

UNIFIED FACILITIES CRITERIA (UFC)

DESIGN: PIERS AND WHARVES



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DESIGN: PIERS AND WHARVES

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U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by \1\ ... /1/)

Change No.	Date	Location
<u>1</u>	<u>1 Sep 2012</u>	<u>Added Appendix C; modified 2-3.1, 2-3.3.4, 2-5, 2-5.1, 2-5.2, 2-5.3, 2-6, 2-8.2.10, 3-3.5.3, 3-4.5, 4-1.3, 5-2.1.1, 5-3.3.1, 6-2.6, 6-8.1, 6-8.1.7 and 7-4.6; minor editorial modifications throughout</u>

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with [USD \(AT&L\) Memorandum](#) dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

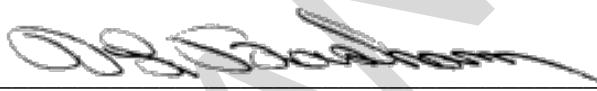
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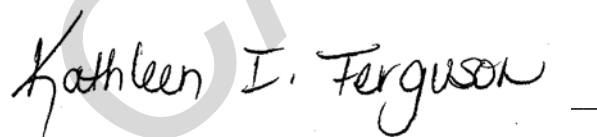
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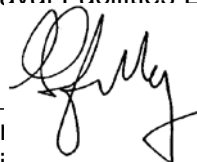
DONALD L. BASHAM, P.E.
Chief, Engineering and Construction Division
U.S. Army Corps of Engineers



The Deputy Civil Engineer
DCS/Installations & Logistics
Department of the Air Force



Director
Chief Engineer
Naval Facilities Engineering Command



Director, P.E.
Director, Installations Requirements and
Management
Office of the Deputy Under Secretary of Defense
(Installations and Environment)

**UNIFIED FACILITIES CRITERIA (UFC)
NEW DOCUMENT SUMMARY SHEET**

Description of Change: UFC 4-152-01, *DESIGN: PIERS AND WHARVES* represents another step in the joint Services effort to bring uniformity to the planning, design and construction of piers and wharves. This UFC contains extensive modifications in the following areas:

- Loads and seismic considerations
- Fender Systems
- Camels and Separators
- Conversion from Mil-Hdbk to UFC and general updates and revisions

Reasons for Change: The existing guidance was inadequate for the following reasons:

- Previous document was nearly 20 years old
- Need to convert to UFC format
- Incorporation of changes described above
- Update to referenced documents

Impact: The following direct benefits will result from the update of 4-152-01, *DESIGN: PIERS AND WHARVES*:

- Although primarily a U.S. Navy document, a single, comprehensive, up to date criteria document exists to cover design of piers and wharves.
- Eliminates misinterpretation and ambiguities that could lead to design and construction conflicts.
- Facilitates updates and revisions and promotes agreement and uniformity of design and construction between the Services.

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CHAPTER 1: INTRODUCTION

1-1 SCOPE.

This UFC contains descriptions and design criteria for pier and wharf construction, including subsidiary, contiguous, and auxiliary structures. Loading details, regulations, furnishings, appurtenances, and other information are discussed when applicable. This UFC provides minimum facility planning and design criteria for efficient homeporting facilities of Naval vessels. Existing ports, facilities, and berths may not meet all criteria and may therefore, perform less efficiently, but do not necessarily require upgrade. This UFC focuses on the entire homeport operation. For example, ships will visit fueling and ammunition piers for short periods, but generally berth at general purpose berthing piers.

1-2 GENERAL FUNCTION.

An important consideration that often comes up has to do with differentiation between homeports and ports of call. Basically, a homeport for a specific ship has been identified as such by Commander Fleet Forces Command and is listed in the Naval Register, <http://www.nvr.navy.mil>. The homeport is where the ship is assigned and offers all requisite services required by the ship to include the full compliment of hotel services. In contrast, a port of call would be any port where a ship stops along the way other than its homeport, or a stop at a fueling pier, an ammunition pier, a supply pier, or a repair pier. The only real requirements for a port of call would be that it has sufficient dredge depth and that it provides secure mooring. Ship does not go cold iron in port of call and uses its organic systems. However, local determinations and justifications can warrant adding specific features at ports of call. Many of the new classes of ships have concepts of operations and special mission requirements that have resulted in making accommodations at ports in forward operating areas that ordinarily would not be required, i.e. hotel services. These are handled on a case-by-case basis and driven by operational requirements. Generally, piers and wharves provide:

- Berths with sufficient dredge depths for vessels.
- Secure mooring for vessels berths.
- Transfer points for cargo and/or passengers between water carriers and land transport.
- Facilities for fitting-out, refit or repair; and specialized functions.

1-3 FUNCTIONAL CATEGORIES.

Piers and wharves are grouped into four (4) primary types as follows:

1-3.1 Type I – Fueling, Ammunition, and Supply.

1-3.1.1 Fueling.

These are dedicated piers and wharves equipped with facilities for off-loading fuel from ship to storage and for fueling ships from storage. For additional design criteria, see UFC 4-150-02, *Dockside Utilities for Ship Service*.

1-3.1.2 **Ammunition.**

These are dedicated piers and wharves used for discharging ammunition for storage and for loading ammunition on outgoing ships. Explosives and ammunition quantity/distance standards are discussed in NAVSEA OP 5, Volume 1, *Ammunition and Explosives Safety Ashore*.

1-3.1.3 **Supply.**

Supply piers and wharves are used primarily for the transfer of cargo between ships and shore facilities. Provide standard gage railroad tracks when supplies will be brought in by rail.

1-3.2 **Type II – General Purpose.**

1-3.2.1 **Berthing.**

These are general-purpose piers and wharves used primarily for mooring ships. Furthermore, berthing facilities may be active, as when ships are berthed for relatively short times and are ready to put to sea on short notice, and inactive, as when they are berthed for long periods in a reserve status. Activities that typically take place on berthing piers and wharves are personnel transfer, maintenance, crew training, cargo transfer, light repair work, and waste handling. Under some circumstances, fueling and weapons system testing may also be carried out in these facilities.

1-3.3 **Type III – Repair.**

An important consideration for repair piers is the need to provide heavy weather mooring capability. This includes properly sized and spaced storm bollards and a compliment of heavy weather mooring lines. This consideration is predicated upon the fact that ships under repair may not be able to get underway during a heavy weather event.

1-3.3.1 **Repair.**

Repair piers and wharves are constructed and equipped to permit overhaul of ships and portions of a hull above the waterline. These structures are generally equipped with portal cranes or designed to accommodate heavy mobile cranes.

1-3.3.2 **Fitting-Out or Refit.**

Piers and wharves for fitting-out are very similar to those used for repair purposes, providing approximately the same facilities. However, fitting-out piers and wharves will have, in addition to light and heavy portal cranes, large fixed tower cranes for handling guns, turrets, engines, and heavy armor.

1-3.3.3 **Floating Drydocks.**

Piers and wharves for floating drydocks are constructed and equipped to permit overhaul of ships above and below the waterline. Some floating drydocks have portal cranes on tracks on the wingwalls and some floating drydocks use cranes from the pier side. The dredge depth at these facilities must accommodate the floating drydock when submerged. Floating Drydocks are normally moored using two or more vertical spuds that maintain the horizontal position of the dock throughout its full range of vertical movement from fully submerged to fully dewatered. The pier/wharf structure must be designed to accommodate mooring spud placement and loading. The pier or wharf layout should also consider personnel, material, and vehicle access to the drydock pontoon deck when the drydock is in the raised (dewatered) position.

1-3.4 **Type IV – Specialized.**

1-3.4.1 **Magnetic Treatment and Electromagnetic Roll piers.**

These are piers that moor ships over an array of underwater instruments and large-area cable solenoids used specifically for removing and/or modifying the magnetic signature characteristics of surface vessels and submarines, as well as calibrating the on-board degaussing systems of mine countermeasure vessels. Magnetic Treatment facility designs vary using slips, T-piers, or single piers depending upon location and requirement. Magnetic Treatment piers designed to accommodate surface vessels are typically configured as T-shapes; whereas, submarines and mine countermeasure vessels are typically treated at drive-in piers built in parallel configurations.

1-3.4.2 **Training, Small Craft, and Specialized Vessels.**

These piers and wharves are typically light structures designed for specific but limited functions. Specific requirements are usually provided by the activity. Additional guidance can be found in \1\ UFC 4-152-07, *Design: Small Craft Berthing Facilities.* /1/

1-4 **FLEXIBILITY OF BERTHS.**

Typically, piers and wharves are designed to provide space, utility service, and other supporting facilities for specific incoming or homeported ships. However, berthing plans and classes of ships berthed change with time. While it is not economically feasible to develop a single facility to accommodate and service all classes of ships presently known, design the facility with a certain amount of flexibility built in for anticipated future changes in the functional requirements. This is especially true for berthing piers and wharves that will be used to accommodate different classes of ships as well as support a variety of new operations.

1-5 **APPURTENANCES AND FEATURES.**

The following is a range of appurtenances and features that may be required for piers and wharves.

- Mooring devices to safely secure the ship.
- Fender systems, camels and separators.
- Hotel and ship service utilities.
- Communications.
- Cranes and crane trackage.
- Access facilities for railroad cars and trucks.
- Waste handling facilities.
- Cargo handling equipment.
- Covered and open storage spaces for cargo.
- Support building, tool shed, office space, and control rooms.
- Lighting poles and equipment.
- Security systems.
- Firefighting equipment.
- Emergency medical facilities.
- Access structures and facilities.
- Fueling facilities.
- Safety Ladders.
- Life-Safety Rings.

CHAPTER 2: FACILITY PLANNING

2-1 LOCATION AND ORIENTATION.

2-1.1 General.

The location and alignment of piers and wharves in a harbor should consider factors such as:

- maneuverability,
- required quayage,
- harbor line restrictions,
- geotechnical conditions,
- isolation requirements,
- prevailing wind and current directions,
- clearance between moored or passing vessels,
- project depth,
- shoaling patterns,
- environmental permit restrictions,
- port regulations and
- landside access/proximity.

For further discussion and criteria, see UFC 4-150-06, *Military Harbors and Coastal Facilities*.

2-1.2 Orientation for Environmental Conditions.

To the extent practicable, orient piers and wharves so that a moored ship is headed into the direction of the prevailing winds and currents. Thus, the forces induced on mooring lines by these conditions would be kept to a minimum. If such an arrangement is not feasible, consider an orientation in which the wind or current holds the ship off the facility, although do not overlook the difficulty in mooring a ship under such conditions. In locations where criteria for both wind and current cannot be met, orient the berth parallel to the direction of the more severe condition. At locations exposed to waves and swell, locate the facility so that a moored ship is headed into the wave or swell front. If planning criteria dictate that a pier or wharf be

oriented so that a moored ship is positioned broadside to the prevailing winds, currents, or waves, consider breast-off buoys to keep the ship off the facility and diminish the possibility of damage to the structure and ship. At oil storage terminals located in areas where meteorological and hydrological conditions are severe, consider using a single point mooring which allows a moored tanker to swing freely when acted upon by winds, waves, and currents from varying directions. See UFC 4-159-03, *Design: Moorings*.

2-1.2.1 **Pier Orientation.**

A pier is oriented either perpendicular to or at an angle with the shore. There are generally slips on both sides, although there are instances where only one side has a slip because of site conditions or because there is no need for additional berthing. Piers may be more desirable than wharves when there is limited space available because both sides of a pier may be used for mooring ships. When both sides of a moored ship need to be accessed, two parallel piers with a slip in between may be preferred. Magnetic Treatment and Electromagnetic Roll piers usually require a magnetic north/south orientation, irrespective of other considerations

2-1.2.2 **Wharf Orientation.**

A wharf is a structure oriented approximately parallel to the shore. Ships can only be moored at the offshore face of a wharf. When water depths close to shore are not adequate to accommodate deep draft ships, the wharf, consisting of a platform on piles, is located offshore in deep water and is connected to shore at one or more points by pile-supported trestles, usually at right angles to the wharf. If the trestle is located at the center of the wharf, the structure is referred to as a T-type wharf; if the trestle is located at an end, the facility is known as an L-type wharf; if trestles are located at both ends, the wharf is called a U-type wharf. Ships may be berthed on both sides of a T- or L-wharf. When the offshore wharf is used for transfer of bulk liquid cargo from the unloading platform to shore via submarine pipelines, the structure is referred to as an island wharf. A trestle from the offshore wharf to shore is not provided and both sides of the island wharf may be used for mooring ships. Launches are used for wharf access. Where a U-shaped berth is formed by a cut into land by two approximately parallel wharves, this may be referred to as a slip. For examples of pier and wharf types, see Figures 2-1 and 2-2. For general cargo, supply, and container terminals, a wharf structure, connected to upland shore area for its full length, is preferred because such an arrangement is more adaptable to loop rail and highway connections and the distance from wharf apron to transit sheds and open storage areas is shorter.

2-1.3 **Vessel Ingress and Egress.**

On occasion, a moored vessel is required to make a hasty departure from its berth and head out to sea. Accordingly, when planning a pier or wharf, consider providing

adequate turning area so that a ship can be turned before it is docked, and moored with a heading that will permit a convenient and rapid departure.

2-1.3.1 **Disaster Control and Emergency Plans.**

In an emergency, tugs may not be available. Therefore, the slip, berth, basin, and channels should allow the ship to get underway without assistance. See \1\ OPNAVINST 3040.5D *Procedures and Operations Reporting Requirements for Nuclear Reactor and Radiological Accidents.* /1/

There will be cases where a ship will not be able to leave prior to heavy weather (such as during a PMA or PIA for CVN). General-purpose berths are normally designed for 64-knot (75-mph (32.9 m/s)) winds. Winds in excess of 64 knots (75 mph (32.9 m/s)), such as may be seen at repair berths, require special considerations. See the heavy weather mooring criteria contained in UFC 4-159-03.

Design facility systems for continuous operation in the event of a power outage, in other words, pier/wharf remains operational with exception of having shore power and lighting.

2-1.3.2 **Harbor Elements.**

Information on channel approaches (outer channels), entrances (inner channels), and turning basins to include recommended widths and depths is contained in UFC 4-150-06.

2-1.4 **Water Depth.**

At locations where the required depth of water is available close to shore and the harbor bottom slopes steeply out to deeper water, it may not be economical to build deep-water foundations for a pier; consider a wharf structure. At locations where water depths are shallow and extensive dredging would be required to provide the required depth of water close to shore, consider locating the facility offshore, in deeper water, by utilizing a T-, L-, or U-type wharf.

2-1.5 **Dolphins.**

These are small independent platforms or groups of piles used by themselves or in conjunction with a pier or wharf for specialized purposes. A mooring dolphin is sometimes used at the offshore end of a pier or both ends of a wharf to tie up the bow or stern line of a ship at a more favorable angle. Mooring dolphins are usually accessed by a catwalk, as illustrated in Figure 2-1, and are provided with a bollard or capstan. Breasting dolphins are sometimes used for roll-on/roll-off facilities and at fueling terminals where a full-length pier or wharf is not required. They may also be used as part of the fender system. A turning dolphin is an isolated structure used solely for guiding the ships into a berth or away from known obstructions.

Occasionally, a mooring dolphin may also be designed to function as a turning dolphin. Approach dolphins are used where the end of a pier or ends of a slip require protection from incoming ships.

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Figure 2-1. Pier and Wharf Types

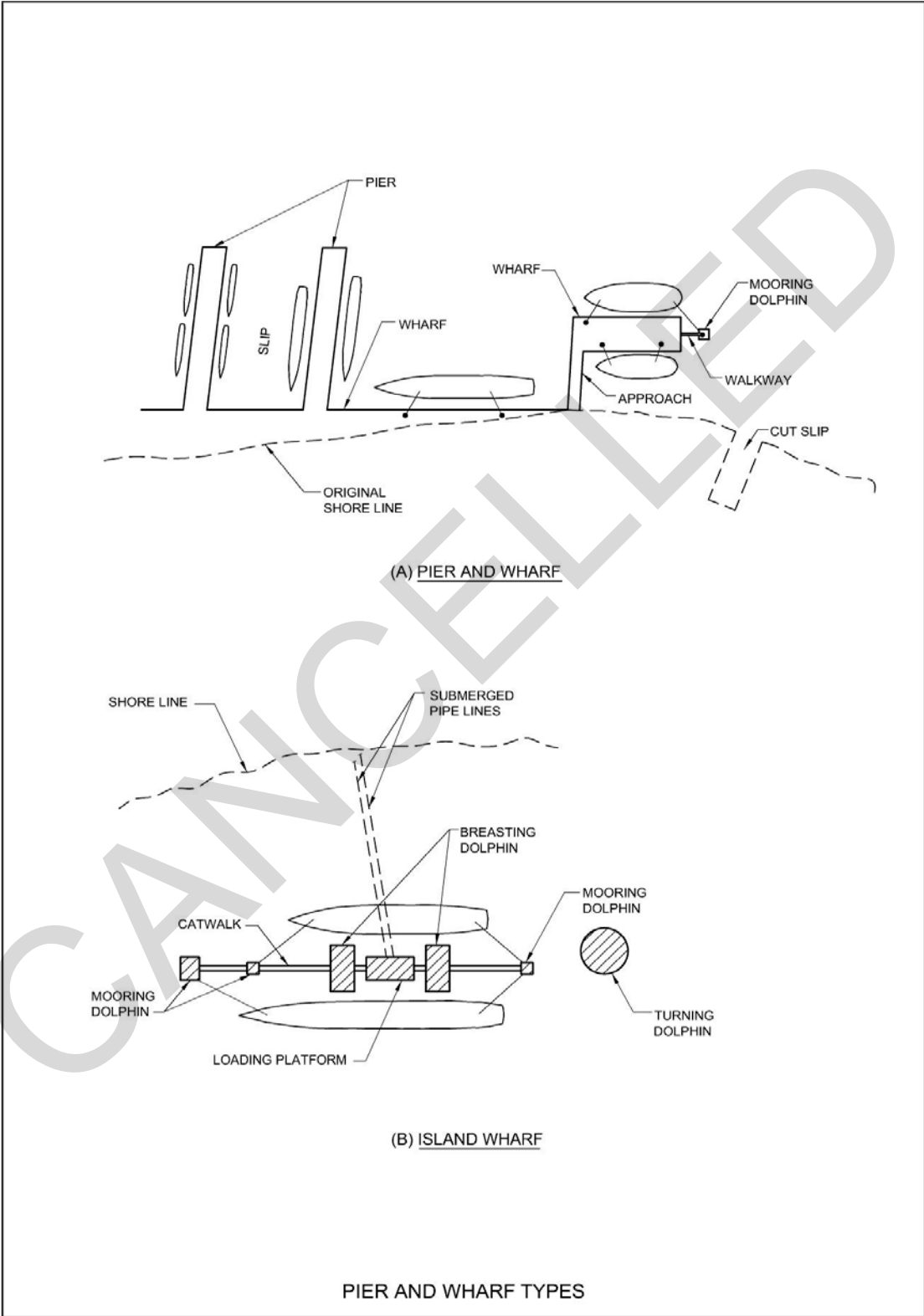
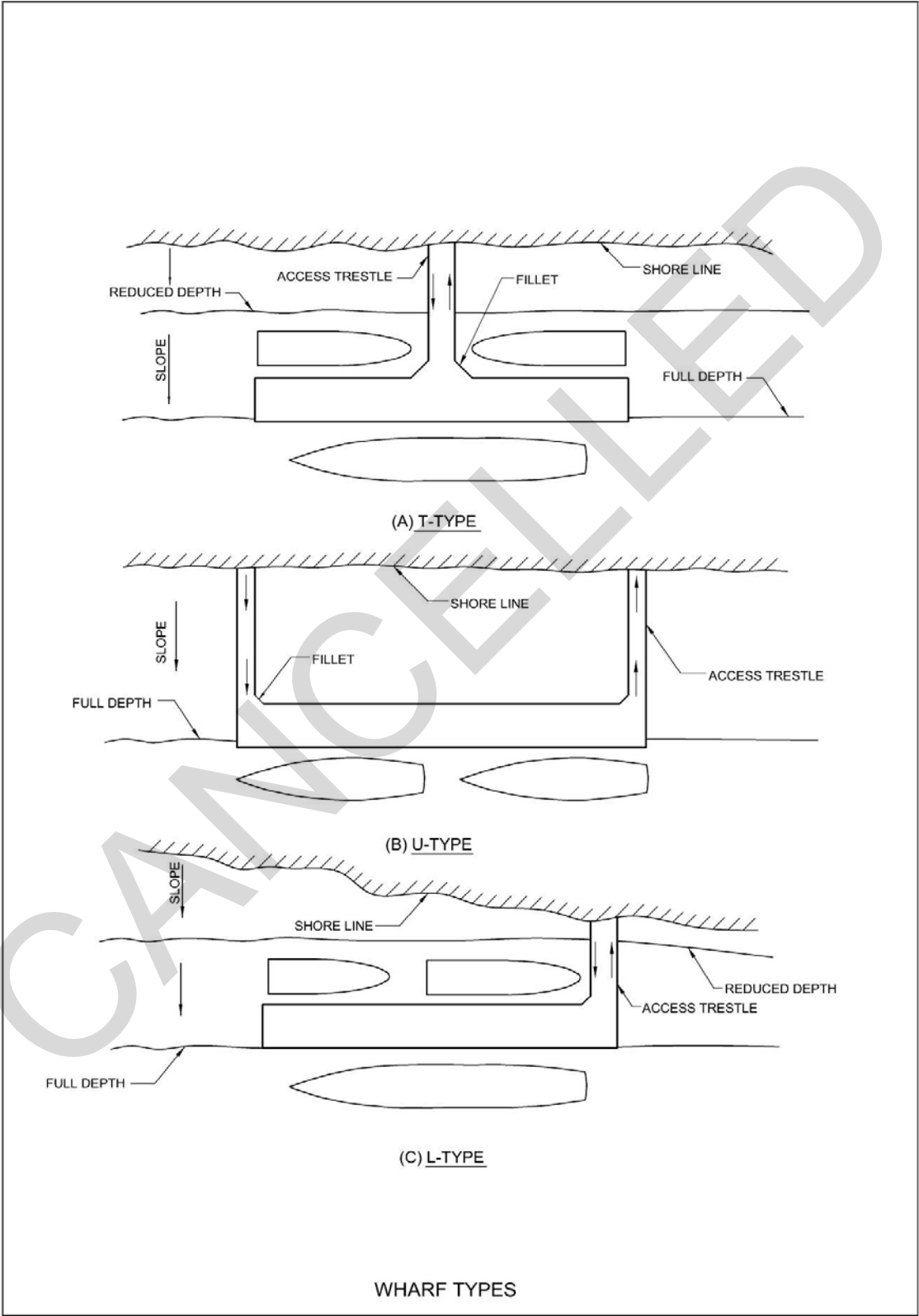


Figure 2-2. Wharf Types



2-2 Coordination of Repair.

2-2.1 General.

Ships will undergo a Phase Maintenance Program based on the Class Maintenance Plan (CMP). These maintenance activities will generally be conducted at a repair berth. Ships in drydock and in inactive status require specialized criteria that NAVFAC will provide as requested. Coordinate capability of local ship repair facilities and salvage operations with NAVSEA SUPSHIP. The following facilities should be available within a reasonable distance from the support facility homeport.

- a. A Ship Maintenance Facility (SMF) housing the machine tools, industrial processes and work functions necessary to perform non-radiological depot level maintenance on ship propulsion plants.
- b. A Maintenance Support Facility (MSF) housing both administrative and technical staff offices supporting ship propulsion plant maintenance, as well as central area for receiving, inspecting, shipping, and storing hazardous/mixed waste materials and maintenance materials, and controlled radiological tank storage.
- c. A Controlled Industrial Facility (CIF) or Radiological Work Facility used for the inspection, modification, and repair of radiological controlled equipment and components associated with Naval nuclear propulsion plants. It also provides facilities and equipment for the treatment, reclamation, and packaging for disposal of radiologically controlled liquids and solids. It includes non-radiologically controlled spaces for administration and other support functions.
- d. Drydock facilities for various classes of ships. Refer to UFC 4-213-12, *Drydocking Facilities Characteristics* for listing and details on active U.S. Navy graving drydocks. Consult with NAVSEA and the ship's Maintenance Program Master Plan and Class Master Plan (CMP) for specific requirements. Few floating drydocks remain active as service craft in the U.S. Navy inventory. Special moorings may be required for floating drydocks and special considerations for dredging (and shoaling) to allow for lowering of the dock is required.
- e. Phased Maintenance Activities (PMA). PMA is a short, labor-intensive availability for ships in a Phased Maintenance Program for the accomplishment of maintenance and modernization. At some Naval stations, PMA is performed at general purpose berthing piers. PMA is discussed in detail in a subsequent section.

2-2.1.1 Aircraft Carriers.

Every 18 months an aircraft carrier will undergo a 6-month “Planned Incremental Availability (PIA)” at the repair berth. For CVN’s, also coordinate with NAVSEA PMS 312 and NAVSEA 08, COMNAVAIRLANT N4, or COMNAVAIRPAC N4. Drydock facilities for CVNs exist only at Puget Sound Naval Shipyard, Norfolk Naval Shipyard, and NorthrupGrumman Newport News. NAVSEA 08 defines emergency drydock facilities for CVNs. CVNs will be located at these facilities when this service is required.

2-3 **OVERALL DIMENSIONS AND CLEARANCES.**

2-3.1 **General.**

The overall dimensions and clearances required for piers and wharves are dependent on characteristics of the ships to be berthed and the support services provided. Comprehensive information on all U.S. Navy ships is found in the following locations:

\1\

- Ships Characteristics Database (SCDB), <http://www.wbdg.org/tools/ships.php?u=7>
- Naval Vessel Register, <http://www.nvr.navy.mil/>
- Military Sealift Command, <http://www.msc.navy.mil/inventory>

/1/

2-3.1.1 **Ship Characteristics.**

Criteria is summarized below with “governing values” provided in Table 2-1.

Table 2-1 Ship Characteristics for Selected Ships

	DRAFT	DISPLACEMENT	LENGTH	BEAM	HEIGHT Above Waterline
SURFACE COMBATANT CG-47	33.4 ft 10.2 m	9962 LT 10125 MT	567 ft 172.8 m	66 ft 20.1 m	
AMPHIBIOUS ASSAULT LHD-1 LPD-17	27 ft 8.2 m	40,674 LT 41,430 MT	884 ft 269.4 m	118 ft 36 m	180 ft 55 m
AUXILIARY AOE-6	41 ft 12.5 m	49,484 LT 50,278 MT	754 ft 230 m	107 ft 32.6 m	
AIRCRAFT CARRIER CVN-68	40.8 ft 12.4 m	104,200 LT 105,854 MT	1123 ft 342.3 m	280 ft 85.3	215 ft 65.5 m
SUBMARINE SSN-21 SSN-774	38 ft 11.6 m	7196 LT 7311 MT	377 ft 114.9 m	42 ft 12.8 m	
SUBMARINE SSBN-726	36 ft 11 m	16740 LT 17008 MT	560 ft 170.7 m	42 ft 12.8 m	

NOTES:

Draft – use the larger limiting draft or maximum navigational draft in determining minimum water depth requirements.

Displacement – use the largest displacement expected of any ship anticipated to use the facility in determining berthing forces on the pier or wharf.

Length – use the overall length for the longest combination of surface combatants, amphibious warfare, combat logistic ships, or CVN that normally use the facility to determine pier and wharf length and utility locations.

Beam – use the widest to determine horizontal clearances and slip width both for single berth and nested configurations. Note that the waterline beam for CVN 68-75 is 134 ft and the width of the flight deck structure (with antenna platforms, walkways, and portable flight deck sections removed) is 252 ft. Without removing these appurtenances, CVN 68 is 260 ft and CVN 76 is 280 ft wide.

Height – use the lightly loaded height of 180 ft (55m) above the waterline. This includes combined superstructure and all communications / antenna array supported by the

superstructure. Governing vessel is the LPD 17. Use the lightly loaded height of 215 ft. above the waterline for CVN's.

2-3.1.2 Supporting Items.

- a. Provide fender / camel systems for the following arrangements:
 - Multiple / nested berths for DD 963, CG 47, DDG 51, FFG 7 (surface combatants),
 - Single berths for LHD, LHA, multiple berths for LPD, LSD (amphibious assault);
 - Single berths for T-AKE, T-AO, T-AOE, (auxiliary)
 - Single berths for CVNs
 - Multiple/nested berths for SSN, SSBN
- b. Aircraft require extensive support. Those requirements are not addressed herein.
- c. A minimum of 5 acres (20,234m²) of laydown area in addition to pier/wharf space is desirable. The laydown area should be within ½ mile (.8km) of the pier or wharf.
- d. Brows and Platforms are usually placed at ship's designated entry/egress points to the main deck. For CV and CVN, two 45-foot brows are usually placed on the ship's #2 elevator and one 60-foot (18.3 m) brow placed between elevators #2 and #3 to the main deck. Brow design length will be based on camel design and resultant standoff distance.
- e. Design facilities (ramps, landings, railings) in accordance with American with Disabilities Act (ADA) of 1990. Technical requirements and guidelines for accessibility to buildings and facilities are found in ICC/ANSI A117.1, *Accessible and Usable Buildings and Facilities* and the *American with Disabilities Act Accessibility Guidelines (ADAAG)*.
- f. Sideport loading ramp access is of primary concern to LHA-1, LHD-1, and LPD-17. For double deck piers special ramps are required to access sideport loading ramp. The study *Amphibious Warfare Ship to Pier Interface Study* provides details on the access problem as well as recommended special ramps.
- g. Generally, design CVN berths to accommodate a variety of other classes of ships as well.

- h. Design general warehouse space to be accessible to large trucks and handling equipment.
- i. Do not permit pier interferences such as utilities and deck appurtenances in the zone of elevators for CVN (#1, #2, and #3), LHA, or LHD. At times these ships may have to move off of their normal berth bridge mark, i.e. move CVN offshore for ordnance load or move LHA/LHD toward bulkhead for stern gate ramp placement. Objective is to keep edge of pier free of obstructions.
- j. Provide parking for ship's government and privately owned vehicles in proximity to entrance to the pier or wharf.
- k. Provide sufficient security for ships on the pier. Consider minimally manned ships. See also paragraph 2-6.
- l. Provide safety equipment.

2-3.2 **Pier and Wharf Length.**

2-3.2.1 **Single Berth.**

The length of pier or wharf should equal the overall length of the largest ship to be accommodated, plus an allowance of 50 ft (15.2 m) at each end of the ship. For aircraft carriers, increase the allowance at each end of the vessel to 100 ft (30.5 m.) Refer to Figure 2-3. Single berths are used by LHA, LHD (amphibious assault ships); T-AKE, T-AO, T-AOE, (auxiliary); and CVNs.

2-3.2.2 **Multiple Berths.**

The length of a pier or wharf should equal the total overall length of the largest ships simultaneously accommodated, plus clear distance allowances of 100 ft (30.5 m) between ships and 50 ft (15.2 m) beyond outermost moored ships. Refer to Figure 2-3. Multiple berths are used by DD 963, CG 47, DDG 51, FFG 7 (surface combatants) and SSN, SSBN submarines.

2-3.2.3 **Container and RO/RO Berths.**

The length of berths used for container or RO/RO berths should account for the requirements of the container cranes or special ramps. Where shipboard ramps are used, provide adequate berth length to allow for efficient vehicle maneuvering.

2-3.2.4 **Submarine Berths.**

For most classes of submarines, a 50-ft (15.2-m) end distance to a quaywall or bulkhead is adequate. The nose-to-tail spacing for multiple berthing should also be a minimum of 50 ft (15.2 m.) However, large submarines such as the Ohio class (Trident) require 150 ft (45.7 m) or more nose-to-tail spacing and clearance to

bulkhead or quay wall. Where explosive safety distance considerations require the use of fragmentation barriers, or specific separation distances, spacing must be adjusted per the requirements of NAVSEA OP-5, *Ammunition And Explosives Safety Ashore*.

2-3.2.5 **CVN Berths.**

CVNs are typically moored “starboard side to” to allow access to the ship’s three elevators for loading/unloading.

2-3.3 **Pier and Wharf Width.**

Pier width as used in this UFC refers to the net operating width of the structure, exclusive of fender systems, curbs, and dedicated utility corridors. Refer to Figure 2-4. This definition also holds for U-, L-, and T-type wharves. However, with reference to wharves, the width should be the dimension to a building, roadway, or other identifiable obstruction. Refer to Table 2-2 for minimum widths established for each functional type other than general purpose berthing piers. Review with specific functional requirements of the individual installation in mind before a final selection is made. Functional requirements include space for: cargo loading operations, line handling, ship maintenance, maintenance of utilities and layout of cables and hoses, solid waste collection, brows and platforms, crane operation, and other operations. For crane operation, consider crane outriggers, tail swing of crane counterweights, and overhang of vessels. For CV’s and CVN’s, coordinate the tail swing of gantry cranes with the overhang of the flight deck and elevators considering available camels and potential list of the ship. Also, these dimensions should not be less than the widths determined by geotechnical and structural considerations. Factors to be considered in the determination of pier and wharf width are discussed below.

2-3.3.1 **Utilities.**

One of the primary functions of a pier or wharf is to provide connections for utilities from ship to shore. Fixed utility terminals are usually provided close to the edge of the pier or wharf along the bullrail. Flexible hoses and cables are then connected to these terminals and to the ship. Depending upon the type of utility hoods, the terminals, hoses, and cables may require 10 to 15 ft (3 m to 4.6 m) of space along the edge that cannot be utilized for any other purpose. Consider the types of utility hoods that require additional edge space for cable and hose laydown. On single deck piers, substations are typically mounted on the deck, which require an additional 25 ft (7.6m) of pier width. Double deck piers are used where the width of the berth area is constrained by adjacent facilities or other limitations. This configuration allows the utility enclosures and the associated hoses, cables and maintenance activities to be segregated from the operational areas and allow crane operations closer to the edge of the pier or wharf.

2-3.3.2. **Berths on One Side.**

For wharves or piers with berths on one side, the minimum width is 66 ft (18.3m) comprised of: 16 ft (4.9m) bollards and utilities, 35 ft (10.7m) mobile crane ops, and 15 ft (4.5m) fire lane). For CVN's with berth on one side, the minimum width is 90 ft (27.4m) comprised of: 20 ft (6.1m) bollards and utilities, 35 ft (10.7m) mobile crane ops, 15 ft (4.5m) fire lane, and 20 ft (6.1m) for loading area.

2-3.3.3 **Berths on Both Sides.**

For Single Deck pier with berths on both sides, the minimum width is 117 ft. (35.7m) comprised of: 32 ft (9.8m) bollards and utilities, 70 ft (21.3m) mobile crane ops/loading area, and 15 ft (4.6m) fire lane). A typical single deck pier is shown in Figure 2-5. For a single deck pier with CVNs (or combination CVN/AOE) berthed on both sides, the minimum width is 150 ft (45.7m) comprised of: 40 ft (12.2m) bollards and utilities; 70 ft (21.3m) mobile crane ops; 25 ft (7.62m) loading area; and 15 ft (4.6m) fire lane. This 150 ft (45.7m) recommended width is based largely upon operational experience of existing facilities.

2-3.3.4 **Double Deck Pier with Berths on Both Sides.**

Minimum width is 93-ft (28.3 m) comprised of: 8 ft (2.4 m) bollards, 70 ft (21.3 m) mobile crane ops/loading area, and 15 ft (4.6 m) fire lane). A double deck pier provides: clear unobstructed pier to ship interface; isolation of operations deck services from lower deck utilities services (i.e. substation located on lower deck); reduced offset requirements for mobile crane operation (thereby reducing the requirement for floating cranes); higher main deck, improving mooring line angles and lessening need for brow platforms; A typical double deck pier is shown in Figure 2-6.

2-3.3.4 **Mobile Crane Operation.**

With the exception of magnetic treatment/electromagnetic roll and fueling piers where a lighter duty mobile crane and/or forklift truck is sufficient, piers and wharves are subject to frequent usage by mobile cranes, forklifts, and straddle carriers. Typically, the cranes will be used to lift light loads (5 to 10 tons) but at a longer reach. This requires a high-capacity crane. If the crane operations are not allowable because of utility trenches and trenches with light-duty covers, such areas should be clearly marked and separated by a raised curb to prevent accidental usage. Typically, mobile crane operators want to get as close as possible to the edge of the pier or wharf to reduce the reach. However, the edges of piers and wharves are also the best places for locating utility trenches and utility trenches. This conflict can be resolved by either designing all utility covers to the high concentrated load from the mobile crane or by allowing crane operations in discrete and dedicated spaces along the edges. Weight-handling equipment requires maneuvering and turnaround space on the deck for effective operation. If possible the deck space should be planned to allow mobile cranes to be backed up perpendicular to the bullrail. This permits the maximum load/reach combination.

Make allowance for tail-swing of crane counter-weight. Refer to UFC 3-320-07N, Weight Handling Equipment and NAVFAC P-307, Management of Weight Handling Equipment. \1\ The Navy Crane Center may also be consulted for operating requirements:

https://portal.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_NCC_pp/1/

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Figure 2-3. Length and Width of Slip

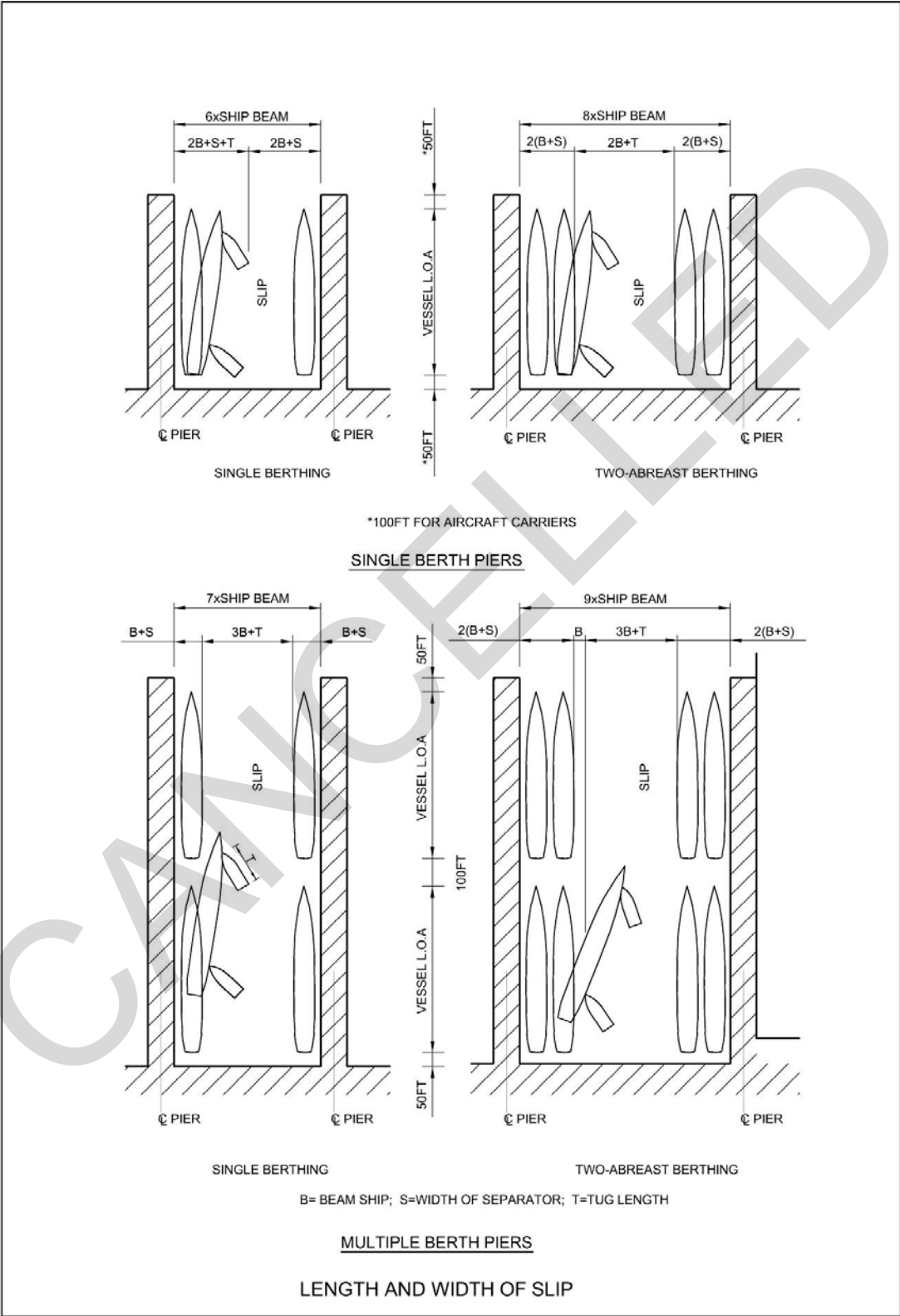


Figure 2-4. Location of Crane Rails, Railroad Tracks, and Utilities

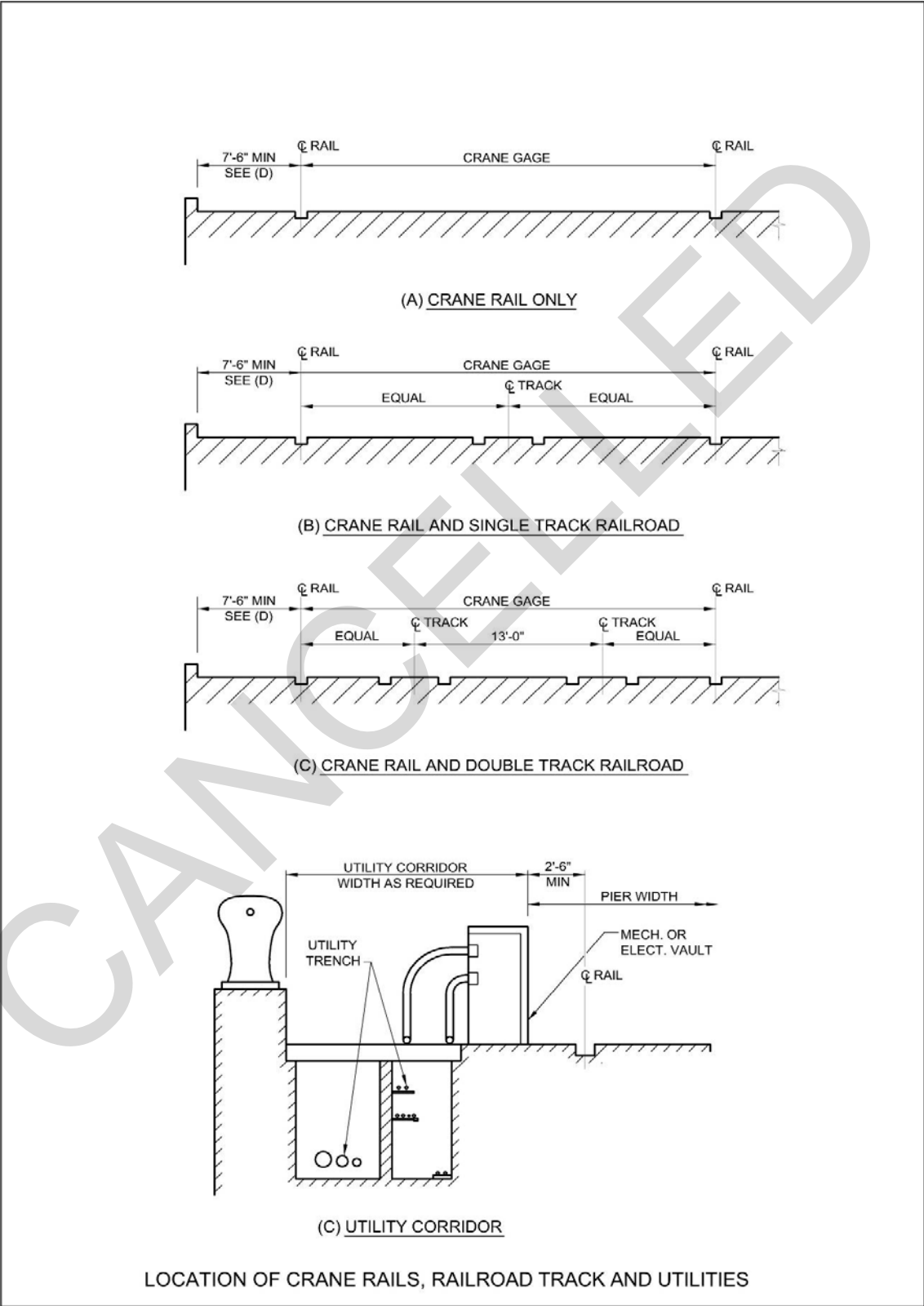


Table 2-2 Typical Single Deck Pier and Wharf Widths

Function Classification	Ship Type	Minimum Pier Width (feet)	Minimum Wharf Apron Width (feet)	Railroad Track (Standard gage)	Rail Mounted Cranes
Ammunition	Ammunition	100	100	--	--
Fitting-out	Destroyer	125	--	2 tracks 1 each side	2 40-ft gage 1 each side
Repair	Cruiser	125	--	4 tracks 2 each side	2 40-ft gage 1 each side
	Auxiliary	125	--	4 tracks 2 each side	2 40-ft gage 1 each side
Fueling	Auxiliary	50	--	--	--
Supply (general cargo)	Auxiliary	125+	80	2 tracks	--
Supply (container cargo)	Auxiliary	125	125	Up to 3 tracks	1 100-ft gage

