender systems. The calculated KE on the pier due to the design docking approach was 40,290 foot pounds.

Maximum loading parallel to the pier was calculated to be approximately 27,000 pounds per chain. This value was used to determine the chain size to be used for the fender system. Hot-dipped galvanized 0.625-inch diameter long link, 95 ksi minimum yield alloy steel chain was selected. The long links of chain allowed direct bolting of chain to chain using 0.75-inch diameter high-strength hot-dipped galvanized bolts to assemble the tires into mats. The mats could then be easily handled at the shop and at the construction site by a small crane with a spreader bar.

The ability of the fender mats to absorb impact loads from a loaded barge was validated by an engineering analysis. The original basis of design indicated the cap beam capable of resisting the 3,000-ton barge docking loads. Calculations confirmed that 18-inch channels could adequately distribute the fender loads to the sheeting.

The anchor plates were designed to resist horizontal loads from barges impacting the bulkhead with lateral motion, causing the fenders to slide laterally and producing lateral loads on the anchor plate. The lateral design load used for each anchor plate dowel (including a minimum safety factor of 1.5) was 42,000 pounds.

The anchor plates also must resist the vertical dead weight of the fenders and the down loads of the barges rising and falling with the tide (as well as with swells) while rubbing against the fenders. An anchor plate is provided for each vertical row, and is designed to take the worst-case loads generated by one vertical row of tires in the fender mat. Based on a 3,000-ton, 300-foot-long barge pressing equally against the fenders along its length and sliding down against the mats, the vertical load calculated was 27,500 pounds per anchor plate.

Given the lateral and vertical anchor loads on the anchor plates, it was decided to attach the anchor plates to the cap beam with anchors grouted to the cap beam and welded to the anchor plate. Each anchor plate was designed to be fixed by one anchor placed vertically into the top of the cap beam and one anchor placed horizontally into the vertical face of the cap beam. The anchors used are 2.5-inch diameter double extra-strong steel pipe 18 inches long (see Figure 10).

The anchor plate was also designed to protect the cap beam from wear from the chain rubbing and sliding on top of it. In order to prevent such wear, the anchor plate is bent at right angles to conform to the edge of the cap beam and extends 22 inches down the face of the cap beam and 22 inches back from the edge on top of the cap beam. The anchor plate is 20 inches in length along the cap beam. An anchor plate of this size provides ample protection to the cap beam even when the support chains swing due to lateral fender movement during docking.

In order to provide adequate distribution of forces from the mounting ring through the plate to the dowel anchors, the anchor plate is constructed of 0.75-inch-thick hot-dipped galvanized steel. The plates are bedded on the top and face of the cap beam in a non-shrink grout to provide a firm load transfer base.

One of the most important design considerations of this project was the method connecting the tires to the vertical support chain. In order to reduce loads on the tire attachments to the vertical chain, the chain is continuous vertically through the tires. Vertical loads on each tire are, therefore, transferred to the support chain and not to next tire above. Each tire is attached at the top and bottom to the vertical chain by short lengths of chain wrapped around both tire beads through holes cut in the side walls and bolted to the support chain. These multiple attachment points to the tires distribute the loads on the tires and utilize the tire bead (the most heavily reinforced part of the tire). In order to prevent damage to barges

