Stress-related "unzipping" of adjacent steel sheets can also be an avenue for soil migration through the bulkhead. This is commonly located deeper in the water column where soil pressures are higher.

Other pathways for soil loss include horizontal joints in sheet piles where a "follower" section of sheet pile has been placed on top of an overdriven sheet pile and locations where storm drains penetrate the bulkhead.

A.8.2.2 Concrete Sheet Pile Bulkheads Prestressed and conventionally reinforced concrete sheet pile retaining structures have proven to be problematic because of loss of retained soil, particularly when the backfill material is a fine-grained, cohesionless material such as hydraulically placed dredged material. The typical pathway for migration of the fill material through the bulkhead is via tongue-and-groove joints between adjacent sheets, as shown in Fig. A-33. As indicated in the discussion for steel sheet pile bulkheads, when subsidence is in the topside pavement, the reason can usually be determined by a careful above and/or below-water investigation of the adjacent retaining structure.

In the case of concrete sheet piles, an obvious indicator of soil migration through the joints is the presence of soil accumulation in a "talus cone" fashion at the bottom of the joint, as seen in Fig. A-34. Presence of this material can only be determined by underwater inspection. Generally, the presence of the accumulated soil is of a different character than the adjacent bottom. If sufficient propeller-wash or other scour-type activity occurs along the wall, the material may not accumulate in the manner shown.

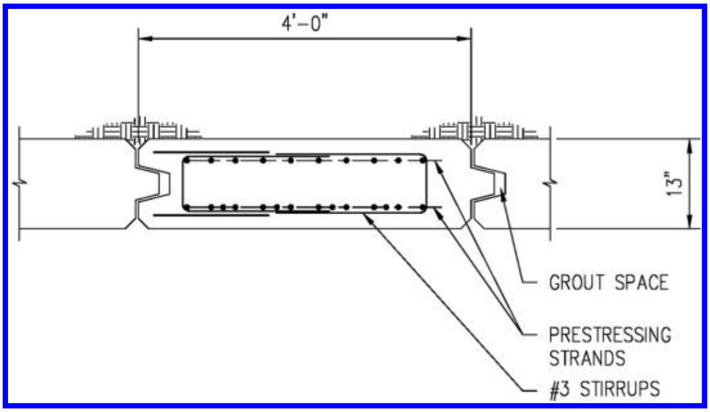

Fig. A-33. Plan section of a prestressed concrete sheet pile with tongue-and-groove joints—a common pathway for soil migration
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

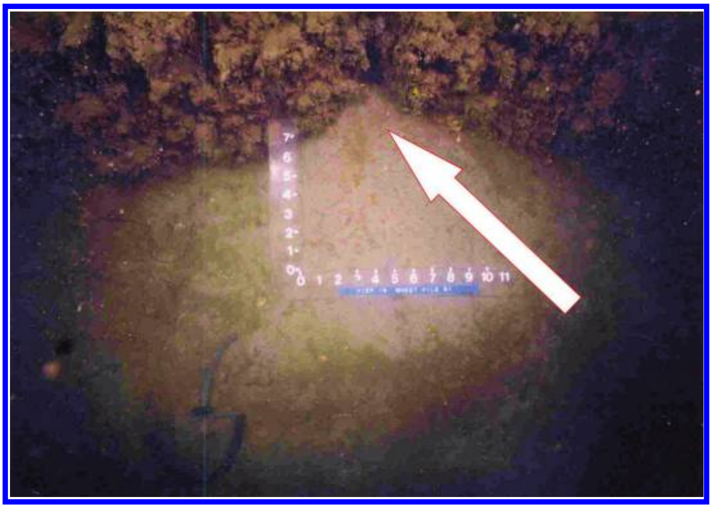

Fig. A-34. Looking down at the bay bottom adjacent to a bulkhead, a "talus cone" accumulation of fill material has leaked through the joint between concrete sheet piles
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