* Width applies when 60-ft camels are used to breast out carriers

Figure 2-5. Single Deck Pier

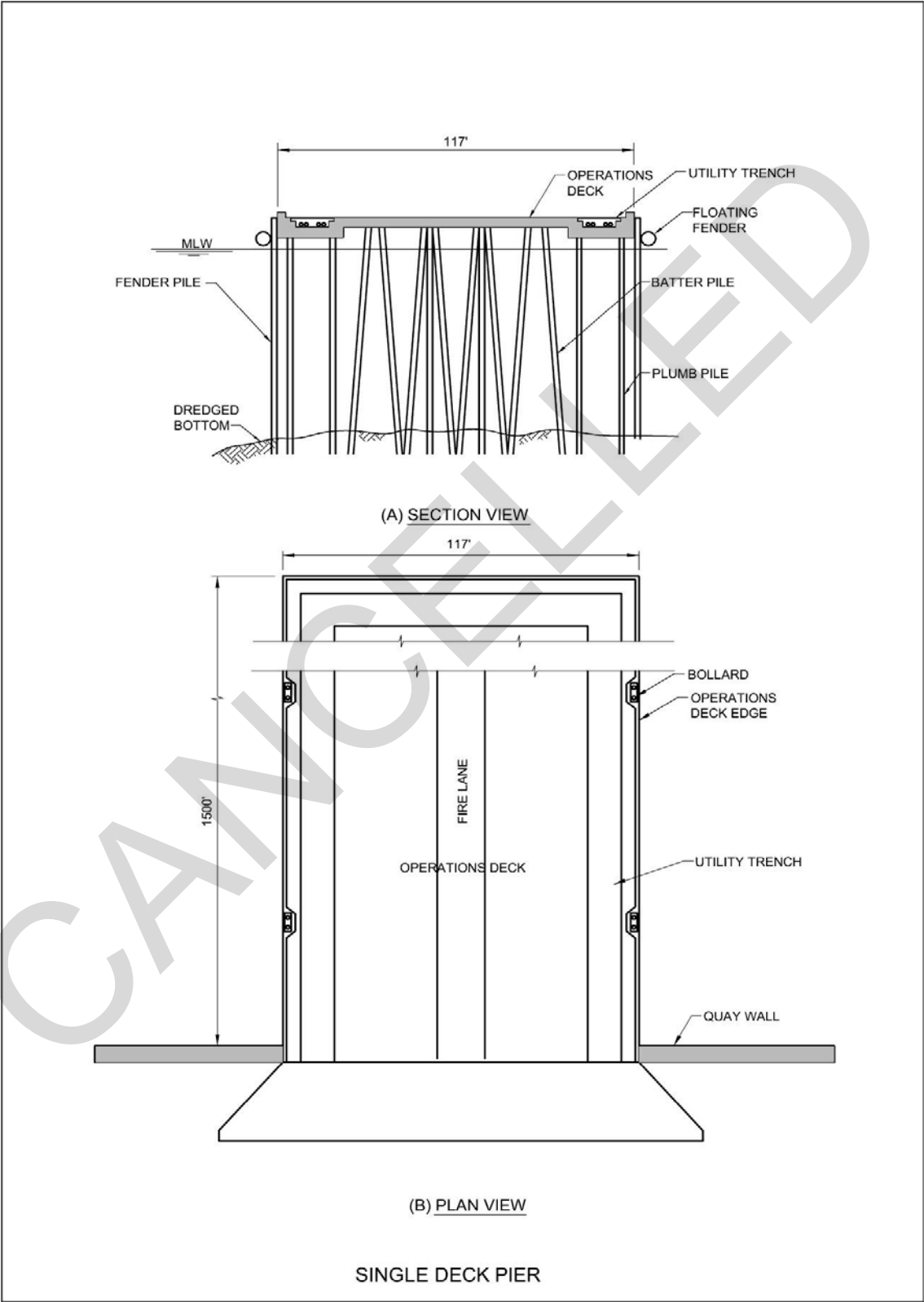
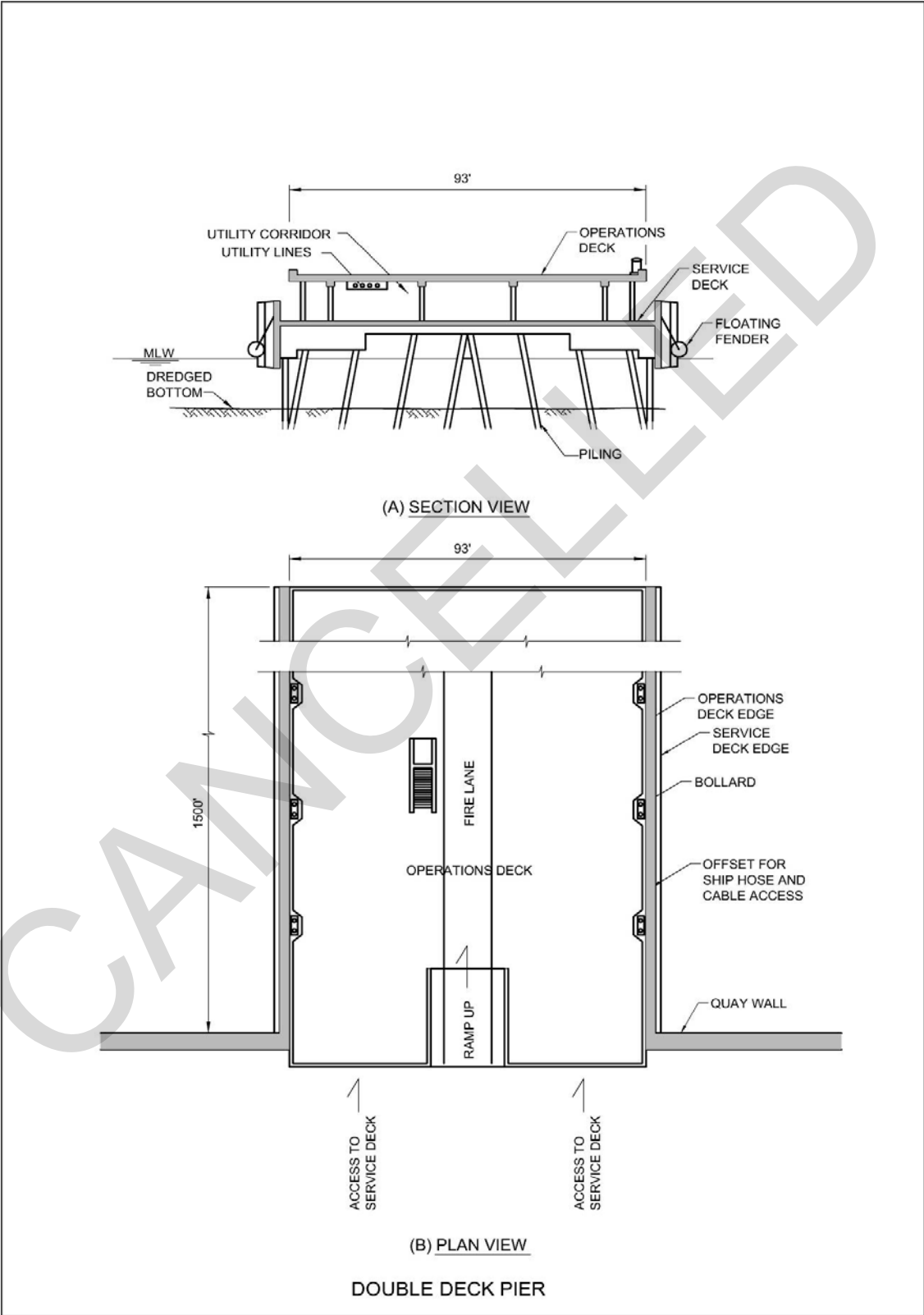


Figure 2-6. Double Deck Pier.



2-3.3.5 Railroad and Crane Trackage.

The number of railroad and crane tracks required and type of weight-handling equipment furnished on piers and wharves are dependent on the type of function, ships to be accommodated, amount of cargo to be handled, and rate of cargo transfer. Specific service requirements of the individual installation should be evaluated in conjunction with the following considerations:

Rail mounted cranes are often needed for loadout in repair, fitting out, and refit facilities. Width requirements depend on equipment selected. The use of wide gage crane service at repair, fitting out, ammunition and supply piers, and wharves should be considered. A rail gage of 40 ft (portal crane gage at PSNS and IMF Bremerton Site is 20 ft) for new cranes, except at container terminals or where it is necessary to conform to gages of existing tracks. When cranes are furnished, the distance from the waterside crane rail to the edge of the pier or wharf should be adequate to provide clearance for bollards, cleats, capstans, pits housing outlets for ship services, crane power conductors, and other equipment. Some electric powered gantry cranes may require either open or covered (panzer-belts) cable trenches in the pier or wharf deck for the power conductors. Where locomotive cranes are used on piers and wharves, the distances between tracks and curbs should be increased to accommodate the tail swings of the crane. For discussion of crane power conductors, see UFC 3-320-07N. For trackage requirements, refer to UFC 4-860-02N, Design: Trackage.

Do not consider railroad trackage for use on berthing piers and wharves (both active or inactive), except at stations where most cargo is received by rail, one or more tracks may be considered for use on active berthing piers. When there are existing railroad networks at the station, tracks should be considered for installation on repair, fitting out, ammunition and supply piers and wharves. When trackage is required along aprons of piers and wharves, at least two tracks should be provided so that one track may be used as a running track when the other track is occupied. Track gage should conform to gage of existing trackage on adjacent piers and wharves to avoid creation of "captive" cranes. Except where local conditions require otherwise, standard gage should be used for trackage. Width of piers and wharves should be adequate to allow passing of trains and forklift trucks (or other material-handling equipment). Make allowances for stored cargo and other obstructions.

Where spousons or flight decks of CVNs or other ship types with large deck overhangs are anticipated to be berthed, locate the crane rail so that all parts of the crane will clear the deck overhang.

Railroad and crane trackage should not be considered for use on piers and wharves used primarily for fueling (petroleum) operations.

When railroad and crane trackage is required on piers and wharves, the spacings shown on Figure 2-4 may be used as a guide.

2-3.3.7 Trucks and Other Vehicles.

A variety of service trucks and vehicles can be expected to use piers and wharves for moving personnel, cargo, containers, and supplies to and from the ships. The width provided must take into account operation and maneuvering of such vehicles. Turnaround areas should be provided.

2-3.3.8 Sheds and Buildings.

Pier and wharf deck is usually too expensive an area for storage sheds, which should therefore be located on land to be cost-effective. Storage sheds and buildings of any kind should be kept off piers and wharves unless their location can be justified by security considerations. Transit sheds may be considered on piers and wharves where a suitable upland area is not available. When used on a pier, the transit shed should be located along the centerline with clear aprons on both sides consistent with the requirements set forth herein but not less than 20 ft (6.1m) or more wide. On wharves, transit sheds and support buildings should be located on the land side edge with a clear apron toward the waterside. In general, support buildings on piers and wharves should be kept as small as feasible and located away from high-activity areas for least interference.

2-3.3.9 Movable Containers and Trailers.

During active berthing of ships, various containers of different sizes are temporarily or permanently located on pier deck to support the operations. These include shipyard toolboxes, garbage dumpsters, training trailers, and supply trucks. Adequate deck space should be available for locating and accessing these containers and trailers.

2-3.3.10 Fire Lane.

Retain and mark, with a painted yellow line, a 15-foot-wide (4.6 m) unobstructed fire lane. Provide a marked (with dashed, painted yellow lines) 2.5-foot wide (0.8 m) "dual use" buffer on both sides of the 15-foot-wide (4.6 m) unobstructed fire lane. Local enforcement would keep this area clear enabling a total available fire lane width of 20 feet. However, encroachment into the "dual use" buffer by cranes is acceptable. Any other encroachment into the "dual use" buffer will be handled on a case-by-case basis. For wharves, provide a 20-foot-wide (6.1 m) unobstructed fire lane immediately adjacent to the operating area. These requirements need not be applied to small craft or yard craft piers.

The following background is necessary to understand the reasoning for the current fire lane width specified for Navy piers. In 1994 a local recommendation was made at Naval Station Norfolk to increase the fire lane width from 12-feet to 15-feet, (3.7 m to 4.6 m) allowing for one-way traffic and some adjacent working area. This

recommendation was endorsed at NAVFAC headquarters and Change 3 was issued to MIL-HDBK-1025/1 *Piers and Wharves*, which stated:

For piers provide a 15-foot-wide unobstructed fire lane independent of net operating width requirements. Locate and mark the lane near the longitudinal pier centerline. For wharves, provide a 15-foot-wide unobstructed fire lane immediately adjacent to the operating area...

Since this time, Navy piers have been and are continuing to be built with a 15-ft (4.6 m) fire lane. Subsequent to this an NFPA requirement calling for 20 ft (6.1 m) fire lanes was identified. The current philosophy is supported by the fact that there are a number of considerations that go into development of pier width and pier area. Width and area must be provided for the following functions in addition to fire protection: berthing, maintenance, crew training, cargo transfer, light repair work, waste handling, fueling/ordnance handling (under some circumstances) and utilities that provide hotel services. Increasing pier width, by another 5 ft (1.5 m), over the length of the pier would cause a significant increase in construction cost and require additional real estate where multiple piers are arranged. Recognizing the fact that area is allotted for crane location along the length of the pier, this area will not be occupied a majority of the time, therefore, it is anticipated that additional area besides the 15-ft (4.6 m) fire lane and 2.5 ft (0.6 m) wide "dual use" buffer will be available along the pier for additional staging in the event of an emergency.

2-3.3.11 **Fuel-Handling Equipment.**

At specified berths, stationary fuel-handling equipment consisting of self-adjusting loading arms is often furnished to offload fuel products from tankers to onshore storage facilities. Pier or wharf width requirements depend on equipment selected and facilities furnished.

2-3.3.12 **Phased Maintenance Activities (PMA).**

The four levels of PMA and their estimated space requirements are as follows and as detailed in Table 2-3.

For additional information, see \1\ NCEL TM-5, Advanced Pier Concepts, Users Data Package and OPNAVINST 4700.7K, *Maintenance Policy for U.S. Navy Ships*. /1/

- a. Intermediate Maintenance Availability (IMA). IMA consists of removal and repair of shipboard equipment performed by Shore Intermediate Maintenance Activity (SIMA) personnel or tender forces, with a duration of approximately 30 days. Gross deck requirements range from 2000 to 3000 ft² (185.5 to 287.8 m²) with work area dimensions varying from 30 x 65 ft (9.1 x 19.8 m) to 30 x 100 ft (9.1 x 30.5 m.)

b. Planned Restricted Availability (PRA). PRA consists of limited repairs of shipboard equipment and systems by contract forces under Supervisor of Shipbuilding and Repairs (SUPSHIP) control, with a duration of 30 to 60 days. Gross deck area requirements are about 10,800 sq ft (1003.3 m²) or 35 x 310 ft (10.7 x 94.5 m).

c. Selected Restricted Availability (SRA). SRA consists of expanded repairs and/or minor ship alterations to shipboard equipment and systems by SUPSHIP contract forces, with a duration of approximately 60 days. Gross deck area requirements are about 18,000 sq ft (1672.2 m²) or 35 x 515 ft (10.7 x 157.0 m.)

d. Regular Overhaul (ROH). ROH consists of major repairs and ship alterations to shipboard equipment and systems by SUPSHIP contract forces, with a duration of six to eight months. Gross deck area requirements are about 23,000 sq ft (2136.7 m²) or 35 x 660 ft (10.7 x 201.2 m.) In addition, there would be a requirement for turnaround areas on deck and warehousing off the pier or wharf.

2-3.4 **Slip.**

2-3.4.1 **General Considerations.**

The clear distance between piers, or slip width, should be adequate to permit the safe docking and undocking of the maximum size ships that are to be accommodated in the slip. The size of a slip should also permit the safe maneuvering and working of tugboats, barges, lighters, and floating cranes. At multiple berth piers, where ships are docked either one per berth, two abreast per berth, or more, sufficient clearance should be available to permit the docking and undocking of ships at the inboard berth without interfering with ships at the outboard berth. Because the size of a slip is affected by docking and undocking maneuvers, consideration should be given to the advice of local pilots who are familiar with the ships to be handled and with prevailing environmental conditions such as winds, waves, swells, and currents. Slip width is also influenced by the size and location of camels/separators used between ship and structure and between ships. The width should be reviewed with specific functional requirements of the individual installation before a final determination is made.

2-3.4.2 **Minimum Slip Length - 1350-1500 ft. (412m-457m) min.**

This range in slip length is based on berthing two CG 47 (lower range) and two LPD 17 (upper range) which provides adequate space for bow and stern lines, provides a safety and security clearance fore and aft of each berth of 50 ft. (15.2m), and facilitates emergency sorties without tug support. For CVN's , provide 1300 to 1325 ft (396.2 to 403.8 m) minimum which allows a safety clearance fore and aft of 100 ft (30.5 m.)

Table 2-3 Estimated Space Requirements for PMA

Activity	PRA	SRA	ROH
COMMAND AREA¹			
Mobile Administration Building	-	2,800	5,600
Parking Area	250	250	500
Bicycle Racks	70	140	200
Subtotal	320	3,120	6,300
OPERATING AREA			
Demineralizer	-	1,500	1,500
Bilge Water/Stripping Tank	-	400	400
Dumpsters	1,150	1,440	1,730
Portable Solid-State Generators	-	240	240
Air Compressors	290	290	290
Welding	1,500	1,500	1,500
Flammable Storage	150	600	600
Transportation Laydown	600	900	1,500
Crane Work	3,850	3,850	5,250
Offload Area (oils, fuels, etc.)	3,00	3,600	4,500
Potable Heads	-	70	70
Additional Brow	-	400	400
Subtotal	10,540	14,790	17,980
Total	10,860	17,980	24,280

¹ For piers with ordnance handling berths, do not provide command area

2-3.4.3 Minimum Width of Slip for Active Berthing.

Minimum slip width: Location of homeport berthing facilities should allow nesting of DDG 51 / CG 47 / DD 963 / FFG 7 class ships. Minimum slip width for surface combatant multiple, nested configuration is 600-ft. (183m). Minimum slip width for single amphibious warfare and combat logistic ship berths is 600-ft (183m).

a. For CVN's, minimum width shall be 600 ft (182.9 m) with no other ships, 800 ft (243.8 m) with CVN on opposite berth. Add 100 ft (30.5 m) to width if other ships are berthed at the bow or stern of the CVN.

b. Minimum width should be the greater of the two dimensions shown on Figure 2-3. Additionally, the width should not be less than 300 ft (91.4 m.) The recommended criteria are applicable only if ships are turned outside the slip area. Refer to SCDB for the beam of typical ship types. At submarine slips, width requirements should be increased by at least four beam widths to account for camels and separators, to provide for ships' vulnerability if their safety is involved, to provide for special maneuvering requirements of other ships during berthing or passing, and to provide for special environmental

conditions such as currents, waves, and winds. The requirements discussed above apply where ships are berthed on both sides of a slip. Where ships are berthed on only one side of a slip, the width may be reduced. See Figure 2-3. When more than two abreast berthing is employed, the width of slip should be increased by one ship beam for each additional ship added in order to maintain adequate clearances between moored ships during berthing and unberthing maneuvers. Thus, for three-abreast berthing on both sides of a slip, the slip width for single-berth piers would be equal to 10 times ship beam and the slip width for multiple-berth piers would be equal to 11 times ship beam.

2-3.4.4 **Minimum Width of Slip for Inactive Berthing.**

At slips containing inactive berths where ships are stored for long periods of time on inactive status in nests of two, three, or more, clear distances between moored ships and slip width may be reduced by one or two ship beams to reflect the reduction in the frequency of berthing maneuvers and the decrease in activities of small boats and floating equipment.

2-3.4.5 **Water Depth in Slips.**

Information on required water depth in slips and at berths is contained in UFC 4-150-06.

2-3.5 **Pier and Wharf Deck Elevation.**

Set deck elevation as high as possible for surface ship berthing and as low as possible for submarine berthing, based on the following considerations:

2-3.5.1 **Overtopping.**

To avoid overflow, deck elevations should be set at a distance above mean higher high water (MHHW) level equal to two thirds of the maximum wave height, if any, plus a freeboard of at least 3 ft (0.9 m.) Bottom elevation of deck slab should be kept at least 1 ft (0.3 m) above extreme high water (EHW) level. Where deck elevation selected would result in pile caps or beams being submerged partially or fully, consideration should be given to protecting the reinforcing from corroding.

2-3.5.2 **Ship Freeboard.**

Consideration should be given to the varying conditions of ship freeboard in relation to the use of brows and the operation of loading equipment such as conveyors, cranes, loading arms, and other material handling-equipment. Fully loaded ships at mean lower low water (MLLW) level and lightly loaded ships at MHHW level should be considered for evaluating the operation of such equipment.

2-3.5.3 **Utilities.**

Deck elevations should be set high enough above MHHW levels to allow for adequate gradients in drainage piping as well as to prevent flooding of utilities/trenches that are located below the pier deck.

2-3.5.4 **Deck Elevation for CVN Berths.**

Deck elevation must not conflict with CVN elevators. When lowered, the lowest projection of the elevator is 9.0 ft (2.74 m) above the design water line for a CVN. Use properly designed camels and pier fendering to provide sufficient standoff to prevent interference.

2-3.5.5 **Adjacent Land.**

If possible, set deck elevation as close as possible to grade of the adjacent land for smooth access of mobile cranes, service vehicles, personnel vehicles, and railroad. Ramps may be used to access the deck set higher or lower than adjacent land. A maximum gradient of 15 percent may be used for such ramps when railroad access is not provided. Consideration should be made to reduce grade to 6 to 8 percent, comparable to state DOT requirements, in cold regions where snow or ice can be a problem. Ramps for pedestrian access should have a gradient less than 12 horizontal to 1 vertical, with 5 ft (1.5 m) minimum landings for every 30 in (762 mm) of rise to conform to American with Disabilities Act (ADA) of 1990. Vertical curves should be large enough so that long wheelbase or long overhang vehicles do not or drag. Where track mounted cranes are specified, all the deck areas serviced by the crane should be kept at the same elevation.

2-3.5.6 **Special Situations.**

For double deck piers or wharves and in situations where a sloping deck is contemplated (for gravity flow of sewer lines), all the above considerations should be evaluated.

2-4 **UTILITIES.**

2-4.1 **General.**

For design criteria of utilities on piers and wharves, refer to UFC 4-150-02. Usually, utility connection points (hoods, vaults, or mounds) are located and spaced along the pier or wharf edge to be as close as possible to the ships' utility terminals in the assumed berthing position. The connection points should be planned and located to accommodate reasonable future changes in berthing plan or in the type of ships served. Typical hotel services are: potable water, non-potable/saltwater, CHT, oily waste/waste oil, compressed air, steam, telecommunications, and shore power. All utility lines should be kept where they can be conveniently accessed from above deck. Typical utility configurations on piers and wharves are described below:

2-4.1.1 Utility Trenches.

These are basically protected trenches running along the waterside edge of a pier or wharf accessed by removable covers from the top. Refer to Figure 2-5. In a pier, the lines can go along one edge all the way to the end and be "looped" to the other edge back to land. In a wharf, the lines can be supplied and returned through smaller lateral "trenches." Where the number and size of lines is large enough, a utility tunnel or gallery can be utilized with access from the top or side. Where a fuel line is provided, it should be kept in a separate trench for containment of leaks.

2-4.1.2 Double Deck Pier.

As shown in Figure 2-6, utility lines are isolated on the lower deck and can be easily accessed. The upper deck is thus clear of all utility lines and terminations and is free for operations.

2-4.1.3 Ballasted Deck.

This concept consists of a sloping deck filled with 1.5 ft (0.46 m) to 3 ft (0.91 m) of crushed rock ballast, which provides a convenient medium to bury the utility lines and crane or rail trackage. The ballast is topped with concrete or asphalt paving, which will provide a firm-working surface for operations. The paving and ballast can be removed to access the utility lines. Concrete pavers have been used successfully for paving ballasted decks and provide improved access to utilities buried in the wharf ballast. Future changes in utilities and trackage can similarly be accommodated. Also, the ballast helps to distribute concentrated load to the deck slab, thus allowing heavier crane outrigger loads.

2-5 LIGHTING.

Pier lighting is needed for security, safety, and operations. Provide safety and operations pier lighting in accordance with UFC 3-530-01, *Design: Interior and Exterior Lighting and Controls* \1\ /1/ and as follows:

2-5.1 Topside Lighting.

\1\ Refer to UFC 3-530-01. Instances of failures of high mast lighting light ring assembly failures have been reported. Additional information is contained in Appendix C. It is imperative that a registered structural engineer review all contract documents (plans and specifications) and construction contract submittals specifically related to high mast light ring assemblies. This is to insure that design of light ring assembly provides for safe lowering, raising, and locking/securing into position. /1/

2-5.2 Lower Deck Lighting.

\1\ Refer to UFC 3-530-01. /1/

2-5.3 **Underdeck Lighting.**

\1\ Refer to UFC 3-530-01./1/

2-6 **SECURITY.**

For waterfront security and anti-terrorism/force protection criteria, refer to future \1\ UFC 4-025-01, Waterfront Security Design, currently in final draft and near final publication. /1/

2-7 **LANDSIDE APPROACHES**

2-7.1 **Function.**

Approaches are required to provide access from shore to piers and wharves located offshore. Usually, the approach is oriented at right angles to the shoreline. Except in special situations, approaches should consist of open-type trestle structures that minimize impediments to water flow and disturbances to the characteristics and ecology of the shoreline. The number, width, and orientation of approaches should consider the volume of traffic flow, circulation of traffic, existing roads on shore side, fire lane requirements, and interruption of service due to accidental collision damage to the approach. As approaches are also used to route utilities to the pier or wharf, the width of approaches will be further influenced by the space requirements of the utility lines being carried. Vehicle and pedestrian approach can usually be combined on the same structure. However, where a large number of personnel are anticipated to access the facility, a separate pedestrian approach should be considered.

2-7.2 **Roadway Width.**

Criteria is provided below:

- a. For infrequently accessed facilities (such as magnetic treatment/electromagnetic roll piers), the approach roadway should have a minimum width of 10 ft (3.1 m) curb to curb for one-lane vehicular traffic.
- b. For fueling piers and wharves, the approach should have a minimum width of 15 ft (4.6 m) curb to curb for clear access of emergency vehicles.
- c. For all other functional types, a two-way 24 ft (7.3 m) wide curb-to-curb roadway should be provided. If two separate one-way approaches are provided for a pier or wharf for incoming and outgoing traffic, each of them may be 12 ft (3.7m) wide curb to curb. In any case, the approaches should be wide enough to permit fast movement of all vehicles anticipated for use on the facility, including emergency vehicles and mobile cranes.

2-7.3 **Walkway Width.**

Separate walkway structures should have a minimum clear width of 3 ft (0.9 m.) Where the walkway is attached to a vehicle traffic lane, provide a minimum width of 2 ft 6 in (0.8 m) clear, from curb to safety railing.

2-7.4 **Roadway Deck Elevation.**

The requirements for pier and wharf deck elevation are also applicable to the approaches. Where the adjacent land is higher or lower than pier or wharf, the approach can be sloped up or down to serve as a transition ramp. For approaches longer than 100 ft (30.5m), the slope should be limited to 6 percent. For shorter approaches, the maximum slope should be 8 percent, 12H:1V.

2-7.5 **Number of Approaches.**

2-7.5.1 **One Approach.**

For fueling and magnetic treatment/electromagnetic roll facilities, at least one single-lane approach structure should be provided, unless the facility is built as an island wharf or pier with access by watercraft.

2-7.5.2 **Two Approaches.**

- a. Where volumes of vehicular movements are large, provide at least two approaches to ensure continuous uninterrupted traffic flows from pier or wharf to shore. At multiple-berth facilities, consider approach structures at least every 500 ft (152.4m).
- b. Where the width of the pier or wharf is not sufficient to permit turning of vehicles, provide two approaches. Thus, vehicular traffic may enter and leave the facility without having to turn around. Since it is easier for a truck to negotiate a left turn, design traffic patterns to favor left turns.

2-7.5.3 **Railroad Access.**

Where rail access is planned for either crane or railroad, a separate approach is not necessary. However, consider a separate walkway. Consider approach slope limit for crane or railroad.

2-7.6 **Turning Room.**

At the intersection of approach and piers and wharves, provide fillets or additional deck area at corners to allow for ease in executing turns. Where a one-lane approach roadway is provided as the only access, provide the pier or wharf with sufficient turnaround space on the facility so that outgoing vehicles do not have to back out along the approach.

2-7.7 **Safety Barriers.**

On all approaches, provide safety barriers adequate for the type of traffic using the facility (pedestrian, vehicular, and/or rail). However, safety barriers should not be provided in areas where mission operations, such as ship or small craft berthing, are performed. Rail only approaches do not normally require safety barriers. Provide traffic barriers between pedestrian and traffic lanes. Traffic and pedestrian barrier design must conform to AASHTO *Guide Specifications for Bridge Railings* and AASHTO *Bridge Guide and Manual Interim Specifications*.

2-8 **STRUCTURAL TYPES.**

2-8.1 **General.**

The three major structural types for piers and wharves are open, solid, and floating. Open type piers and wharves are pile supported platform structures that allow water to flow underneath. Figure 2-7 illustrates the open type. Solid type uses a retaining structure such as anchored sheet pile walls or quaywalls, behind which a fill is placed to form the working surface. Solid type will prevent stream flow underneath. Figure 2-7 illustrates the solid structural type. Floating type is a pontoon structure that is anchored to the seabed through spud piles or mooring lines and connected to the shore by bridges or ramps. A floating double deck pier is shown in Figure 2-8. This pier is currently under development by NFESC, more information can be obtained at:

\1\ https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_NFESC_pp. /1/ All structure types can be either single or double level.

2-8.2 **Selection of Type.**

Numerous factors influence the selection of one structural type over the other. Evaluate each of these factors against the construction and operating costs of the facility before a final decision is made on the structural type. Place greater emphasis on selecting the type that will withstand: unexpected berthing/mooring forces, adverse meteorological and hydrological conditions, and the corrosive effects of a harsh marine environment such that it will require little or no maintenance. The geotechnical characteristics of a given site, and economic analysis of alternate structural types will often dictate structural requirements. For instance, in areas with poor near surface soils but with good end bearing for piles, an open pile supported structure with a shallow bulkhead (or no bulkhead) will be most economical. Conversely, in areas with good near surface soils and poor pile bearing, a solid bulkhead may be more economical.

2-8.2.1 **Shoreline Preservation.**

The structural type is seriously influenced by aquatic and plant life existing along the shore of the planned facility. In environmentally sensitive areas such as river estuaries, the solid-type wharf, which would disturb or destroy a considerable length

of shoreline, should not be considered. Select the open structural type, which would have the least impact on the shoreline.

2-8.2.2 **Bulkhead Line.**

When the facility extends beyond an established bulkhead line (the limit beyond which continuous solid-type construction is not permitted) use open type construction.

2-8.2.3 **Tidal or Stream Prisms.**

Where it is required to minimize restrictions of a tidal or stream prism (the total amount of water flowing into a harbor or stream and out again during a tidal cycle) use open type construction.

2-8.2.4 **Littoral Drift.**

Along shores where littoral currents transporting sand, gravel, and silt are present, use open type construction to mitigate shoreline erosion and accretion.

2-8.2.5 **Ice.**

In general, open type structures are vulnerable and should be carefully investigated at sites where heavy accumulations of sheet or drift ice occur. Also, when ice thaws, large blocks of ice may slide down the piling, impacting adjacent batter or plumb piles. Thus, the solid type may be preferable at such sites.

Figure 2-7. Open and Solid Type Piers/Wharves.

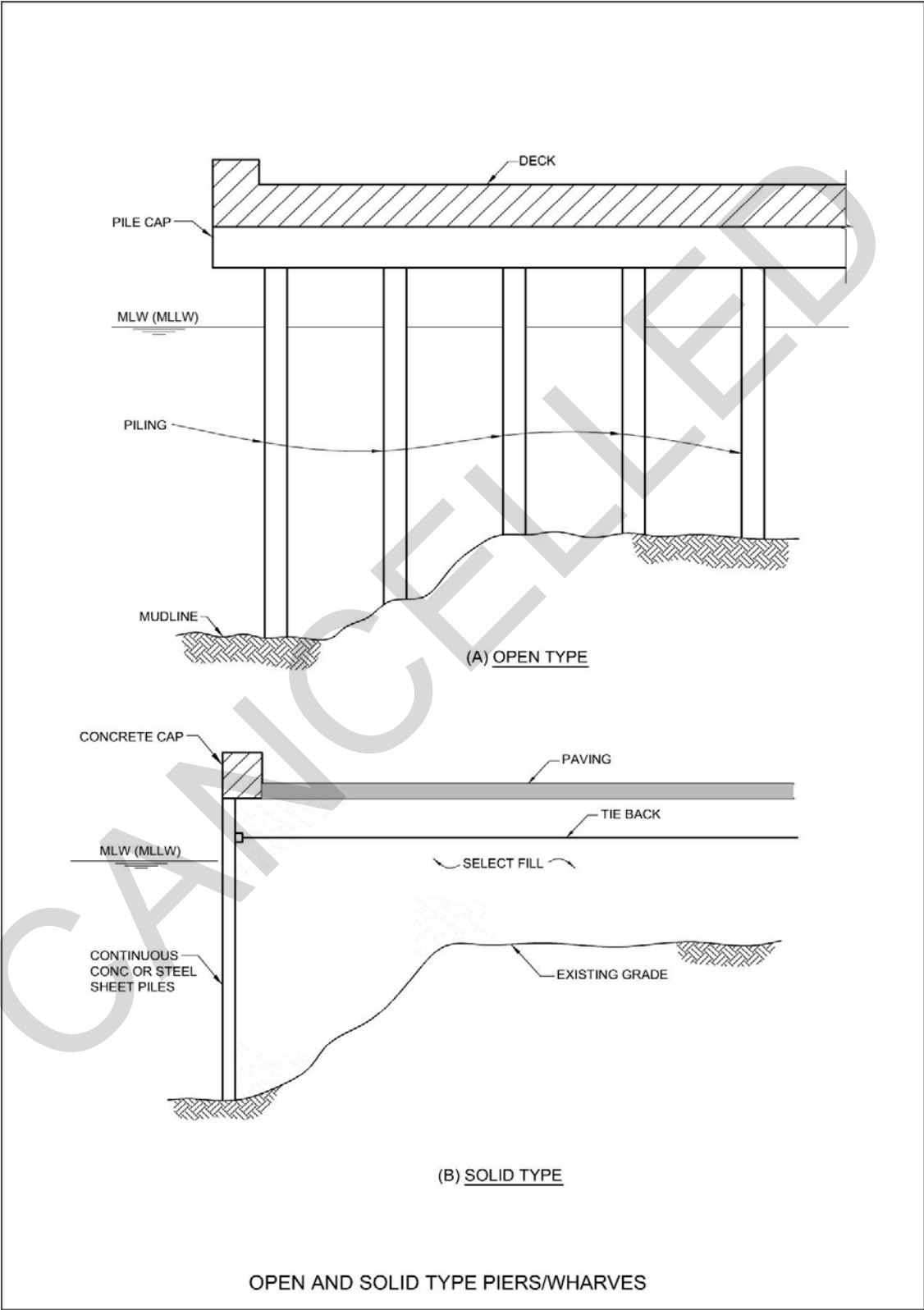
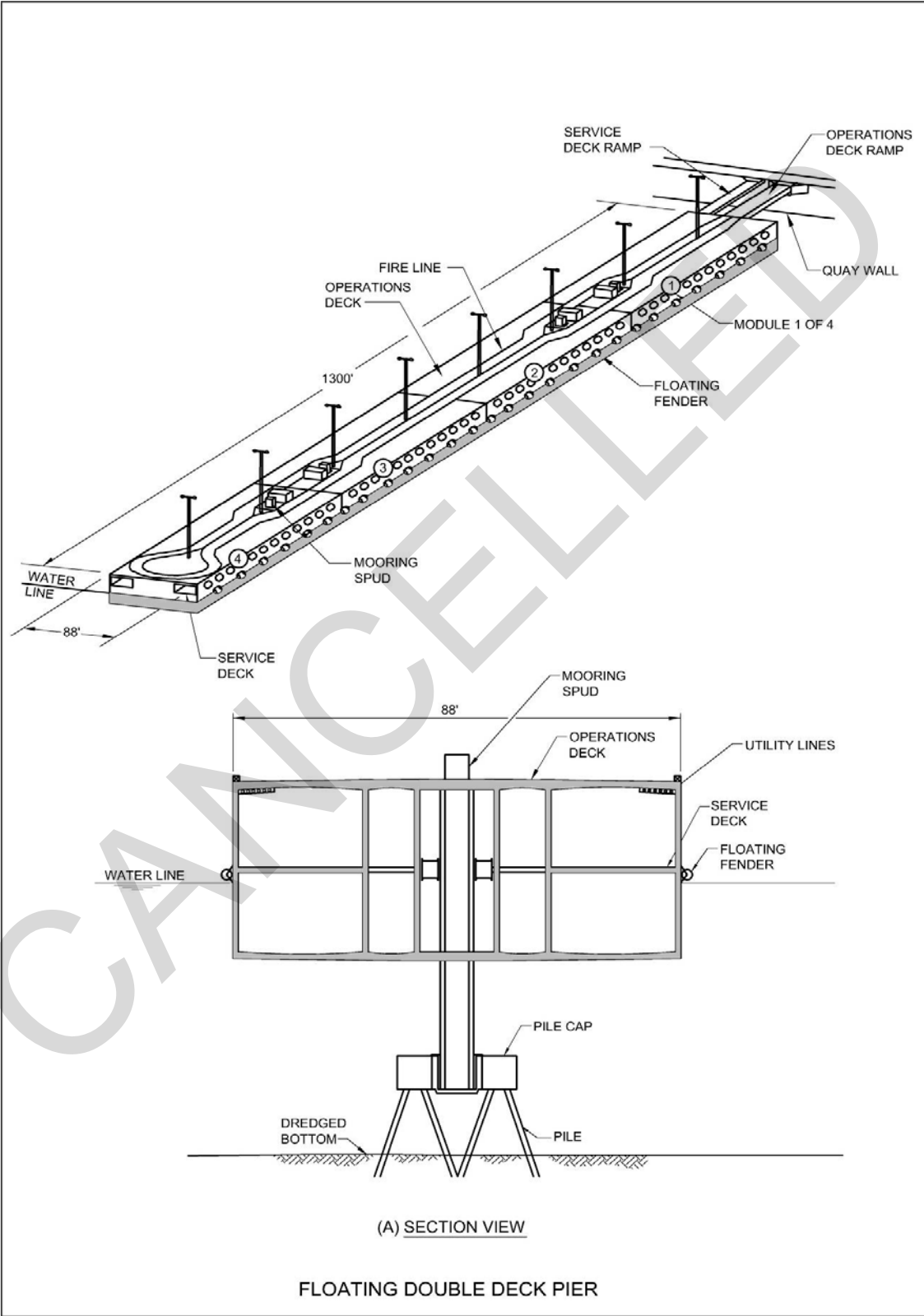


Figure 2-8. Floating Double Deck Pier.



2-8.2.6 **Earthquake.**

In areas of high seismic activity, carefully consider construction utilizing sheet pile bulkheads or walls because of the high lateral earth pressures that can develop on the sheet piling. When a pile-supported platform (with curtain wall) is used for a wharf structure in conjunction with hydraulic fill, which is susceptible to liquefaction, consider a rock dike to resist the lateral forces that may be caused by liquefaction of the fill. The use of an engineered soil filter fabric between the rock dike and granular fill should also be considered. In areas of extremely high seismic risk, and where tsunamis and seiches are anticipated, seriously consider the floating type as it is less likely to be affected by or will suffer only minor damage from the seismic activity.

2-8.2.7 **Water Depths.**

Consider open type construction in all depths of water when accommodating naval vessels, cargo vessels, and tankers. Depth limits for solid-type construction, utilizing sheet pile bulkheads, are imposed by the magnitude of the applied surcharge, subsurface conditions, and freeboard of the bulkhead above the low waterline. Generally, anchored sheet pile bulkheads may be considered in water depths up to 30 to 35 ft (9.1 to 10.7 m,) where favorable soil conditions exist. When greater water depths are required at solid type bulkhead structures, consider the use of relieving platforms, bulkheads consisting of reinforced high-strength steel sheet piles, or cellular construction.

2-8.2.8 **Subsurface Conditions.**

Generally, subsurface conditions do not limit the use of open type construction. For almost all subsurface conditions, with the possible exception of rock close to the harbor bottom surface, suitable piles or caissons can be designed. Where rock is close to the surface and pile seating may be difficult and costly, consider cellular construction. When open type construction must be used in an area where rock is close to the surface, piles should be socketed and anchored into the rock. Consider sheet piling, used for bulkheads or retaining walls in conjunction with platform wharf structures or combination piers, only when subsurface conditions indicate that suitable anchorage and restraint for the toe of the sheet piling can be achieved and where select material is available for backfill.

2-8.2.9 **Fill Loss.**

When precast concrete and steel sheet pile bulkheads are used in pier and wharf construction, take special care to prevent fill leaching through the interlocks, causing subsidence of retained fill. Install a filter blanket or other method that could prevent or control fill leaching to reduce subsidence and consequent paving maintenance.

2-8.2.10 **Advance Bases and Remote Areas.**

NAVFAC's Contingency Engineering Group is responsible for providing support in delivering engineer services to forward environments. This support enables engineer response to the full range of expeditionary (non-permanent) services, i.e. piers, wharves, and causeways at advance bases and remote areas. NAVFAC's Contingency Engineering Group is supported by the Naval Facilities Engineering Logistics Center, the Naval Facilities Engineering Service Center's Amphibious Operations and NAVFAC's Sealift Support Program Office. These groups, working together, develop and manage sealift support products including modular, floating and elevated piers, wharves, and docks; powered and non-powered causeways; roll-on/roll-off floating platforms; and fabrication of special craft and bulk liquid transfer systems. Some examples are noted below

- a. **Steel Pontoon Wharf.** Modular steel pontoon structures may be used for temporary facilities to berth ships up to loaded drafts of 30 ft (9.1 m.) This structure type may be provided where it is not advisable to construct a fixed facility and at advanced bases where versatility and ease of deployment are required. The allowable uniform loading is limited, as is the capacity for mobile cranes.