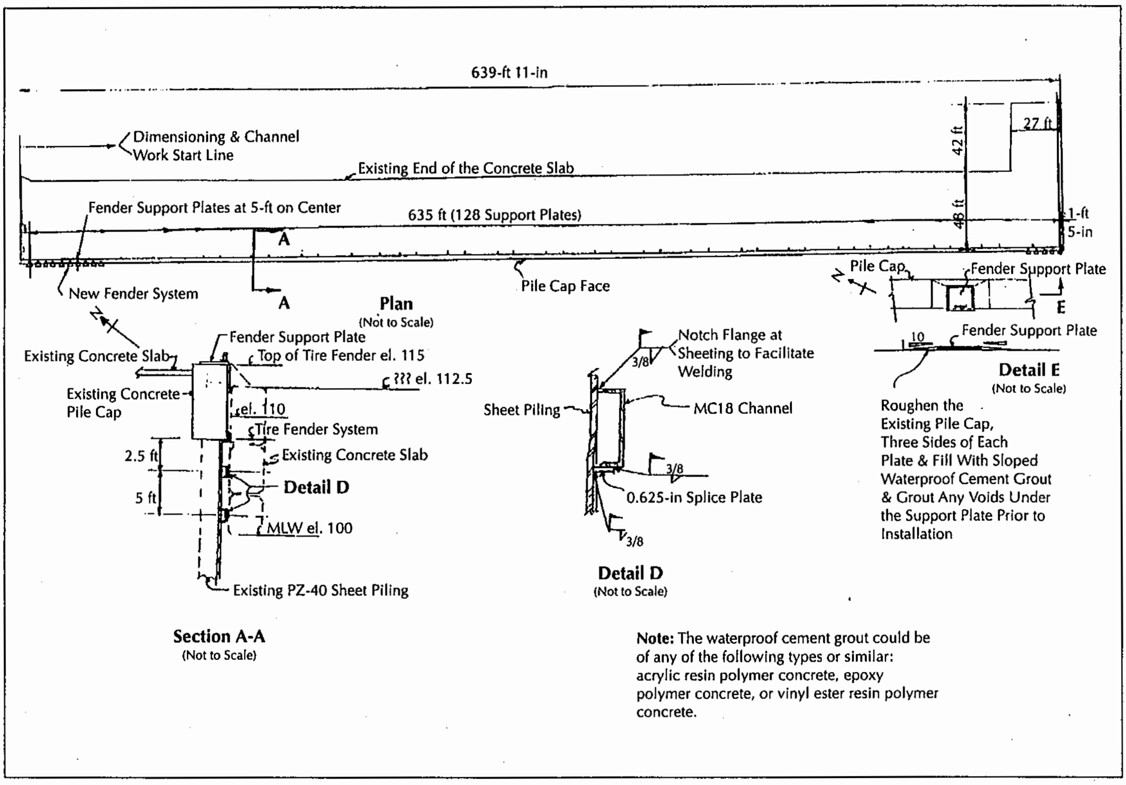

FIGURE 11. The channel plate for the used tire fender system.

and to the bulkhead sheeting, the tire beads were compressed together during assembly to keep the connecting chain and bolts as short as possible in order to prevent chain contact with the barge hulls or the sheeting. This connection design was selected after several other prototype connection types were tried using metal clips or long bolts.

The horizontal connections between tires is similar to the vertical chain support except that the horizontal chains are not continuous horizontally across the fender mat. This design allows the mat to stretch when subjected to the lateral loads that might be expected during docking. This stretching reduces peak lateral loads on the vertical chain supports and anchor plates and absorbs docking energy.

The horizontal channels slow down the continual wearing away of the protective oxide coating on the sheeting. They also spread the load from the docking impact across the sheeting in order to prevent local impact damage to the sheeting. The selection of the size of the channel was also based on the fact that the width of the channel would have to provide an acceptable bearing area with the tires as well as structurally distributing loads to the dock's sheet piling system. An MC18x42.7 channel was selected as sufficient to spread the impact loads (see Figure 11). Because of the irregularity of the face of the sheeting and the locations of the channels in the tidal zone, the welding of the channels to the sheeting was the most difficult aspect of the construction of the fender system. Much of the attachment welding for the lower channel was done under water.

The minimum useful life required for this fender system was ten years, based on the time needed to finish the construction of the wastewater treatment plant at Deer Island. Even though tires have a very long aging life expectancy, the demanding conditions at the barge dock caused some concern and a monitoring program was established. Thus far, monitoring of the fender system has detected minimal wear. It was expected that occasional accidental damage would occur that would have to be repaired. In fact, the fender system has suf-