A.8.2.3 Pendant Wall Structures "Pendant wall" elements are typically associated with wharf construction, where a retaining element is needed to delineate the transition from landside to waterside, as shown in Fig. A-35. The design intent for these structures is for the pendant wall to be sufficiently embedded in the rock revetment so that backfill material behind the pendant wall is retained. For this design to be effective, the rock revetment must be designed with an adequate filter material to prevent migration of the backfill material (usually fine-grained, cohesionless hydraulically placed fill) through the revetment. Subsidence of the backfill material placed behind the pendant wall, in a manner similar to that shown in Fig. A-31, is a common phenomenon with structures of this type. Subsidence is typically caused by one or more of the following (Fig. A-35):

- Settlement or movement of the revetment slope, undermining and exposing the bottom of the pendant wall;
- Improper design of the revetment filter material; and
- Backfill leaking through the pendant wall, typically at the location of drains or construction joints.

Evidence of soil migration underneath the pendant wall is shown in Figs. A-36 and A-37. The resultant void beneath the surface typically results in depressions in the pavement and ultimately pavement failure. Careful examination of the topside surfaces is warranted with these structures. If

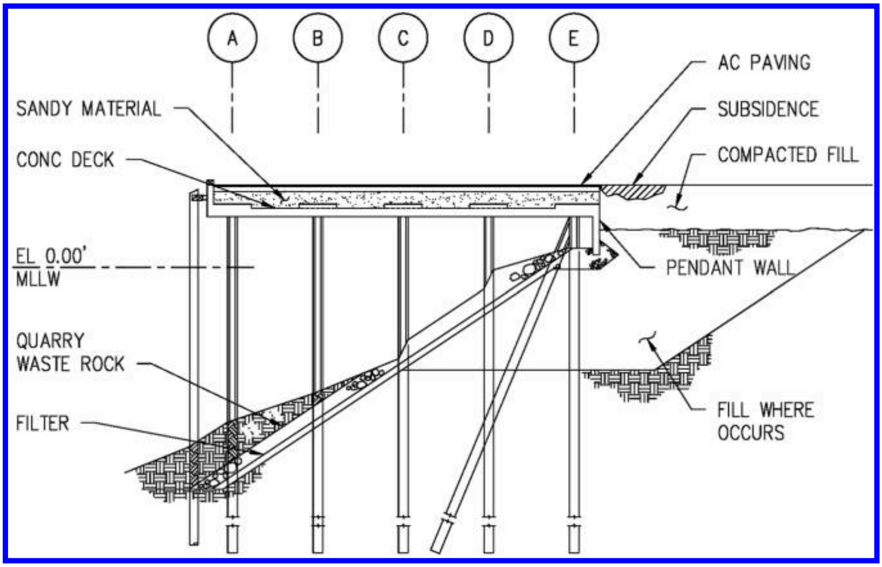

Fig. A-35. Marginal wharf cross section of pendant wall configuration; movement of the rock revetment slope often leads to exposure of the bottom of the pendant wall, resulting in subsidence of the soil behind the wall
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

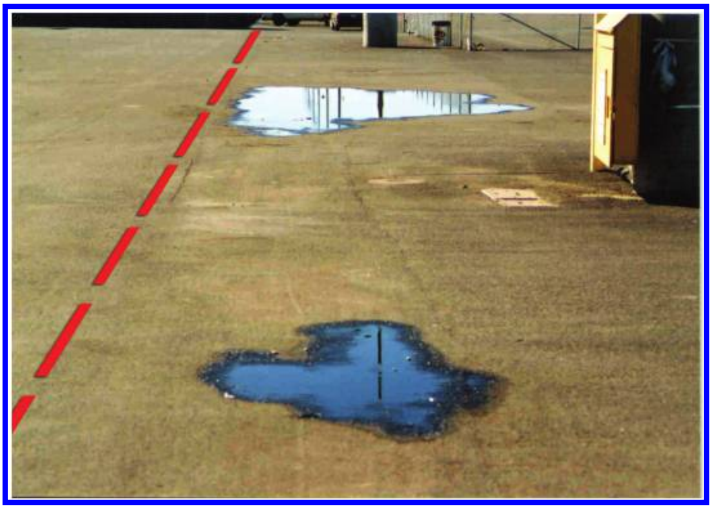

Fig. A-36. The ponding seen in this photo indicates subsidence, probably through the pendant wall below (delineated by the dashed line)
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