- b. **Navy Lightered (NL) P-Series Pontoon Structures.** Navy lighterage structures, when joined together, form a roadway to permit movement of vehicles, personnel and supplies from ship to shore during amphibious operations. In addition to bridging the gap between ships and the beach, floating causeways may be used as lighterage barges to transport vehicles and supplies to a wharf or to a beach, or may serve as piers for unloading small craft. NL pontoons are reinforced, welded steel cubes, 5 ft (1.5 m) long, 7 ft (2.1 m) wide, and 5 ft (1.5 m) high, capable of accommodating HS-20 truck loading as specified by AASHTO. Pontoons are assembled into strings which are joined to form pontoon barges and pontoon bridge units. Thus, a 3 x 15 pontoon consists of 3 strings of 15 pontoons each. The primary NL lighterage structures are 3 x 15 causeway sections of both powered and non-powered variety. Two powered configurations include the Side Loadable Warping Tug (SLWT) and the Causeway Section Powered (CSP). Three non-powered configurations include: the Causeway Section Non-powered Intermediate (CSNP-IN), the Causeway Section Non-powered Beach (CSNP-BE), and the Causeway Section Non-powered Offshore (CSNP-OS). These powered and non-powered causeway sections can work together in various configurations to form barge ferries, floating piers, elevated piers, and Roll-On/Roll-Off Discharge Facilities (RRDF) used to assist downloading RO/RO ships while moored in stream. \1\ /1/ Improved Navy Lighterage System (INLS). NAVFAC's Sealift Support Program Office is currently working on a more efficient method of moving equipment from ships to shore in locations where conventional port facilities may be unavailable, damaged, inadequate, or nonexistent. The primary purpose of INLS is to support ship offload but can be used to construct piers and wharves when needed. This new system

will replace the existing Navy Lighter (NL) system, which has been in use since World War II. INLS is comprised of powered and non-powered floating platforms assembled from interchangeable modular components. Where NL sections are assembled from smaller pontoons, each INLS module is fabricated using a traditional tug or barge monohull. Each nonpowered platform is 80 ft (24.4 m) long by 24 ft (7.3 m) wide by 8 ft (2.4 m) high and each powered craft hull is 87 (26.5 m) ft long by 24 ft (7.3 m) by 8 ft (2.4 m) with additional height for the pilot house and mast. This provides INLS with much greater seakeeping capability when compared with NL. In addition, INLS will be faster than NL, with a 10 knot (5.1 m/s) speed. The basic platforms of INLS are a Warping Tug, a Causeway Ferry, a Floating Causeway and a Roll-on/Roll-off Discharge Facility. The Floating Causeway serves as a pier to support both the offload of the lighterage and to tie up small vessels. The pier is dug into the beach at the shore end and moored in place using standard drag anchors.

c. Jack-up Barge. This type consists of a structural steel seaworthy barge provided with openings for steel caissons, which are lowered to the harbor bottom when the barge has been floated into final position. The barge may be completely outfitted during construction with ship fenders, deck fittings, and utilities including power, lighting, communications, water supply, sanitary facilities, etc., so that once it is jacked into position and utility tie-ins are made, it is ready to receive ships. Circular pneumatic gripping jacks, mounted on the deck above the caisson openings, permit the barge to be elevated in steps. The barge is loaded with steel caissons, a crane for pile erection, and other tools and materials required for the fieldwork, and is towed to the site. At the site, the barge is moved into approximate position and the caissons are dropped through the jacks and hull by the crane. The caissons, suspended above the harbor bottom and supported by engaging the jacks, are seated into the harbor bottom by dead weight. The barge-like deck is jacked to the required elevation and locked. Each caisson is then released from its jack and driven to refusal or required penetration. When all caissons are driven, the hull of the barge is welded to the caisson, the jacks are removed, and the caissons are cut off flush with the deck and capped with steel plates. In some situations, the caissons are filled with sand to avoid buoyancy problems. Jack-up barge type structures are also constructed using hydraulic jacks and open-trussed towers instead of pneumatic jacks and circular caissons.

d. Template. This type involves the fabrication of the various structural components of the pier, transportation of the prefabricated units to the construction site by barge, and erection of the prefabricated units to form the completed facility. As noted under jack-up barge, the template type pier may be outfitted, beforehand, with the utilities, deck fittings, and services that are needed to produce a fully working berthing facility. The prefabricated

structural steel units consist of templates, deck assemblies made up of cap beams or trusses and stringers, tubular piles, fender units, decking (timber or concrete), fittings, and miscellaneous hardware. The template is an assembly consisting of four or more tubular columns connected with tubular bracing and welded together to form a structure of height approximately equal to the depth of water in which it is to be installed. A floating crane is used to transfer the template from the transporting barge and position it on the harbor bottom. Steel piles are placed through the template tubular columns and driven to refusal or the required penetration. If the harbor bottom is very soft, the template is held in a suspended condition while the steel tubular piles are placed and driven through the template columns. After pile driving, the space between the piles and the template columns is filled with grout. As succeeding templates are erected, deck units, decking, fender units, and fittings are placed to form the completed marine facility. Based on past experiences, it is estimated that a prefabricated template type structure, 90 ft (27.4 m) wide x 600 ft (182.9 m) long, could be erected in about 21 days and a structure of the jackup type could be erected in about 3 days. An advantage of the jackup barge structure is that it can be moved and reused at other sites. For permanent facilities in remote areas, the floating type has advantages as the onsite construction is minimized.

e. **Container-Sized Modular Pontoons.** Commercially available modular causeway systems are becoming increasingly popular for naval operations. The pontoons are made from container-sized modules that can be stored and transported in commercial container ships. The modules are lifted out and assembled on calm water or launched from a ship's deck. Cleats, bits, and other hardware can be installed and removed as needed. With minor modifications, the individual modules can be structured to accommodate power units and fuel tanks for use as a powered causeway. The connector pieces are interchangeable and removable for rapid repairs. The modular causeway system makes it possible to transport the causeway to the amphibious operations area on a container ship or an auxiliary crane ship for rapid deployment."

f. **The Modular Elevated Causeway (ELCAS(M))** is a temporary pierhead and 24 ft (7.3 m) wide roadway made from connected ISO-compatible P40-Series steel pontoons elevated on piles and extending seaward across the surf zone to a distance up to 3,000 ft (914.4 m) from the beach. The entire ELCAS(M) pier facility, including the necessary construction and installation equipment, is designed to be transported on one Transport-Auxiliary Crane Ship (TACS). The actual system installation length is determined by the requirement to reach a maximum water depth at the pierhead of 20 ft (6.1 m) Mean High Water; with the underside of the pier structure a minimum of 15 ft (4.6 m) above the Mean Low Water level based on a tidal range of 8 ft (2.4 m). The primary function of the system is to provide throughput of

containerized cargo over the surfzone offloaded from lighterage at the pierhead, which is carried by trucks to the beach. Construction of the pier system is accomplished in a cantilever fashion from one constructed 40-ft (12.2 m) section to the next, from the beach out to the pierhead over the surfzone with no construction equipment operating from platforms on the water. The ELCAS(M) system is intended to assist Marine Corps and Joint Service Expeditionary Force logistics support requirements, specifically through Joint Logistics Over the Shore (JLOTS), Logistics Over the Shore (LOTS), or Amphibious Assault Follow-on Echelon (AFOE) operations by providing suitable port facility for the transfer of containerized cargo from displacement-type lighters. \1\ /1/

g. The Amphibious Bulk Liquid Transfer System (ABLTS) is a self-contained fuel and water system capable of deploying 10,000 feet of 6-inch fuel hose line and 4-in (100 mm) water hose line from a designated ship to an ABLTS Beach Interface Unit (BIU) ashore. Forces ashore or using service will interface shoreward to the ABLTS BIU with their ashore bulk fuel and water systems.

ABLTS consists of three primary subsystems:

- 6-in (152 mm) fuel subsystem (contained on two hose reels that each support 5,000 ft (1524 m) of 6-in (150 mm) hose line).
- 4-in (102 mm) water subsystem (contained on one hose reel that supports 10,000 ft (3048 m) of 4-in (100 mm) hose line).
- Collateral equipment (mostly contained in two 20-ft (6.1 m) ISO containers).

ABLTS is designed to be deployed from NL and INLS causeways. ABLTS is forward deployed with the Military Sealift Force (MPF) ships. ABLTS can also be transported by truck, rail, and air on C-5 or C-130 aircraft. \1\ /1/

2-8.2.11 **Construction Time.**

Where an existing pier or wharf has to be replaced in active naval stations, the floating type has the advantage of minimizing the "downtime." Conventional construction may take too long where the loss of berths cannot be tolerated. The floating type in such situations may turn out to be the most expedient.

2-8.2.12 **Ship Contact.**

In certain situations, where tugboats or camels are not available, sheet pile bulkheads located along the offshore face of pier and wharf structures may be less desirable than open type construction because of the greater danger for contact

between the sheet piling and the bulbous bow or sonar dome of a ship during berthing and unberthing maneuvers.

2-8.2.13 **Track Mounted Crane.**

Where a track-mounted crane is required for the pier or wharf, the solid type may not be suitable. The susceptibility of the solid filled type to settlement and movement will make it very difficult to maintain the close tolerance required for rail gage, elevation, and alignment. The surcharge loading on the sheet pile will also be considerable. For such cases, use an independent pile supported track.

2-8.3 **Construction.**

Several aspects of construction that are unique to each structural type should be considered.

2-8.3.1 **Open.**

For open type wharves and landside ends of open piers, the following schemes should be considered for retaining upland fill:

- a. Platform on Piles and a Curtain Wall at the Inshore Face. See Figure 2-9. The underwater slope should be as steep as possible, as limited by both constructional and geotechnical parameters, thus making the pile-supported platform narrow and more economical. In seismically active areas, where hydraulic fill susceptible to liquefaction is used for upland fill, a rock dike may be used instead of the granular fill dike to resist the lateral forces caused by liquefaction of the fill. The use of a filter fabric also should be considered at the hydraulic fill interface.
- b. Platform on Pile and a Sheet Pile Bulkhead at the Inshore Face. See Figure 2-9. The sheet pile bulkhead permits a narrower platform. The cost tradeoff between platform width and bulkhead height should be investigated as the bulkhead may be found to cost as much or more than the pile supported platform width saved.

2-8.3.2 **Solid.**

Retaining structures may be constructed by the following means:

- a. Sheet Pile Bulkhead. See Figure 2-10. The bulkhead consists of a flexible wall formed of steel or concrete sheet piling with interlocking tongue and groove joints and a cap of steel or concrete construction. The bulkhead is restrained from outward movement by placing an anchorage system above the low water level. Many types of anchorage systems can be used. The most common types in use in the United States consist of anchor rods and deadman anchors. The latter could be made of concrete blocks, steel sheet

piling, or A-frames of steel, concrete, or timber piles. In countries outside the United States, an anchorage system consisting of piles, attached near the top of the sheet pile bulkhead and extending at batters up to 1 on 1 to embedment in firm material, is often used. Rock or earth anchors consisting of high-strength steel rods or steel prestressing cables are sometimes preferred in place of the anchor batter piles. Provide granular free-draining material adjacent to sheet pile bulkheads, extending from dredged bottom to underside of pavement on grade. Grade this material to act somewhat as a filter to limit subsequent loss of fines through the sheet pile interlocks. Placement of free-draining material should be in stages, commencing at the intersection of sheet piling and dredged bottom and progressing inshore. Eliminate mud and organic silt pockets. In general, do not consider hydraulic fill for backfill unless provision is made for the effects of fill settlement, potential liquefaction of fill in seismic zones, and high pressure exerted on sheet piling. Consider vibro-compaction for consolidation of hydraulic fill. In areas with tidal ranges greater than 4 ft (1.2 m,) provide 2 in (51 mm) diameter weep holes for the sheet piles above the mean low water level. When weep holes are used, provide graded filters to prevent loss of finer backfill material. Provide openings in pavement or deck for replenishment of material in order to compensate for loss and settlement of fill. In general, flexible pavement using asphaltic concrete is preferred over rigid pavement with portland cement concrete, as it is more economical to maintain and better able to accommodate underlying settlement.

Figure 2-9. Open Type Wharf Concepts.

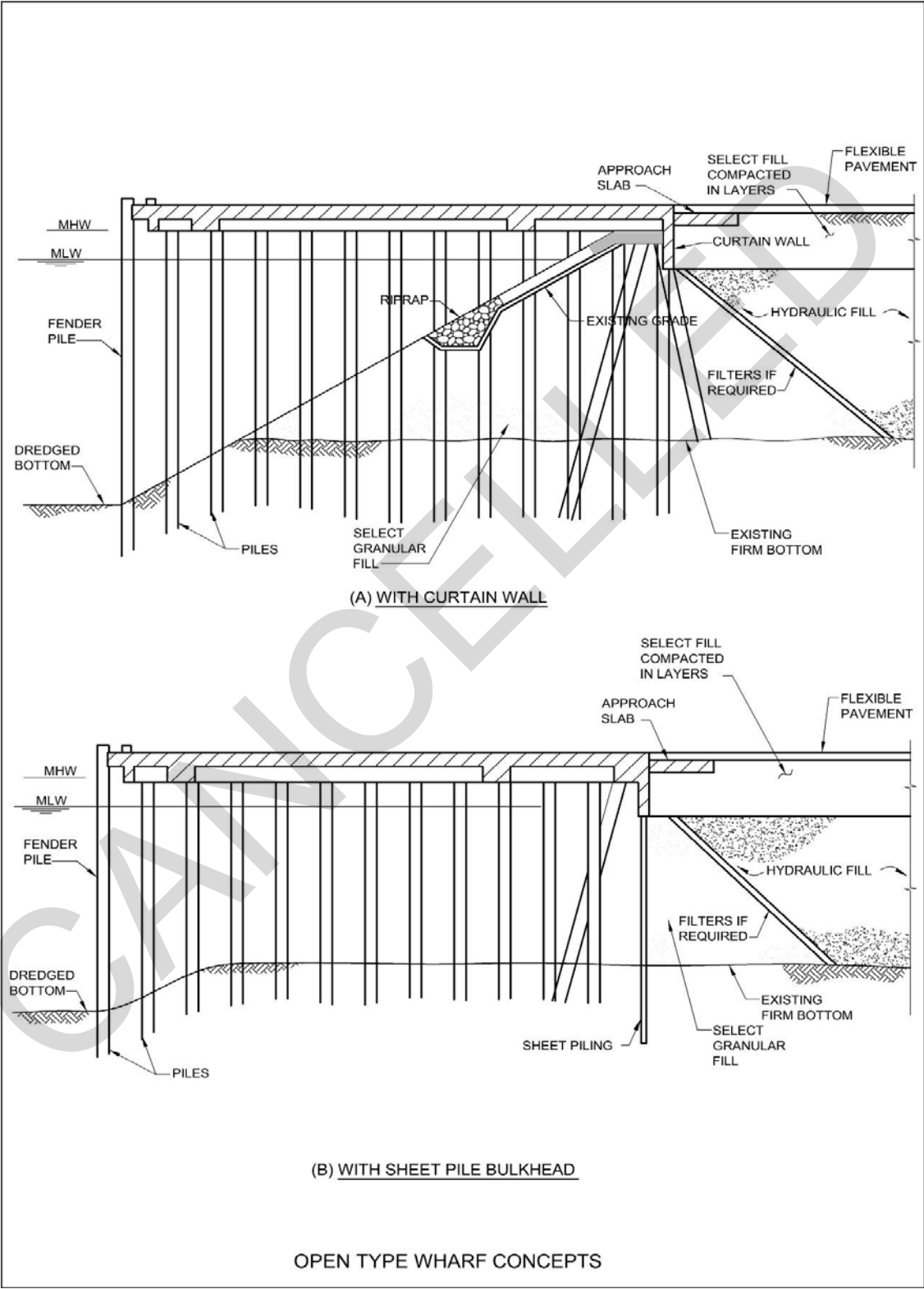
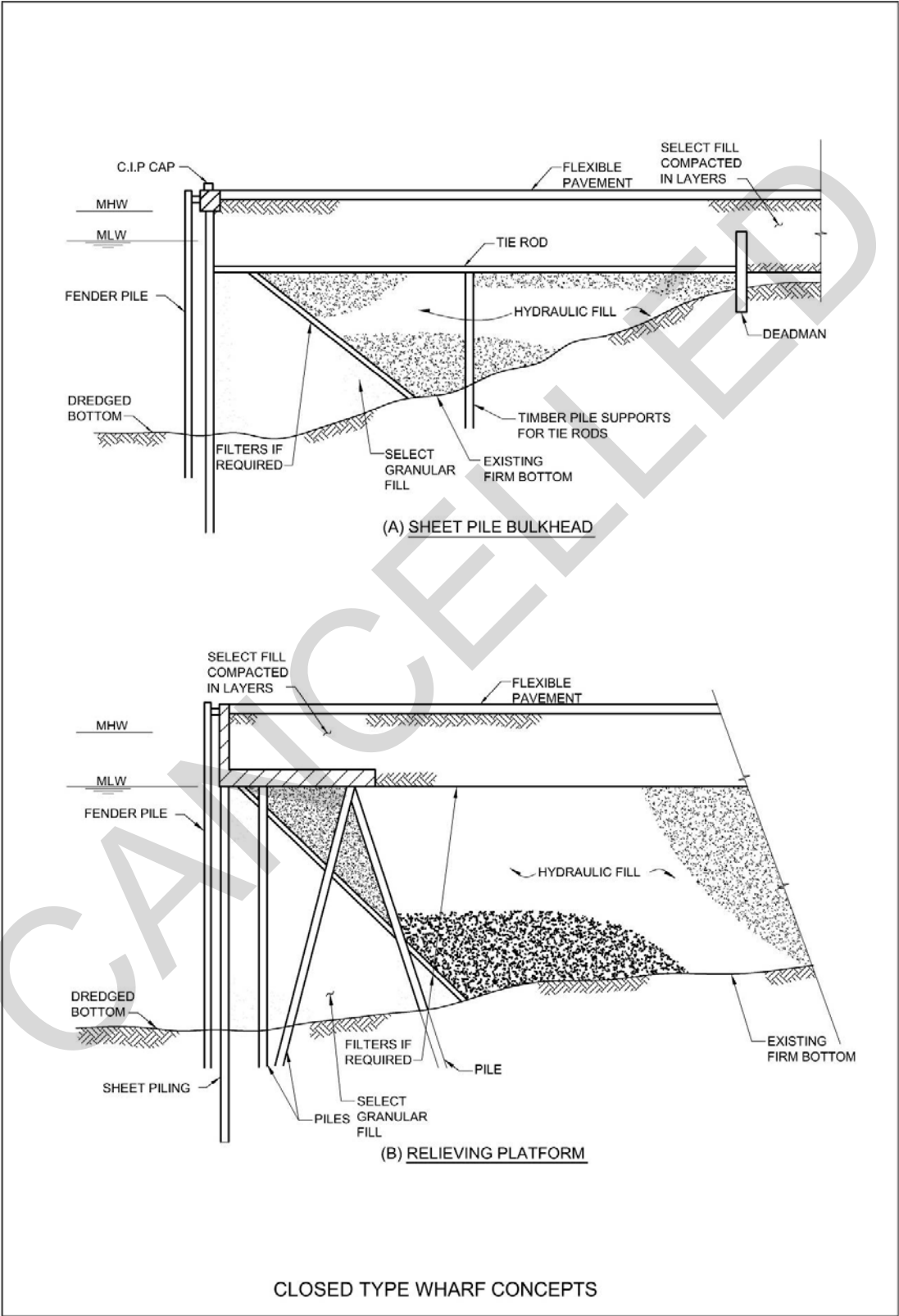


Figure 2-10. Closed Type Wharf Concepts.

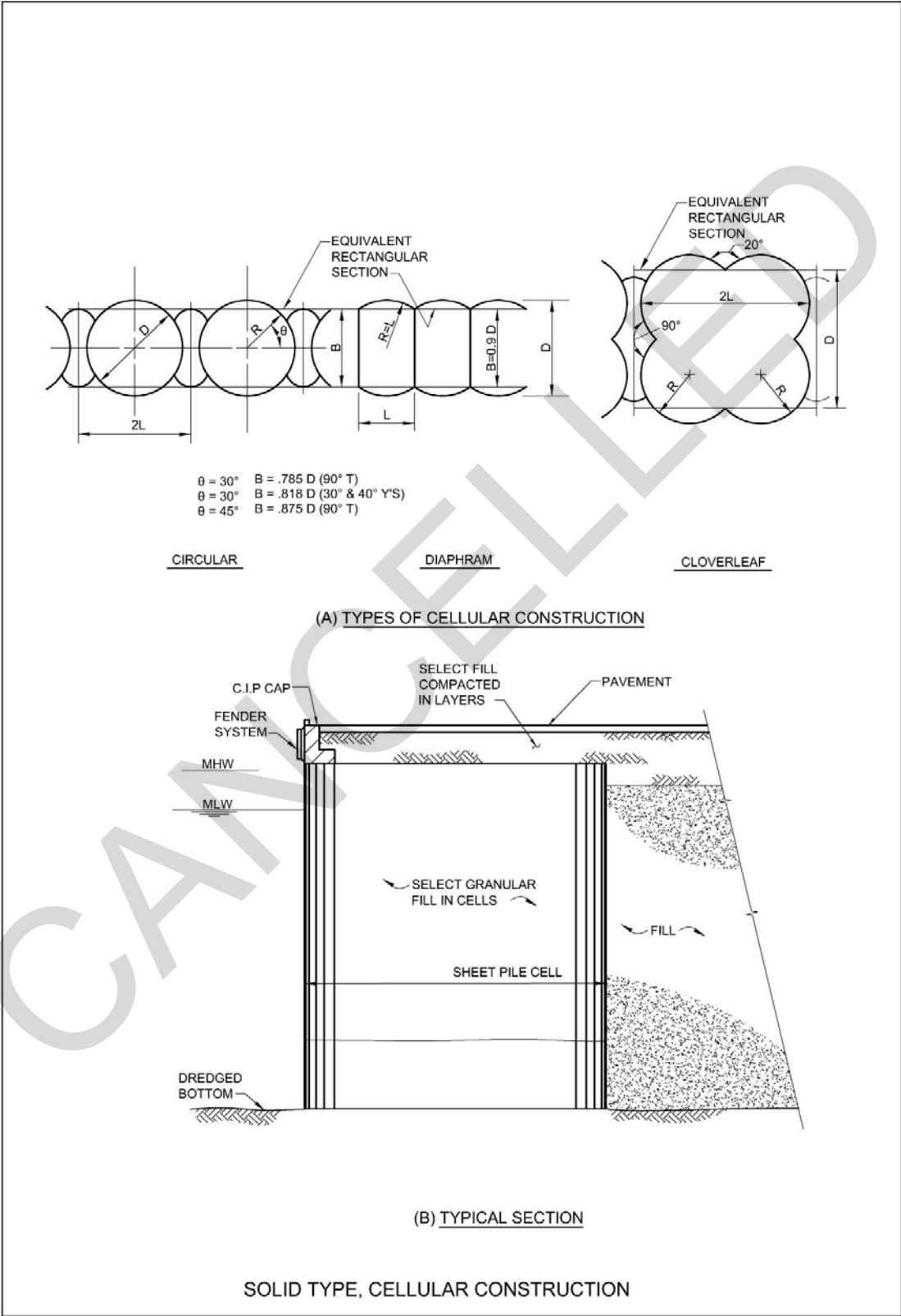


b. Sheet Pile Bulkhead and Relieving Platform. The relieving platform is used in conjunction with a sheet pile bulkhead to reduce the lateral load on the sheet piling created by heavy surcharges and earth pressures. See Figure 2-10. Lateral restraint is provided by the batter piles supporting the relieving platform. A variation of this type of construction is to use only vertical piles for the relieving platform and to furnish an independent anchorage system consisting of tie rods and deadman, similar to the types specified for sheet pile bulkheads.

c. Cellular Construction Consisting of Sheet Pile Cells. For design procedures and selection of type, see UFC 3-220-01N, *Geotechnical Engineering Procedures for Foundation Design of Buildings and Structures*. Cellular structures are gravity retaining structures formed from the interconnection of straight steel sheet piles into cells. Strength of cellular structures derives from resistance to shear caused by friction of the tension in the sheet pile interlocks and also from the internal shearing resistance of the fill within the cells. Accordingly, clean granular fill materials such as sand and gravel are usually used to fill the cells. Extreme care must be exercised in the construction of cellular structures because excessive driving onto boulders or uneven bedrock may cause ruptured interlocks, which can later unzip under hoop tension (from filling) and cause failures of the cell. Movement and expansion of cells must be compensated for during construction of the cells and fill placement carefully controlled if satisfactory alignment of the face of the wharf is to be maintained. Cellular structures are classified according to the configuration and arrangement of the cells. Three basic types are discussed below and are shown on Figure 2-11.

- Circular. This type consists of individual large-diameter circles connected together by arcs of smaller diameter. Each cell may be completely filled before construction of the next cell is started. Construction of this type is easier than the diaphragm type because each cell is stable when filled and thus may be used as a platform for construction of adjacent cells. Because the individual cells are self-supporting units, accidental loss of one cell will not necessarily endanger adjoining cells. Compared to a diaphragm type cellular structure of equal design, fewer piles per linear foot of structure are required. The diameter of circular cells is limited by the maximum allowable stresses in the sheet pile interlocks and, when stresses are exceeded, cloverleaf cells are used.

Figure 2-11. Solid Type, Cellular Construction.



- Diaphragm. This type consists of two series of circular arcs connected together by diaphragms perpendicular to the axis of the cellular structure. The width of cells may be widened by increasing the length of the diaphragms without raising interlock stress, which is a function of the radius of the arc portion of the cell. Cells must be filled in stages so that the heights of fill in adjoining cells are maintained at equal levels to avoid distortion of the diaphragm walls. Diaphragm type cells present a flatter faced wall than circular cells and are considered more desirable for marine structures.
 - Cloverleaf. This type is a modification of the circular cell type and is generally used in deep water where the diameter required for stability would result in excessively high interlock stress if diaphragms were not added.
- d. Reinforced Concrete Caisson. See Figure 2-12. In this type of construction, concrete caissons are cast in the dry, launched, and floated to the construction site where they are sunk on a prepared foundation. The caisson is filled with gravel or rock and a cast-in-place retaining wall is placed from the top of the caisson to the finished grade. This type of construction is prevalent in countries outside the United States.
- e. Precast Concrete Blocks. See Figure 2-12. This form of solid wharf is a gravity type wall made up of large precast concrete blocks resting on a prepared bed on the harbor bottom. A select fill of granular material is usually placed in the back of the wall to reduce lateral earth pressures. This type of construction is popular outside the United States.

2-8.3.3 Floating.

Construction of the floating type usually requires a flood basin, graving dock, or drydock. The units are essentially constructed in the dry and floated out and transported (on their own or on barges) to the site. Availability of such a facility and transportation of the floating units through open ocean waters and restricted inland waters for deployment at the site are serious considerations. In this respect, the floating type has a significant advantage over others in that the bulk of construction activity can be shifted to other parts of the country where labor, economic, and environmental conditions are more favorable. Other concepts of construction such as barge-mounted construction and floating-form construction are described in NCEL UG-0007, *Advance Pier Concepts, User's Guide*.

2-9 HYDRAULIC FILL.

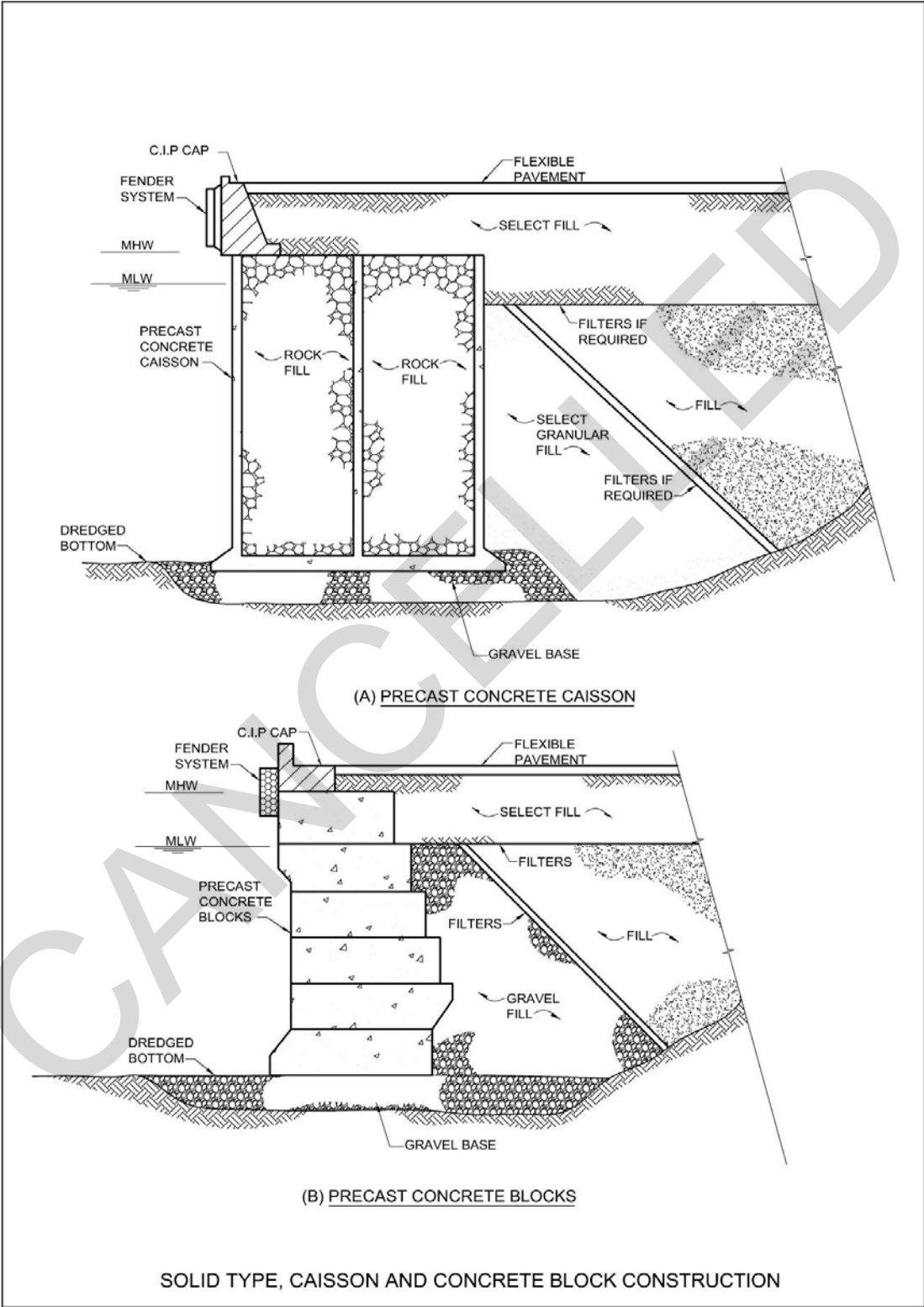
The soil drawn up by the suction head of a dredge, pumped with water through a pipe, and deposited in an area being filled or reclaimed is referred to as "hydraulic fill." At port and terminal facilities, where land is not available onshore and where

dredging is required to provide adequate water depths for vessels at berths and approach channels, hydraulic fill is commonly used for land reclamation because of its availability and low cost.

Hydraulic fill may be of good quality, consisting of granular materials, or may consist of plastic organic silt, which is considered poor quality. When hydraulic fill is used, the stability of the structure retaining the fill must be investigated, taking into consideration the effects of adjacent surcharge loadings in addition to the loadings from the fill. The placement of a select granular fill adjacent to the retaining structure may be required if the hydraulic fill is of poor quality. Hydraulic fill is in a loose condition when placed. To avoid fill settlements due to loadings from other structures, stacked cargoes, and mobile equipment, stabilization of the fill may be required. In areas of seismic activity, investigate the liquefaction of hydraulic fills. Stability with regard to both settlements and liquefaction may be enhanced by methods such as deep densification or by use of sand drains. Material other than hydraulic fill should be used when the cost of material obtained from onshore borrow areas is cheaper than the cost of material obtained from offshore borrow areas or where good quality fill material is required and is not available offshore.

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Figure 2-12. Solid Type, Caisson and Concrete Block Construction.



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CHAPTER 3. LOAD REQUIREMENTS

3-1 GENERAL.

Where loading conditions exist that are not specifically identified in this UFC, rely on accepted industry standards. However, in no case will other standards supersede the requirements provided by this UFC.

3-2 DEAD LOADS.

3-2.1 General.

The dead load consists of the weight of the entire structure, including all the permanent attachments such as mooring hardware, light poles, utility booms, brows, platforms, vaults, sheds, and service utility lines. A realistic assessment of all present and future attachments should be made and included. Overestimation of dead loads generally will not adversely affect the cost of the structure. However, overestimation of dead loads would not be conservative for tension or uplift controlled design. Also, for floating piers and wharves, overestimating of dead loads would overstate draft and could have a significant effect on cost.

3-2.2 Unit Weights.

Use actual and available construction material weights for design. See Table 3-1 for unit weights that should be used for construction materials (unless lesser unit weights can be demonstrated by local experience):

Table 3-1 Unit Weights

Material	Unit Weight, pcf
Steel or cast steel	490 pcf
Cast iron	450 pcf
Aluminum alloys	175 pcf
Timber (untreated)	40 to 50 pcf
Timber (treated)	45 to 60 pcf
Concrete, reinforced (normal weight)	145 to 160 pcf
Concrete, reinforced (lightweight)	90 to 120 pcf
Compacted sand, earth, gravel, or ballast	150 pcf
Asphalt paving	135 to 150 pcf

3-3 VERTICAL LIVE LOADS.

3-3.1 General.

Although a number of loading conditions will be presented in subsequent sections, the advent and subsequent heavy usage of mobile cranes on piers will generally

produce the controlling loading condition. For example, on a general purpose berthing pier, a design drawing will typically present different design live loads including uniform, vehicular (i.e. HS 20-44), forklift, and maximum outrigger float load. The outrigger load from the mobile crane invariably controls with the other loads more or less provided for informational purposes.

3-3.2 Uniform Loading.

See Table 3-2 for recommended uniform loadings for piers and wharves. Impact is not applied when designing for uniform loads.

Table 3-2 Vertical Live Loads for Pier and Wharf Decks

Classification	Uniform Loading (psf)	Mobile Crane (tons)	Rail-Mounted Crane (tons)	Other Handling Equipment (tons)
Ammunition	600	90	--	20-lift truck
Berthing (carriers)	800	140	--	20-lift truck
Berthing (all others)	600	90	--	20-lift truck
Berthing (submarines)	600	100	--	20-lift truck
Fitting-out	800	140	60/151 Portal	20-lift truck
Repair	600	140	60/151 Portal	20-lift truck
Fueling	300	50	--	10-lift truck
Supply (general cargo)	750	140	--	20-lift truck
Supply (containers)	1,000	140	40/50 (long tons) Container	20-lift truck 33-straddle carrier

*psf can be converted to pascals (Pa) by multiplying by 47.88026.

3-3.3 Truck Loading.

Calculate truck wheel loads in accordance with the American Association of State Highway and Transportation Officials (AASHTO) *Standard Specifications for Highway Bridges* except as modified below. In the design of slabs, beams, and pile caps, apply an impact factor of 15 percent. Structural elements below the pile caps need not be designed for impact. When truck loading is transferred through 1.5 ft (0.45 m) or more of crushed rock ballast and paving, and for filled construction, the impact forces need not be considered for design. Also, check with local activity for use of an overload vehicle such as weapons cradles, missile hauling vehicles, etc. which may have significantly higher wheel loads.

3-3.4 Rail-Mounted Crane Loading

3-3.4.1 Portal Cranes.

For design of new piers and wharves, the specific wheel load information about the crane(s) to be used should be obtained. If the crane resources are not known at the time of design, consult the Navy Crane Center for design loading and crane

procurement. When choosing design wheel loads, consideration should be given to flexibility allowing for different makes of cranes and ultimate crane replacement as well as future use of the pier or wharf. Piers and wharves have greater longevity than rail-mounted cranes. To this end, a wheel load of 110,000 lbs (4990 Kg) minimum on 4-ft (1.2m) centers allows for a practical range of options. See Table 3-2 for typical rated capacities of cranes for a variety of pier and wharf deck uses. Figure 3-1 lists a sampling of wheel loads for 60 ton and 151 ton capacity portal cranes recently procured by the Navy. These cranes were procured around capacities of existing piers and wharves and have wheel loads that are somewhat restrictive for new design. The values provided are typical for existing equipment used by the Navy and are useful for design feasibility studies on existing structures. The rail gage should be approximately 30 feet minimum for a 60 ton capacity portal crane, and up to 40 feet for a portal crane of 100 tons capacity greater. For handling of fuel containers at Repair or Fitting Out Piers, portal cranes with up to 151-ton capacity are required.

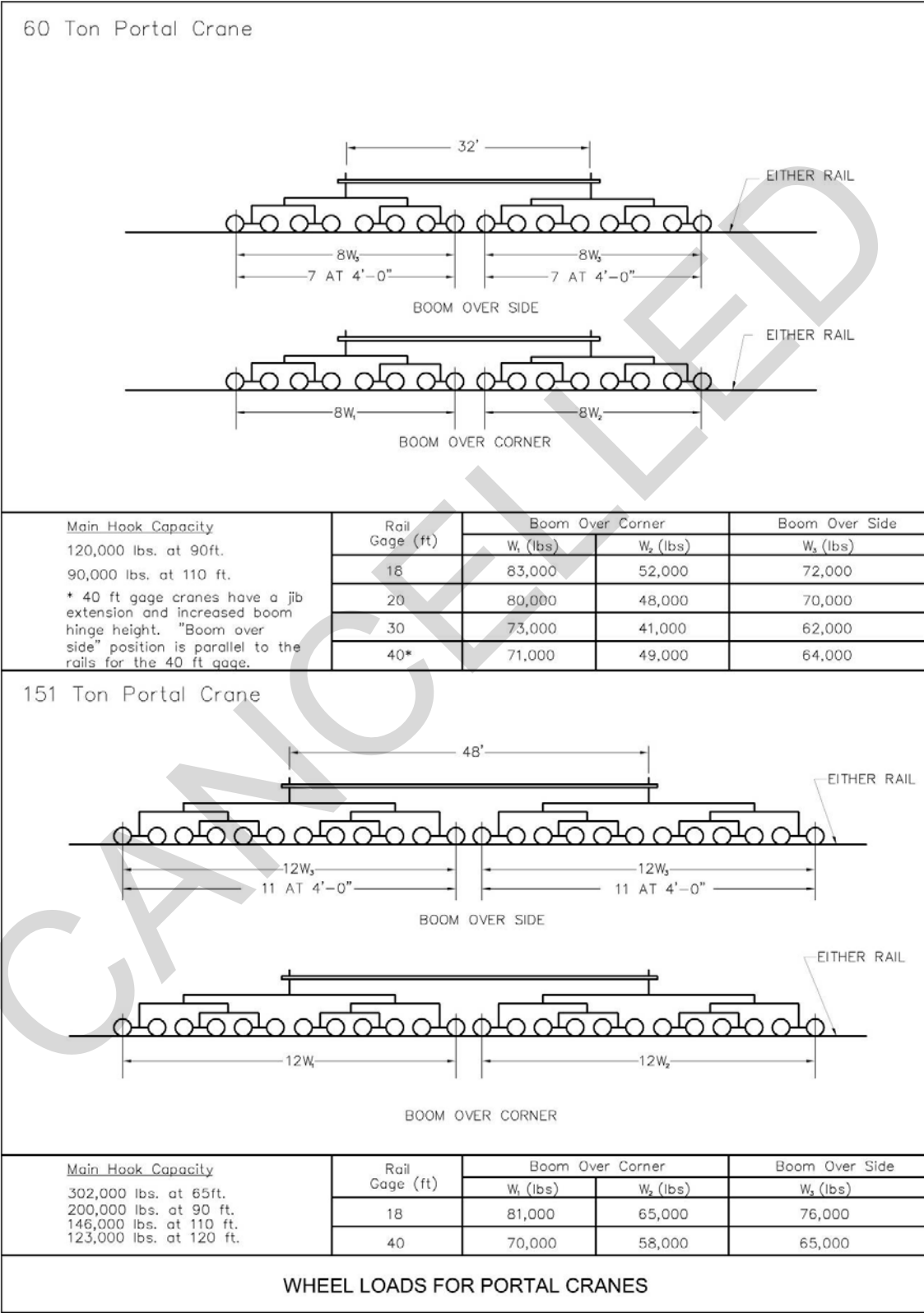
3-3.4.2 **Container Cranes.**

See Figure 3-2 for crane configuration and wheel loads of container cranes and Table 3-2 for the rated capacities of container cranes applicable to piers and wharves. The configuration and wheel loads are derived from several manufacturers and should be used only as a guide. A recent trend in the shipment of containerized cargo is to use larger ships, and this is the driving force in the design of container cranes. The size of the ship to be serviced will dictate the capacity, configuration, operational characteristics, and gage of the crane. The evolution in container crane design has been to increase the gage to 100 ft (30.5 m) and outreach on the boom to 150 ft (45.7 m) and larger while maintaining the lift capacity between 40 and 50 long tons. Hence, specific information on the size of the ship to be serviced and details from the crane manufacturer needs to be obtained for final crane design.

3-3.4.3 **Wheel Load Uncertainty.**

Portal and container cranes are usually procured separately from the construction funds. The maximum allowable wheel loads are normally specified on the crane procurement documents. The number and spacing of wheels are critical to the structural capacity of an existing facility and structural design of a new facility. Having established the required capacity and configuration of a crane, the designer of a pier or wharf should consult with the Navy Crane Center and obtain wheel loads for which the supporting structure should be designed. In the absence of hard information, the 110,000 lb (4990 kg) wheel load presented in paragraph 3-3.4.1 may be used for portal cranes. However, the container crane wheel loads presented in Figure 3-2 are only provided as a guide. The design characteristics noted in paragraph 3-3.4.2 must be determined in order to determine realistic wheel loads.

Figure 3-1. Wheel Loads for Portal Cranes



3-3.4.4 **Impact.**

Apply an impact factor of 25 percent to the maximum listed wheel loads for the design of deck slab, crane girders, and pile caps. The impact factor is not applicable to the design of piles and other substructure elements.

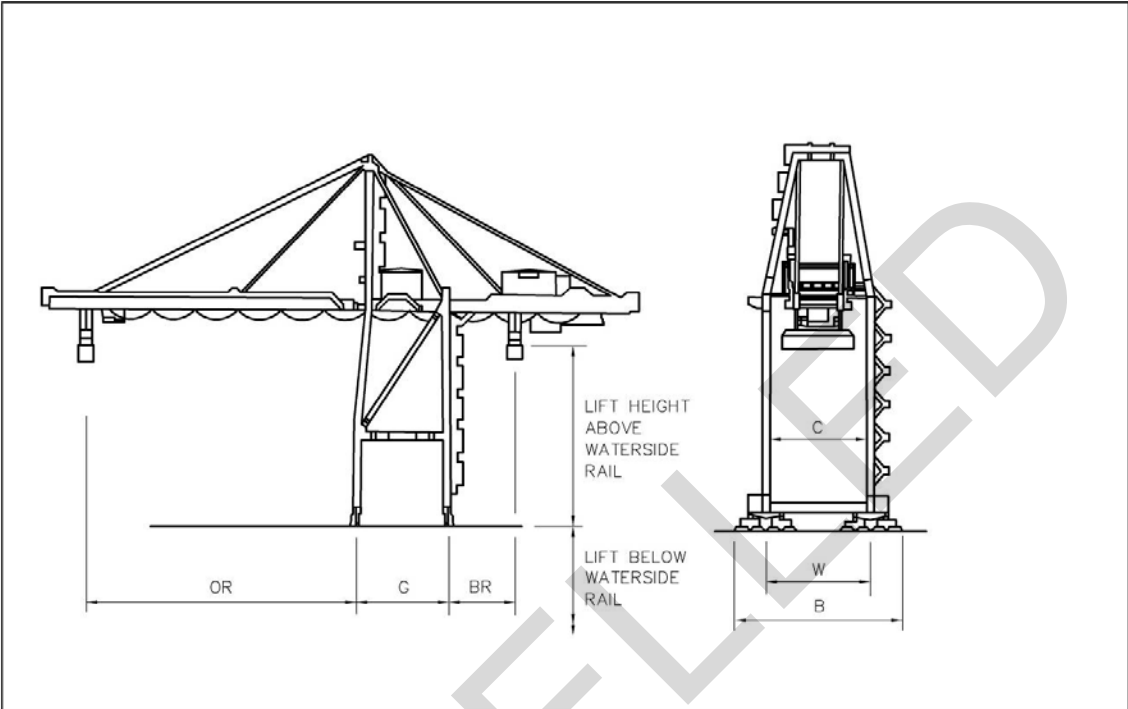
3-3.5 **Mobile Crane Loadings.**

The deck design for open and floating structural types of piers and wharves is usually controlled by mobile crane loading. However, the operational constraints imposed by under specifying mobile crane loadings are severe. Consequently, take care to specify realistic loading. Refer to Table 3-2 for designated mobile cranes applicable to each functional type of pier and wharf. As a minimum design the pier or wharf for the designated mobile crane, however, check with the local activity to confirm whether a crane larger than that designated could be used at the facility.

3-3.5.1 **Wheel Loads.**

See Figure 3-3 for wheel loads for 50-, 70-, 90-, 115-, and 140-ton capacity mobile cranes. The information in Figure 3-3 is for typical truck cranes, although rough-terrain type mobile cranes are also used on piers and wharves. Tire contact area should be as defined by AASTHO. As a rule of thumb, ground pressures for "on rubber" lifts are about 10 percent higher than tire inflation pressure. Crane manufacturers recommend that the majority of lifts be made on outriggers. In addition, capacities for "on rubber" lifts are substantially less than for "on outrigger" lifts. Hence, loads for "on rubber" lifts are not listed. Design all piers and wharves and their approaches for the wheel loads from the designated truck crane.