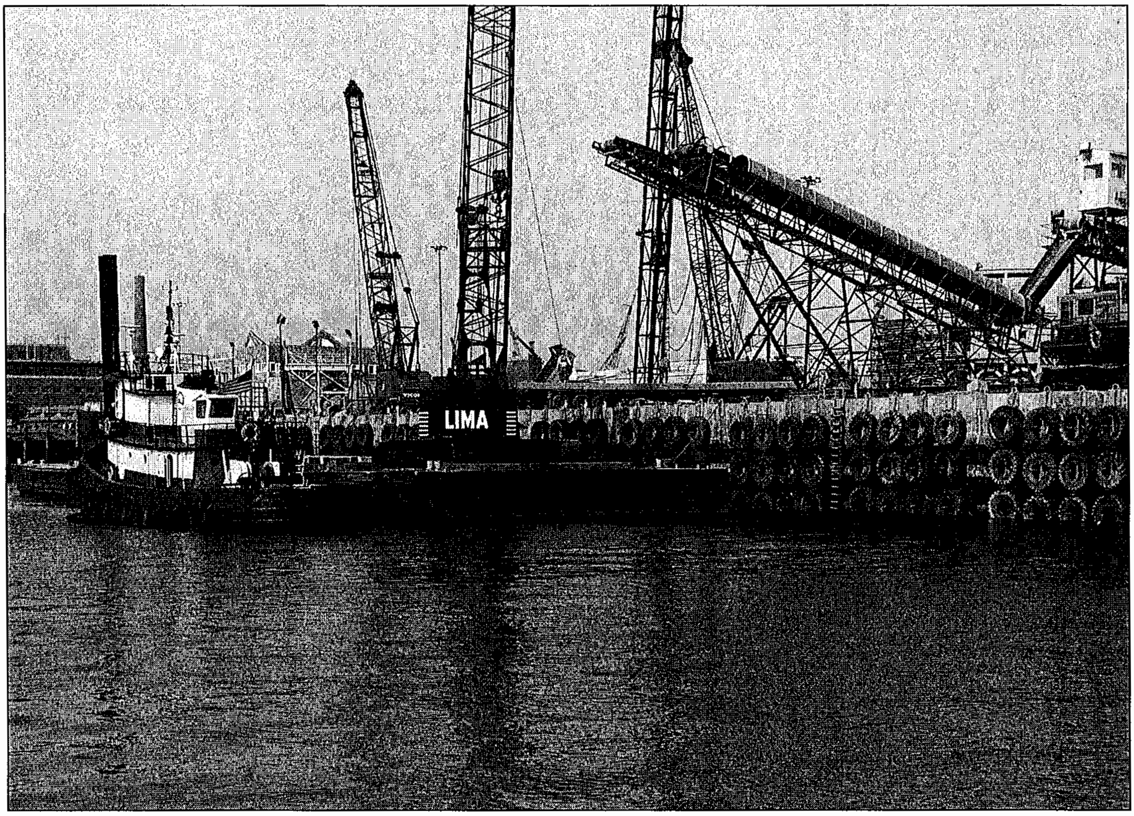

FIGURE 12. The used tire fender system at berth #2, with a docked barge.

fered some damage to date, but not from docking causes. The primary determinant for the life expectancy of the fender system is the corrosion resistance of the chains and bolts (necessitating hot-dipped galvanization).

Operational Experience

The tire fender system has been in operation since 1994 with minimal damage to date caused by any of the barge operations (see Figure 12). The most significant damage to the fenders was caused by a large hydraulic excavator that ripped up several anchor plates while removing excavate from the top of the cap beam. This damage is considered to be caused by misuse. The remaining anchor plates in the damaged mat held the mat in place and continued to funtion. All loads were transferred to the remaining anchor plates by the horizontal tie chains.

A questionnaire was drawn up and given to tug boat captains using the facility in order to evaluate its performance. Five captains responded to the questionnaire. They had an average of five years of experience each as tug boat operators. Their opinions were unanimously supportive of the tire fender system and they all felt that the system worked well in protecting the vessels and the facility. If given a say in choosing fender systems, they would choose it over a wood pile system.

Summary

Used tires have several inherent engineering properties that can be used to advantage for marine fendering. These beneficial properties include:

- The resilience and toughness of the rubber; and,
- The tensile strength of the steel or synthetic fabric reinforced sidewall, tread areas and beads that assist in resisting large tensile forces.

In fact, the reinforcement in the used tires makes them superior in many cases to new rubber products that do not have any reinforcement. The unique aspect of this project was the use of simple but effective tire arrangements and connections to take maximum advantage of all these used tire properties.

The used tire design selected in this project provided an inexpensive, low-maintenance-cost fender system that provides excellent protection to both vessels and the facility. These savings in installation and maintenance costs benefit the MWRA's rate payers and reflect its continuing efforts to provide quality service at the lowest cost. Additional benefits that were derived from using the used tire design include:

- A useful second-life recycling option for normally discarded used tires; and,
- The elimination of additional permitting requirements that would have been required for systems that required additional piles.

In several respects, a lack of basic engineering data on the properties of the used tires limits the ability of the engineer in evaluating their full potential. For this reason, further tests are being conducted on used tires that will provide additional information.

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