Fig. A-37. The pavement has failed entirely as a result of soil migrating from beneath the pendant wall below (indicated by the dashed line)
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

subsidence is suspected, special care should be taken with below-deck/underwater inspections in and around the affected area. Periodic monitoring of the pavement surfaces by topographic survey is an effective means of monitoring changes in condition.

A.9 FLOATING STRUCTURES

A.9.1 General

Floating structures are defined as any structure that is intended to remain floating during their service life. They can be moored or self-propelled. Examples of floating structures are large storage containers, drydocks, ferry slip docks, guide walls for navigation locks, breakwaters, bridges, and piers. Floating structures are used when great water depths and/or poor channel bottom conditions preclude the use of ordinary substructure units, or at sites where large water level fluctuations need to be accommodated. Typically, the material used to construct these structures is composed of concrete or steel.

Floating bridges, ferry slip docks, breakwaters, and guide walls for navigation locks typically consist of concrete pontoons at the water surface.

Most concrete pontoons are designed and constructed as a series of long, rectangular barges, with interior egg-crate bulkheads both longitudinally and transversely. The pontoons provide the superstructure for the bridge (or ferry slip dock) or serve to carry a bridge (or ferry slip dock) superstructure. In the case of the guide walls for navigation, the pontoons serve as the entry channel wall(s). The position of the pontoons is either maintained by anchor cables that inhibit movement by working against the buoyancy of the hollow design of the pontoons or are held in place by open pile clusters with a concrete cap.

Floating piers and docks typically consist of a deck that comprises one or more concrete or steel pontoons; however, timber, aluminum, and composite materials have been used as the pontoon material. Steel pontoons are typically required to have double-walled construction throughout the structure. Pontoons are anchored to the channel bottom and connected to the shore via bridges or ramps. Typically, the spud piles of floating piers are made of steel, concrete, or timber, and the connection hardware generally comprises hot-dip galvanized steel, marine grade stainless steel, or aluminum.

The anchor cables of floating structures are typically structural strand made up of small-diameter, stranded steel wires or large-diameter chain. An anchor cable may either consist of a single run between pontoon and anchor or two runs resulting from a cable that is looped through the anchor. The cables are either attached to the anchors by means of a cable socket along with various pins, eyebars, and pin plates or threaded through the anchor with jewels around the cable to protect it. The cables enter the pontoons through ports, and within the pontoon is a means of tensioning the anchor cable to draw the pontoon downward and thereby stabilizing it.

A wide variety of anchor designs are used for floating structures, including drag-embedment anchors, pile anchors, deadweight anchors, suction pile anchors, and direct-embedment anchors. A comprehensive description of these anchor types can be found in Section A.11.

A.9.2 Typical Components and Problem Areas

Table A-11 summarizes the specific components of the floating structures that are typically inspected and the typical items of concern for each component of the structures.

A.9.2.1 Floating Concrete Pontoons Floating concrete pontoons are normally constructed of segmental precast, prestressed concrete, utilizing either standard-weight concrete or lightweight concrete. Lightweight concrete is typically 25% less in unit weight than standard-weight concrete, which results in a shallower draft but requires additional reinforcement in the concrete. The concrete interior and exterior surfaces of the pontoon need to be inspected for typical concrete deficiencies. Of particular concern is any