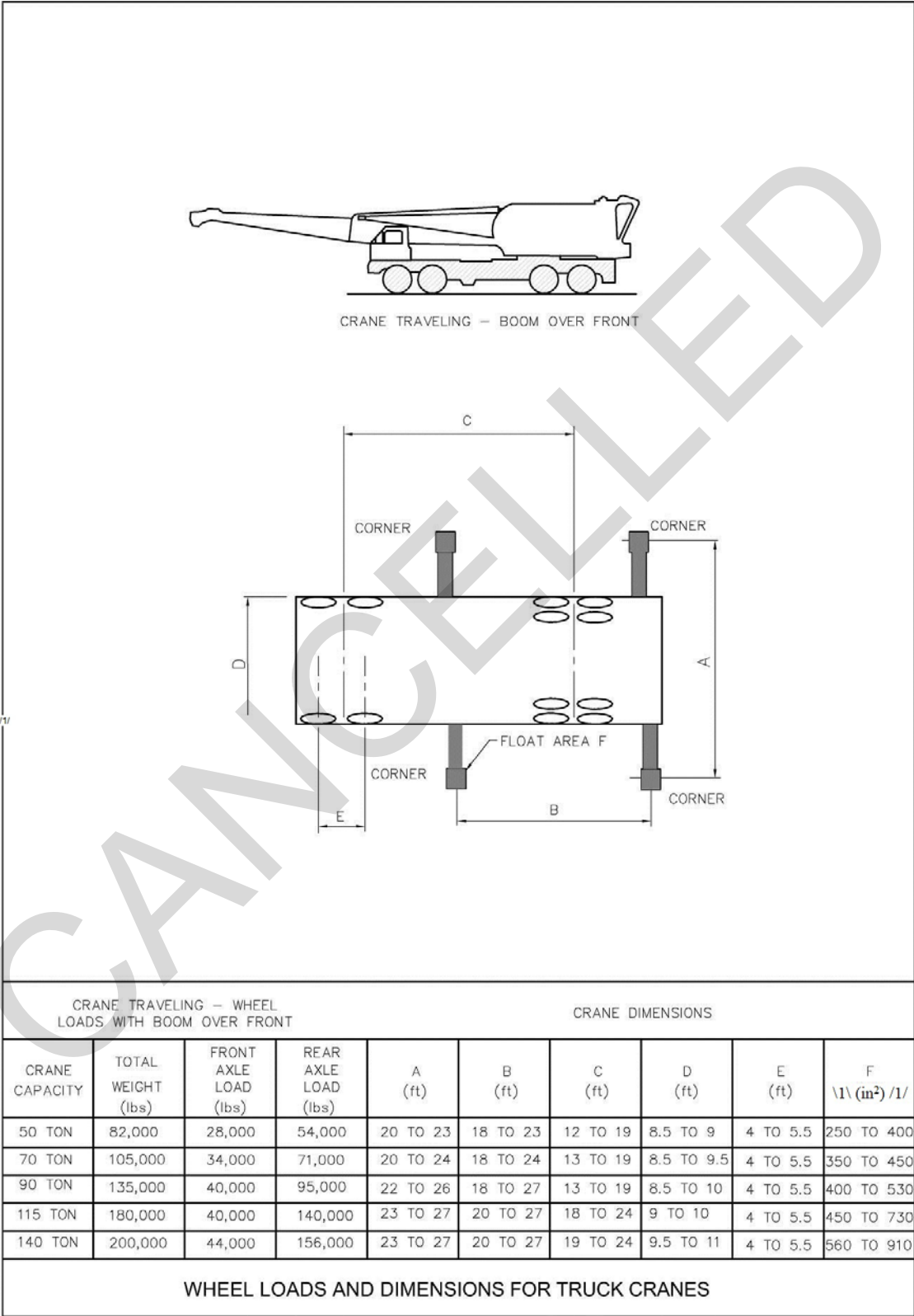
Figure 3-2. Configuration and Wheel Loads for Container Cranes



ITEM			CRANE CAPACITY	
			40' LONG TONS	50' LONG TONS
GAUGE – G			50' TO 100'	100'
OUTREACH – OR			115' TO 155'	125' TO 172'
BACK REACH – BR			30' TO 60'	30' TO 60'
WHEEL BASE – W			45' TO 55'	45' TO 55'
CONTAINER CLEARANCE – C			55' TO 60'	55' TO 60'
BUMPER TO BUMPER – B			79' TO 90'	85' TO 90'
WHEEL SPACING (8 WHEELS/LEG)			4' TO 5'	4.5' TO 5'
LIFT HEIGHT ABOVE WATERSIDE RAIL			90' TO 110'	89' TO 110'
LIFT HEIGHT BELOW WATERSIDE RAIL			55'	65'
MAXIMUM WHEEL LOAD IN KIPS (UNFACTORED WITH 10 PSF WIND)	OPERATING	WATERSIDE RAIL	87 ^k TO 120 ^k	110 ^k TO 170 ^k
		LANDSIDE RAIL	75 ^k TO 112 ^k	95 ^k TO 125 ^k
	STOWED	WATERSIDE RAIL	56 ^k TO 135 ^k	90 ^k TO 150 ^k
		LANDSIDE RAIL	60 ^k TO 150 ^k	100 ^k TO 165 ^k

CONFIGURATION AND WHEEL LOADS FOR CONTAINER CRANES

Figure 3-3. Wheel Loads and Dimensions for Truck Cranes



3-3.5.2 **Outrigger Float Loads.**

Table 3-3 lists outrigger float loads for different capacity cranes.

Table 3-3 Outrigger Float Loads for Mobile Cranes

Capacity (tons)	Radius (ft)	Boom Over Corner (lbs)	Boom Over Back or Side (ea)(lbs)
50	20 and less	97,000	89,000
	30	83,000	69,000
	40	78,000	60,000
	50 and more	72,000	55,000
70	20 and less	130,000	114,000
	30	115,000	90,000
	40	104,000	85,000
	50 and more	99,000	78,000
90	20 and less	160,000	144,000
	30	144,000	120,000
	40	130,000	107,000
	50 and more	117,000	98,000
115	20 and less	195,000	183,000
	30	180,000	151,000
	40	156,000	131,000
	50 and more	144,000	120,000
140	20 and less	232,000	207,000
	30	222,000	176,000
	40	211,000	164,000
	50	198,000	150,000
	60 and more	187,000	142,000

The maximum single float load from a boom over corner position and maximum concurrent pair of float loads from a boom over side and back positions are listed. Typically, the float loads are at the maximum when lifting the rated load at a short radius (20 ft (6.1 m) and less) and should be used for design. However, for existing piers and wharves, the other listed loads may be used to analyze deck capacity. Typical outrigger float spacing is shown in Figure 3-3. Apply outrigger float loads to a 1.5 ft by 1.5 ft (0.46 m by 0.46 m) area unless actual float size is known, in which case use the actual float size for analysis.

3-3.5.3 **Impact.**

Apply an impact factor of 15 percent for all wheel loads ≤ 1 when designing slab, beams, and pile caps. The impact factor need not be applied when designing piles and other substructure elements, when designing filled structures, and where wheel loads are distributed through paving and ballast (1.5 ft (0.46 m) or more).

3-3.6 **Forklift and Straddle Carrier Loadings.**

3-3.6.1 **Forklifts.**

See Figure 3-4 for wheel loads from forklifts. Determine contact areas for wheel loads in accordance with AASHTO. For hard rubber wheels or other wheels not inflated, assume the wheel contact area to be a point load.

3-3.6.2 **Straddle Carriers.**

See Figure 3-5 for wheel loads for a straddle carrier. The straddle carrier shown is capable of lifting a loaded 20-ft (6.1 m) container or a loaded 40-ft (12.2 m) container.

3-3.6.3 **Impact.**

Apply an impact factor of 15 percent to the maximum wheel loads in the design of slabs, beams and pile caps. The impact factor need not be applied when designing piles and other substructure elements, when designing filled structures, and where wheel loads are distributed through paving and ballast (1.5 ft (0.46 m) or more).

3-3.7 **Loading on Railroad Tracks.**

For freight car wheel loads, use a live load of 8000 lbs/ft of track corresponding to Cooper E-80 designation of the American Railway Engineering Association (AREA) *Manual for Railway Engineering*. In the design of slabs, girders, and pile caps, apply an impact factor of 20 percent. Impact is not applicable for the design of piles and filled structures, or where loads are distributed through paving and ballast (1.5 ft (0.46 m) or more).

3-3.8 **Buoyancy.**

Typically, piers and wharf decks are not kept low enough to be subjected to buoyant forces. However, portions of the structure, such as utility trenches and vaults, may be low enough to be subject to buoyancy forces, which are essentially uplift forces applied at the rate of 64 psf (3064.3 Pa) of plan area for every foot of submergence below water level.

3-3.9 **Wave Loading.**

For piers and wharves exposed to waves which may produce significant lateral or hydrostatic forces, determine wave loading in accordance with the procedures defined in UFC 4-150-06.

3-3.10 **Application of Loadings.**

3-3.10.1 **Concentrated Loads.**

Wheel loads and outrigger float loads from designated pneumatic-tired equipment, such as trucks, truck cranes, forklifts, and straddle carriers may be oriented in any direction and the orientation causing the maximum forces on the structural members should be considered for design. Significant loads from fuel containers at Repair or Fitting Out Piers exceeding 300 kips (1334.5 kN) may be encountered. Design trench covers, utility trench covers, and access hatch covers to handle the concentrated loads, where they are accessible to mobile equipment. However, designated areas on the pier deck may be exempted from wheel loads or outrigger float loads, or designed for lesser loads, when curbs, railings, and other physical barriers are provided to isolate those areas from vehicle access. Concentrated wheel loads from these vehicles are applied through small "footprints" to the deck structure. The distribution of these loads and computation of maximum moments and shears may be in accordance with the AASHTO *Standard Specification for Highway Bridges*. However, this method is conservative and more reasonable results may be obtained using \1\ NCEL R-935, *Lateral Load Distribution on One-Way Flat Slab /1/* ; *Influence Surfaces for Elastic Plates*, for different edge conditions; or finite element analysis.

Figure 3-4. Wheel Loads for Forklifts

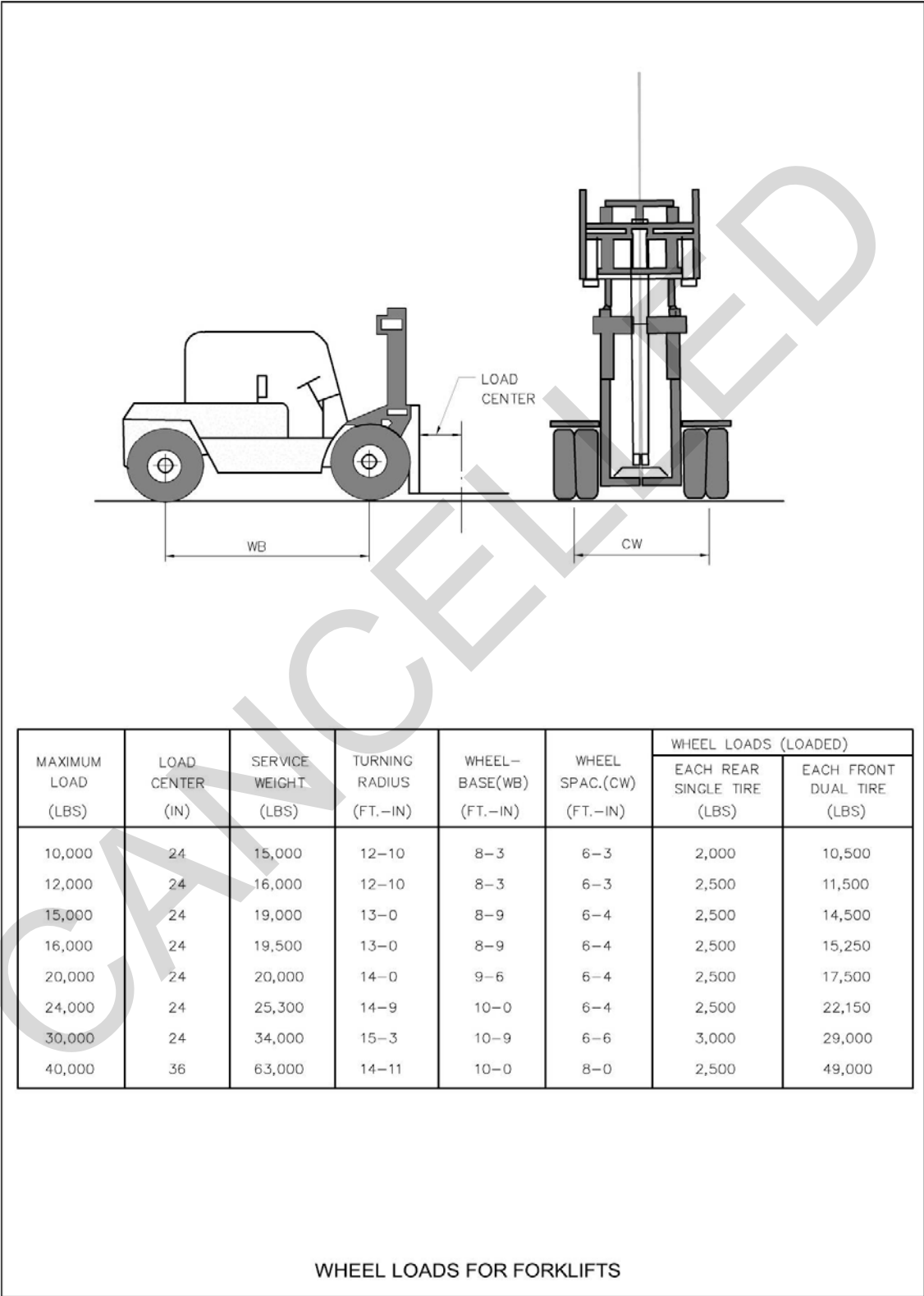
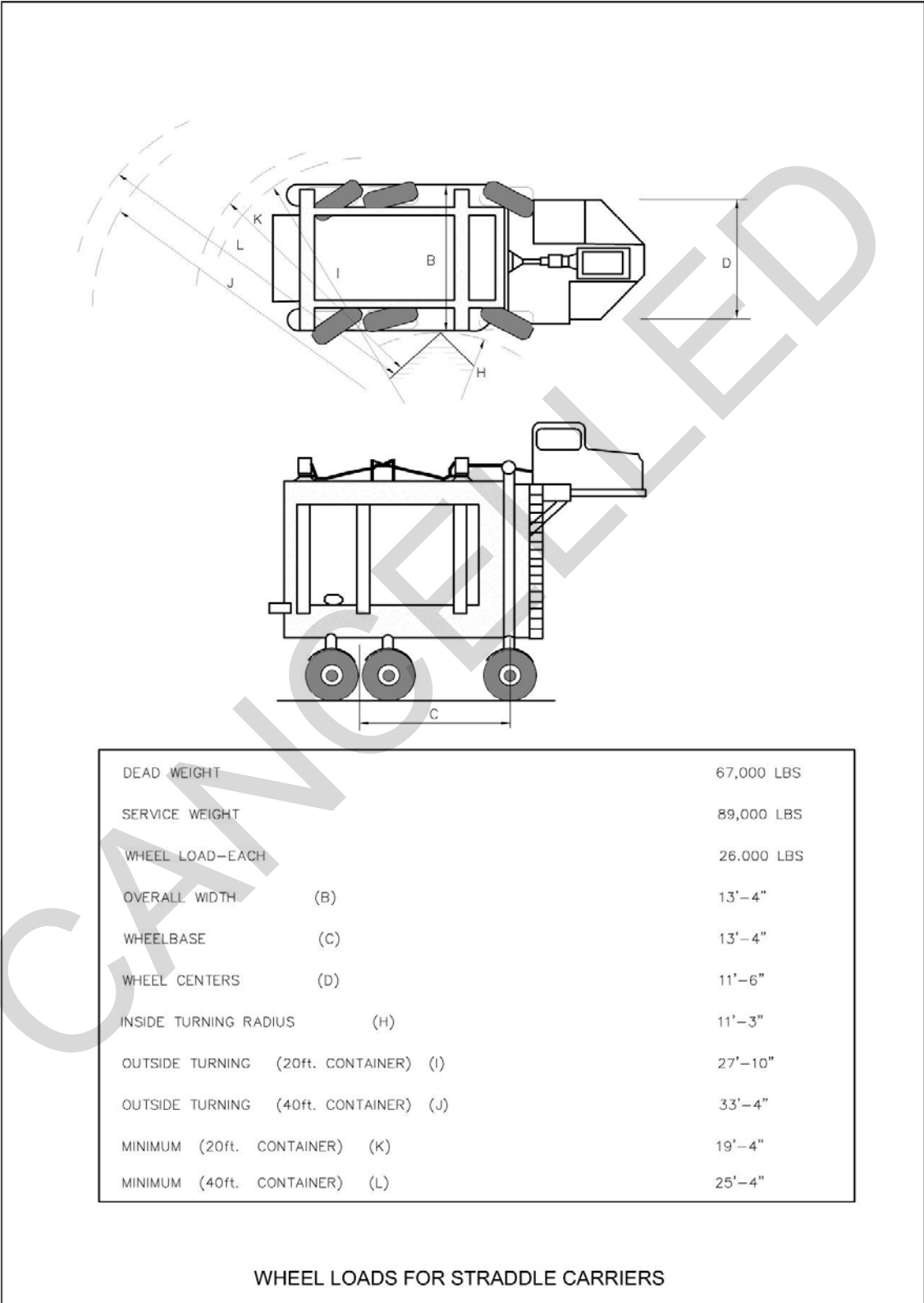


Figure 3-5. Wheel Loads for Straddle Carriers



3-3.10.2 **Simultaneous Loads.**

Generally, apply uniform and concentrated live loads in a logical manner. Designated uniform live loadings and concentrated live loading from pneumatic-tired equipment should not be applied simultaneously in the same area. However, uniform live load should be assumed between crane tracks (for 80 percent of gage). When railroad tracks are present between crane tracks, both track loads should be applied simultaneously. However, the maximum loads from each track need not be assumed. Unique operations may warrant a more conservative approach, i.e, during a “trans-shipment operation (handling of fuel containers), there could be a portal crane straddling a railroad car loaded with a container, with another container sitting on the pier deck in the immediate vicinity.

3-3.10.3 **Skip Loading.**

For determining the shear and bending moments in continuous members, apply the designated uniform loadings only on those spans that produce the maximum effect.

3-3.10.4 **Critical Loadings.**

Concentrated loads from trucks, mobile cranes, forklifts, and straddle carriers, including mobile crane float loads, are generally critical for the design of short spans such as deck slabs and trench covers. Uniform loading, mobile crane float loading, rail-mounted crane loading, and railroad loading are generally critical for the design of beams, pile caps, and supporting piles.

3-4 **HORIZONTAL LOADS.**

3-4.1 **Berthing Loads.**

Procedures for calculation of berthing loads are found in paragraph 5-2 of this UFC.

3-4.2 **Mooring Loads.**

Procedures for calculation of mooring loads are found in UFC 4-159-03.

3-4.3 **Wind Loads on Structures.**

Use Section 1609 of the *International Building Code* to provide minimum wind load on structures.

3-4.4 **Loads on Piles.**

In addition to the axial loads, bending moments, and shears caused by lateral loads at deck level due to berthing, mooring and seismic forces, piles are also subjected to other types of lateral loads acting along the length of the pile.

3-4.4.1 **Current and Waves.**

These loads are applied at and near the water level and may be significant where large size piles are used in high-current waters. An estimate of current and wave forces can be made using the UFC 4-150-06.

3-4.4.2 **Sloping Fill Loads.**

These loads are transmitted along the shaft of the piles by the lateral movement of the soil surrounding the piles beneath the structure, such as may occur along a sloping shoreline at marginal wharves, as shown in Figure 2-9. The maximum moments in the piles for this category of loadings are determined by structural analysis and the methods outlined in UFC 3-220-01N after the conditions of pile support in the pile cap and the soil have been established and the effective length of pile has been determined.

a. Piles of relieving platform types of solid wharves, shown on Figure 2-10, may be subjected to lateral earth loads if the stability of the slope beneath the platform is minimal and soil creep occurs. In such cases, stabilizing measures should be introduced, prior to installation of piles, to prevent movement of the soil along the slope. Among the stabilizing measures that may be used are surcharging (preloading), installation of sand drains or soil compaction piles, or replacement of unstable materials. If the piles supporting the structure are used to increase slope stability, or if time-dependent stabilizing measures are introduced after the piles are in place, calculate the resistance to soil movement provided by the piles and the piles checked for the bending moments induced by the calculated lateral earth loads, in addition to the increased loading caused by the downdrag of the settling soil.

b. The pile resistance to soil movement may be obtained from a stability analysis by determining the additional resistance, provided by the piles, which will provide a factor of safety that corresponds to zero soil movement. The minimum factor of safety required for this type of analysis varies and should be selected after evaluating the soil conditions, which exist at the site. The embedment length of piles needed for developing the required lateral resistance may be determined in accordance with the criteria given in UFC 3-220-01N.

3-4.4.3 **Pile Driving Loads.**

Piles are subjected to high compressive and tensile stresses during driving and should be proportioned to resist these in addition to the service loads. Where prolonged driving in alternately soft and hard layers of soil or driving through stiff "quaky" clays is anticipated, very high tensile stresses are set up and will require a higher level of prestress (1000 psi (6894.8 kPa) or more) in prestressed concrete

piles. Give attention to controlling driving stresses by specifying frequent cushion replacement, and by requiring use of hammers capable of adjusting driving energy.

3-4.5 **Earthquake Loads.**

\1\ /1/

3-4.5.1 **Determine Seismic Use Group:**

- a. SUG III: Structures having significant importance and where the impact of being out of operation is critical (High Risk).
- b. SUG II: Structures having moderate importance where the impact of being out of operation for repairs is tolerable (Moderate Risk).
- c. SUG I: Structures not falling into SUG III, or II (Low Risk).

3-4.5.2 **Determine Seismic Design Category:**

(Based on *International Building Code*, 2003, Table 1616.3)

3-4.5.3 **Determine Seismic Analysis Procedure:**

	SDC A	SDC B	SDC C	SDC D	SDC E	SDC F
SUG I	Note A	Note A	Note A	Note A	Note B	Note B
SUG II	Note A	Note A	Note A	Note B	Note B	Note B
SUG III	Note A	Note A	Note B	Note B	Note B	Note B

Note A: Performance Based Seismic Design not required. Lateral loads from berthing and mooring of vessels will likely govern the design. Determine seismic forces utilizing the Equivalent Lateral Force procedure from SEI/ASCE 7-02, *Minimum Design Loads for Buildings and Other Structures*, paragraph 9.5.5 and utilizing the Design earthquake motion corresponding to Seismic Performance Level 2 as defined in Table 4-2 of *Marine Oil Terminal Engineering and Maintenance Standards*, June 2003, California State Lands Commission Marine Facilities Division

Note B: Performance Based Seismic Design required according to the provisions of *Marine Oil Terminal Engineering and Maintenance Standards*, June 2003, California State Lands Commission Marine Facilities Division as described below. The seismic criteria within this reference was provided by John Ferritto of the Naval Facilities Engineering Services Center (NFESC) through a Cooperative Research and Development Agreement, and based primarily on *Seismic Criteria for California Marine Oil Terminals, Vol.1 and Vol.2*, April 1999, Technical Report TR-2103-SHR, Naval Facilities Engineering Service Center, Port

Hueneme, CA, which developed and expanded upon *Design Criteria for Earthquake Hazard Mitigation of Navy Piers and Wharves*, February 1997, Technical Report TR-2069-SHR, Naval Facilities Engineering Service Center, Port Hueneme, CA.

3-4.5.3 Performance Based Seismic Design Provisions.

a. Earthquake Loads: Follow the provisions of *Marine Oil Terminal Engineering and Maintenance Standards*, Section 3.4. The spectral acceleration values for earthquakes with a 2 and 10 percent probability of exceedance in a 50-year period are typically well defined. To obtain seismic spectral accelerations for other recurrence intervals use the following formula based upon the procedure presented in Section 1.6.1.3 of FEMA 356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*.

Equation 3-1

$$S_i = S_{i(10/50)} (C_i),$$

where:

S_i = Spectral acceleration parameter (“i” = “s” for short-period, or “i” = “1” for 1 second period)

$S_{i(10/50)}$ = Spectral acceleration parameter (“i” = “s” for short-period, or “i” = “1” for 1 second period) at a 10% probability of exceedance in 50 years

C_i = Modifier provided in Tables 3-4 and 3-5 below (“i” = “s” for short-period, or “i” = “1” for 1 second period).

Table 3-4 Values of C_s , Modifier for Short-Period Spectral Acceleration

Design Earthquake Probability of Exceedance in 50 Years

Region	10 %	15 %	20 %	50 %	65 %	75 %
California	1.0	0.83	0.72	0.44	0.36	0.32
Pacific Northwest	1.0	0.79	0.67	0.36	0.29	0.25
Eastern US	1.0	0.72	0.56	0.23	0.17	0.14
Other locations	1.0	0.79	0.67	0.36	0.29	0.25

Notes:

1. The modifier C_s includes a statistical adjustment factor, “ P_R ”, and a location adjustment factor, “n”, as defined in section 1.6.1.3 in FEMA 356, *Prestandard and Commentary for the Seismic*

Rehabilitation of Buildings, Nov. 2000. The value of “n” is taken as 0.54 for locations outside of the continental US.

2. This table is valid at locations where the Mapped MCE spectral acceleration for short-periods, S_S , is less than 1.5g.

Table 3-5 Values of C_1 , Modifier for 1-Second Period Spectral Acceleration

Design Earthquake Probability of Exceedance in 50 Years

Region	10 %	15 %	20 %	50 %	65 %	75 %
California	1.0	0.83	0.72	0.44	0.36	0.32
Pacific Northwest	1.0	0.77	0.64	0.33	0.26	0.22
Eastern US	1.0	0.71	0.55	0.22	0.16	0.13
Other locations	1.0	0.77	0.64	0.33	0.26	0.22

Notes:

1. The modifier C_1 includes a statistical adjustment factor, “ P_R ”, and a location adjustment factor, “n”, as defined in section 1.6.1.3 in FEMA 356, *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, Nov. 2000. The value of “n” is taken as 0.59 for locations outside of the continental US.

2. This table is valid at locations where the Mapped MCE spectral acceleration for short-periods, S_S , is less than 1.5g.

b. Load Combinations: combine earthquake forces with other loadings according to paragraph 3-5 of this UFC.

c. Seismic Analysis and Structural Performance: Follow the provisions of *Marine Oil Terminal Engineering and Maintenance Standards*, June 2003, California State Lands Commission Marine Facilities Division, Section 4, as modified below.

Replace “MOT” with “Piers and Wharf Structures”

Replace Section 4.1.3 with the following: “Piers and Wharves shall be categorized into one of three risk classifications (high, moderate or low) according to SUG.

SUG III = High Risk Classification

SUG II = Moderate Risk Classification

SUG I = Low Risk Classification

Retitle section 4.2 “Existing and New Piers and Wharves”.

Delete section 4.3 in its entirety.

Structural Analysis and Design of Components: Follow the provisions of *Marine Oil Terminal Engineering and Maintenance Standards*, June 2003, California State Lands Commission Marine Facilities Division, Section 7 as modified below.

Replace "MOT" with "Piers and Wharf Structures"

3.4.5.5 Dynamic Fill Loads.

In general, piles subjected to seismic forces behave as flexible members and their behavior is controlled primarily by the surrounding soil. Both vertical and batter piles move together with the surrounding soil during an earthquake. Provided that shear failure or liquefaction of the surrounding soil does not occur during ground shaking, the pile-supported structure will move a limited amount and remain stable after an earthquake. The magnitude of the horizontal movement depends on the earthquake magnitude and duration, design details of the platform, flexibility of the piles, and the subgrade modulus of the foundation soil. If the soil surrounding the piles is susceptible to liquefaction or if slope failure occurs, the piles will move excessively, resulting in serious damage to the piles and the structure. For these conditions, remove and replace unstable materials. When the piles penetrate a deep soft layer first and then a stiff layer of soil, the soils displace cyclically back and forth during an earthquake. During the cyclic ground shaking, the piles will move with the ground and return essentially to their original position if the soil does not fail during these cyclic displacements. Accordingly, if piles are to continue to safely support loads after an earthquake, it will be necessary for the piles to have the capability to withstand the induced curvature without failure.

3-4.5.6 Embankments and Fills.

For determining the stability of embankments and fills at solid wharves, when subjected to earthquake forces, refer to UFC 3-220-01N.

3-4.5.7 Floating Structures.

Usually, floating structures are not directly affected by seismic events. However, waves created by offshore seismic activity such as a seiche or tsunami will affect floating structures. Also, the mooring system employed (spud piles and chain) will be subjected to the ground motions and should be investigated.

3-4.6 Earth and Water Pressures on Retaining Structures.

3-4.6.1 Static Case.

Static earth pressures, acting on retaining structures, are determined in accordance with the criteria detailed in UFC 3-220-01N.

3-4.6.2 Dynamic Case.

Seismic forces may cause increased lateral earth pressures on earth retaining wharf structures accompanied by lateral movements of the structure. The degree of ground shaking that retaining structures will be able to withstand will depend, to a considerable extent, on the margin of safety provided for static loading conditions. In general, wharf retaining structures, designed conservatively for static loading conditions, may have a greater ability to withstand seismic forces than those designed, more economically, by less conservative procedures. Methods for determining lateral earth pressures due to seismic forces are discussed in UFC 3-220-01N.

3-4.6.3 **Water Pressure.**

Consider pressures due to water level differentials, resulting from tidal fluctuations and/or groundwater accumulations, in the design of sheet pile bulkheads, cells, and curtain walls, and in stability investigations for embankments and fills. Consider additional loading due to hydrodynamic pressure for retaining structures as addressed in UFC 3-220-01N in seismic areas.

3-4.7 **Thermal Loads.**

3-4.7.1 **Temperature Differential.**

The effect of thermal forces that build up in the structure due to fluctuations in temperature will vary from those measured at the time of construction. For piers and wharves, the large body of adjacent water has a substantial moderating effect on the structure. Consequently, the structure may not attain an overall temperature ± 10 deg. F (± 12.2 deg. C) to 20 deg. F (± 6.7 deg. C) higher or lower than the water temperature. The effect will be even less for ballasted deck construction. However, unballasted decks may see a large temperature differential through depth. Solid-type piers and wharves and floating structures are less likely to be affected by temperature variations.

3-4.7.2 **Pile-Supported Structures.**

Typically, decks of pile-supported structures will be subjected to temperature differential. However, since the axial stiffness of the deck elements will be much higher than the flexural stiffness of piles, the deck will expand or contract without any restraint from piles (for narrow marginal wharves, the short inboard piles may offer some restraint, and hence need to be analyzed) and will subject the piles to bending moments and shear forces. Locate batter piles so as not to restrain thermal motion (usually in the middle portion of a long structure).

3-4.8 **Ice Forces.**

In addition to the weight of accumulated ice on the structure, consider the forces exerted by floating ice. The principal modes of action of floating ice are shown in Figure 3-6 and discussed below.

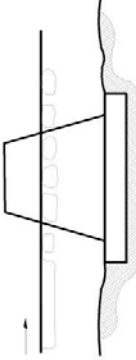
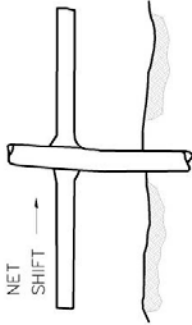
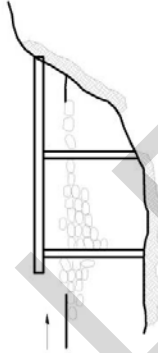

3-4.8.1 **Dynamic Impact.**

Follow the criteria in the AASHTO standard to the extent feasible. For lightly loaded structures and for open pile platforms, these criteria may result in structures of unreasonable proportions. In such cases, consider reducing the AASHTO criteria in accordance with the Canadian code. See *Dynamic Ice Forces on Piers and Piles*. The values of effective pressure are

- AASHTO 400 psi (2757.9 kPa);
- Canadian Code 100 to 400 psi (689.5 to 2757.9 kPa) (highway bridges); and
- Canadian Code 200 to 250 psi (1379.0 to 1723.7 kPa) (wharf piles).

CANCELLED

Figure 3-6. Principal Modes of Ice Action

NO.	DESCRIPTION	TYPICAL ENVIRONMENT	ILLUSTRATION
1	IMPACT OF MOVING SHEETS AND FLOES.	RIVERS AT BREAK-UP, COASTAL WATERS WITH APPRECIABLE CURRENTS	
2	STATIC PRESSURE FROM EXPANDING OR CONTRACTING SHEETS.	LAKES, SHELTERED COASTAL WATERS, TEMPERATURE CHANGES AND JACKING BY REFREEZING OF CRACKS.	
3	SLOW PRESSURE FROM ICE PACK OR JAM.	EXPOSED COASTAL WATERS, RIVERS.	
4	VERTICAL MOVEMENT	TIDAL LOCATIONS WITH HEAVY ICE BUILD-UP.	

PRINCIPAL MODES OF ICE ACTION

3-4.8.2 **Static Pressure.**

Freshwater ice will exert less pressure on a structure than seawater ice of the same thickness. For freshwater ice, assume pressures of 15 to 30 psi (103.4 to 106.8 kPa). For sea ice, pressures of 40 psi (275.8 kPa) to as much as 150 psi (1034.2 kPa) may be assumed. These are maximum values and relate to crushing of the ice. If the ice sheet can ride up on the nearby shore, the pressure exerted will be less than if the ice sheet is confined within vertical boundaries.

3-4.8.3 **Slow Pressure.**

Broken ice floes will exert less pressure than a solid ice sheet. In general, the pressures developed in this mode of action will be less than those to be experienced under the static pressure mode of action. Reliable values of pressure are not presently available.

3-4.8.4 **Vertical Movement.**

Assume that the structure will lift or depress a circular sheet of ice. Calculate the radius of the affected ice sheet on the basis of the flexural strength of ice as 80 to 200 psi (1379.0 kPa.) Check the shear on the basis of the strength (and adhesion) as 80 to 150 psi (551.6 to 1034.2 kPa.) Consider the formation of bustle (added thickness) of ice around the structure. See *Ice Pressure on Engineering Structures*.

3-4.9 **Shrinkage.**

Open pier and wharf decks, which are usually constructed from concrete components, are subject to forces resulting from shrinkage of concrete from the curing process. Shrinkage loads are similar to temperature loads in the sense that both are internal loads. For long continuous open piers and wharves and their approaches, shrinkage load is significant and should be considered. However, for pile-supported pier and wharf structures, the effect is not as critical as it may seem at first because, over the long time period in which the shrinkage takes place, the soil surrounding the piles will slowly "give" and relieve the forces on the piles caused by the shrinking deck. The *PCI Design Handbook* is recommended for design.

3-4.10 **Creep.**

This is also a material-specific internal load similar to shrinkage and temperature and is critical only to prestressed concrete construction. The creep effect is also referred to as rib shortening and should be evaluated using the *PCI Design Handbook*.

3-5 **LOAD COMBINATIONS.**

3-5.1 **General.**

Proportion piers and wharves to safely resist the load combinations represented by Tables 3-6 and 3-7. Analyze each component of the structure and the foundation elements for all the applicable combinations. Tables 3-6 and 3-7 list load factors (f) to be used for each combination and the percentage of unit stress applicable for service load combinations.

Equation 3-2

$$S_i \text{ or } U_i = f_D (D) + f_L (L_c + I \text{ or } L_u) + f_{Be} (Be) + f_B (B) \\ + f_C (C) + f_E (E) + f_{Eq} (Eq) + f_W (W) + f_{Ws} (Ws) \\ + f_{RST} (R + S + T) + f_{Ice} (Ice))$$

where:

- S_i = Service load combination
- U_i = Ultimate load combination
- f_x = Load factor listed in Tables 3-6 and 3-7

3-5.2 Load Symbols.

The following load symbols are applicable for Equation 3-1:

- D = Dead load
- L_u = Live load (uniform)
- L_c = Live load (concentrated)
- I = Impact load (for L_c only)
- B = Buoyancy load
- Be = Berthing load
- C = Current load on structure
- Cs = Current load on ship
- E = Earth pressure load
- EQ = Earthquake load
- W = Wind load on structure

- Ws = Wind load on ship
- R = Creep/rib shortening
- S = Shrinkage
- T = Temperature load
- Ice = Ice pressure

3-5.3 **Load Factor Design.**

Concrete structures for piers and wharves may be proportioned using the Load Resistance Factor Design (ultimate strength) method; however, they should be checked for serviceability and construction loads. Load combinations are presented in Table 3-6.

3-5.4 **Service Load Design.**

Timber structures for piers and wharves should be proportioned using the service load combinations and allowable stresses. Concrete and steel structures may also be designed using the above approach. The service load approach should also be used for designing all foundations and for checking foundation stability. Load combinations are presented in Table 3-7.

Table 3-6 Load Combinations – LRFD

VACANT	1(a)	2(b)	3(c)	4(d)	5(e)	6(f)	7(g)	8(h)
D	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
L	0	1.6 ^{1/1}	1	0	1	1	0	0
B	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
Be	0	0	0	0	0	0	0	0
C	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
Cs	0	0	0	0	0	0	0	0
E	0	1.6	0	0	0	0	1.6	1.6
EQ	0	0	0	0	0	1	0	1
W	0	0	0	0.8	1.6	0	1.6	0
Ws	0	0	0	0	0	0	0	0
RST	0	1.2	0	0	0	0	0	0
Ice	0	0.2	0	0	1	0	1	0

BERTHING	1(a)	2(b)	3(c)	4(d)	5(e)	6(f)	7(g)	8(h)
D		1.2	1.2		1.2	1.2		
L		1.6 ^{1/1}	1		1	1		
B		1.2	1.2		1.2	1.2		
Be		1.6	1		1	1		
C		1.2	1.2		1.2	1.2		
Cs		0	0		0	0		
E		1.6	0		0	0		
EQ		0	0		0	1		
W		0	0		1.6	0		
Ws		0	0		0	0		
RST		1.2	0		0	0		
Ice		0.2	0		1	0		

MOORING	1(a)	2(b)	3(c)	4(d)	5(e)	6(f)	7(g)	8(h)
D	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
L	0	1.6 ^{1/1}	1	0	1	1	0	0
B	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
Be	0	0	0	0	0	0	0	0
C	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
Cs	1.4	1.2	1.2	1.2	1.2	1.2	0.9	0.9
E	0	1.6	0	0	0	0	1.6	1.6
EQ	0	0	0	0	0	1	0	1
W	0	0	0	0.8	1.6	0	1.6	0
Ws	0	0	0	0.8	1.6	0	1.6	0
RST	0	1.2	0	0	0	0	0	0
Ice	0	0.2	0	0	1	0	1	0

^{1/1} 1.3 for maximum outrigger float load from a truck crane /1/

- (a) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 1
- (b) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 2
- (c) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 3a
- (d) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 3b
- (e) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 4
- (f) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 5
- (g) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 6
- (h) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.3.2 Equation 7

Table 3-7 Load Combinations - Allowable Stress Design

VACANT	1(a)	2(b)	3(c)	4(d)	5(e)	6(f)	7(g)	8(h)	9(i)	10(j)
D	1	1	1	1	1	1	1	1	0.6	0.6
L	0	1	0	0.75	0	0	0.75	0.75	0	0
B	1	1	1	1	1	1	1	1	0.6	0.6
Be	0	0	0	0	0	0	0	0	0	0
C	1	1	1	1	1	1	1	1	0.6	0.6
Cs	0	0	0	0	0	0	0	0	0	0
E	0	1	1	1	1	1	1	1	1	1
EQ	0	0	0	0	0	0.7	0	0.525	0	0.7
W	0	0	0	0	1	0	0.75	0	1	0
Ws	0	0	0	0	0	0	0	0	0	0
RST	0	1	0	0.75	0	0	0	0	0	0
Ice	0	0.7	0.7	0	0	0	0	0	0.7	0

BERTHING	1(a)	2(b)	3(c)	4(d)	5(e)	6(f)	7(g)	8(h)	9(i)	10(j)
D		1		1			1	1		
L		1		0.75			0.75	0.75		
B		1		1			1	1		
Be		1		0.75			0.75	0.75		
C		1		1			1	1		
Cs		0		0			0	0		
E		1		1			1	1		
EQ		0		0			0	0.525		
W		0		0			0.75	0		
Ws		0		0			0	0		
RST		1		0.75			0	0		
Ice		0.7		0			0	0		

MOORING	1(a)	2(b)	3(c)	4(d)	5(e)	6(f)	7(g)	8(h)	9(i)	10(j)
D	1	1	1	1	1	1	1	1	0.6	0.6
L	0	1	0	0.75	0	0	0.75	0.75	0	0
B	1	1	1	1	1	1	1	1	0.6	0.6
Be	0	0	0	0	0	0	0	0	0	0
C	1	1	1	1	1	1	1	1	0.6	0.6
Cs	1	1	1	1	1	1	1	1	0.6	0.6
E	0	1	1	1	1	1	1	1	1	1
EQ	0	0	0	0	0	0.7	0	0.525	0	0.7
W	0	0	0	0	1	0	0.75	0	1	0
Ws	0	0	0	0	1	0	0.75	0	1	0
RST	0	1	0	0.75	0	0	0	0	0	0
Ice	0	0.7	0.7	0	0	0	0	0	0.7	0

- (a) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 1
- (b) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 2
- (c) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 3
- (d) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 4
- (e) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 5a
- (f) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 5b
- (g) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 6a
- (h) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 6b
- (i) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 7
- (j) SEI/ASCE 7-02 Minimum Design Loads for Buildings and Other Structures, 2.4.1 Equation 8

CHAPTER 4. STRUCTURAL DESIGN

4-1 CONSTRUCTION MATERIALS.

4-1.1 Timber.

For the major functional types of piers and wharves such as ammunition, berthing, repair, fitting-out/refit, and supply facilities subject to high concentrated wheel loads, timber construction should not be considered. Timber may be more effective and optimal for fender systems, dolphins, walkways, utility trays, and deck-supported small buildings. For light-duty piers and wharves, such as fueling, temporary, and Magnetic Treatment and Electromagnetic Roll piers, timber framing for deck and piling may be considered. Consult with the local activity and Facilities Engineering Command (FEC) for local requirements and restrictions on the use of treated timber. Obtaining permits for treated timbers, especially creosoted fender pile, is becoming very difficult in various areas of the country.

4-1.1.1 Preservative Treatment.

All timber members, with the exception of some fender piling, exposed to the marine environment and immersed in salt water or fresh water should be pressure treated with oilborne (creosote, pentachlorophenol) or waterborne (salts) chemical preservatives to protect against deleterious effects of decay, insects, and marine borers. In warmer waters, where severe marine borer activity can be anticipated, employ dual treatment using both creosote and salt. Consult the staff entomologist at the cognizant FEC for specific information on marine organisms present and the treatment required.

If possible, make pressure treatment after all holes and cuts are made. When holes and cuts are made in the field, treat timber members with preservative to prevent decay from starting in the holes or cuts. Consult a staff entomologist for the proper preservative. Field treatments are difficult in the tidal zone and are typically not very effective against marine borers. Therefore, whenever possible, design and detailing should avoid the necessity for making cuts or holes on underwater timber members. For example, avoid bracing or connections below mean high water. All connection hardware should be suitable for the saltwater exposure. For above water construction, waterborne salt treatment is preferable to creosote treatment due to the staining effect that creosote treatment produces.

4-1.1.2 Timber Species.

Douglas fir and southern pine are the most popular species for waterfront construction. Southern pine piles are limited to 65 ft (19.8 m) in length, whereas Douglas fir piles and poles can be used in up to 100-ft (30.5 m) lengths. Large beams and timber sizes needed for chocks and wales are generally available

only in Douglas fir and southern pine. Treat chocks and wales with waterborne salts and not oilborne preservatives such as creosote. Evaluate the cost and availability of timber piles and other members for the project.

4-1.2 **Steel.**

When protected against corrosion by the use of coal tar epoxy or other marine coatings and cathodic protection systems, steel construction may be considered for all types of marine structures. Active cathodic systems are difficult to design, construct, and maintain properly, therefore, passive systems are preferred. Additional steel thickness may be provided as a sacrificial corrosion allowance. Steel is particularly adaptable for use: in template and jack-up barge construction at advance base facilities; as piles for structures located in deep water where high lateral forces must be resisted; as fender piles and fender panels; as piles for structures located in areas of high seismic activity; and where difficult driving is anticipated. When the utilization of other construction materials is considered feasible, the use of steel construction may be restricted due to cost and maintenance considerations.

4-1.3 **Concrete.**

For piers and wharves, concrete is generally the best material for construction. Properly designed and constructed facilities are highly durable in the marine environment. New advances in concrete technology have improved concrete durability. Concrete enhanced with fly ash, silica fume and corrosion inhibitors has demonstrated superior performance and should be used whenever possible. \1\ UFGS 03 31 29 *Marine Concrete* contains the latest developments in marine concrete. /1/ Concrete is immune to marine borer and insect attack and is incombustible. Concrete is also ideal for deck construction in open-type piers and wharves and, when properly designed, is more economical for floating structures. Proprietary stainless steel reinforcement bars, wires, and strands have been developed for use in concrete construction where nonmagnetic properties are desired as in Magnetic Treatment and Electromagnetic Roll piers.

4-1.3.1 **Precast Concrete Piles.**

Precast concrete piles should preferably be prestressed to resist the tensile forces frequently encountered during driving. Corrosion of reinforcement in prestressed concrete piles can be controlled by proper mix design and, in extreme cases, by epoxy coating the reinforcement. However, exercise sufficient control during driving of concrete piles to minimize cracking. Where difficult driving into very compact sands, gravels, or rock is anticipated, the tip of the piles may be equipped with a WF-shape or H-pile "stinger" to achieve needed penetration. Very large hollow cylindrical piles (48-in. diameter and larger) have also been successfully employed for waterfront construction on the East coast.

However, longitudinal cracking was encountered with these same types of piles during construction of Pier D at Bremerton, Washington.

4-1.4 **Composites.**

Composites made of concrete and steel, concrete and fiberglass, plastic and fiberglass, and plastic and steel have been successfully employed in piers and wharves. Composites offer many advantages over conventional materials but often have limitations that need to be considered. Some advantages may include improved corrosion resistance, lightweight, and ease of construction. Some of the disadvantages may include low strength, UV light deterioration, long-term durability and high cost.

4-1.4.1 **Concrete and Steel.**

Concrete-filled pipe piles, steel H-piles with a concrete casing, and steel beams with concrete decks are the more common composite types. The concrete casing or jacket for the steel H-piles may be required only in the splash or tidal zone. However, due to instances of severe deterioration of the pile just below the jacket, the jacket must be extended to ELW or to below mudline. Concrete may also be added to steel pipe piles for deadweight purposes to resist uplift forces or to increase the stiffness of the pile.

4-1.4.2 **Concrete and Fiberglass.**

Concrete-filled fiberglass piles have been used in facilities where high axial capacities are not required. The lightweight fiberglass piles are easily installed and do not require high capacity handling equipment.

4-1.4.3 **Plastic and Fiberglass.**

Fiberglass reinforced plastic piles and beams have been successfully used in pier and wharf construction primarily as fender piles, wales and chocks.

4-1.4.4 **Plastic and Steel.**

Recycled plastic piles with steel cage reinforcement have also been used in pier and wharf construction.

4-1.5 **Aluminum.**

For deck-supported structures and for support of piping and conduits, aluminum members are useful. However, do not use unprotected aluminum underwater or in the splash zone. To prevent corrosion, aluminum should be electrically isolated from adjacent materials by nonconductive gaskets, washers, or bolt sleeves. Aluminum construction may be used in the superstructure of Magnetic

Treatment and Electromagnetic Roll piers, due to the nonmagnetic characteristics of the material.

4-1.6 **Plastics.**

Fiberglass-reinforced plastics (FRP), ultra high molecular weight (UHMW) plastics, and high-density polyethylene (HDPE) are being increasingly used in waterfront construction. FRP grating and shapes are highly durable in the marine environment when shielded from ultraviolet rays. UHMW plastics are useful in fender systems design as rub strips where a high abrasion resistance and low coefficient of friction are required. UHMW plastics are available in various grades. The use of corrosion-resistant fiber reinforced plastic (FRP) components including reinforcing bars, prestressing tendons, structural shapes, and unidirectional or woven fabrics, are being developed and have been successfully used in the repair of piers and wharves. Consider using these materials when the situation warrants, but special attention must be given to the design of connections. Carefully evaluate the use of FRP components as structural elements for new construction.

4-2 **ALLOWABLE STRESSES.**

4-2.1 **General.**

Allowable stresses for materials used in pier and wharf construction generally conform to industry standard codes for the type of material and the purposed application unless modified herein. Allowable stresses for fender system design are discussed in Chapter 5.

4-2.2 **Timber.**

Design timber structural elements in accordance with UFC 1-200-01, *General Building Requirements*. Allowable stresses are generally not affected by preservative treatment. However, modulus of rupture and modulus of elasticity are considerably reduced by preservative treatment. When preservative treatment for fire retardation is used, the allowable stresses should be reduced by 10 percent.

4-2.3 **Steel.**

Design steel structural elements in accordance with UFC 1-200-01.

4-2.4 **Concrete.**

Design concrete structural elements in accordance with UFC 1-200-01. For prestressed concrete members, "zero" tension design is preferred. All reinforced concrete deck members should meet the crack control requirements for severe exposure.

4-2.5 **Other Materials.**

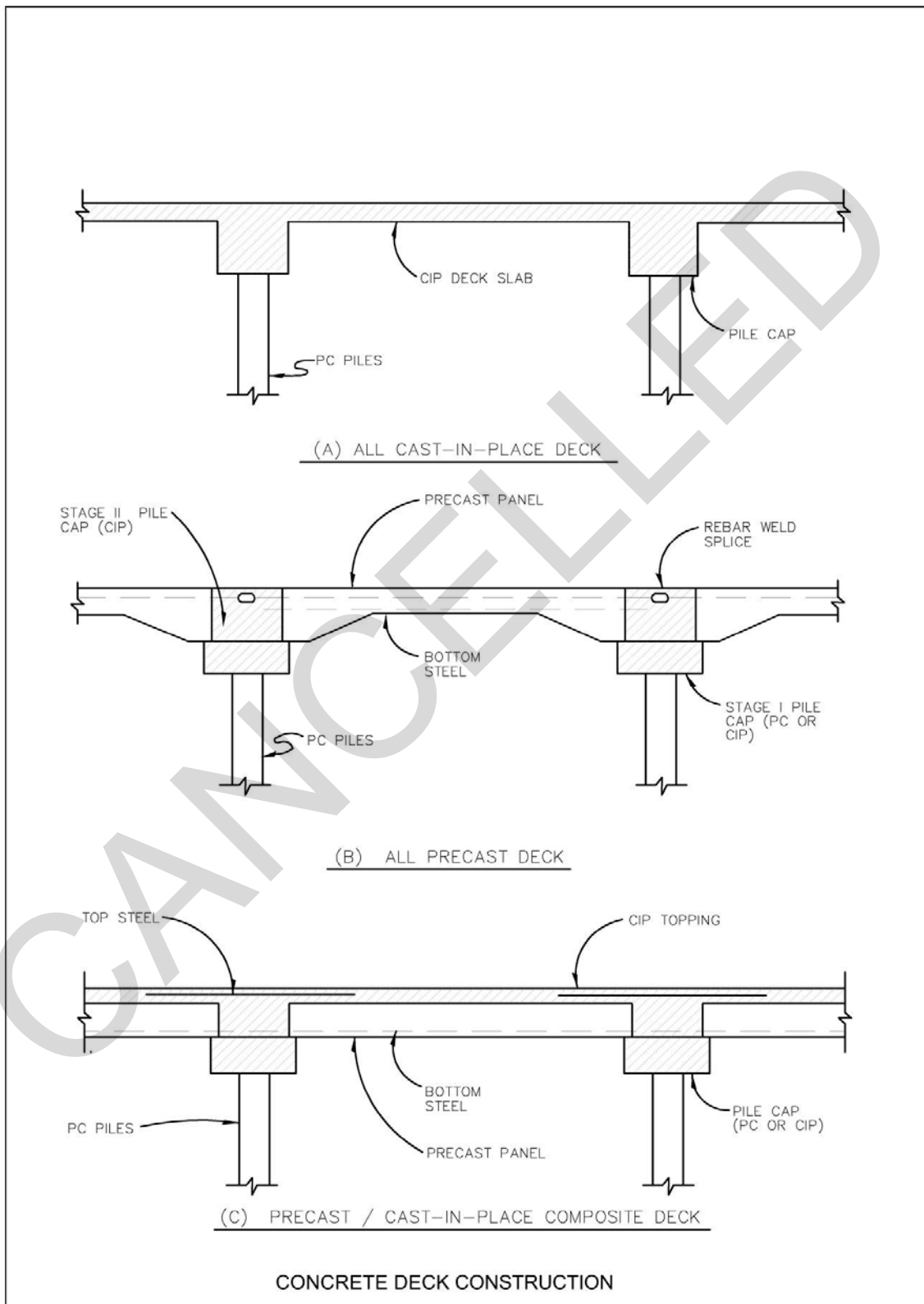
Fiberglass-reinforced plastics (FRP), ultra-high molecular weight (UHMW) plastics, and other new materials should be governed by the accepted industry standards for structural design and detailing.

4-3 **DECK STRUCTURE DESIGN.**

4-3.1 **Deck Framing.**

Concrete is generally considered the best material for deck framing and should be used for most pier and wharf decks. Although timber, steel, steel/concrete composite, and timber/concrete composite decks have been used in the past, they are neither cost-effective nor suitable for the high concentrated load capacities currently demanded of decks. From durability, maintenance, and life-cycle-cost viewpoints, a concrete deck is superior and is highly recommended. The deck framing should be slabs supported on pile caps, using an all cast-in-place, all precast, or composite construction, as shown in Figure 4-1. For the concentrated loads which typically control the deck design, a solid slab with its high punching shear resistance is recommended. Framing systems using thin slabs, as in cast-in-place slab/beam/girder systems, should not be used because of the tendency to spall along beam/girder corners and edges. Occasionally, where high concentrated loads are not specified, voided slabs may be used. Map cracking in the cast-in-place topping at the precast panel joints is sometimes seen. To control the cracking, transverse post-tensioning is sometime utilized. For distribution of horizontal loads, pier and wharf decks should be continuous, with as few expansion joints as possible. Where expansion joints are needed, the deck on each side of the joint should be supported on a separate pile cap or girder.

Figure 4-1. Concrete Deck Construction



4-3.2 **Pile Caps.**

It is often cost-effective to orient pile caps (and hence pile bents) transverse to the length of the structure. This orientation provides improved lateral stiffness for berthing and mooring forces. When this orientation is used, longitudinal pile caps are not needed unless crane trackage support or longitudinal seismic resistance is to be provided. For marginal wharves where lateral loads from mooring and berthing loads are transferred to the land, a longitudinal orientation of the pile cap may be considered if feasible for construction. Moments and shears on pile caps from live loads should take into account the elastic shortening of the piles and the effect of soil deformation at and near pile tips. For computation of forces from high concentrated loads, the cap behaves as a beam on elastic foundation, and distributes the concentrated load to a number of piles adjacent to the load. While hand calculations are acceptable, a stiffness analysis using a computer is recommended.

4-4 **SUBSTRUCTURE DESIGN.**

4-4.1 **Pile Bent Framing.**

A pile-supported framing system is the most popular form for substructure design for open piers and wharves. Several framing concepts for open piers and wharves and marginal wharves are illustrated in Figure 4-2. Many variations and combinations of the illustrated concepts are possible.

4-4.1.1 **All Plumb Pile System.**

The lateral loads are resisted by "frame action," whereby the piles and the cap form a moment frame and resist the lateral load primarily by the flexural stiffness of the piles. However, for narrow structures, lateral deflection may be high for even small lateral loads. Also, sidesway is not prevented, which increases the effective length of the pile as a column. If piles vary in unsupported length, the shorter piles will attract a large portion of the lateral load. Because the piles are more efficient for axial loads and less so for bending moments, this framing usually is restricted to shallow waters and light lateral loads. However, for wide structures with a large number of piles, the total stiffness of the system may justify a reduced effective length. A more in-depth stability analysis is needed to validate a reduced effective length. Large diameter steel pipe and precast/prestressed concrete cylinder piles can provide improved lateral stiffness and are attractive for use in areas of high seismic activity.

4-4.1.2 **Plumb/Batter Pile Systems.**

In this type of framing, all the vertical loads are primarily handled by the plumb piles, and lateral loads are resisted primarily by the batter piles. The behavior of the system is one of "truss action." This system is more cost-effective as the

lateral loads are resisted primarily by the axial stiffness of the batter piles. However, very high forces are transmitted to the caps, which will have to be designed and detailed to resist these forces. In areas of high seismic activity, the increased stiffness of the system reduces the period and leads to higher earthquake loads.

4-4.1.3 **All Batter Pile System.**

This system is a compromise between the two above, and is cost-effective in some circumstances. With this system, the batter slope may be near vertical. Natural periods can be as high as several seconds, making the approach attractive for seismic areas.

4-4.1.4 **Batter Pile System with Seismic Isolation.**

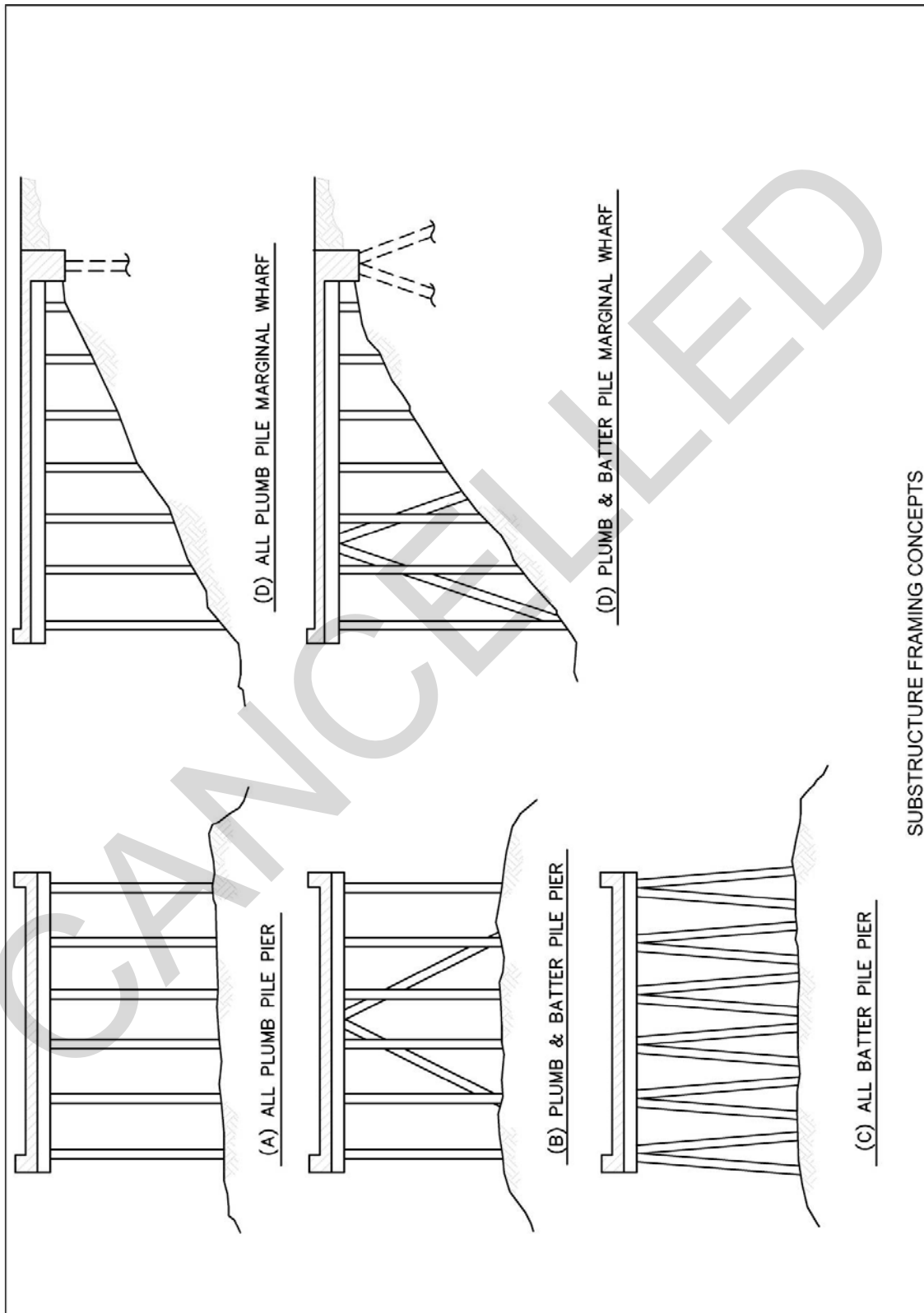
This system incorporates calibrated isolators or seismic fuses between the wharf deck and batter piles. The system allows for high displacements of the wharf deck once a threshold lateral load causes the isolator slip. Consider the magnitude of lateral berthing and mooring forces such that they do not exceed the threshold lateral force of the isolator. In this case a separate fendering structure may be required.

4-5 **MOORING HARDWARE.**

4-5.1 **General.**

Ships are usually moored to bollards, bitts, and cleats. Occasionally, ships may be tied to a quick-release hook. The position of a ship on a berth is usually controlled by utility hookup and brow location requirements. The crew in charge of tying up the ship will usually tie the lines to whatever mooring hardware is convenient to give the required horizontal angle. This often results in lines tied to a lower capacity cleat while a high-capacity bollard may only be a few feet away. Hence, consider using only one type of high-capacity mooring hardware throughout the facility. When possible, size this mooring hardware for the maximum size vessel that could possibly use the facility. Space hardware to maximize the berth flexibility for use by ships other than the specific vessel the berth was designed to accommodate. In addition, mooring hardware requirements will depend on the mooring service type assigned to the berth as defined in UFC 4-159-03. For mooring service types III and IV, consider providing additional heavy weather mooring hardware. Balance the desire to provide the higher capacity hardware with the additional cost of the higher strength hardware and supporting structure. The geometry of the hardware should preclude mooring lines from slipping off, as the mooring angle is often very steep.

Figure 4-2. Substructure Framing Concepts



4-5.2 **Hardware Types.**

Additional information (such as tabular data and figures) on mooring hardware is contained in UFC 4-159-03, UFC 4-150-08, *Inspection of Mooring Hardware*, and NFESC TR-6014-OCN, *Mooring Design Physical and Empirical Data*. The following are the most commonly used types of mooring hardware:

4-5.2.1 **Bollards.**

A bollard is a short single-column cast-steel fitting that extends up from a baseplate that is secured to a strong point of a shore structure or berthing facility. Bollards are used in snubbing or checking the motion of a ship being moored, by tightening and loosening mooring lines that are fastened to them. Bollards are also used for securing a ship that has been placed in its final moored position. Do not use bollards without ears in facilities where a high vertical angle of the mooring line is anticipated, to prevent lines from slipping off.

4-5.2.2 **Bits.**

Bits are short, double-column, cast-steel fittings fastened to the deck of berthing facilities. They are used to snub and secure a vessel. The double-columns allow for convenient and rapid tying and releasing of mooring lines, as well as for guiding a line through to other hardware.

4-5.2.3 **Cleats.**

Currently, available cleats are low-capacity, cast steel deck fittings having two projecting arms that are intended to be used for securing mooring lines of small craft. They are provided at most naval facilities. Given a choice, line-handling crews will use cleats in preference to bollards or bits, even for large ships, as the possibility of line slippage is remote. However, cleats can easily be overloaded when they are used in lieu of major fittings such as bollards. Because of the low holding capacity of cleats, they should not be used in combination with higher capacity deck fittings.

4-5.2.4 **Chocks.**

Chocks are either stationary or roller-equipped cast deck fittings that are used to train the direction of a mooring line. Chocks are available either open at the top, permanently closed, or closed by a hinged closing piece.

4-5.2.5 **Capstans.**

Ships outfitted with winch-mounted wire rope mooring lines require greater pulling power than can be provided by one or two deck hands to draw out the ship's lines. The assignment is handled by capstans mounted along the face of the wharf. The capstans are small electric winches of 5 to 10 hp with a drum

rotating about a vertical axis. The capstan is used by a deck hand that receives a messenger line at the end of which is fastened the sling of the wire rope hawser. The capstan, receiving several winds of the messenger line, provides the pulling power needed to draw out the wire rope hawser. The messenger line is then returned to the ship. Capstans are also used as primary guidance (breasting and in-haul) to berth ships in drydocks and slip-type berths (Trident facilities). For these uses, the capstans are of larger capacity and are typically two-speed.

4-5.2.6 **Quick-Release Hooks.**

The quick-release hook, generally mounted on a swivel base, is a deck fitting used to receive mooring lines. When a ship is required to make a hasty departure from its berth, a tug on the hook's release mechanism unfastens the mooring line. The mechanism can also be tripped from the ship when a tag line is provided. Thus, a ship can make a sudden departure without the assistance of shore personnel. Quick-release mooring hooks with integral power capstans are necessary for securing the steel mooring lines on petroleum tankers at fuel piers, while bollards are needed for the supplementary lines other than steel.

4-5.3 **Strength.**

The required strength of mooring hardware and its fastenings is determined by the breaking strength of the strongest mooring line or lines that may be fastened to it. Mooring hardware can and does receive more than one line and as many as three are not unusual. The sizes of mooring lines are limited to those that can be conveniently handled by deck hands. Thus, wire rope lines generally do not exceed 1 1-3/4 in (44.5 mm) diameter.

4-5.4 **Placement.**

If a berthing facility were always to receive the same class of ship, each of which had identical arrangements for putting out mooring lines, a specific pattern for mooring hardware spacing, based on the ship's fittings, would be satisfactory. However, most naval berthing facilities require a high degree of flexibility in order to be able to receive several types and sizes of ships. Therefore, a universal pattern for mooring hardware spacing is preferred. Mooring hardware spaced at 60 ft on centers along the berthing face of a structure will, in most instances, provide the number of fittings required to secure the ships during the periods of time that wind velocities and conditions of sea do not exceed the design criteria established for mooring service types I and II. Mooring service types III and IV will likely require additional high capacity storm bollards which are normally set back at least 100 feet from the face of the berth to provide a shallow line angle.

- a. A berthing facility that will accommodate ships having large wind presentments, such as aircraft carriers, should be outfitted with 12 – 100 ton bollards at 100-ft (30.5 m) centers and 4 – 200 ton storm bollards at

each end. Locate the storm bollards, which would be used to secure breasting lines, inshore from the face of the wharf, thus reducing vertical angles and permitting the use of longer (safer) mooring lines.

b. At submarine berths where mooring lines go down to the submarine, locate the mooring hardware as close as possible to the waterside edge of the bullrail to minimize chafing of the lines. Where this is not feasible, cast a continuous smooth member, such as a bent plate, in the concrete bullrail, as shown in Figure 4-3.

4-6 **MOORING DOLPHINS/PLATFORMS.**

4-6.1 **Design.**

The primary load for a mooring dolphin comes from the tension in the mooring line. It is typically constructed as an open pile supported structure. Where filled (solid) construction is permitted, a single sheet pile cell may be used. When a platform is provided for the dolphin, it should be large enough to allow a 3-ft-wide (0.9 m) walking space all around the mooring hardware.

4-6.2 **Construction.**

Timber mooring dolphins can be constructed from 7, 19, or 37 wood piles with a king pile in the center and other piles arranged in a circular pattern around the king pile. A 19-pile dolphin is illustrated in Figure 4-4(A). Limit the use of timber dolphins to facilities not requiring high capacity mooring points. Timber dolphins may be required for magnetic sensitive facilities. In areas with ready access to timber piles, timber dolphins may be popular for small craft, tugs, patrol craft and barges. For higher loads, a concrete dolphin is preferred, which is illustrated in Figure 4-4(B). Because both timber and concrete dolphins can be expected to move significantly (1 to 6 in (25 to 150 mm)) from the lateral load, design and detail the access walkway to allow for this movement. For situations where significant pile pullout capacities are needed, consider steel spin fin piles.

Figure 4-3. Bullrail Details

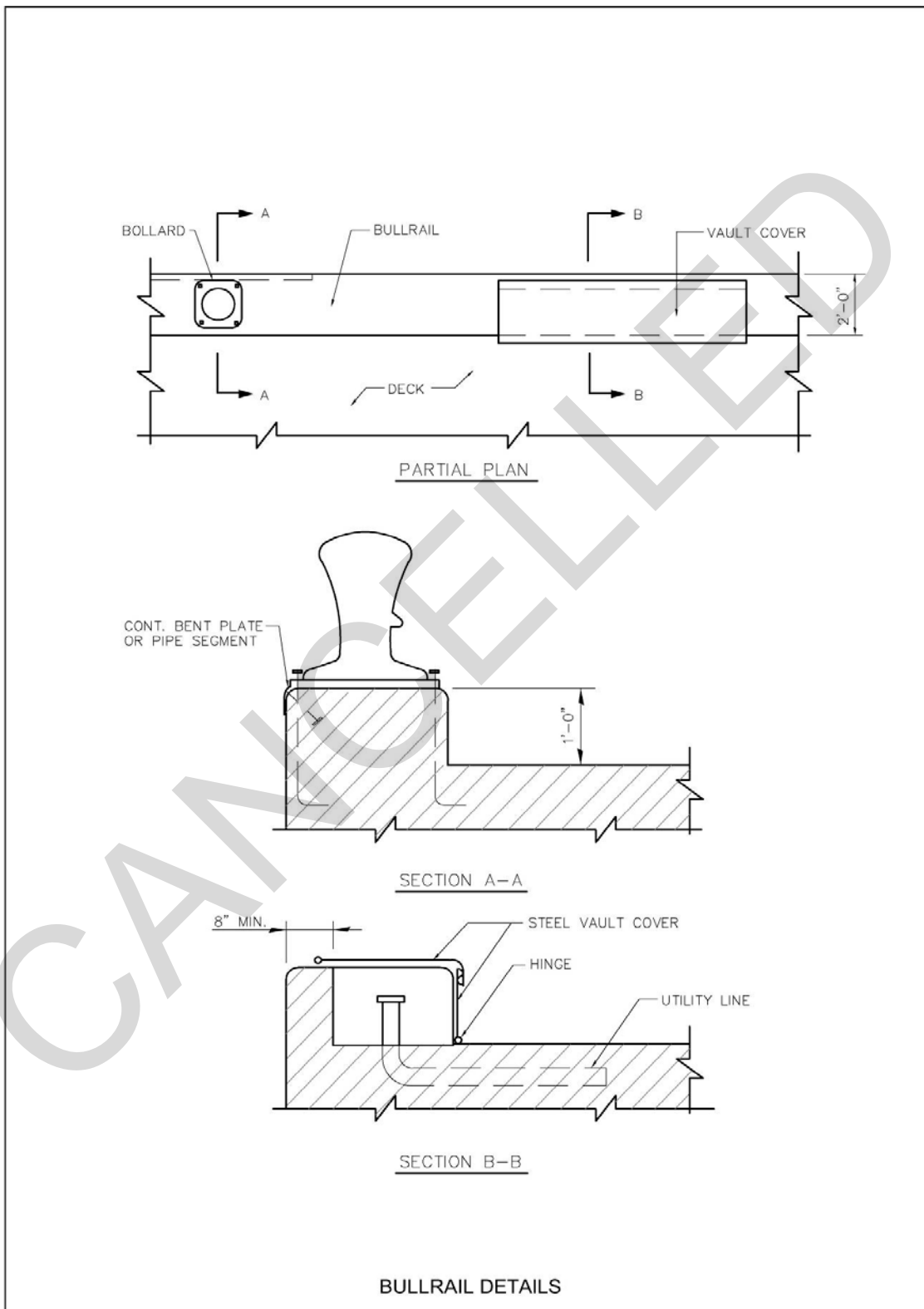
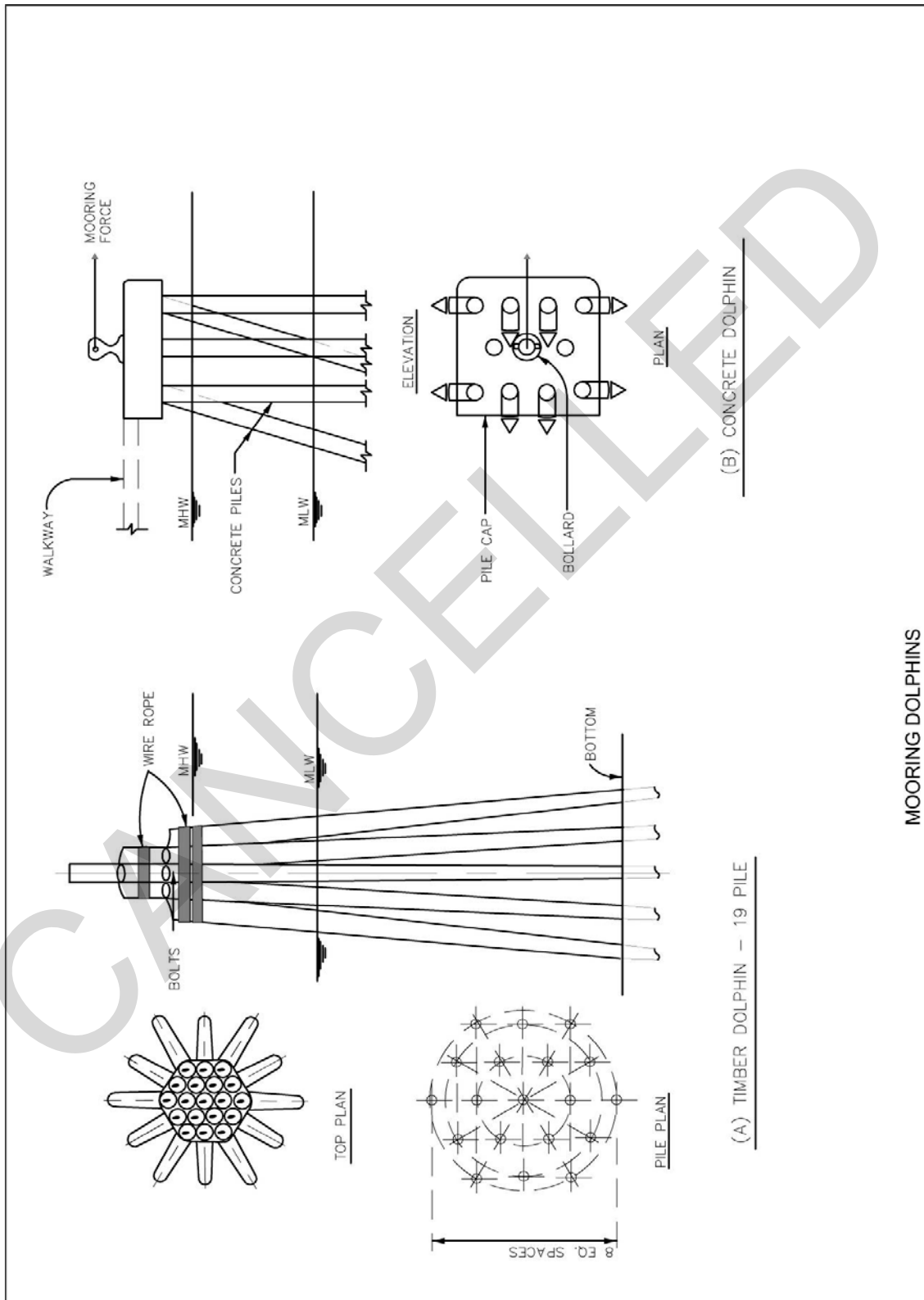


Figure 4-4. Mooring Dolphins



MOORING DOLPHINS

4-7 MISCELLANEOUS CONSIDERATIONS.

4-7.1 Expansion Joints.

Because expansion joints require frequent maintenance for proper functioning, piers and wharves should use as few joints as possible. The size and number will depend on the temperature range and structural system employed. Provide expansion joints at the junction of an approach with the main structure and such other places where there is a major structural discontinuity. Provide additional expansion joints where necessary to limit buildup of thermal loads. (See also Chapter 3, discussion on Thermal Loads.) Continue the joint through railroad tracks and crane rail tracks. Recommended details are shown in Figures 4-5 and 4-6. Likewise, detail utilities crossing expansion joints to accommodate the expected longitudinal and lateral movements.

4-7.2 Drainage.

Pier and wharf decks should be sloped in transverse and longitudinal direction to deck drains or scuppers to provide for drainage of storm water. Where permitted, the storm water can be drained off to the water below; however, if fuel, oils, and chemicals are to be handled on the facility, the storm water should be collected and piped off for treatment. A complete review of local jurisdictional requirements for storm water management and treatment required for each facility may vary significantly between locations. It is customary to use subsurface drains in ballasted decks to handle any small amounts of water that may seep through the paving. This water is normally not collected.

4-7.3 Bullrail.

On all waterside edges of piers and wharves, provide a curb or bullrail 10 to 12 in (254 to 305 mm) high by 12 to 24 in (3.5 to 610 mm) wide. Some mooring hardware may be accommodated within the 24-in (610 mm) width, thus permitting a clear inside face for easy snow removal and line handling. As shown in Figure 4-3, it is also generally possible to house utility vaults within the width of the bullrail. The bullrail should be sufficiently reinforced and anchored to the deck structure. When a continuous bullrail is available, it may be reinforced to serve as chord member for a structural diaphragm.

4-7.4 Utility Trench.

Because the utility services are mostly needed along the pier or wharf edge, the main utility trenches on single deck piers should be kept close to the bullrail. The trench may be underhung or kept above, as shown in Figure 4-7. The trench covers should be removable and made of concrete, steel, or composite construction. Although the trench covers need not be watertight, use a good seal at joints to prevent accidental seepage of spilled liquids. Frequently spaced

drains should be placed along the trench to prevent flooding. Provide adequate width and depth to allow access for maintenance of utilities.

Figure 4-5. Railroad Track Support

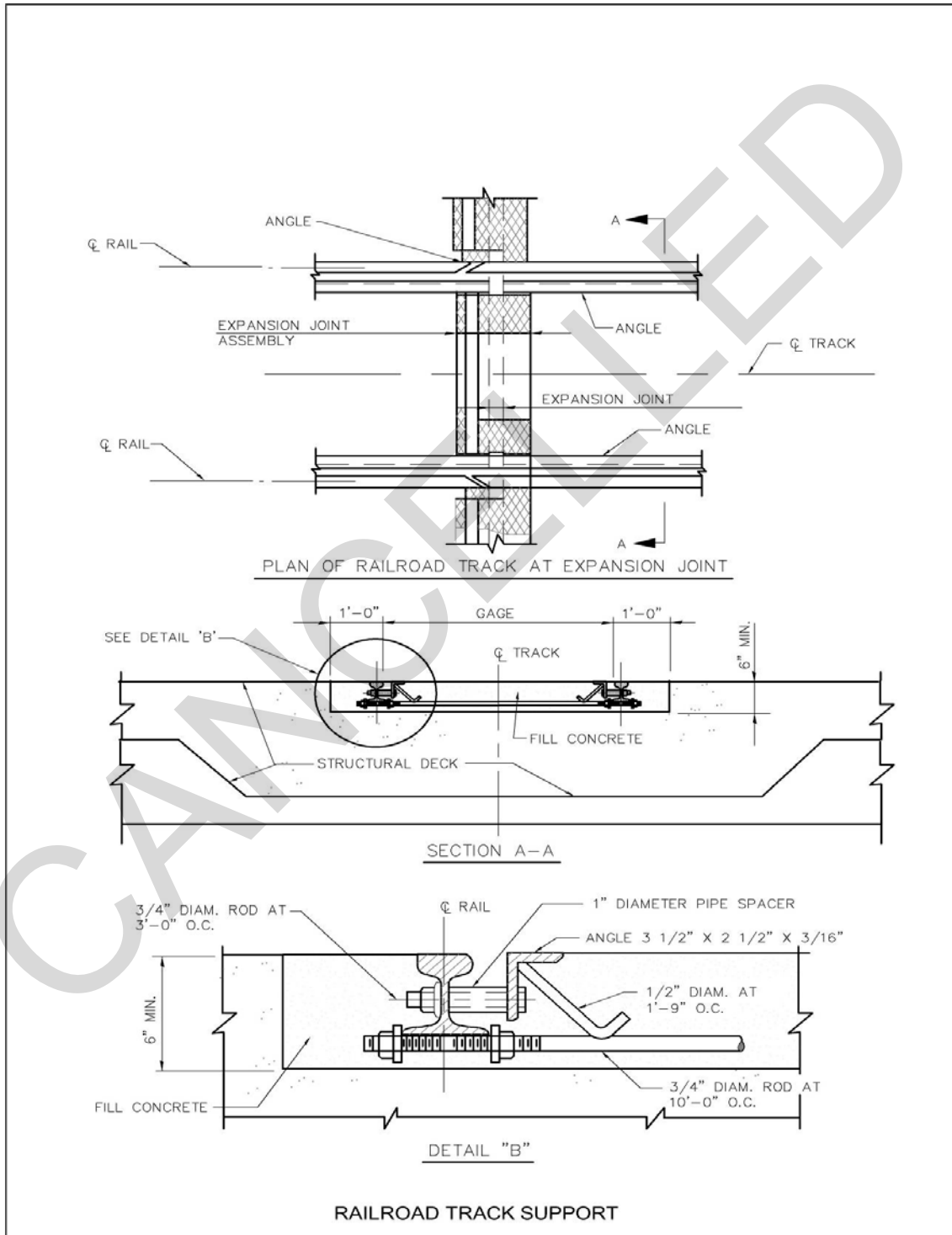


Figure 4-6. Crane Rail Support

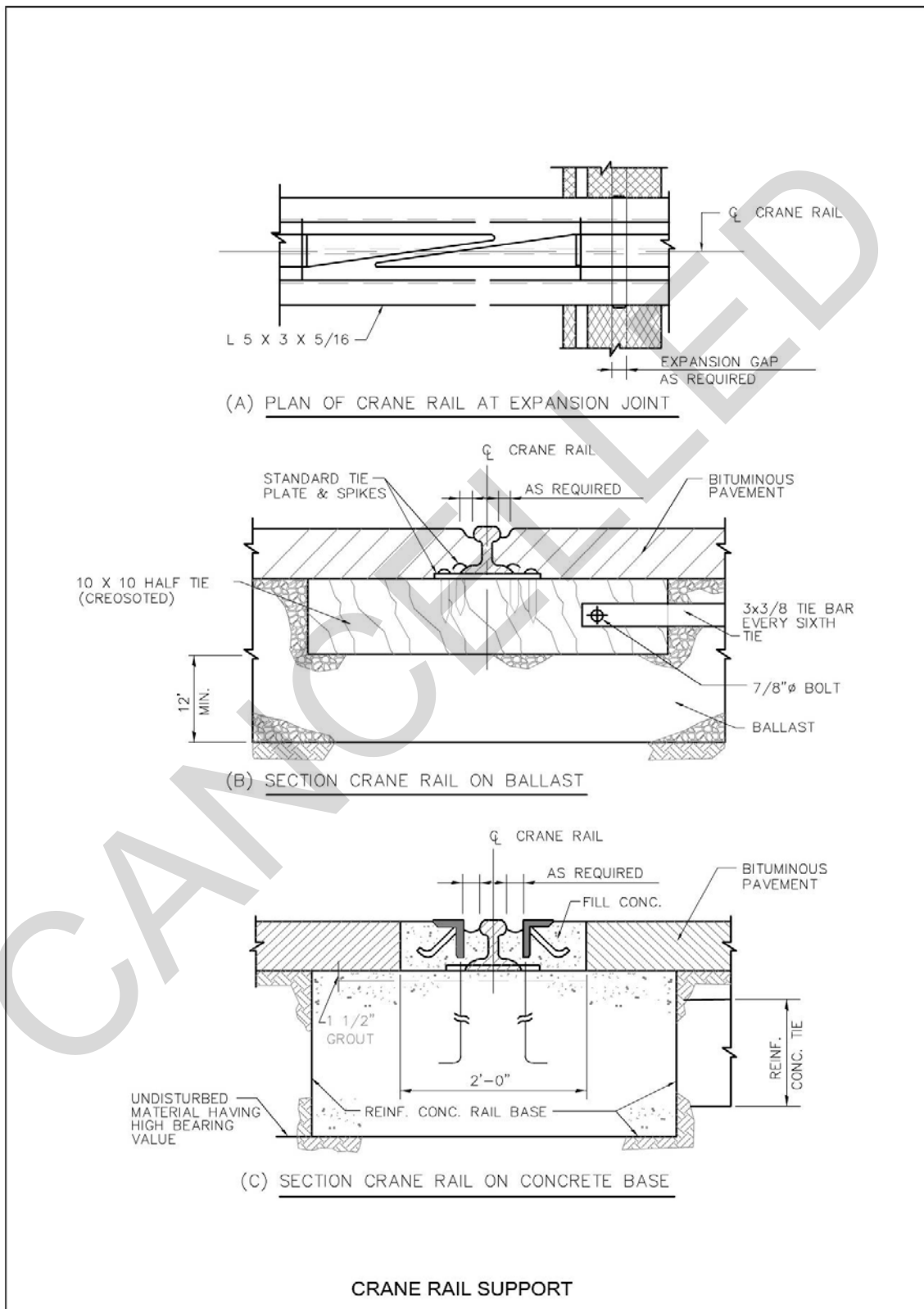
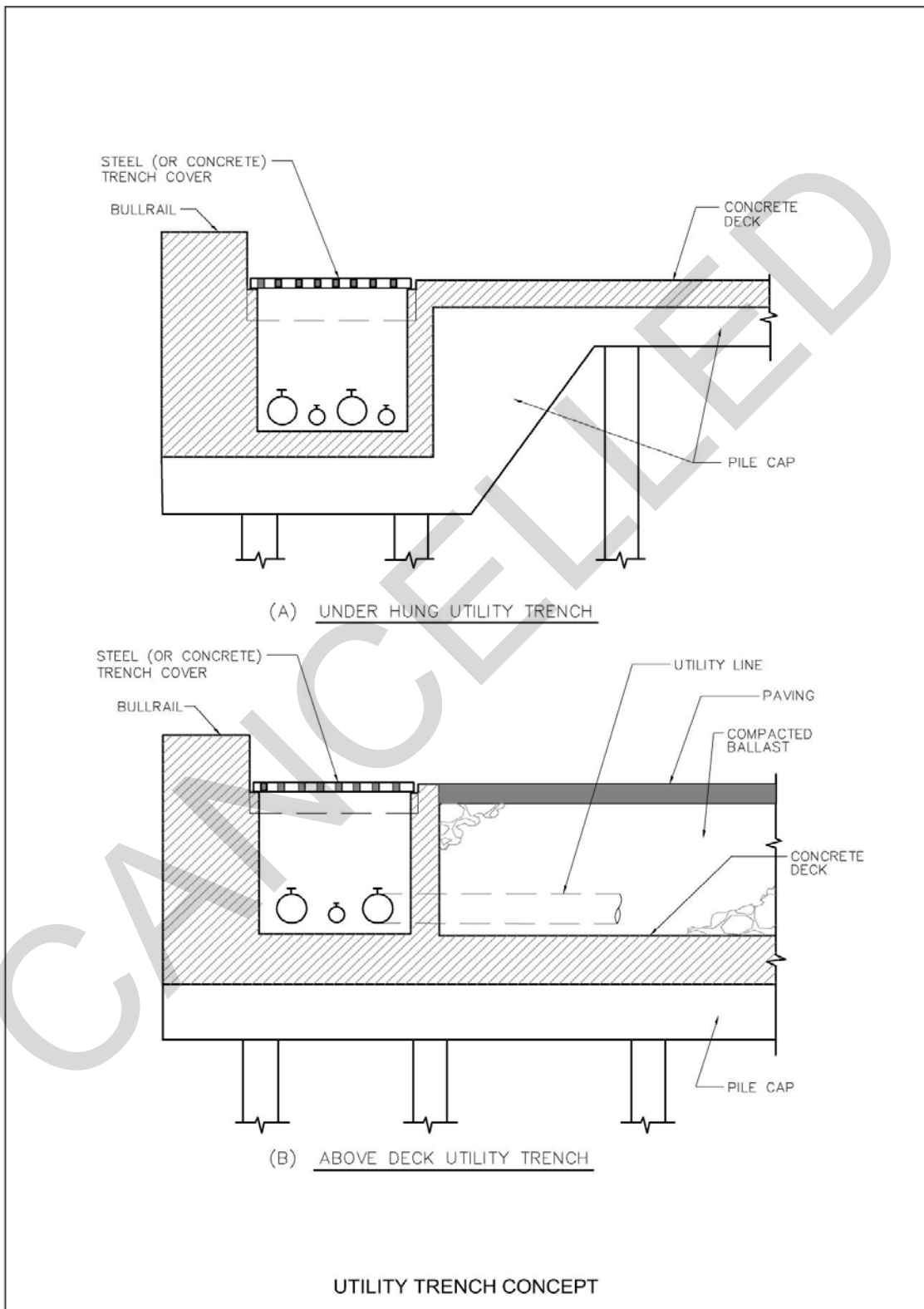


Figure 4-7. Utility Trench Concept



4-7.5 **Utility Hoods.**

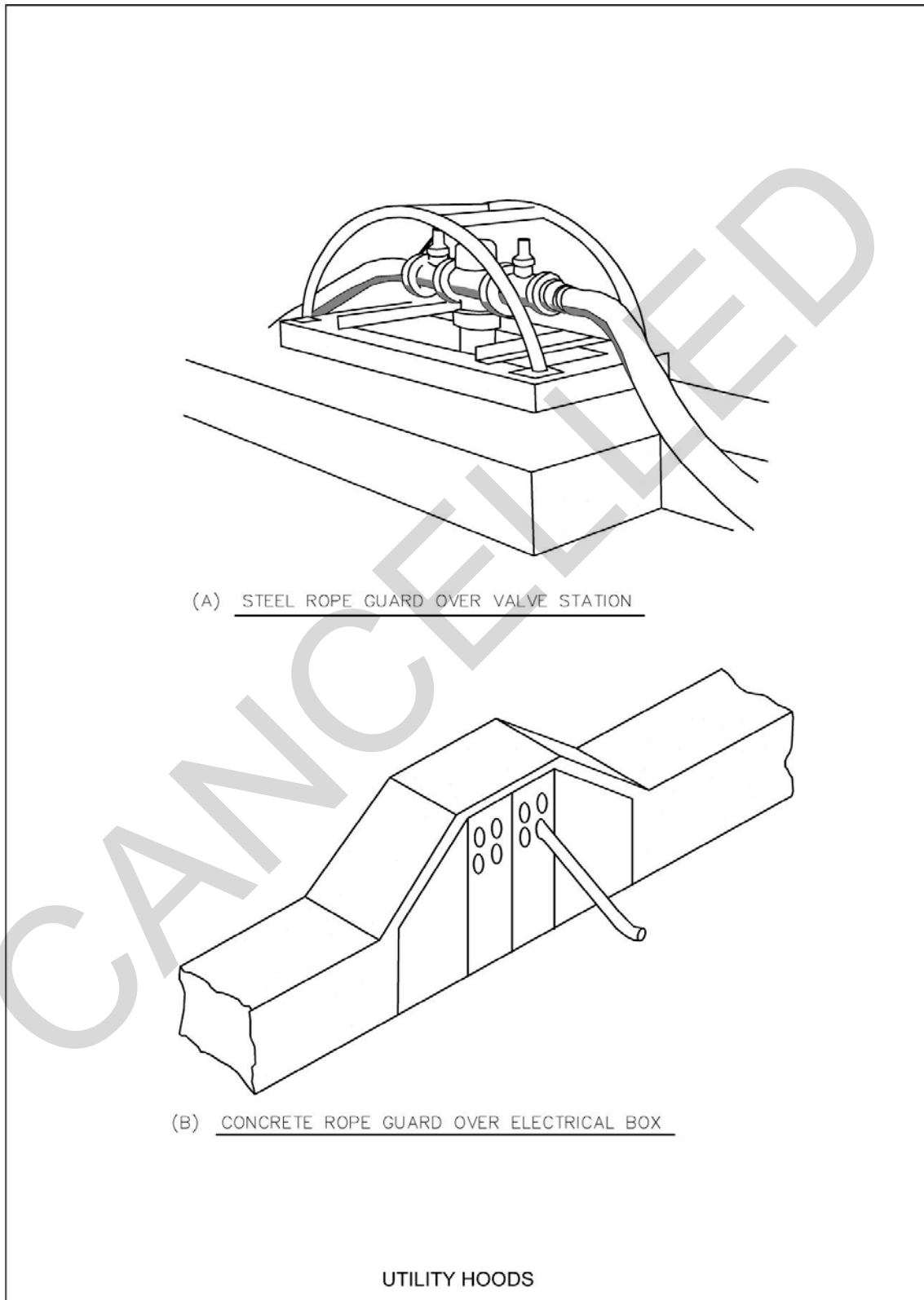
Protect connection points or "utility risers" projecting above deck or bullrail from snagging of mooring lines by pipe rails or concrete hoods, as shown in Figure 4-8. Alternatively, when the bullrail is wide enough, employ hinged utility covers like the one shown in Figure 4-3. For convenience of the users, the risers should not face away from the ship, and should be adequately sized for ease of operation.