Table A-11. Floating Structures: Checklist for Underwater Inspections

Component	Section or Part	What to Look for	Comments
		Floating Bridges	
Pontoon	Submerged surfaces	• Cracks, spalls, and loss of section; waterlogged filler material between steel double walls	• Cracks or deep section loss may allow water infiltration
	Joints	• Torn, loose, or bulging rubber membrane • Exposed and/or deteriorated grout • Excessive pontoon misalignment	
Anchor cable	Pontoon port	• Misalignment and cable abrasion	
	Cable	• Coating condition, corrosion, wire section loss, broken and/or braided wires, and potential sources of cable abrasion	• Exterior wire breaks related to stress may suggest comparable numbers of interior broken wires; stress breaks may also indicate end of cable's useful life
	Anchor attachment assembly or jewels	• Corrosion, misalignment, looseness, and cable abrasion or strain	
Anchor	Anchor assembly	• Misalignment or movement, instability, undermining, and inadequate embedment or ballast quantity	

		Floating Piers	
Pontoon	Submerged surfaces	• Material deterioration • Waterlogged Styrofoam filler	• Cracks or deep section loss may allow water infiltration
	Joints	• Damaged and/or deteriorated joint filler and connections • Excessive pontoon misalignment	
Spud pile	Submerged surfaces	• Ordinary pile considerations • Wear or abrasion related to misalignment	
Tension line	Pontoon or anchor attachments	• Corrosion, misalignment, looseness, and line abrasion or strain	
	Cable or chain	• Corrosion, cathodic protection anode consumption (chains), breaks and/or abrasion, and potential sources of abrasion	• Catenary chains may be subject to wear at mudline
Anchor	Anchor assembly	• Misalignment or movement, instability, and inadequate embedment	

cracking or deep section loss that could allow water to infiltrate the concrete and, thus, the inner compartment of the pontoon. Floating pontoons will sometimes experience dynamic excitation due to the waves travelling obliquely to the axis of the bridge, thus lengthening the effective span between crests to much longer than the wavelength. This, in turn, leads to harmonic response by the pontoon. Any cracking in the concrete can become a through crack; then the opening and closing sucks in water and closes, leading to hydraulic fracture. Therefore, a sufficient steel area must cross all potential cracks to stay below yield at the ultimate tensile strength of the concrete. Where a series of pontoons is employed, the rubber membranes and/or grout that are typically used in the joints between pontoons should be inspected for indications of a lack of integrity. Pontoon alignment across the joints should also be examined for indications of excessive differential movement.

The access hatch or point of entry to the pontoon should be inspected for degradation of the sealing material and degradation of the surrounding concrete or steel material. When in the closed position, the hatch door should be watertight; check for gaps around the edges. If the pontoon has multiple compartments, the bulkhead portal doors should be inspected in a similar manner to the access hatch. These types of inspections are most likely confined space inspections and require proper training, specialized equipment, and compliance with local and federal regulations. Refer to Section 34 of USACE (2008) for guidance on confined space inspections.

In some cases, the pontoons may have utility conduits, plumbing, duct banks, and/or cathodic protection systems. The overall condition of these systems should be inspected to identify general deterioration and to determine if the utility conduits and plumbing are broken or detached. Beyond the general condition inspection of these systems, a specialized inspection may be required.

A.9.2.2 Floating Pontoon Anchor Cables and Chains Anchoring cables should be inspected for condition of protective coatings, extent of corrosion, and amount of individual wire section loss. In a strong current flow environment (2 to 3+ knots), vibration of the anchor cable can occur and further cause cyclic dynamic oscillations that can lead to fatigue, both in the cable and at the connection hardware. Cable misalignment and wire abrasion should also be checked at the pontoon ports. At the anchors, the attachment assemblies or jewels should be examined for any deterioration, looseness, or misalignment and for any adverse effects to the anchor cable. Of particular importance is the identification of any broken individual wires along the cable. When possible, determine the source of wire breakage that is abrasion or stress related, because exterior stress breaks typically suggest a comparable number of interior broken wires and also indicates that the end of the cable's useful life is approaching. The inspection of each anchor cable should also identify any potential sources of cable abrasion, such as items hung on the cable (netting, anchor ropes, etc.) or obstructions at the channel bottom. See Section A.11 for additional inspection considerations.

Anchor chains should be inspected routinely for corrosion and section loss of the individual links, the amount of wear between adjoining links, possible stretch of the chain over five continuous links, and alignment with the anchoring system. The anchor chains should be routinely inspected at critical locations throughout the chain assembly, including the riser section, catenary section, dip section, and the ground section. See Section A.11 for additional inspection considerations. In some cases the anchor chain will have cathodic protection throughout the system and should be inspected as described in Section A.14.

A.9.2.3 Floating Steel Pontoons The steel portions of the pontoons should be inspected for the typical material deficiencies. Of particular importance is any cracking, holes, or deep section loss that may allow water to infiltrate the interior cavities of a pontoon. In some cases, the steel pontoons will have double walls along the exterior portion of the hull. Therefore, both interior and exterior examinations of the walls are necessary. Where Styrofoam filler is used in steel pontoons, any exposed filler should be examined for material integrity and any indications of being waterlogged. The joints between pontoons and related connections and/or fillers should be inspected for deterioration, damage, missing or deficient items, and other considerations, as described in Section A.9.2, where applicable.

A.9.2.4 Floating Pier Spud Piles or Tension Lines Floating pier spud piles should be examined for the conditions associated with piles, as described in Section A.2. In addition, the piles should be checked for any excessive wear or abrasion resulting from misalignment. The top of the spud piles should be checked for a protective cap or coating that minimizes deterioration and water accumulation. Where tension lines are involved, the lines and attachment assemblies at either end should be examined for deterioration, breaks, abrasion, and other considerations, as described in Sections A.10 and A.11, where applicable.

A.9.2.5 Floating Drydocks This section covers the basic components of a floating drydock system. For comprehensive inspection techniques related to floating drydocks refer to ASCE (2010). A floating drydock consists of a pontoon with stabilizing wing wall(s) and mechanical and electrical equipment to permit the controlled flooding and emptying of the ballast tanks. A floating drydock is most conveniently inspected by having it drydocked as a unit and by performing the inspection in the dry. Self-docking may be an alternative for some floating drydocks, whereby portions of the structure are removed and drydocked on the remaining structure. In some cases, access to submerged portions of the pontoon is possible by creating controlled list or pitch of the drydock through the flooding of selected ballast compartments.

Those portions of the floating drydock that may require underwater inspection include the pontoon hull and water intakes.

A.10 MOORING HARDWARE AND FENDER SYSTEMS

A.10.1 General

Mooring hardware and fender systems are the primary components in the berthing of vessels at any waterfront facility. The fender system is vital to providing protection for the waterfront structure and for the vessel. The fender system must be able to resist a strong impact when a vessel first makes contact with the structure and for it to be able to withstand continuous loading from environmental conditions such as wind, current, and waves. Once a vessel is alongside the structure, the vessel's mooring lines are connected to the mooring hardware that is mounted to the structure. Typically, onboard winches allow the mooring lines to be adjusted to position the vessel. As with fender systems, mooring hardware must be able to withstand constant environmental forces in addition to strong gusts increasing tension on individual mooring hardware.

A.10.2 Typical Components and Problem Areas

Mooring hardware and fender systems are no different from typical structural components, with common problem areas stemming from fatigue (cyclic loading), sudden high impact (overloading), and prolonged environmental exposure. Table A-12 and Table A-13 summarize what to look for when inspecting the condition of mooring and fender system components, respectively.

A.10.2.1 Mooring Hardware Mooring hardware is comprised mainly of bollards, bitts, cleats, and hooks, which have various functions on the wharf structure to secure vessel mooring lines. A general overall inspection of the mooring system should be performed, noting location and type of mooring components; typical use of the system; and obvious deterioration, damage, or missing components.

A.10.2.1.1 Bollards, Bitts, and Cleats Most bollards, bitts, and cleats are of steel construction and subject to the same deterioration causes and