4-7.6 **Wearing Course.**

Generally, a wearing course is not needed for concrete deck structure. However, for precast concrete decks, an asphalt concrete or cement concrete wearing surface may be utilized to provide a slope for drainage. For ballasted decks and for solid (filled) type construction, a wearing course is necessary. For these applications, asphaltic concrete is preferred over cement concrete as the former is easier to repair and maintain and better tolerates substrate movement.

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Figure 4-8. Utility Hoods



CHAPTER 5 FENDER SYSTEMS

5-1 GENERAL CONSIDERATIONS.

5-1.1 Description.

The fender system is the interface between the ship and the shore facility. During the berthing of a ship, the fender system is meant to act as a buffer in absorbing or dissipating the impact energy of the ship without causing permanent damage to the ship or the shore facility. Where ships are to be berthed against relatively inflexible solid piers and wharves, protection of the ship is a critical function. When ships are to be berthed against pile-supported piers, wharves, and dolphins (which are relatively flexible), protection of the structure may be the more serious concern. Once the ship is successfully berthed and moored to the shore facility, the fender system continues to provide the interface between ship and shore and transmits the environmental loads (wind, waves, and current) on the ship to the structure. For submarine and other low-profile ship berthing, the fender system also provides a physical barrier to prevent the vessel from going underneath the pier.

5-1.2 Berthing Practice.

The selection and design of a fender system is highly dependent on the berthing practice employed at the particular facility. Typically, two or more tugboats assist large ships into the berth. In some locations, smaller ships may be allowed to come in on their own power. When assisted by tugs, the ship would arrive off the berth and parallel to it. The ship then stops dead in the water and the tugs push and pull the ship transversely toward the berth in an attempt to make contact with as much of the fender system as possible. When unassisted by tugs, the smaller ship will be eased into its berth at some slight angle, referred to as the angle of approach. In both cases, the initial contact is limited to a relatively small portion of the fender system. Assumptions will have to be made regarding the approach angle and contact length.

5-1.3 Camels and Separators.

Camels are located between ships and piers or wharves. Separators are located between nested ships. This practice is the most significant difference between commercial ship berthing and naval ship berthing. Berthing against camels concentrates the impact energy to a small length of the fender system as well as applies the energy at some distance below the deck. This aspect must be recognized in all fender system design for Navy ships. A fender system designed for commercial ships will, in general, not be satisfactory for Naval applications. The practice of using camels has resulted in a general trend for a minimum of hull protrusions near the waterline. Fender systems with higher

fender contact area are more susceptible to damage from longitudinal movement of the vessel due to snags.

5-1.4 **Systems Approach.**

The impact energy of the berthing ship is absorbed in a complex system of interconnected elements. For the system shown in Figure 5-1, the load passes from the ship's hull to the camel, which is backed by a series of fender piles. The fender piles, in turn, are supported by rubber fender units at the deck level. In this case, the ship's energy is absorbed by the ship's hull, rubbing strips, separator, fender piles, and rubber fenders at deck level. The system can be modeled as shown in Figure 5-1. The energy absorbed and the force developed, by each element can only be solved by an iterative process.

5-1.5 **Functional Requirements.**

5-1.5.1 **Energy Absorption.**

Design all fender systems for absorption of the ship's berthing energy in all the structural types of piers and wharves.

5-1.5.2 **Normal Berthing.**

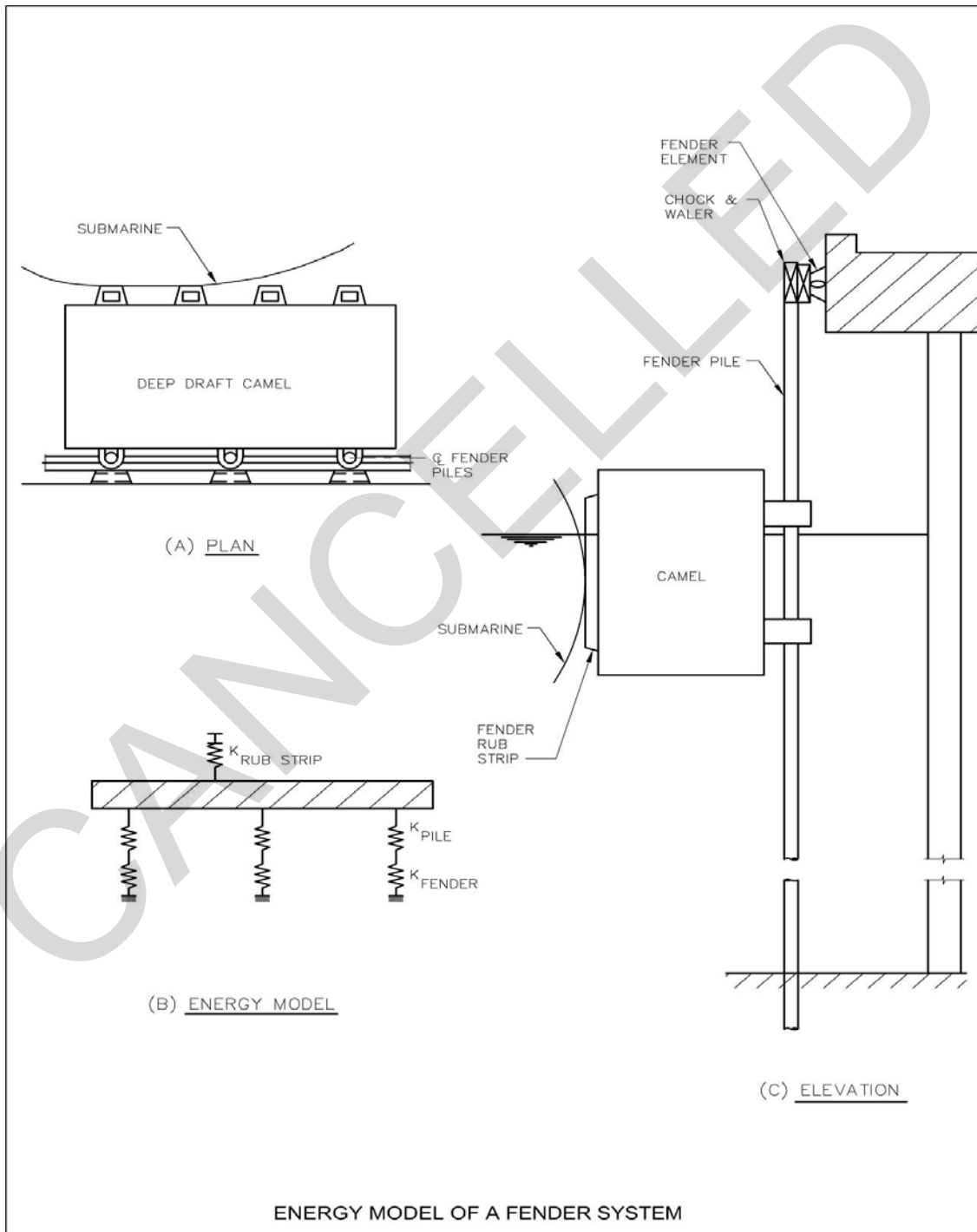
The fender system should be able to absorb the energy from normal berthing operations within the working stress or acceptable deformation range as defined in this section. Some manufacturers indicate a load deflection curve tolerance of plus or minus 10%. If this is determined to be the case, the design reaction on the structure should be increased by 10% and the energy absorption for design should be decreased by 10%. Variations in the speed of testing of fenders may affect the resulting load-deflection curves. Where the test loads are applied rapidly, i.e., at a speed comparable to the actual ship berthing, the load-deflection will indicate higher reaction and energy than if the test load is applied slowly. Therefore, take care when comparing test results from different manufacturers, and make appropriate adjustments in the factors of safety used in design. Differences of in the order of 30% can be expected.

5-1.5.3 **Accidental Berthing.**

Because the fender system is less expensive than the ship or the berthing structure, some damage to it may be permissible and acceptable. So, in the event of an accidental situation, it is the fender system that should be "sacrificed." Loss of the berth has a much more serious consequence than loss of part or all of the fender system in terms of the cost and time required to restore the facility. The cost and time to repair a damaged ship is of much greater concern than the berth and the fender system. The accidental condition may be caused by increased approach angle or approach velocity or a unique situation

that cannot be anticipated. In the absence of any other accident scenario, increase the berthing energy as calculated in this chapter by at least 50 percent and the fender system should be capable of providing this "reserve" capacity at or near failure of the system materials.

Figure 5-1. Energy Model of a Fender System



5-1.5.4 **Moored Condition.**

All fender systems selected should be capable of safely transferring the environmental loads on the ship to the mooring structure.

5-1.5.5 **Hull Damage.**

Design all fender systems to prevent permanent deformation of the ship's hull. It is much more expensive to repair a ship's hull than rehabilitate a damaged fender system. The composition of a typical Navy hull is steel plating welded to longitudinal (horizontal) stiffeners at 2 to 4 ft (0.6 to 1.2 m) on center. The stiffeners span from 5 to 20 ft (1.5 to 7.6 m) depending on the vessel. Generally, the stiffeners are of sufficient strength to preclude failure from fender loading. However, the hull plating may yield when subjected to a uniformly distributed overload on the panel. Fender systems with rigid face elements or in combination with rigid camels tend to concentrate the reaction forces on the ships frames versus the hull plating due to the relative stiffness of the frames.

5-2 **BERTHING ENERGY DETERMINATION.**

5-2.1 **Methods.**

The following methods can be used in the determination of berthing energy of the ship.

5-2.1.1 **Kinetic Method.**

The kinetic energy method has been the widely accepted method for piers and wharves of Naval facilities. When the displacement tonnage of the ship is known, the energy equation can be written as:

Equation 5-3

$$E_{\text{ship}} = \frac{1}{2}Wv^2/g$$

where

E_{ship} = Berthing energy of ship (ft-lbs)

W = Weight of the ship in pounds (displacement tonnage x 2,240)

g = Acceleration due to gravity (32.2 ft/second²)

v = Berthing velocity normal to the berth (ft/second)

However, there are several factors that modify the actual energy to be absorbed by the fender system. The expression can be written as

Equation 5-4

$$E_{\text{fender}} = C_b \times C_m \times E_{\text{ship}}$$

where:

E_{fender} = Energy to be absorbed by the fender system

C_b = Berthing coefficient = $C_e \times C_g \times C_d \times C_c$. Sometimes Eccentricity (C_e), geometric (C_g), deformation (C_d), and configuration (C_c) coefficients are combined into a single value called berthing coefficient.

C_m = Effective mass or virtual mass coefficient

Each of these coefficients is discussed separately below.

c. Eccentricity Coefficient (C_e). During the berthing maneuver, when the ship is not exactly parallel to the berthing line, not all the kinetic energy of the ship will be transmitted to the fenders. Due to the reaction from the fender, the ship will start to rotate around the contact point, thus dissipating part of its energy. Treating the ship as a rigid rod of negligible width in the analysis of the energy of impact on the fenders leads to the simple formula:

Equation 5-5

$$C_e = k^2 / (a^2 + k^2)$$

where

k = Radius of longitudinal gyration of the ship, ft.

a = Distance between the ship's center of gravity and the point of contact on the ship's side, projected onto the ship's longitudinal axis, ft.

Values of C_e typically are between 0.4 and 0.7. The values for C_e may be computed from Figure 5-2.

d. Geometric Coefficient (C_g). The geometric coefficient, C_g , depends upon the geometric configuration of the ship at the point of impact. It varies from 0.85 for an increasing convex curvature to 1.25 for concave curvature. Generally, 0.95 is used for the impact point at or beyond the quarter points of the ship, and 1.0 for broadside berthing in which contact is made along the straight side.

e. Deformation Coefficient (C_d). This accounts for the energy reduction effects due to local deformation of the ship's hull and deflection of the whole ship along its longitudinal axis. The energy absorbed by the ship

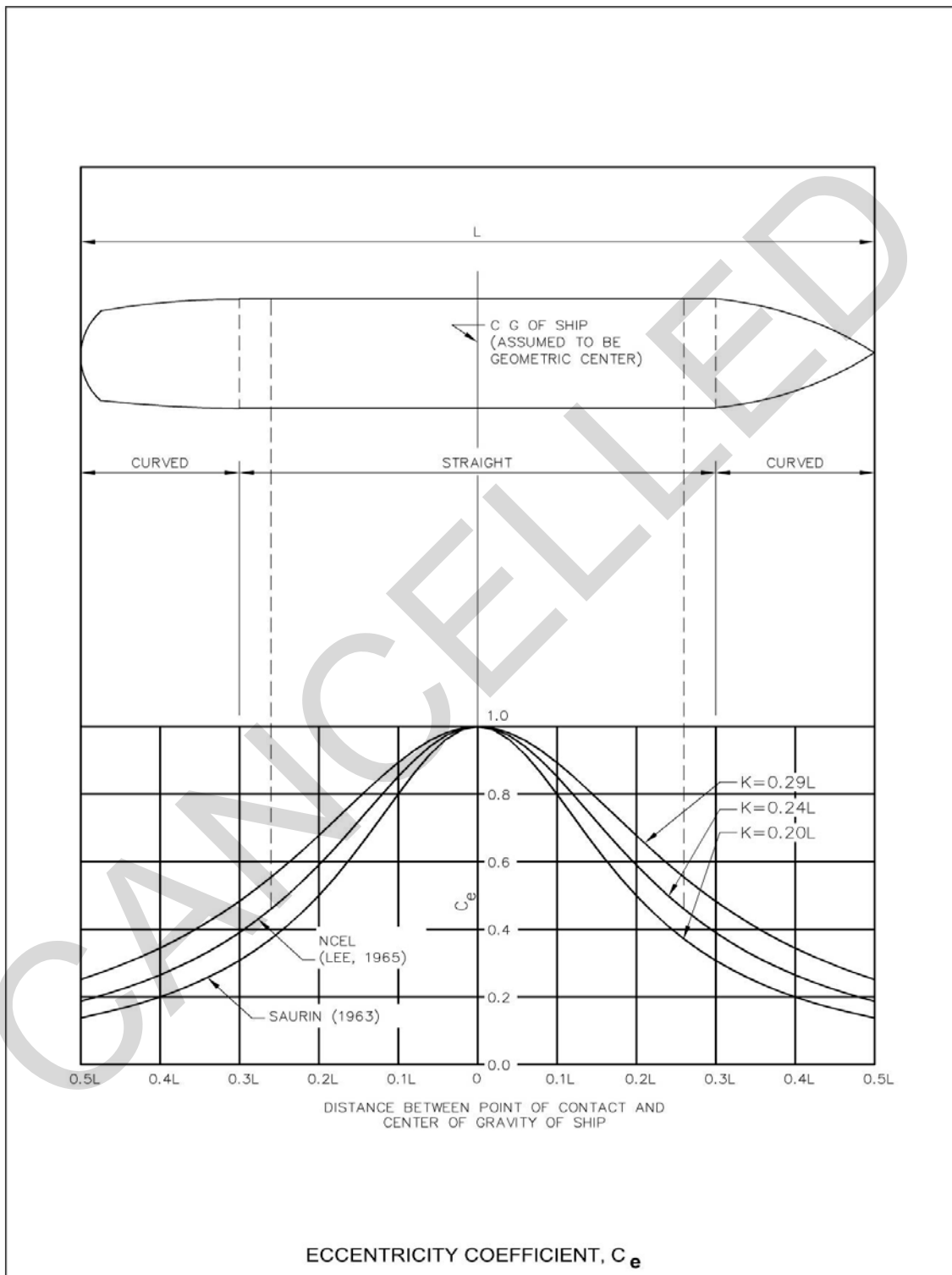
depends on the relative stiffness of the ship and the obstruction. The deformation coefficient varies from 0.9 for a non-resilient fender to nearly 1.0 for a flexible fender. For larger ships on energy-absorbing fender systems, little or no deformation of the ship takes place; therefore, a coefficient of 1.0 is recommended.

f. Configuration Coefficient (C_c). This factor has been introduced to take into account the difference between an open pier or wharf and a solid pier or wharf. In the first case, the movements of the water surrounding the berthing ship are not (or hardly) affected by the berth. In the second case, the water between the berthing ship and the structure is squeezed, which introduces a cushion effect that represents an extra force on the ship away from the berth and reduces the energy to be absorbed by the fender system. Therefore, a reduction factor has to take care of this effect. Experience has indicated that for a solid quaywall about one quarter of the energy of the berthing ship is absorbed by the water cushion; therefore, the following values for C_c appear to be justified:

- For open berth and corners of solid piers, $C_c = 1.0$.
- For solid piers with parallel approach, $C_c = 0.8$.
- For berths with different conditions, C_c might be chosen somewhere between these values.

g. Effective Mass or Virtual Mass Coefficient (C_m). When a ship approaches a dock, the berthing impact is induced not only by the mass of the moving ship, but also by the water mass moving along with the ship. The latter is generally called the "hydrodynamic" or "added" mass. In determining the kinetic energy of a berthing ship, the effective or virtual mass (a sum of ship mass and hydrodynamic mass) should be used. The hydrodynamic mass does not necessarily vary with the mass of the ship, but is closely related to the projected area of the ship at right angles to the direction of motion. Other factors, such as the form of ship, water depth, berthing velocity, and acceleration and deceleration of the ship, will have some effect on the hydrodynamic mass. \1\ Procedures for determining added mass are contained in TR-6074-OCN, *Added Mass for Berthing U.S. Navy Vessels*. /1/

Figure 5-2. Eccentricity Coefficient, C_e



h. v Berthing or Approach Velocity (v). It should be noted that the kinetic energy of the berthing ship is a function of the square of the normal component of its approach velocity. Thus, the kinetic energy, as well as the resultant force on the berthing structure, is sensitive to changes in approach velocity. By doubling the design value of the approach velocity, the ship's kinetic energy is quadrupled. Design values used for the approach velocity normal to the berth may vary from 0.25 to 1.50 fps (0.076 to 0.46 m/sec), depending on the size of the ship being docked and the tug assistance that is employed. Larger vessels with adequate tugboat assistance can generally berth gently and the lower design velocity may be used. Smaller vessels that self-dock may approach the wharf at considerably higher speeds and, accordingly, the higher design velocity should be used. The berthing velocity is also affected by the difficulty of the approach, maneuvering space for tugs (slip width), and location of the pier or wharf facility. Anticipate higher approach velocities when the berth is located in exposed waters where environmental loads cause difficulty in controlling the ship. Also, currents in tidal estuaries in protected waters can be of major concern. Approach velocity normal to the berth may be taken from Figures 5-3 and 5-4. Determining whether a facility is "exposed," "moderate," or "sheltered" depends on the environmental conditions at the site and is a matter for professional judgment by the designer. Most naval facilities in the United States are situated in protected waters and can be taken as "sheltered." Where high currents (0.3 fps (0.091 m/sec) or more) or strong winds (40 knots (20.4 m/s) or more) occur frequently, a "moderate" condition should be assumed. The "exposed" condition may be used when unusually severe currents and winds are present. However, local experience with ship berthing should control the selection.

Figure 5-3. Berthing Velocity for Small Ships (up to 20,000 tons)

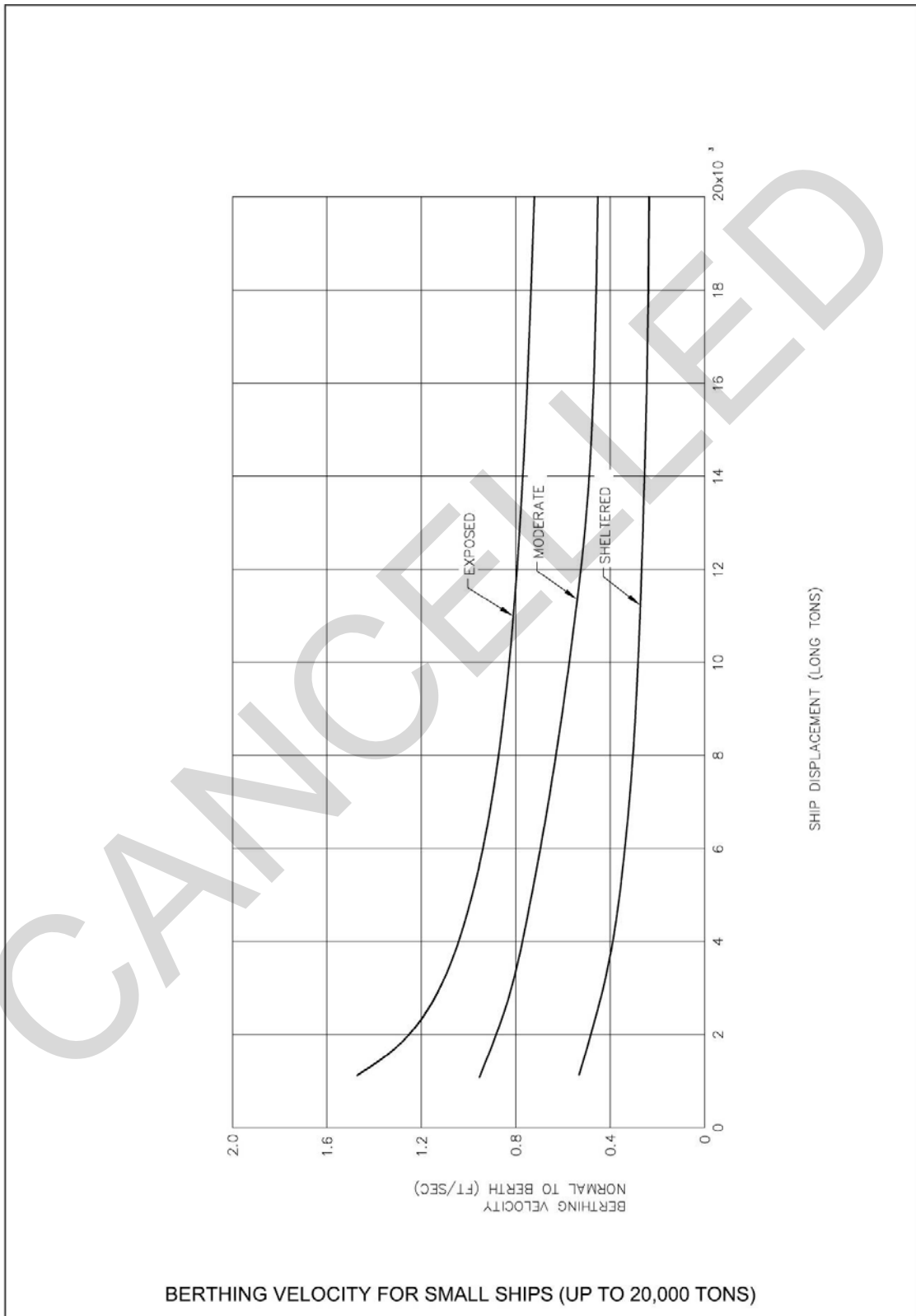
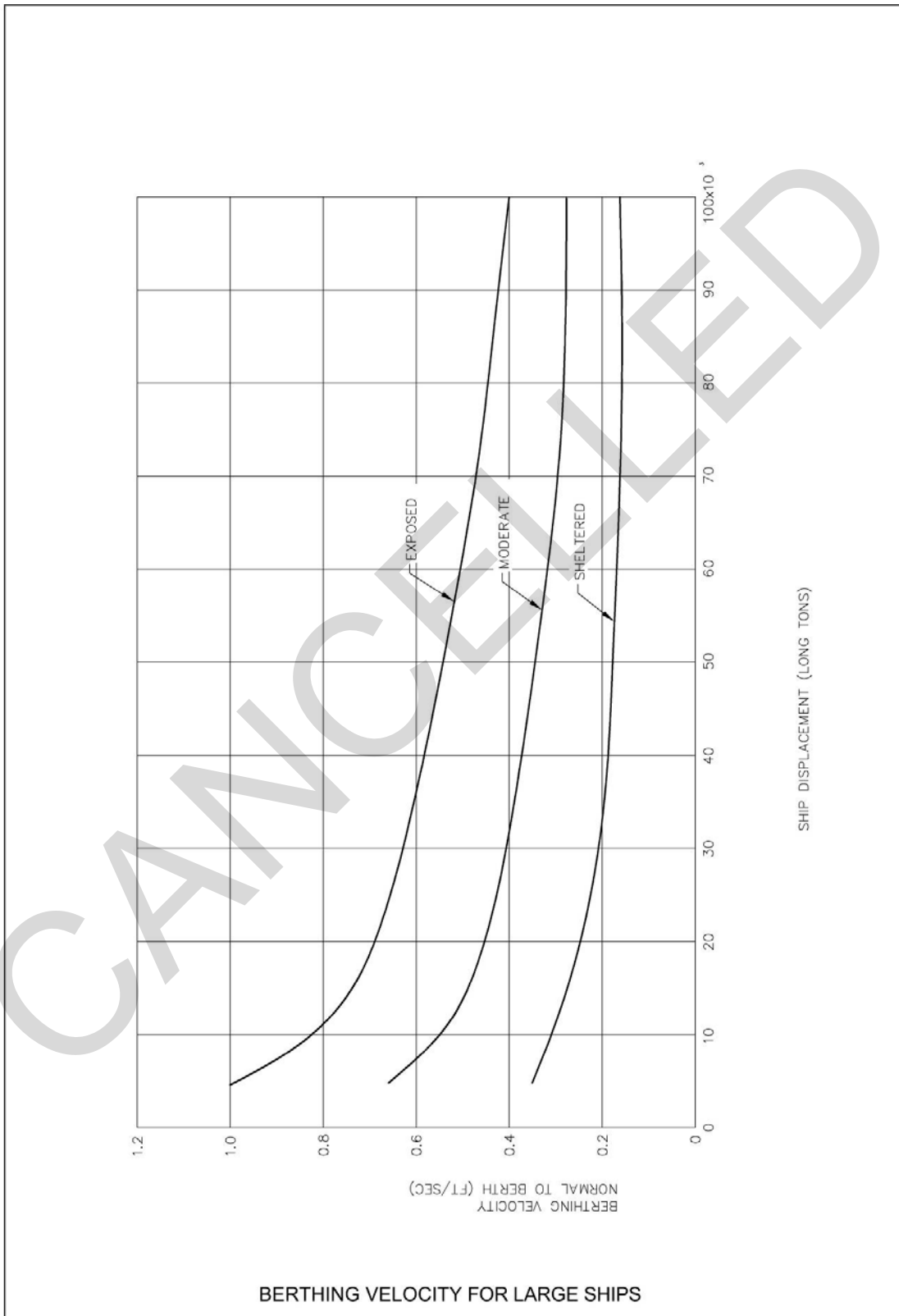


Figure 5-4. Berthing Velocity for Large Ships



\1\1/

- i. Berthing Energy for Submarines. \1\ Procedures for determining berthing energy for submarines are contained in TR-6064-OCN, *Berthing Guidelines for Submarines*. /1/

5-2.1.2 Berthing Models.

- a. Statistical Method. This method is based on actual measurements of the energy of the impact at existing berths. This method is closely related to the conditions of the site where the measurements were taken and is dependent on the fender layout and construction, e.g., distance between piles, and the loading condition of the ship.
- b. Scale Model. This method, which makes use of a small-scale model test of the berth to be designed in a well-equipped hydraulic laboratory or ship model basin, suffers from the scale and viscosity effects and requires experienced interpretation.
- c. AQWA. The Naval Facilities Engineering Service Center (NFESC-ECDT) typically uses the COTS AQWA software package to perform a dynamic analysis of berthing through six degrees of freedom in the time domain.
- d. Analytical Model. NFESC has developed an analytical model that can accurately predict ship berthing impact forces. The model employs a computational fluid mechanics approach, coupling a Reynolds-Averaged Navier-Stokes (RANS) numerical method with a six-degree-of-freedom motion program for time-domain simulation of ship and fender reactions. The model has been verified with data from small-scale and full-scale tests. Results from the new model for two ship classes yield added mass coefficients close to those calculated by the PIANC formula as long as the depth-to-draft ratio exceeds 1.2. When the underhull clearance becomes small, i.e. for depth-to-draft ratios less than 1.2, predicted added mass coefficients can exceed the PIANC values. Added mass values of 5.0 or higher are predicted for ships berthing against open piers (pile supported) equipped with soft fenders, such as pneumatic or foam-filled cushions. Consider using higher values for the added mass coefficient under these conditions.
- e. BeAN. The two previous rigorous analytical models can produce results of superior accuracy, however, they are not always required or always suitable for all cases of analysis. A software program for berthing analysis, BeAN (ref *Software Development for Berthing Analysis and*

Structural Loading on Waterfront Facilities), has been developed. BeAN is a simplified, desktop mathematical model that calculates time histories of fender forces, deflections, and vessel motions. The model examines open or closed type berthing facilities, various depths, eccentric or centric vessel impact, and nonlinear fender structures.

5-3 **TYPES OF FENDER SYSTEMS.**

5-3.1 **General.**

Fender systems absorb or dissipate the kinetic energy of the berthing ship by converting it into potential energy in the fender materials. This could be in the form of deflection of a fender pile, compression of a column of rubber, deformation of a foam-filled cylinder, torsion of a steel shaft, or pressuring of a pneumatic fender.

5-3.2 **Fender Piles.**

This is the most commonly used system in existing Navy piers and wharves. This system is stiff and lacks the capacity for large deflection which results in high reaction loads and frequent breakage of piling and hull damage. This system employs a series of closely spaced fender piles (5- to 10-ft spacing (1.5 to 3 m)) connected together by chocks and wales. A rubber fender unit is mounted between the wale and the berthing structure. A series of diagonal chains from the structure to the wale completes the system. Tight-fitting joints between chocks, wales, and pile head, with proper tension splices that provide compression and tension continuity along the face of berth must be provided. Ships may be berthed either directly against fender piles or by using additional fenders or camels between the ship and the fender piles. When camels are used, the fender piling must be sized to resist the resulting bending. In the working stress range, there is an approximate linear relationship between reaction force and deflection. When used with floating camels, which tend to cock between the ship and the piles, the ship's energy may become concentrated on just one or two piles. Hence, unless the floating camel is tightly secured to the piles (guided by piles), the system will not work well and frequent damage will occur. The pile-rubber system is not recommended for solid and other types of piers and wharves where full deflection of the piles within the working range will be inhibited. When this system is employed throughout the length of berth, the rubber fender units should be sized for direct berthing of ships (without the use of camels).

5-3.2.1 **Timber Fender Piles.**

Timber fender piles have historically been the system of choice. Although timber fender piles are still in use, environmental concerns coupled with advances in

other fender pile material, have led to a trend in replacement of this type of system.

5-3.2.2 **Steel Fender Piles.**

Steel HP sections, wide flange sections and pipes have been used for fender elements. These pile sections are typically epoxy coated and incorporate a cathodic protection system. Steel fender piles are typically limited to use with foam-filled or hydro-pneumatic fenders since they have a limited range of elastic deflection. The typical steel system is comprised of steel HP sections driven vertically and connected to a steel wale. The wale is attached to the supporting structure by a system of rubber fenders and chains. Steel fender systems have been successfully used. However, due to the additional costs of maintenance and the cathodic protection systems, their use has been somewhat limited when compared to other systems. Plastic coated steel pipe has been used for fender systems in circumstances where large deflections are not anticipated. (*Marine Fender Systems.*)

5-3.2.3 **Concrete Fender Piles.**

Concrete fender piles are the most prevalent system in use. Square prestressed concrete fender piles have been tested and proven to have high-energy absorption fendering capabilities and greater strain energy at collapse than either timber or steel fender piling. They are typically 18- to 24-in² (1161 to 1548 mm²) prestressed concrete and have served well as primary fender piles for berthing and mooring. Typically, energy-absorbing piles are 18 in² (1161 mm²) and reaction piles (used with foam filled fenders) are 24 in (1548 mm²) square. The fender piles are usually connected to a chock and wale system at the deck level and supported by rubber fender units at the bullrail. In the working stress range, there is a linear relationship between reaction force and deflection. Figure 5-5 shows a prestressed concrete fender pile installation. Additional guidance and design aids for concrete fender piles is contained in NCEL TM 53-89-03, Prestressed Concrete Fender Piling User Data Package and NCEL CR 89.005, Prestressed Concrete Fender Piles: Fender System Designs. A test program conducted for concrete fender piles is documented in NCEL R-927, Laterally Loaded Partially Prestressed Concrete Piles. Key findings were:

- partial prestressing to 600 psi (4136.9 kPa) was sufficient to close flexural cracks;
- 18 in² (1161 mm²) pile with 20 0.5 in (52 mm) diameter prestress strands in a rectangular configuration confined by No. 3 ties with a 3-in (76 mm) pitch performed best; and

- 65 ft (19.8 m) lengths can be expected to perform well under cyclic load with an ultimate energy capacity of 30 ft-kips (2 m/kN) and a post ultimate capacity of more than 60 ft-kips (4 m/kN.)

Figure 5-5 Foam-filled Fender System.

Foam-filled fender, concrete fender piles, steel frame and polyethylene rub strips.
(Marine Fender Systems, by T.E. Spencer, ASCE PORTS 2004).



5-3.2.4 Composite Fender Piles.

There are two primary types of composite fender piles. One type of composite pile is made of fiber reinforced plastic (FRP) in the form of a tube that can be filled with concrete for greater strength and stiffness. Figure 5-6 shows an FRP fender pile system. Because of a higher susceptibility to abrasion and impact damage, the thermoset FRP tube type pile should have rubberized abrasion strips installed at potential contact points with berthed vessels.

The second type of composite pile is made of thermoplastics (such as high-density polyethylene, HDPE) and reinforced with either steel or FRP strands. Figure 5-7 shows a plastic fender pile system. The reinforced thermoplastic type pile generally exhibit larger load-deflection properties compared to conventional wood, steel or concrete piles. To ensure uniform loading and avoid premature

failure of fender system components, these type piles should not be used in parallel or mixed with conventional type piles in the same system. Relevant work to date on composite fender piles includes TM-2158-SHR, *Study of Recycled Plastic Fender Piles*. Follow on work to this is contained in SP-2005-SHR, *Limited Flexural Tests of Plastic Composite Pile Configurations*, which includes flexural load tests to failure and cyclic tests to determine the stiffness (EI), load/deflection, linearity, hysteresis, energy absorption, degradation, and failure mode. Tests showed that composite piles absorb more energy than timber piles, but are not as stiff. This could pose a problem in the composite fender pile deflects too much. Polymer composite piles are presently at the acceptance phase of development and not yet in the large-scale use phase of development. Much has been happening in the way of codes and standards development for polymer composite piles over the last decade. The Navy is awaiting an ASTM document under Subcommittee D20.20 Plastic Products and in particular, finalization of draft standard X-20-51c, *Standard Specification for Polymeric Piles*. From this point the Navy can develop a more comprehensive UFGS covering polymer composite piles as well as more definitive design criteria. To date, composite piles have been used primarily for corner protection, as secondary fender piles, and as primary fender piles for small craft facilities.

Figure 5-6 Fiberglass Fender Pile System.

Fiberglass fender pile, plastic pipe wear surface, top support and cap. (*Marine Fender Systems*).



Figure 5-7 Plastic Fender Pile System.

Plastic piles, plastic block and cylindrical rubber fender. A plastic camel is floating in the water. (*Marine Fender Systems*).



5-3.3 **Fenders.**

5-3.3.1 **General.**

The Navy \1\ has developed UFGS 35 59 13.16 Marine Fenders as the governing specification for selection of marine fenders. /1/

5-3.3.2 **Directly Mounted Fender Units.**

In this system, individual fender units like the end-loaded, rubber shear, or buckling type, are attached directly to the pier or wharf face. For narrow tidal

range in solid piers and wharves, and for narrow vessel size range, this system may be cost-effective for direct berthing of surface ships. Although this system is very popular in commercial piers and wharves throughout the world, it may not be suitable for some Naval facilities. This system is subject to damage from snagging on ship protrusions at levels of 8 to 10 ft (2.4 to 3.5 m) above the water line and from vertical loads resulting from snags on rails and protrusions during falling tides or from lateral loads due to snags on protrusion during longitudinal movement of the ship.

- a. End-Loaded Rubber Fenders. These work by elastic compression of hollow rubber cylinder elements with small length-to-diameter ratios. As shown in Figure 5-8(A), steel fender panels with special rubbing material facing are usually required to minimize wear. The reaction force is an exponential function of the deflection. These fenders are usually attached directly to the pier or wharf structure in the form of a "cell fender."
- b. Rubber Shear Fenders. The potential energy in these units is stored as elastic shear deformation of the rubber. Usually, a solid rubber block is vulcanized between two metal plates and the force is transferred through a fender frame or panel, as shown in Figure 5-9. These fenders are highly sensitive to proper manufacturing and installation as they depend on the bond between steel plates and the rubber. The force-deflection relationship is essentially linear.
- c. Buckling Fenders. These fenders operate on the buckling column principle, in which a molded column of rubber is loaded axially until it buckles laterally. The end-loaded cylinder fenders described earlier are actually a buckling fender in principle. Most buckling fenders are not well suited for direct contact with a moving ship and hence are used with an abrasion or protector panel, as shown in Figure 5-10. The reaction force is linear up to a level when the pure compression behavior changes to the buckling mode. Hence, initially a relatively high reaction is built up with a small deflection, which then stays constant through the rest of the deflection range. Because buckling fenders are intended to buckle in a predetermined direction, any lateral deflection can significantly reduce their effectiveness. When lateral loads in either direction (parallel to length of berth or up/down) are anticipated, a cell-type fender is preferred. These fenders are becoming increasingly popular for berthing very large ships as they can absorb very high energy with a constant reaction force.

5-3.3.3 Side-Loaded Rubber Fenders.

These are hollow rubber units available in trapezoidal, circular, square, or D-shapes that, when loaded at their side, deform by trying to flatten out. See Figure 5-8(B). The potential energy is stored by a combination of compression and bending of the rubber elements. The reaction force is an exponential

function of the deflection and the performance curve is quite similar for all the shapes. Fenders having a curved rather than flat external surface increase in stiffness more gradually as the area of contact increases during deformation. All these fenders experience a sharp and rapid increase in stiffness when the amount of deflection completely collapses the open bore, regardless of their external contour.

Side-loaded rubber fenders will not absorb large amounts of energy and generally are not used alone. They are usually provided at the top of fender piles between the wale and berthing structure. A series of diagonal chains from the structure to the wale completes the system. When used with tight fitting joints between chocks, wales, and pile head, and when proper tension splices that provide compression and tension continuity along the face of the berth are used, the system has worked very well in both naval and commercial facilities. Ships may be berthed either directly or a floating camel may be used. When camels are used, size the fender piling to resist the resulting bending.

Both timber and steel piles have been used successfully, with timber being the more common. Prestressed concrete piles are also a viable alternative, exhibiting high-energy absorption capabilities. This type of system provides good berthing flexibility. Ships of different sizes, tug boats, submarines, and barges can be accommodated without any modification. However, when used with floating camels, which tend to cock between the ship and the piles, the ships energy may become concentrated on just one or two piles. Hence, unless the floating camel is tightly secured to the piles (guided by piles), the system may be subject to increased damage. The pile-rubber system is not recommended for solid and other types of piers and wharves where full deflection of the piles within the working range will be prevented. When this system is employed throughout the length of berth, size the rubber fender units for direct berthing of ships (without the use of camels).

5-3.3.4 **Floating Fender Units.**

This system consists of pneumatic or foam-filled fender units and a backing system. As the fender units can be positioned to float with the tide, several surface ship types can be handled. Design the backing system to work with the fender unit for the full tidal range. Because the floating units are usually rather large, they provide a good standoff. The berthing structure may be designed with the backing system at different points along the length of berth and the fender units moved around as berthing plans change. When clustered piles or sheet piles are used for the backing system, additional energy can be absorbed by the piles and their support systems at the deck level.

Figure 5-8. Side-loaded and End-loaded Rubber Fenders

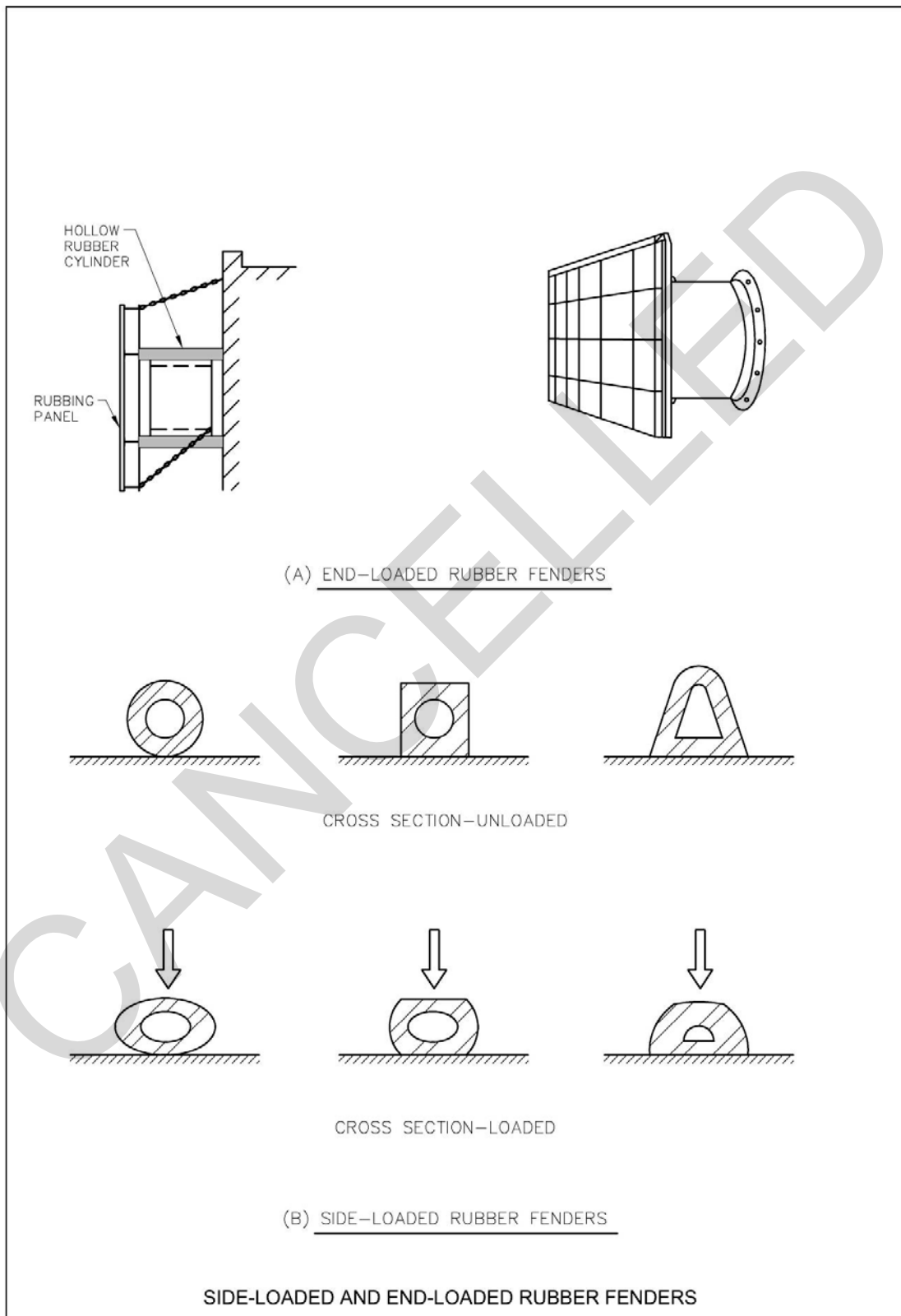


Figure 5-9. Shear Fender

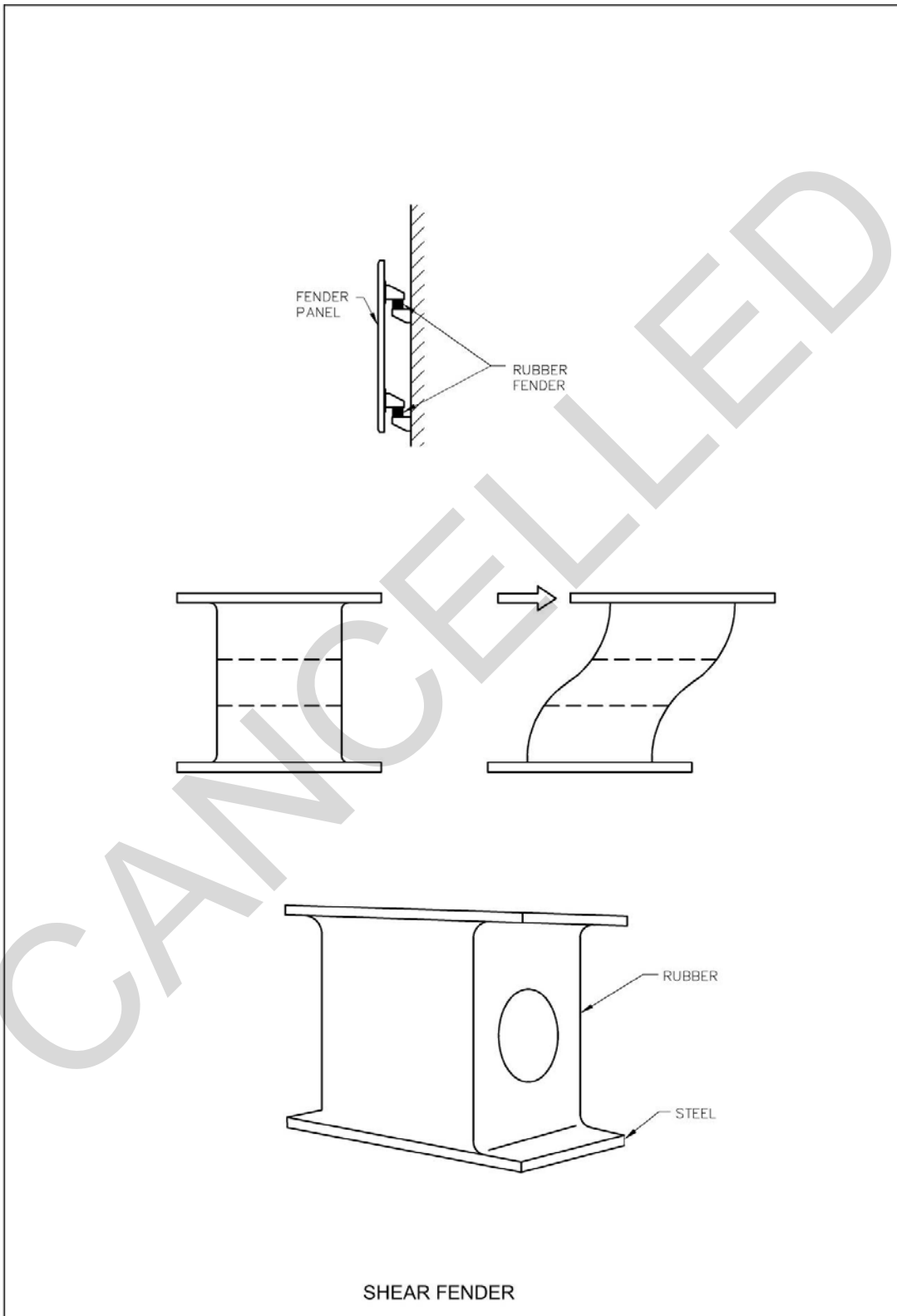
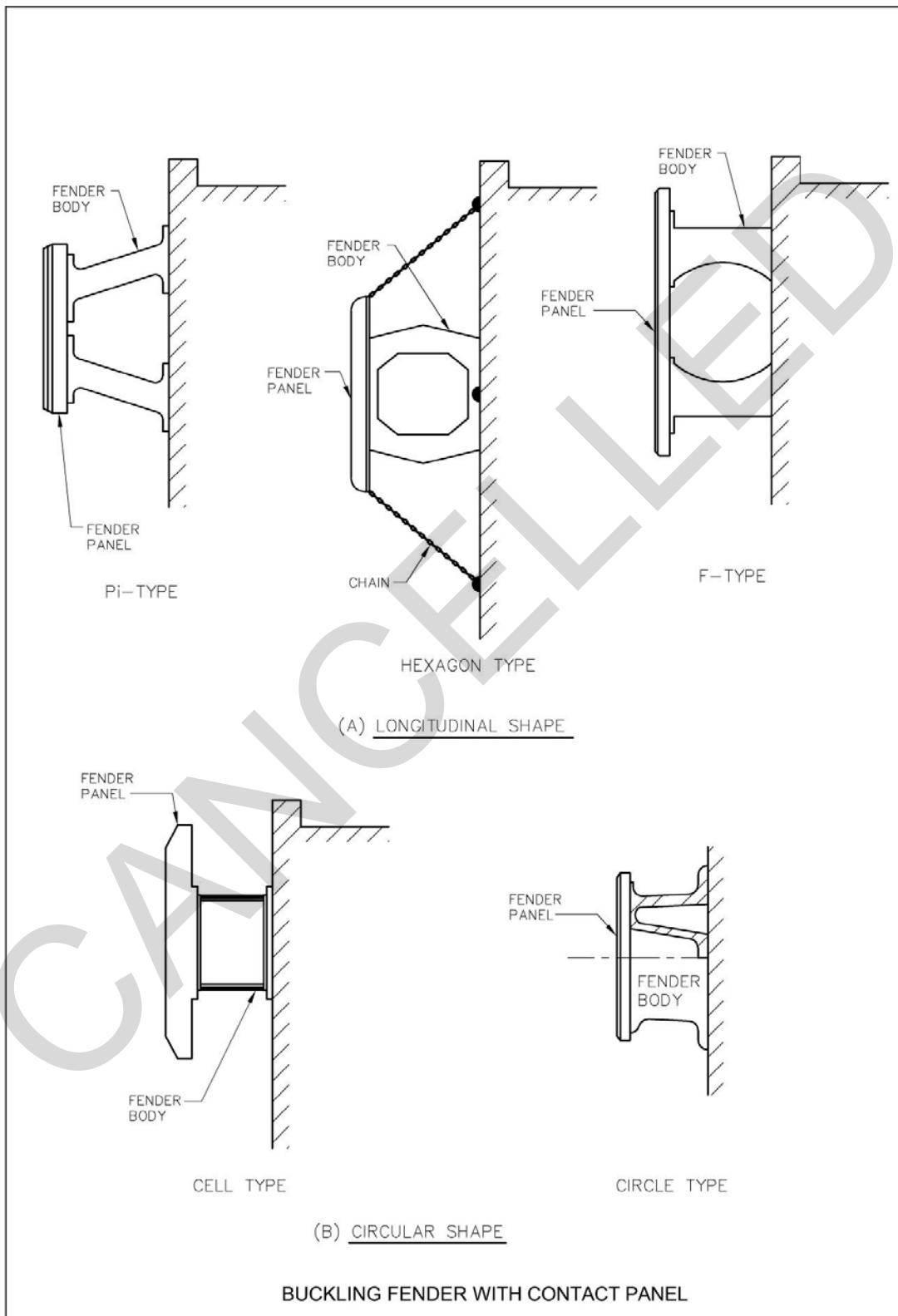


Figure 5-10. Buckling Fender with Contact Panel



a. **Pneumatic / Hydro-Pneumatic Fenders.** The potential energy in these fenders is stored by the elastic compression of a confined volume of air. By varying the internal pressure of air, the energy-absorption characteristic can be changed. To prevent the air pressure from increasing to a "blowout" level, pneumatic fenders are provided with a relief valve or deflection limiter within the body of the unit. The shell construction for these fenders is similar to an automobile tire with several laminations to provide the high tensile strength required. The surface pressure of these fenders is uniform, resulting in uniform hull pressure. Reaction force is an exponential function of deflection. The basic types of pneumatic fenders in common use are discussed below:

- **Air Block and Air Cushion.** The shells for these are chemically bonded and mechanically coupled to a rigid mounting plate that can be attached to a solid face of the berthing structure. See Figures 5-11(C) and 5-11(D).
- **Floating.** The floating type is usually cylindrical in shape with hemispherical ends and is attached to the structure by chains. It floats on the water and rises and falls with the tide. The unit requires a backing system to distribute the load. As shown in Figures 5-11(A) and 5-11(E), large floating pneumatic types are sometimes covered with a net of used automobile tires and cylindrical rubber sleeves to protect the fender from puncture and abrasion. The tire net and chains also form the means for rigging and attaching the fender to the pier.
- **Tire.** This type consists of a large-diameter tire mounted on an axle and backed by rollers. The unit can be mounted with its axis of rotation vertical or horizontal. This type is particularly suited for pronounced corners of the structure where ships may have approach difficulties. See Figure 5-11(B).
- **Hydro-Pneumatic.** This type of fender has been developed for use with submarines and consists of a vertically mounted cylindrical pneumatic fender partially filled with water and backed by a closely spaced group of fender piles. A ballast weight is added to adjust the degree of submergence of the fender to coordinate the vertical center of the fender with the horizontal center of the submarine hull; see Figure 5-12. The fender unit floats with the tide and therefore stays in the same relative position with the vessel. For 11-ft (3.3 m) diameter by 32 to 35-ft (9.7 to 10.7 m) high submarine hydro-pneumatic fenders, a vertical and horizontal skin strength of 4,600 lbs/in (82.1 kg/mm) is required. Reduce the hanging counterweight as much as practically feasible. For the fender size mentioned, a

hanging counterweight around 13,900 lbs (6305 kg) is recommended.

b. **Foam-Filled Fenders.** These are constructed of resilient, closed-cell foam surrounded by an elastomeric skin. Provide additional protection against abrasion by thicker elastomeric coatings or an external tire net, similar to the floating pneumatic type. The fender requires a backing system to distribute the load. Netless fenders cost more due to the need for thicker skins and coatings. However, the greater hull marking of the tire net and occasional maintenance need suggest that netless fenders may be preferred. The unit can either be utilized as a floating fender, moving up and down with the tide and held in place with chains or can be suspended from the pier/backing system. The cellular structure of the foam filling reacts like hundreds of millions of individual pneumatic fenders in deforming and absorbing the energy. The foam contains the air within its cellular structure and tends to compress upon itself rather than bulge peripherally. The foam-filled fenders have a high-energy absorption with comparatively small reaction force. Surface pressure of the fender is not quite uniform when it is compressed, so the hull pressure over the contact area is not quite uniform. Where rough concrete surfaces of the backing surface or prestressed concrete piles is a concern, use UHMW pads or strips to protect the skin of the foam filled fender. See Figure 5-5 for a typical foam-filled fender installation.

5-3.3.5 **Combination System.**

Any of the above-mentioned fender systems may be combined in the same berth to make up the deficiency of another. A berth may have either the floating fender units or directly mounted fenders at discrete points, with the in-between spaces filled up by the pile/rubber system designed to work with separators. Floating fenders and directly mounted fenders may be used alternately along solid or double deck types of piers and wharves.

5-3.3.6 **Monopile System.**

This fendering system is based on the use of a floating ring-shaped resilient fender unit that rides up and down on a large steel pile driven to the seabed. Special low-friction bearing pads are usually installed on the inner surface of the hull of the ring fender so that the fender unit can rotate and slide freely on the pile. This unique ability makes the monopile system very suitable for corner protection of piers and wharves and entrances to a narrow slip. The units can also work well as breasting and turning dolphins. Energy is absorbed both by the steel monopile in flexure and by the ring-shaped fender unit. This system is illustrated in Figure 5-13.

Figure 5-11. Pneumatic Fenders

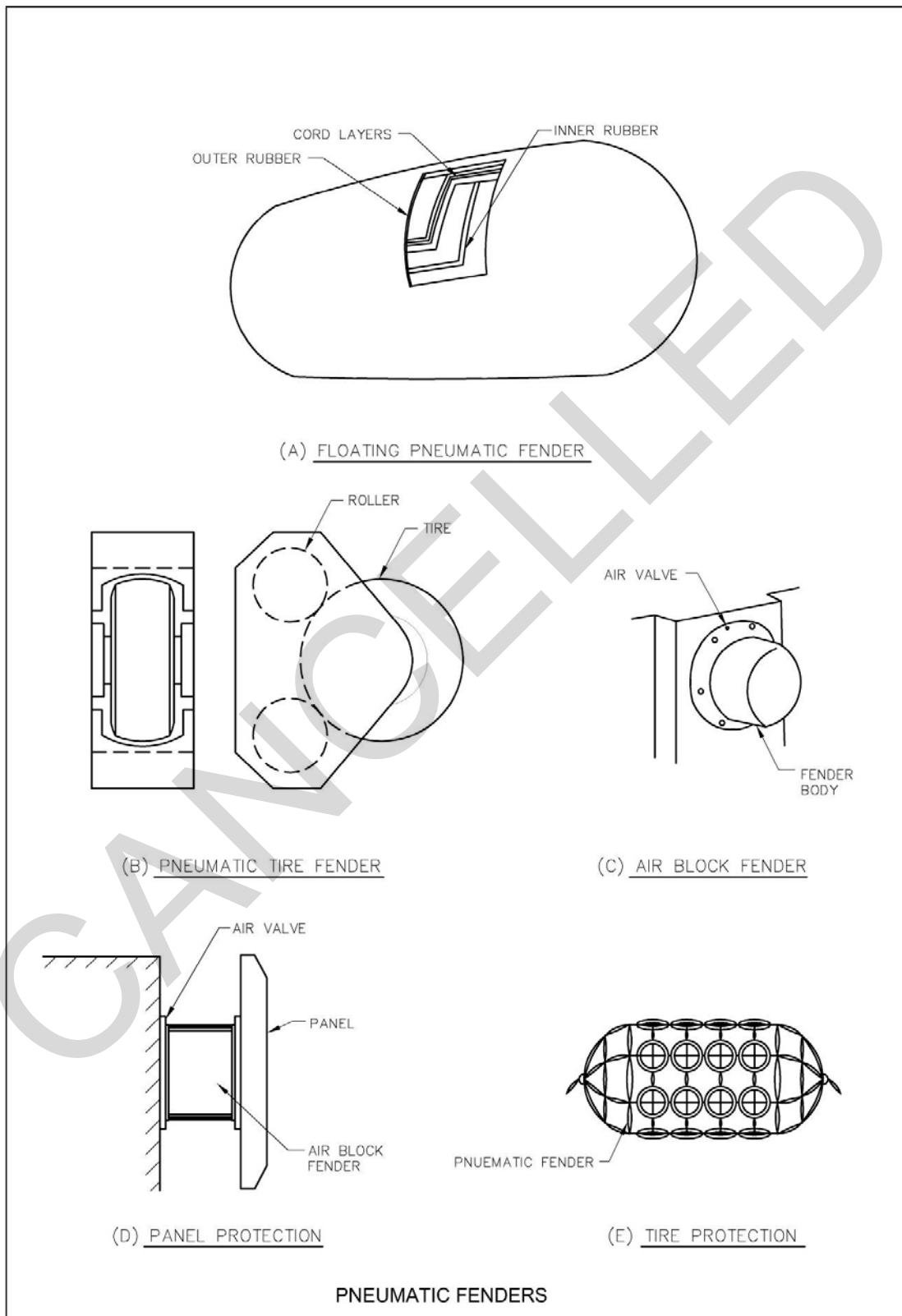


Figure 5-12 Hydro-pneumatic Fender.

Hydro-pneumatic fender and counter weight being installed (*Marine Fender Systems*).



5-4 **SELECTION AND DESIGN OF FENDER SYSTEMS.**

5-4.1 **General.**

The major factors influencing the selection of the best fender system for a particular situation include the following:

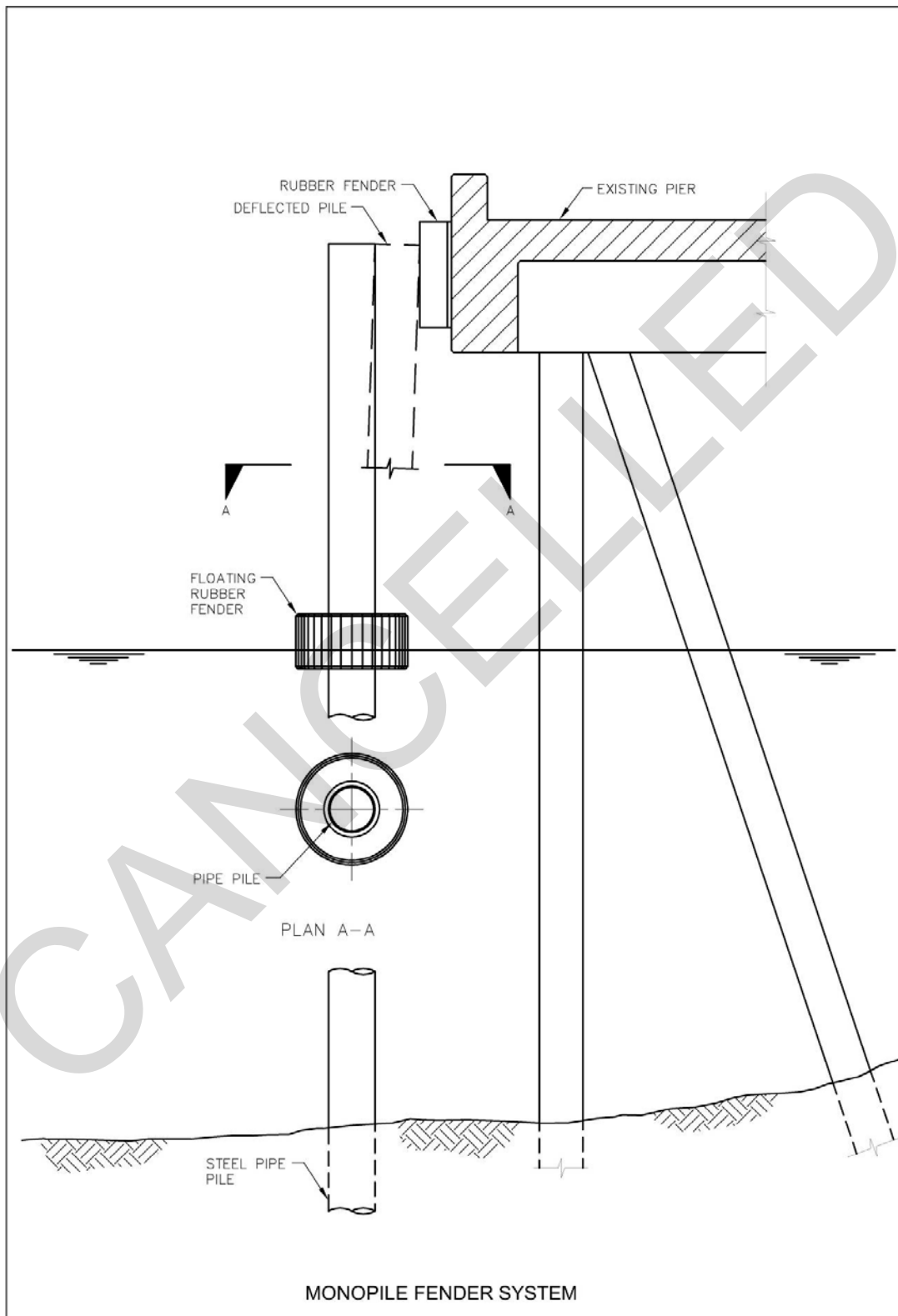
5-4.1.1 **Energy-Absorption Requirements.**

The fender system must have sufficient energy-absorption capacity to absorb the kinetic energy of the berthing vessel.

5-4.1.2 **Reaction Force.**

This is the force that is exerted on the ship's hull and on the berthing structure during impact. The reaction force has a significant effect on the design of the berthing structure.

Figure 5-13. Monopile Fender System



5-4.1.3 **Hull Pressure.**

This is the pressure exerted on the ship's hull by the fender unit and is derived by dividing the reaction force by the fender area in contact with the ship. Hull pressure must be limited to levels that will not cause permanent damage to the berthing ship.

5-4.1.4 **Deflection.**

This is the distance, perpendicular to the line of the berth that the face of the fender system moves in absorbing the ship's kinetic energy. The magnitude of the deflection allowable will be controlled by other protrusions from the berthing face and the ship.

5-4.1.5 **Reaction/Deflection Relationship.**

The nature of the reaction deflection relationship determines the relative stiffness of the fender system.

5-4.1.6 **Long-Term Contact.**

This includes the changes in environmental conditions (i.e., wind, current, waves, and tide) during loading and unloading at the berth. The fender system should not "roll up," tear, abrade, or be susceptible to other forms of damage when subject to long-term contact.

5-4.1.7 **Coefficient of Friction between the Face of the Fender System and the Ship's Hull.**

This determines the resultant shear force when the ship is berthing with longitudinal and/or rolling motion and may have a significant detrimental effect on the energy-absorption performance of the fender system. The magnitude of the shear force also may have a significant effect on the cost of the berthing structure.

5-4.1.8 **Degree of Exposures.**

Where the berth is exposed to severe wind, current, and/or wave action, the fender selection may be governed by the design mooring conditions rather than berthing conditions.

5-4.1.9 **Life-Cycle Costs.**

Evaluate capital costs for both the fender system and the structure; also evaluate costs for operation, maintenance, and repair.

5-4.1.10 **Berthing Practice.**

The capability of the crews responsible for berthing the ship will have an effect on the energy-absorption requirement of the fender system. The berthing velocity and angle of approach are affected by the local berthing practice.

5-4.1.11 **Maintenance.**

Where maintenance is expected to be infrequent, a simple, possibly less efficient, fender system may be preferable to a system requiring a higher degree of maintenance.

5-4.1.12 **Local Experience.**

Consider fender types already used locally because their performance under actual conditions is known. Also, there may be an advantage in having interchangeability of spares, particularly if the number of new fenders required is small.

5-4.1.13 **Frequency of Berthing Operations.**

A high frequency of berthings normally justifies greater capital expenditures for the fender system.

5-4.1.14 **Range of Ship Sizes Expected to Use the Berth.**

While the energy-absorption capacity of the fender system may be selected for the largest ship expected to use the berth, the fender system must be suitable for the full range of ships that the berth will accommodate. The effect of hull pressure and fender stiffness on the smaller vessels may have a significant influence on the selection and arrangement of the fenders.

5-4.1.15 **Shape of Ship's Hull in Contact with the Fender System.**

Where vessels with unusual hull configurations or protrusions are expected to use the berth or where the berth must accommodate barges, pay special attention to the selection and arrangement of the fender system.

5-4.1.16 **Range of Water Level to be Accommodated.**

The fender system must be suitable during the full range of water levels that may occur at the berth. The design must consider both the largest and smallest vessels, in both the loaded and light conditions, at high and low water levels. Where extreme water level variations occur, consider using floating fender systems.

5-4.1.17 **Camels.**

The size, type, and number of camels used in berthing operations will seriously influence selection of the fender system.

5-4.2 **Fender System Behavior.**

The fender systems having the most promise for new installations can be classified into three groups in terms of their behavior:

5-4.2.1 **Flexible Pile Types.**

The flexible pile types, or various fender piles discussed earlier, have basically a linear force-deflection relationship. Cantilevered piles or "monopile" systems likewise have a basically linear force-deflection relationship.

5-4.2.2 **Buckling Column Types.**

The buckling column types behave linearly up to a point where the rubber starts to buckle and behave nonlinearly from there on. Because the buckling type fender systems have the highest energy-absorption capacity for a given deflection and reaction, they are in very wide use in commercial piers and wharves. Due to the nature of the reaction/deflection/energy-absorption relationship of these types of fenders, a very high reaction (close to maximum) occurs during virtually every berthing operation and the berthing structure must be designed with this fact in mind. This fact also causes the fender to be relatively rigid when smaller ships use a berth designed for larger ones.

Many buckling-type fenders cause rather high contact pressures against the ship's hull and consequently require a panel to distribute and thus reduce the pressure. Size and locate the panel to ensure proper contact with both the largest and smallest vessels to use the berth. Another characteristic of these fenders to consider is their lowered performance when impacted by a vessel approaching at an angle to the berth or with a velocity component in the longitudinal direction. The reduction in energy-absorption capacity may be as much as 20 percent when the approach angle is 5 deg. to 10 deg., with additional reduction when combined with shear strain.

5-4.2.3 **Pneumatic, Foam-Filled and Side-Loaded Rubber Fenders.**

The pneumatic, foam-filled, and side-loaded rubber fenders exhibit very similar behavior with the reaction force building up more than proportional to increasing deflection. The floating pneumatic and foam-filled fenders have a similar appearance and similar reaction/deflection relationship. Compared to the buckling types, these fenders require greater deflection for a given reaction and energy-absorption capacity. The pneumatic and foam-filled fenders present a very large surface to the ship's hull and consequently have low hull contact pressures. This eliminates the need for a panel between the ship and the fender.

With the pneumatic and foam-filled types of fenders, the maximum reactions will normally occur only a very few times during the life of the facility, permitting the use of higher stress levels in the supporting structure. However, they require a rather large, solid face on the supporting structure, which may increase its costs. The main difference between pneumatic and foam-filled fenders is that the former will lose its strength completely when punctured by ship protrusions and that the latter may lose a significant part of its energy-absorption capacity under repeated heavy loadings.

These behaviors are illustrated in Figure 5-14.

5-4.3 Evaluation of Fender Systems.

5-4.3.1 Equal Energy and Reaction.

Figure 5-14(A) illustrates the reaction-deflection characteristics of the three types of fender systems. The area under each of the reaction/deflection curves represents the energy absorbed by that type of fender. Each of the curves in the figure represents fender systems with equal rated reactions and equal energy-absorption capability. It is evident from the figure that, while the fenders of the various types illustrated provide equal energy absorption at equal rated reactions, the energy-absorption capacity is achieved through different deflections, with the buckling type deflecting the least.

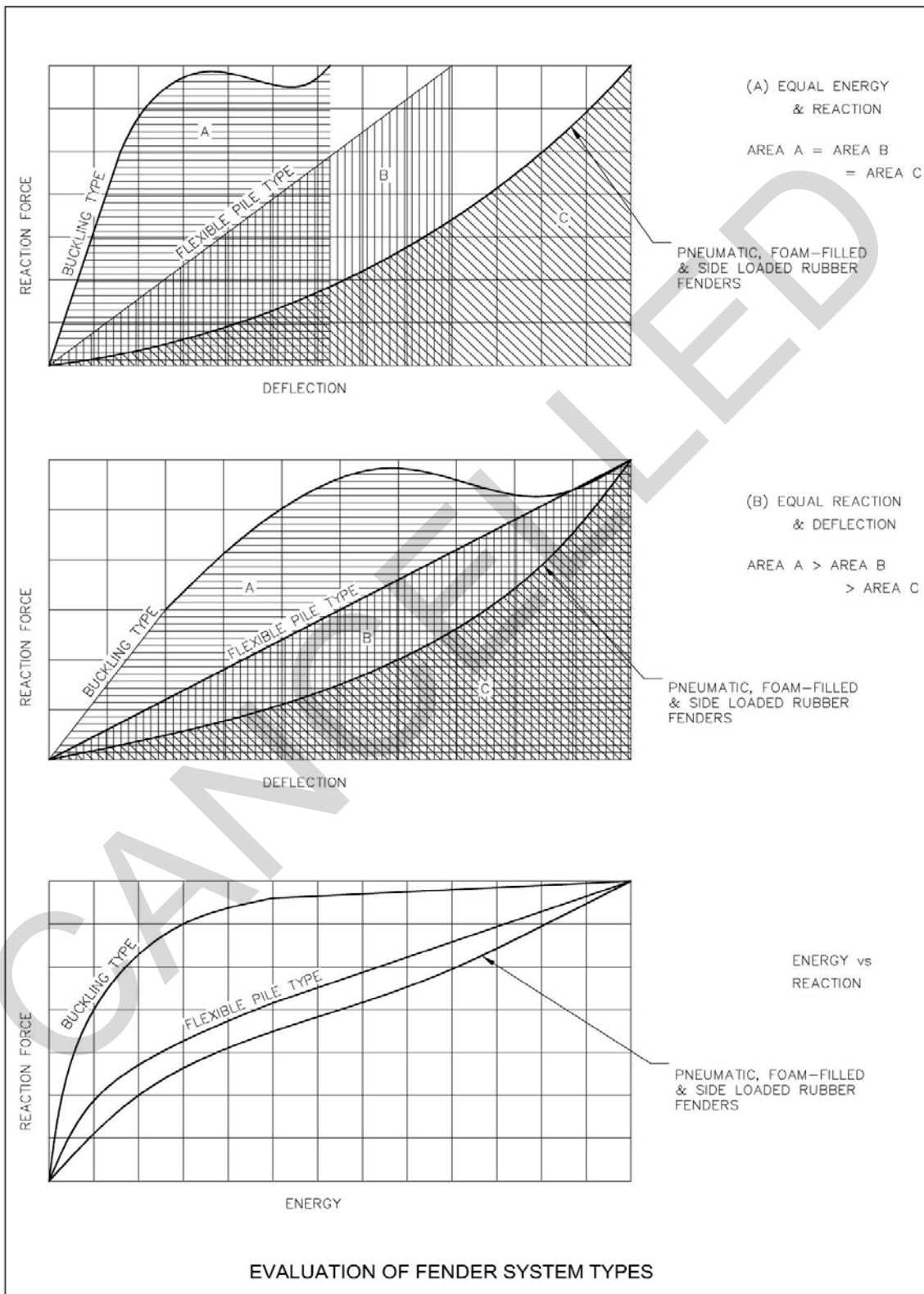
5-4.3.2 Equal Reaction and Deflection.

A comparison of the various types of fenders may alternatively be considered on the basis of equal rated reaction and equal deflection, as illustrated in Figure 5-14(B). This situation often occurs when new fender units are installed in conjunction with, and compatible with, an existing fender system. It may also occur when a replacement fender system is installed in an existing facility with cargo transfer equipment of limited reach. It is evident from the figure that the buckling type fenders have considerably more energy-absorption capacity for the same reaction and deflection than the other types.

5-4.3.3 Reaction versus Energy Absorbed.

Comparing the various types of fender systems from the point of view of the reaction force that is developed for a given energy-absorption capacity, as illustrated in Figure 5-14(C), it is evident that the pneumatic, foam-filled, and side-loaded rubber type fender units are the "softest." They have greater energy-absorption capacity at reaction levels less than their maximum rated reaction. This characteristic makes these fenders particularly attractive at berths that must accommodate a wide range of vessel sizes because the fenders will deflect significantly even when subjected to relatively small berthing impacts.

Figure 5-14. Evaluation of Fender System Types



5-4.3.4 **Accidental Overloads.**

Also to be considered in the selection of a fender system is the consequences of an accidental overload of the system. The buckling and side-loaded rubber fenders "bottom out" if compressed beyond their maximum rated deflection, with resultant high reaction forces and the potential for severe damage to the berthing vessel and the support structure. The reaction of flexible pile fender systems will continue to increase at a uniform rate when overloaded until the yield stress of the pile material is reached, at which point continued deflection will occur as the material yields with no appreciable increase in reaction. Foam-filled fenders, when compressed beyond their maximum rated deflection, will exhibit a steadily increasing reaction and will incur permanent deformation and consequent loss of future energy-absorption capacity. The pneumatic fenders are normally fitted with relief valves so that when overloaded they continue to absorb energy with no increase in reaction beyond that which corresponds to the relief valve setting and no permanent damage to the fender unit.

5-4.4 **Fender System Design.**

5-4.4.1 **Ship Contact.**

While the ideal berthing process would attempt to engage as many fender units as possible, in reality, at the time of impact, the ship will be at a slight angle to the berth and contact will be made over a small length. Design discrete fender units such as the buckling column type or the floating type, for one unit providing the full energy with a minimum of two units installed per berth. For the continuous system using flexible piles and fenders, the length of contact will be a function of the ship's hull radius at the level where contact is made, the flexibility and spacing of fender units, and the stiffness of the chock and wale assembly in the horizontal plane. The problem is analogous to a beam on an elastic foundation. In the absence of more rigorous analysis, the following assumptions for contact length may be made:

- 20 ft (6.1 m) for cruisers, destroyers, and frigates.
- 40 ft (12.2 m) for battleships, amphibious warfare ships, and auxiliary ships.

When berthing is made with camels, assume only one camel to be in contact at the time of impact, with a minimum of two camels installed per berth. Where the camels are guided by fender piles, assume all the piles to be effective in sharing the energy. When free-floating camels are used, not all the piles backing the separator will be effective. Local experience should dictate and a more conservative assumption should be made.

5-4.4.2 **Allowable Hull Pressure.**

When the ship's energy is resisted through foam-filled or pneumatic fenders, the resulting force is concentrated in a small area of the ship's hull. In such cases, the allowable pressure on the ship's hull becomes a critical design issue. Most fast combatants have a thin hull plating with a low allowable hull pressure. For more specific information on the ships being berthed, consult NAVSEA. See TR-6015-OCN, *Foam Filled Fender Design to Prevent Hull Damage*, and note that values in Table 7 are based on yielding of the hull plating and include a 1.5 safety factor. Consequently, when checking for an accidental condition, the allowable value may be increased by up to 50 percent.

5-4.4.3 Allowable Stresses.

Because ship berthing is a short-term impact type of loading, the following increases over previously published values are permitted. The fender system may be designed as a Class B structure.

- a. Timber. For operating condition, the allowable stress in flexure (tension and compression) may be taken as 0.67 X modulus of rupture or the published allowable values increased by a factor of 2.0, whichever is less. For the accidental condition, the stress-strain curve may be assumed to be linear up to 0.9 X modulus of rupture, which should be taken as the limit.
- b. Steel. For operating condition, the allowable stress in flexure (tension and compression) may be taken as 0.8 X yield stress. For the accidental condition, full yield stress may be used. However, the sections used should satisfy compactness requirements or the allowable stress reduced proportionately. Members should be sufficiently braced for development of the yield strength.
- c. Concrete. Design reinforced and prestressed concrete members not intended for energy absorption with a load factor of 1.7 over forces developed due to operating condition; they will be satisfactory for the accidental condition. Do not allow further prestressed members to develop tensile stresses in excess of $12 f'_c$ (f'_c = 28-day compressive strength) in the precompressed zone. Prestressed concrete members specifically designed for energy absorption will have a maximum allowable working energy (E_{wc}) equal to 0.67 x the applied load (P) x the deflection at the point of the applied load. Three criteria must be satisfied to determine the maximum allowable working energy (E_{wc}) in the pile section for a given length:
 - Maximum concrete compressive strain must be equal to or less than 0.0021 in/in (00021 mm/mm.)

- Maximum stress in the prestressing steel at working energy must be equal to or less than 210,000 psi (1 447 898.9 kPa.)
- The working energy (E_{wc}) must be no more than 2/3 of the nominal pile energy (E_{nc}). This provides a minimum factor of safety of 1.5 in case of overload of the pile.

5-4.4.4 Coefficient of Friction.

As the ship is berthed against the fender system, there will be force components developed in the longitudinal and vertical directions also. As the coefficient of friction between rubber and steel is very high, special fender front panels have been developed with reduced friction coefficient. Ultra high molecular weight (UHMW) plastic rubbing strips have been successfully used in front of timber piles. The following friction coefficients may be used in the design of fender systems.

- Timber to steel..... 0.4 to 0.6
- Urethane to steel..... 0.4 to 0.6
- Steel to steel..... 0.25
- Rubber to steel..... 0.6 to 0.7
- UHMW to steel..... 0.1 to 0.2

5-4.4.5 Temperature Effects.

Fender piles, backing members, etc., are not affected by temperature fluctuations and can be expected to perform normally. However, in colder temperatures, rubber fender units become stiffer and their performance will be affected significantly. Hence, evaluate the energy-absorbing capability of the rubber unit and the fender system as a whole based on the lowest operating temperature expected. Carefully design and detail UHMW rubbing strips which have a significantly higher rate of expansion than steel or concrete to operate effectively.

5-4.5 Corner Protection.

Provide all corners of piers and wharves and entrances to slips with fender piles, rubbing strips, and rubber fenders for accidental contact with ships or routine contact with tugs. Use any of the different types of fender piles mentioned. See Figure 5-15 for typical details.

5-4.6 Support Chains.

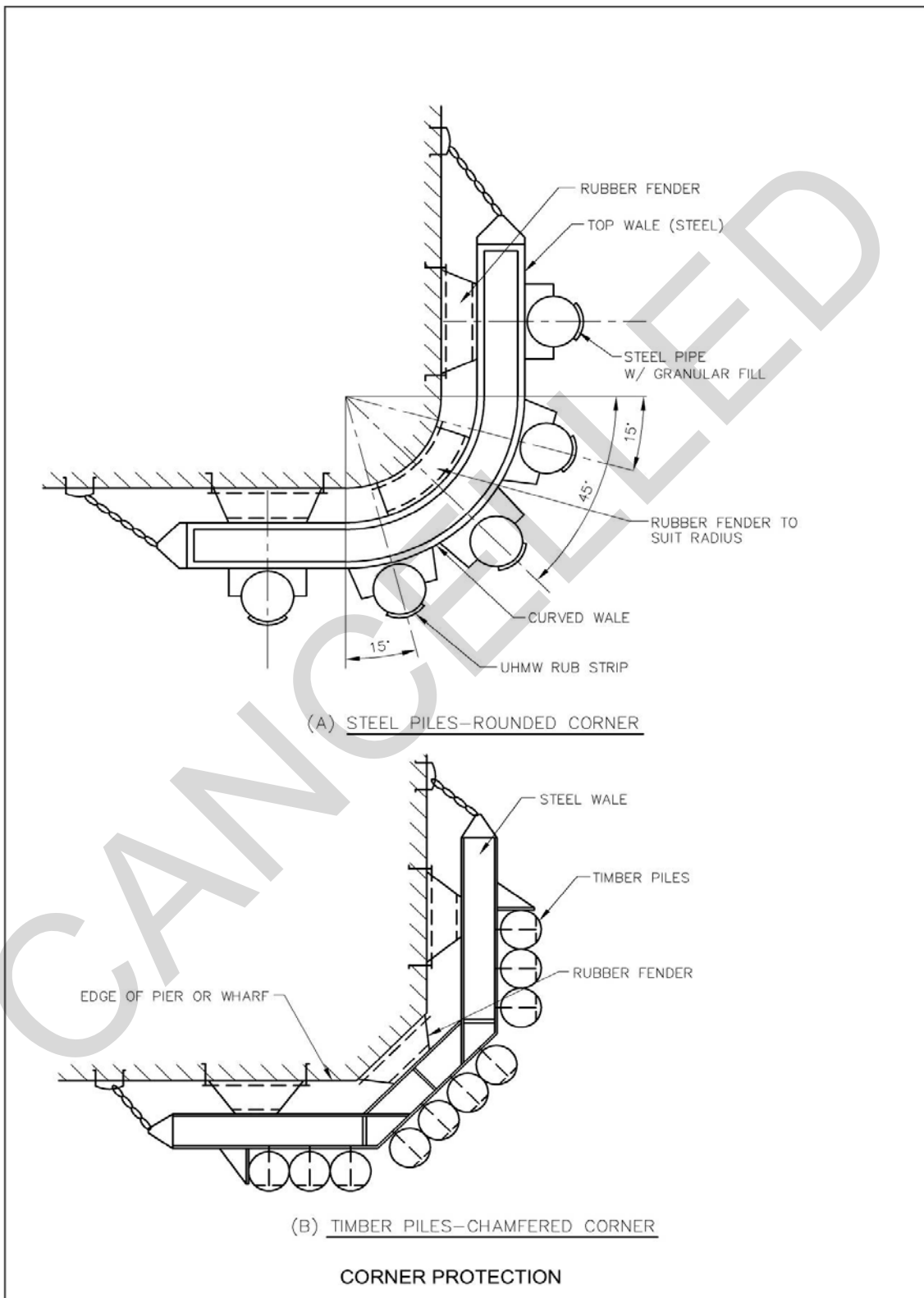
Chains are commonly used in fender systems when a tension member is needed. Chains are used in continuous fender systems and large buckling and cell type units to resist the sudden energy released. For pneumatic and foam-filled resilient fender units, the chain is used to suspend the units. Chain smaller than 3/8 in (9.5 mm) is not recommended. For better corrosion resistance, zinc coating is preferred. A common weldless high-test chain is usually more cost-effective than the stud link variety.

5-4.7 **Chocks and Wales.**

For selection and design of chocks and wales refer to SP-2045-SHR, *Proposed Design Criteria for Chocks and Wales*.

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Figure 5-15. Corner Protection



CHAPTER 6 CAMELS AND SEPARATORS

6-1 FUNCTION AND APPLICATION.

Camels are devices used between the ship and the pier or wharf structure. Camels are a NAVFAC responsibility. Separators are devices used between adjacent multiple berthed (nested) ships to provide a "standoff" or separation. Separators are a NAVSEA responsibility. As mentioned in the previous section, design of fender piles or other backing system is required to provide the structural interface between the camel and the pier/wharf structure. Camels and separators are used at Navy piers and wharves for the following reasons:

6-1.1 Hull Maintenance.

During active berthing, the ship's crew typically performs cleaning, painting, light hull repairs, and other routine maintenance activities on the ship. These activities are best performed when the ship is kept off the structure at discrete points.

6-1.2 Overhangs and projections.

Aircraft carriers that have large overhangs at the flight deck level, and several other ship types having bulges and projections at the side, require camels to prevent damage to the ship at these projections. Other protrusions include air masker bands, soft sonar domes, and stabilizer fins.

6-1.3 Special Hull Treatments.

Some ships are equipped with special hull treatments that can get damaged through constant rubbing against the structure. Camels and separators with rub strips can minimize the contact area and control the damage.

6-1.4 Submarine Berthing.

Navy submarines are typically berthed using camels. The submarines may be moored to the camels or moored directly to the berthing structure. Submarines require the camels to prevent damage to diving planes, screws, fairings, and the special hull treatments.

6-1.5 Multiple Berthing (Nesting).

Separators are required between ships that have to be berthed abreast for ship-to-ship transfer operations or for lack of berthing space at a naval station.

6-1.6 Fender Protection.

When the existing fender system can suffer damage due to motions of moored ships, a camel can be useful in reducing the damage as long as it is properly placed and the ship is properly moored.

6-2 **CAMELS.**

6-2.1 **Log Camels.**

These are large-diameter turned timber logs (24- to 36-in (610 to 914 mm) diameter 40 to 50 ft (12.2 to 15.2 m) long,) held in the desired position from the deck by nylon ropes or chains. They are usually allowed to float with the tide. The longer length is preferred as they can distribute the load to a greater number of piles. Multiple log camels are made from several smaller diameter logs held together by wire rope at ends and at center. They are not as efficient as the single log camels. Plastic coated steel pipes have also been used successfully as camels. The pipe core is generally filled with foam to ensure positive flotation. Log camels fabricated from recycled plastics and composite materials are available. Sometimes a series of used tires may be fitted through the log to provide some energy absorption. Log camels do not provide much of a separation. When a wider separation is needed, other types of camels are more appropriate.

6-2.2 **Timber Camels.**

These consist of several large timbers connected together by struts and cross braces to form a large crib. Additional flotation units may be inserted between the timbers for a higher freeboard. Wear causes bolt heads to become exposed and thus cause damage to hulls.

6-2.3 **Steel Pontoon Camels.**

These are made of cubical or cylindrical steel pontoons connected by structural framing. The pontoons should preferably be filled with foam to reduce the risk of losing flotation by accidental puncturing of the units.

6-2.4 **Deep-Draft Camels.**

For submarine berthing where a good portion of the body is below the waterline, all the above camels are inadequate, as the camel will ride up on the submarine during berthing. Hence, deep-draft camels have been developed. They have limited energy absorption and a narrow working platform. These camels work well when mooring against a tender ship and for multiple berthing. When used against an open pier or wharf, these camels will require solid backing elements (below waterline) from the fender system.

6-2.5 **Hydro-Pneumatic Fenders.**

Although discussed previously under fenders, in section 5.0, this type of fender has been used as a camel for attack submarines at a number of locations.

6-2.6 **Composite Camels.**

NFESC has developed a composite camel for use in berthing of submarines; see Figure 6-1. The camels are manufactured from composite materials intended to provide an extended service life over steel construction. The camels were developed and funded under a NAVFAC RDT&E effort and have been successfully used at SUBASE New London since mid 2000. \1\ Subsequently, a NAVFAC standard design has been developed and can be obtained at: http://www.wbdg.org/ccb/browse_cat.php?c=233. /1/

6-3 **Loads.**

The camel loads are computed from berthing and mooring analysis of the ship, camel, fender, and structure system resisting the lateral loads. All the ship's berthing reaction loads as well as current and wind loads are transmitted through the camels to the pier or wharf structure. Assume all horizontal loads to be acting uniformly along the length. Design deck elements of large camels for 50-psf (2394.0 Pa) vertical live load. Check the camel assembly for fabricated camels for lifting stresses. Where the pick-up points and rigging configurations are critical to control lifting stresses in the camels, provide clearly marked pick-up points or pad-eyes. For complex lifting requirements, provide lifting diagrams on the design drawings.

Figure 6-1. Composite Camel



6-4 **GEOMETRY.**

The shape and size of fabricated camels are governed by the ship's geometry at waterline.

6-4.1 **Ship's Lines.**

For large vessels such as CVs or CVNs, design camels for berthing a single class of ship. Shape the bearing face between camel and vessel to approximate the lines of the ship at waterline. Because hull lines vary with conditions of draft and trim, generally only a rough match is possible. Therefore, provide the outboard camel bearing face with rubber fenders or other means to produce some flexibility in the bearing face, thus compensating for minor hull line variations. Where hull line variations are large, adapters or telescoping devices may be required. Except for straight-sided ships, usually a single line bearing between separators and ships is provided.

6-4.2 **Length and Width.**

Provide adequate length of camels in order to keep the contact pressure between camel and hull and between camel and pier fenders within allowable limits. This is particularly important where compressible fender faces are used

that transfer reaction pressure directly to the hull plate versus the frames of the vessel. The length should not be less than the distance between three frames of the ship, three fenders or fender piles on the pier, or 30 ft (9.1 m,) whichever is greatest. Minimum camel width is determined by the ship's roll characteristics and freeboard, the presence of any overhanging projections on a ship and vertical obstructions on the dock such as gantry cranes or light poles.

6-4.3 **Depth.**

Provide adequate depth for submarine camels and separators to maintain contact with ship and pier/wharf in the full tidal range.

6-5 **STABILITY.**

There is usually some eccentricity between the horizontal load applied on the ship-side and the horizontal reaction provided on the dock-side. This is due to tilting of the camels (from imperfect flotation, buoyancy tank taking on water, etc.) and tendency of the camel to ride up and down with the vessel due to tidal fluctuations. The camel should have sufficient width, depth, and weight to provide roll stability for counteracting the effect of the load eccentricity and should have means of adjusting for variations in tilt and trim.

6-6 **LOCATION.**

For fine-lined ships, camels should generally be placed within quarter points of the ship to give strength and to bear on a reasonably straight portion of the hull. For straight-sided ships, camels may be located beyond the quarter points. Provide at least two camels for each class of ships. Camels should not be placed so as to bear directly against structural piles.

6-7 **MISCELLANEOUS CONSIDERATIONS.**

6-7.1 **Protection.**

Consider outfitting steel separators with a suitable protective coating or a cathodic protection system, depending on relative costs.

6-7.2 **Buoyancy Tanks.**

Buoyancy tanks should be compartmented or foam filled. Provide drainage plugs used for pressure testing the buoyancy tanks. Where pontoon camels are assembled in a single line, they should be ballasted for stability through plugged openings provided for this purpose. Consider the buoyancy of framing members and the weight of paint, if any, in the buoyancy and stability computations. Where buoyancy tanks are not foam filled to allow filling with ballast water or weights to adjust trim and freeboard of the camel, provide easily accessible

fill/pumpout and vent connections. These connections can be used to pump out excess water that leaks into the tanks.

6-7.3 **Abrasion.**

Camel fenders rubbing against a hull remove its paint. Exposed surfaces are subject to corrosive action, especially at the waterline. For these reasons, it is desirable to have camel fenders rub against hulls above the waterline where the hull can be repainted if necessary.

6-8 **CAMEL DESIGNS.**

6-8.1 **Submarine Camels.**

\1\ Drawings/information on the camels described below may be obtained from the NAVFAC NAVFAC LANT Code CI1 office. /1/

6-8.1.1 **Submarine Mooring Camel** (NAVFAC Dwg 1404664-1404666).

This tapered camel is framed from steel pipe with timber members on the front of the camel to support the rubber fender elements. This camel is intended for use with the SSN-688 class submarine.

6-8.1.2 **Submarine Mooring Camel** (NAVFAC Dwg 1404943-1404947).

This is a non-tapered version of the camel described above.

6-8.1.3 **Attack Submarine Camel** (NAVFAC Dwg 1404667-1404670).

This camel is intended to replace the tapered camel described above. This camel is trapezoidal in shape and is framed from steel pipe. This camel is intended for use with both the SSN-688 and SSN-21 class submarines.

6-8.1.4 **Attack Submarine Camel** (NAVFAC Dwg 10400031-10400034).

This camel reflects recent revisions made to the attack submarine camel described above.

6-8.1.5 **Trident Submarine Camels.**

Specifically designed camels using guide piles along the specific wharves are used for trident submarine homeports at both Kings Bay, Georgia and Bangor, Washington.

6-8.1.6 **Hydro-Pneumatic Fenders.**

These fenders are serving as camels and are used at a number of submarine ports throughout the Navy.

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6-8.1.7 **Composite Camels.** (NAVFAC Dwg 14019607-14019615)

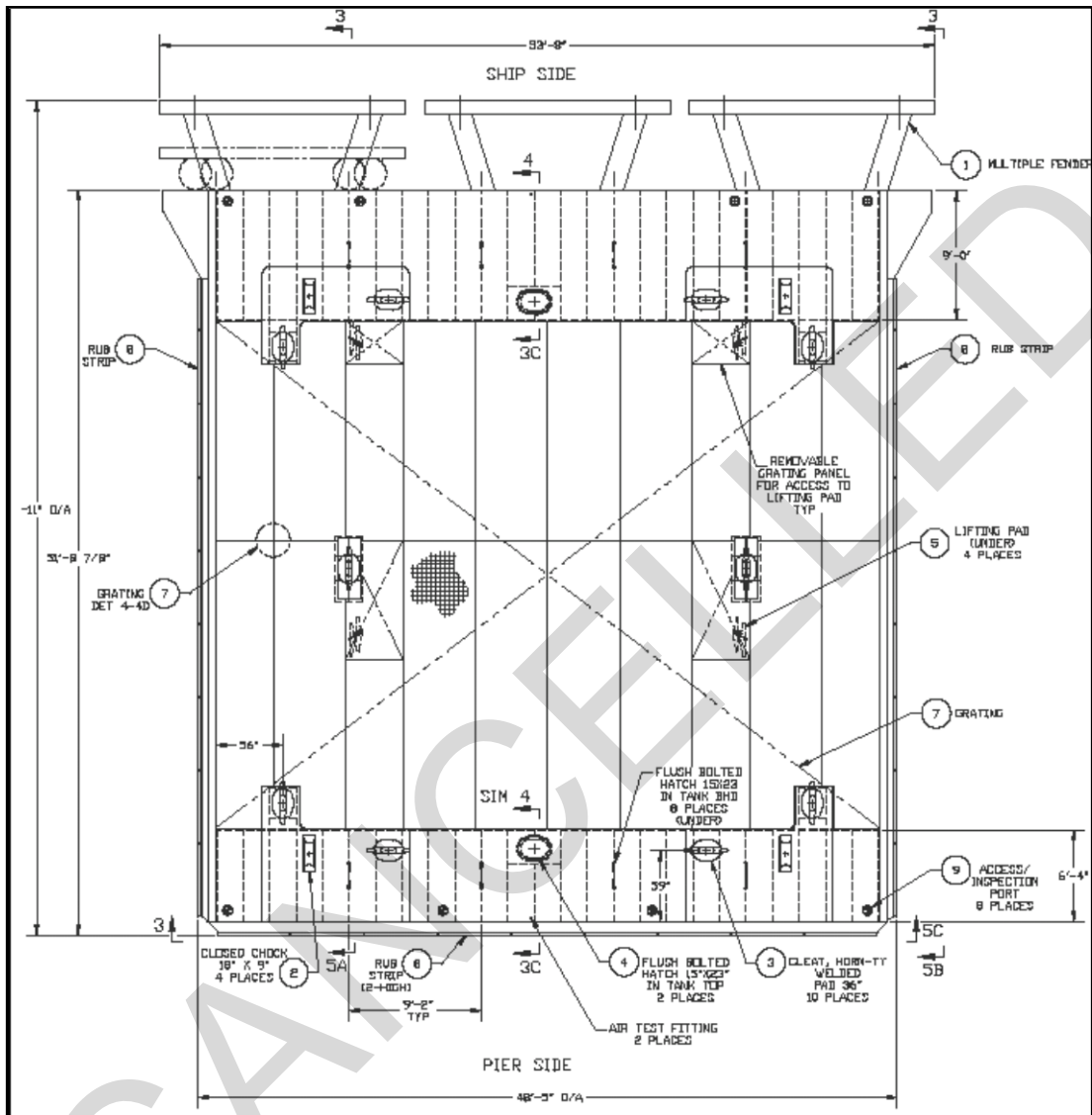
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6-8.2 **Aircraft Carrier Camels.**

Currently, aircraft carrier camels designed specifically for CVN-68 class aircraft carriers are available through an indefinite quantity contract (N00189-00-D-0254). This five-year contract \1\ expired /1/ in September 2005. Camel design is proprietary. To date, seven sets of camels have been ordered: 4 for Naval Station Norfolk, 2 for Naval Station San Diego, and 1 for Naval Station Mayport. On 2 September 04 an exercise was conducted in berthing CVN-65 alongside Pier 6 South at Naval Station Norfolk. This was to learn more about CVN berthing at a double deck pier. One significant finding was the need to increase the width of the aircraft camel by approximately 5 ft (1.5 m) to give additional standoff. Figure 6-2 shows a CVN camel in plain view.

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Figure 6-2. Aircraft Carrier Camel



The following pertinent information is provided for the CVN camels:

- Construction – steel floating frame pontoon
- Loads - 1500 kip (6672.3 kN) lateral and 500 kip (2224.1 kN) longitudinal reaction force transmitted to the camel fender system along the length of the camel. Values were based on maximum wind and current forces associated with heavy weather conditions (95 mph (42.5 m/s) wind and 1 knot (0.51 m/s) current) and breasting reaction associated with CVN berthing assuming a maximum approach velocity of 0.5 ft/sec (0.15 m/sec).

- Suitable for placement along the flat side of the hull approximately between frames 110 and 190 with an allowable hull pressure of 30 psi (206.8 kPa.)
- Working surface designed for 100 psf (4788.0 Pa)
- Size: 48'-5" (14.7 m) wide with standoff of 57'-11" (17.7 m) (undeflected fender)
- Weight: 95.4 long tons
- Light draft: 3.66' (1.1 m); Live load draft: 4.34' (10.4 m)
- Light freeboard: 3.3' (1 m); Live load freeboard: 2.4' (0.73 m)

6-9 **SEPARATORS.**

As mentioned previously, separators are a NAVSEA responsibility. Design for a universal submarine-to-submarine type separator is found on NAVSEA Dwg 6983485. A useful reference from NAVSEA is NSTM 018, Chapter 611, *Fenders and Separators*.

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CHAPTER 7 ACCESS

7-1 GENERAL.

Several access structures are used in piers and wharves for moving personnel and cargo, and accommodating selected utility lines. They have unique design requirements. Some are of standard design while others are designed and constructed specifically to go with the facility. The access facilities covered by this manual are landing float, brow or gangway, brow platform, walkway or catwalk, and ramp. Utility booms are discussed in UFC 4-150-02. Where there is a potential need for access by a physically handicapped person, meet the applicable requirements of the *Americans with Disabilities Act Accessibility Guidelines* and the *Uniform Federal Accessibility Standards*, and when they differ, the one with the greatest accessibility requirement will govern.

7-2 SAFETY.

Safety on piers and in pier design is an important consideration. Consider operational uses and where possible provide safety precautions, protections and warnings to minimize the potential hazards. Double deck piers require additional safety considerations. Potential uses and needs for pier deck space are unlimited and each must be evaluated based on the local requirements. It is essential that safety and operators be involved in the pier design, so potential uses can be identified, categorized and policy determined. In particular high-voltage electrical, fall hazards, trip hazards, and access to industrial or mechanical areas are issues that require additional consideration. In light of this, a study was conducted entitled, *Lower Deck Pier Safety Study*. Numerous activities were examined in detail and a matrix developed specifying essential use activities as well as prohibited activities. Although this study was somewhat site specific for Naval Station Norfolk, it should be consulted for details on safety solutions and recommendations. For example, the study provides useful information such as details on all signage required and detailed plan views of both upper and lower decks for the double deck piers at Naval Station Norfolk which show:

- Utility locations
- Activity areas
- Striping
- Transit paths
- Vehicle turn locations
- Curb, fencing, guardrail, handrail, lighting, life ring, fall protection and signage locations

7-3 **LANDING FLOAT.**

When piers and wharves need to be accessed from the waterside by small craft such as patrol boats (which cannot berth directly), a landing float and a brow are required.

7-3.1 **Materials.**

Flotation units may consist of foams of polystyrene and polyurethane, fiberglass-reinforced polyester resin shells with or without foam cores, metal pontoons, metal pipes, metal drums, and hollow concrete sections. Timber logs, the earliest form of flotation unit and the cheapest, have a tendency to become waterlogged and their use is not recommended. Decks of floats are variously made out of wood planks, plywood, plywood and fiberglass-resin coatings, concrete, and nonskid metal surfaces. Framework for floats is generally of preservative-treated timber, although steel and aluminum are often used. All ferrous metal hardware should be galvanized or otherwise protected from corrosion.

7-3.2 **Mooring Systems.**

Anchor floats to prevent movement by wind, current, waves and impact from the ships. Anchorage may consist of individual vertical (guide) piles, frames of batter and vertical piles, and cables or chains. When piles are used to anchor small floats, guides are furnished to secure the float to the anchor pile. Commonly used guides are rigidly braced metal hoops of pipes, rollers, or traveler irons. Chains and flat bar guides should not be used as they cause the float to hang up on the piles. See Figure 7-1 for details. This system works well for shallow waters with a large tidal range. In deeper water, the pile head may have to be supported by the structure or pile driven deeper. Anchorage may also be obtained from a cable or chain system attached to the ocean bottom or to the fixed pier or wharf structure.

7-3.3 **Live Loads.**

Design stages for landing personnel only for a uniform live load of 50 lbs/ft² (244 kg/m²) or a concentrated live load of 500 lbs (226.8 kg) placed at any point on the deck surface. The float should not tilt more than 6 deg. from the horizontal when applying the concentrated live load of 500 lbs (226.8 kg.)

7-3.4 **Freeboard.**

Floating stages for small craft usually ride with the deck from 15 to 20 in (381 to 508 mm) above the water surface under dead load. Live loads usually lower the float about 8 to 10 in (203 to 254 mm).

7-3.5 **Fendering.**

Provide fenders on all floating stages. For small craft berthing, fenders may consist of soft, flexible rubbing strips (rubber tires, sections of hose).

7-3.6 **Fittings.**

Provide a minimum of three cleats (5,000-lb. (2268 kg) capacity) for securing small craft.

7-3.7 **Finish.**

Provide the deck with a nonskid surface. Where wheels or rollers from a brow will be resting on the float, provide guide channels or a skid plate to prevent damage to the float.

7-3.8 **Reinforced Plastic Landing Float.**

The float shown in Figure 7-2 is constructed of a planking material, referred to as "rovon planks," formed by wrapping glass roving, spirally, around rigid polyurethane foam cores. For extra strength, several wrappings may be applied. The float is 60 ft (18.3 m) long, 14 ft (4.3 m) wide, and 5 ft 4 in (7.6 m) deep. It weighs about 26,000 lbs (11793.6 kg.) The deck is covered with a nonskid coating. In unloaded condition, the float draws 2 ft 1 in (0.64 m) of water and in a loaded condition the float, designed for a uniform live load of 100 lbs/ft² (488 kg/m²) or a concentrated load of 500 lbs (2268 kg) placed at any point on the deck, draws 3 ft 7 in (1.1 m) of water. Cleats and a timber fender system are provided. A 12- by 12-in (305 by 305 mm) timber member is attached at each end to receive timber pile guides located at each corner. For additional details, refer to R605. The float is light, strong, and has a high roll stability due to the catamaran-type hull construction.

7-3.9 **Concrete Float Elements.**

Concrete encased plastic foam elements designed for use in concrete floating docks for marinas can be connected together in various configurations to be used as work floats. The mass added by the concrete encasement creates a very durable float that is less affected by waves and live loads than more lightweight systems.

7-4 **BROW OR GANGWAY.**

Brows are used for access to landing floats from the pier or wharf structure, however they are more frequently used to provide personnel access from a pier or wharf to a berthed ship.

Figure 7-1. Small Floating Stage

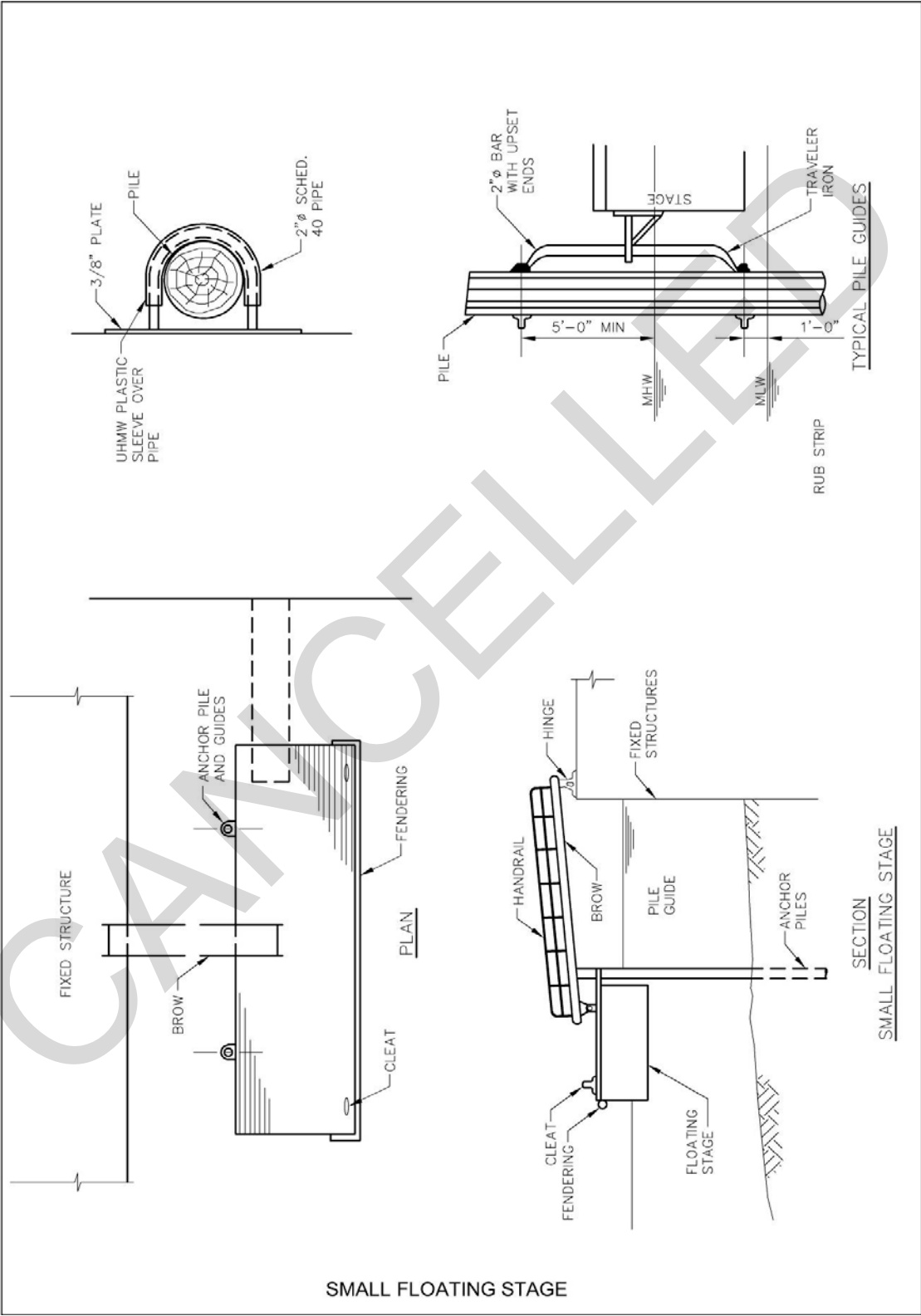
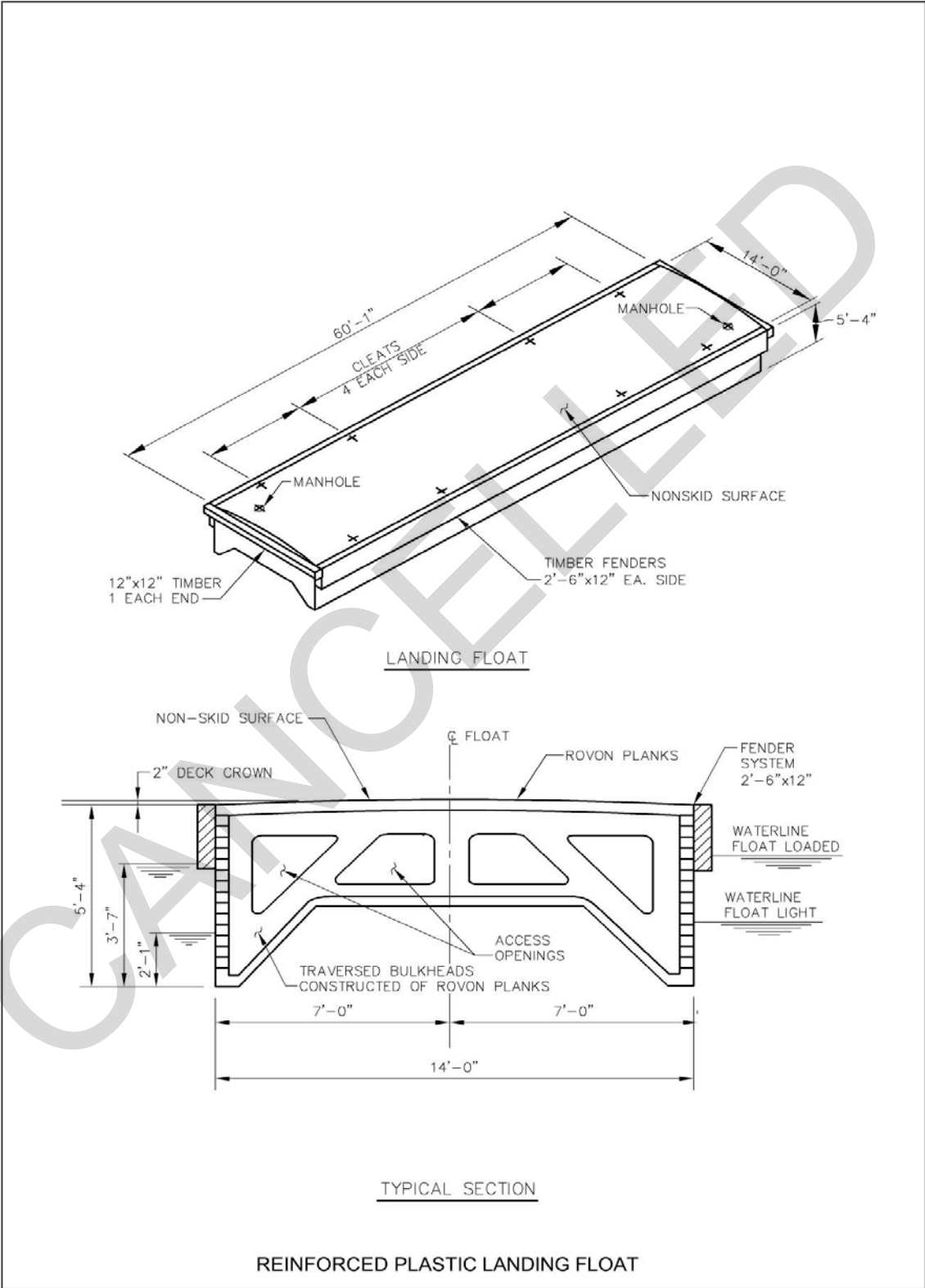


Figure 7-2. Reinforced Plastic Landing Float



7-4.1 **Length.**

Brows should be of sufficient length so that the slope will not exceed 1.5 horizontal to 1.0 vertical at the worst condition.

7-4.2 **Widths.**

Widths should be 36-in (914 mm) minimum (clear) passage for one-way traffic and 48-in (1220 mm) minimum (clear) passage for two-way traffic. Provide a 60-in (150 mm) minimum (clear) passage for two-way traffic when personnel carry small loads.

7-4.3 **Construction.**

Use fiberglass, aluminum, steel, timber, or a combination of these materials. Aluminum and fiberglass are generally preferred for the low weight to strength ratio and corrosion protection.

7-4.4 **Live Load.**

Design the brow structure for a uniform live load of 75 lbs./ft² (366 kg/m²) and a concentrated live load of 200 lbs (90.7 kg) applied anywhere. A reduction in the live load to 50 lbs./ft² (244 kg/m²) may be permissible where the brow is to be used in conjunction with a landing float. For calculation of reaction to the landing float, the live load can further be reduced to 25 lbs./ft² (122 kg/m².)

7-4.5 **Handrails.**

Design handrails to resist 50 lbs per lineal foot (75.6 kg per lineal meter,) applied in any direction at the top. Design handrails to resist a single concentrated load of 200 lbs (90.7 kg,) applied at any direction at any point along the top. It is assumed that the uniform load and the concentrated load do not act concurrently. The handrail may be designed to serve as the top chord of a truss when sufficiently braced.

7-4.6 **Safety.**

Provide safety devices to keep the brow from rolling off the platform deck and to prevent movement of the platform while in use. Clip safety chains into position for personnel safety. Large tidal variations are a problem because these may cause the brow to roll off the platform. A similar situation exists when high winds, currents, and extreme tides pull a ship away from the pier. Numerous accidents have been associated with brows being supported by pallets either on the ship end or pier end of the brow. Brows are not to be used in conjunction with pallets. If a platform is necessary, it shall be properly engineered, designed, and built under the technical cognizance of NAVFAC. /1/

7-5 **BROW PLATFORMS.**

Brow platforms are used when a brow from ship deck to pier deck is not practical, or presents an obstruction. Examples are portal crane trackage along repair berths, large tidal variations, and great height from deck to pier. Aircraft carriers (CVs and CVNs) usually use one brow forward and two aft. These brows require platforms 20 ft (6.1 m) or higher. This platform is basically a truncated tower, with typical measurements of 12 x 12 ft (3.7 by 3.7 m) at the base, while the top deck is 5 ft (1.5 m) wide and 10 ft (3 m) long. If small stair platforms are built alternately opposite hand, the requirement for a large platform can be met by lashing two of the smaller ones together. Sometimes the ship end of the brow can be connected to a rotatable platform which is permanently fixed to the ship by means of pins that lock the brow pivot hooks to the circular rotating portion of the rotatable platform. Construction materials and live load requirements are the same as for brows.

7-6 **BROW AND PLATFORM DESIGNS.**

Standard designs for brows and platforms are found in NAVFAC Dwg SD1405000-1405041 and may be obtained from NAVFAC EICO.

7-7 **WALKWAY OR CATWALK.**

These are permanent personnel access bridges installed between shore and different elements of piers and wharves. One example is a walkway between the pier or wharf structure and a mooring dolphin located some distance away as shown in Figure 2-1.

7-7.1 **Width.**

For walkways between shore and a U-shaped wharf, a 4-ft (1.2 m) width is recommended. For infrequently used walkways, the minimum width should be 3 ft (914 mm.)

7-7.2 **Live Load.**

Design all walkway structures for 100 lbs./ft² (488 kg/m²) live load.

7-7.3 **Construction.**

Walkway decking should be slip-resistant aluminum or fiberglass grating. Framing may be wood, aluminum, or fiberglass members. In view of the light loads encountered, piles supporting deck stringers can be of treated timber. Where loads and installation difficulty make timber piles inadequate, concrete and steel piles may be used.

7-7.4 **Handrails.**

Provide handrails on either side of the walkway. Consider handrails for use along edges of approach trestles and along non-berthing extents of docks or wharves.

7-8 **RAMPS.**

Transfer bridges or ramps are sometimes required for moving vehicles or heavy cargo from ships, similar to a roll-on/roll-off (RO/RO) operation. MSC RO/RO ships do not require any special features on existing Navy piers. Sideport ramps are stowed and handled by the ship. Sternport ramps are hinged to the vessel and extend to dockside or floating equipment (lighters, causeways, stages). These ships also have conventional cargo gear.

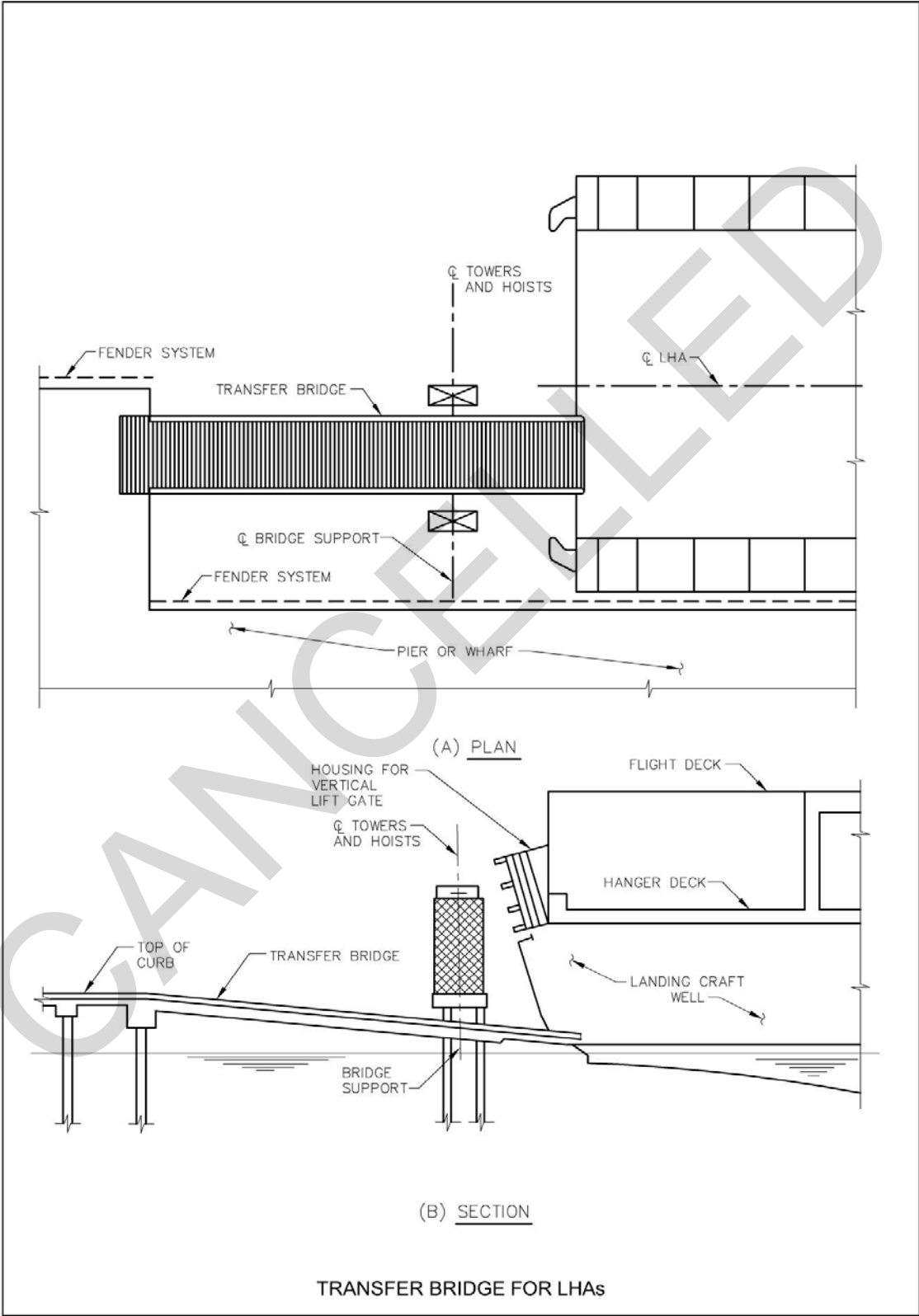
The LHA-class of amphibious assault ships has vertical lift stern gates, possess RO/RO capability. Installations accommodating vessels of this type should consider the use of a ramp or transfer bridge, as shown on Figure 7-3, to minimize the time required for movement of vehicular equipment and for loading of supplies. Design and construction of ramps should be similar to highway bridges. One key issue regarding ramps is clearance from pier/wharf edge obstructions, i.e. utility risers, cleats, bollards, etc. When designing piers and wharves, consider the specific location for ramp landing as well as structural deck strength.

As discussed previously in Chapter 2, sideport loading ramp access for LHA, LHD, and LPD-17 class ships is an important consideration, particularly on double deck piers.

7-9 **ACCESS LADDERS AND LIFE RINGS.**

Provide ladder access from pier or wharf deck to waters at a maximum spacing of 400 ft (121.9 m) on centers or within 200 ft (61 m) of the work area per 29 CFR 1917.26, *First Aid and Lifesaving Facilities*. Such ladders should be at least 1 ft 4 in (0.38 m) wide and should reach the lowest water elevation anticipated. Safety cages are not required. Locate the ladder on either side for a pier (50 ft (15.2 m) or more wide) and on the waterside for a wharf at places convenient to anyone who might accidentally fall into the water. Also, 29 CFR 1917.26 requires that a U.S. Coast Guard-approved 30 in (762 mm) life ring with at least 90 ft (27.4 m) of line attached be available at readily accessible points at each waterside work area where the employee's work exposes them to the hazard of drowning. Interpret as one life ring per wharf.

Figure 7-3. Transfer Bridge for LHAs



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APPENDIX A REFERENCES

GOVERNMENT PUBLICATIONS

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<p>2. Unified Facilities Guide Specifications</p> <p>http://www.wbdg.org/</p>	<p>\1\ UFGS 03 31 29, Marine Concrete /1/</p>

<p>3. U.S. Navy, Office of the Chief of Naval Operations</p>	<p>OPNAVINST 3040.5D, Procedures and Operations Reporting Requirements for Nuclear Reactor and Radiological Accidents</p> <p>OPNAVINST 4700.7K, Maintenance Policy of Navy Ships</p>
<p>4. Naval Facilities Engineering Command, Engineering Innovation and Criteria Office, 6506 Hampton Blvd, Norfolk, VA 23508-1278</p>	<p>\1\ MIL-HDBK-1025/1, Piers and Wharves /1/</p> <p>P-307, Management of Weight Handling Equipment</p>
<p>5. Naval Facilities Engineering Command, Atlantic</p>	<p>Amphibious Warfare Ship to Pier Interface Study, 10 Feb 2004</p> <p>Lower Deck Safety Study, Pier 11, Naval Operations Station Norfolk, 16 April 2004</p> <p>\1\ /1/</p>
<p>6. Naval Facilities Engineering Service Center, 1100 23rd Avenue, Port Hueneme, CA 93043</p> <p>https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_NFESC_pp</p>	<p>NCEL CR 89.005, Prestressed Concrete Fender Piles: Fender System Designs</p> <p>NCEL R-927, Laterally Loaded Partially Prestressed Concrete Piles</p> <p>NCEL R-935, Lateral Load Distribution on One-Way Flat Slab</p> <p>NCEL TM-5, Advanced Pier Concepts, Users Data Package</p> <p>NCEL TM 53-89-03, Prestressed Concrete Fender Piling User Data Package</p> <p>NCEL, UG-0007, Advance Pier Concepts, Users Guide</p> <p>SP-2005-SHR, Limited Flexural Tests of Plastic Composite Pile Configurations</p>

	<p>SP-2045-SHR, Proposed Design Criteria for Chocks and Wales</p> <p>TM-2158-SHR, Study of Recycled Plastic Fender Piles</p> <p>\1\ /1/</p> <p>TR-2069-SHR, Design Criteria for Earthquake Hazard Mitigation of Navy Piers and Wharves, February 1997</p> <p>TR-2103-SHR, Seismic Criteria for California Marine Pile Terminals, Vol 1 and Vol 2, April 1999</p> <p>TR-6014-OCN, Mooring Design Physical and Empirical Data</p> <p>TR-6015-OCN, Foam Filled Fender Design to Prevent Hull Damage</p> <p>\1\</p> <p>TR-6064-OCN, Berthing Guidelines for Submarines</p> <p>TR-6074-OCN, Added Mass for Berthing U.S. Navy Vessels</p> <p>/1/</p> <p>TR-R-605, Reinforced Landing Float and Brow</p>
<p>7. Naval Sea Systems Command, Washington, DC</p>	<p>\1\ NAVSEA OP-5, Ammunition And Explosives Safety Ashore /1/</p> <p>Naval Ships Technical Manual, NSTM 018, Chapter 611, Fenders and Separators, December 2001</p>
<p>8. U.S. Army Corps of Engineers, Army Cold Regions Research Laboratory</p>	<p>Ice Pressure on Engineering Structures, Monogram III-B1B</p>

9. Federal Emergency Management Agency	\1\ FEMA 356, Prestandard and Commentary for the Seismic Rehabilitation of Buildings, November 2000 /1/
10. Code of Federal Regulations	29 CFR 1917.26, First Aid and Lifesaving Facilities
11. \1\ U.S. Access Board /1/	\1\ Americans with Disabilities Act Accessibility Guidelines (ADAAG) Uniform Federal Accessibility Standards /1/
12. California State Lands Commission	Marine Oil Terminal Engineering and Maintenance Standards, June 2003

NON-GOVERNMENT PUBLICATIONS

1. American Association of State Highway and Transportation Officials (AASHTO) http://www.aashto.org	\1\ <i>AASHTO Bridge Guide and Manual Interim Specifications</i> <i>AASHTO Guide Specifications for Bridge Railings</i> /1/ AASHTO Standard Specifications for Highway Bridges, 17th Edition
2. \1\ American Railway Engineering and Maintenance-of-Way Association (AREMA) http://www.arema.org/ /1/	Manual for Railway Engineering
3. American Society of Civil Engineers http://www.asce.org/	SEI/ASCE 7-02, Minimum Design Loads for Buildings and Other Structures

4. International Code Council (ICC) \\1\ http://www.iccsafe.org /1/	International Building Code 2003 ICC/ANSI A117.1, Standard on Accessible and Usable Buildings and Facilities, 1998
5. \\1\ Precast / Prestressed Concrete Institute http://www.pci.org /1/	PCI Design Handbook

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Rizos, D.C. and Stehmeyer, C. H., Jr., Software Development for Berthing Analysis and Structural Loading on Waterfront Facilities, ASCE PORTS 2004.

Spencer, T.E., Marine Fender Systems, ASCE PORTS 2004

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APPENDIX B GLOSSARY

Breasting Dolphin – A freestanding independent structure that a vessel will bear against when current, wind or berthing motion moves the ship into the pier or wharf. Breasting Dolphins are typically equipped with energy absorbing fender systems and are pile supported or solid fill structures.

Bullrail – A wide low curb along the outboard edge of the pier or wharf. The bullrail may be cast-in-place concrete, steel or timber. Bullrails may be fixed or removable. Mooring hardware is often mounted on top of the bullrail.

Camel – A floating structure used to separate a moored vessel from the pier or wharf. Camels are used with ships that have hull configurations that do not match well with typical pier or wharf fender systems, such as, submarines or where vessels require an offset from the pier or wharf due to deck or superstructure overhangs such as an aircraft carrier.

Cold Iron – Used to describe the condition of a ship when all shipboard boilers, engines, and generators are inoperative during repairs or due to intentional shutdown and can furnish none of the ship's required services.

Dolphins – A free standing pile supported or solid filled structure used for mooring and berthing vessels, protection of the end of piers or wharves, turning ships, or protection of bridge substructure.

Drydocks – A specialized facility used for the repair of ships where the vessel is removed from the water or placed within a lock and the water is removed leaving the ship in the dry to facilitate repairs.

Fenders – Energy absorbing devices used on the face of a pier, wharf or dolphin to protect the ship and shore facility from damage due to contact between the two during berthing and mooring.

Homeport - Port for a specific ship that has been identified as such by Commander Fleet Forces Command and is listed in the Naval Register, <http://www.nvr.navy.mil> . The homeport is where the ship is assigned and offers all requisite services required by the ship to include the full compliment of hotel services.

Hotel Services – Dockside utilities provided for a ship at a berth (also called ships services, utility services, and cold iron services).

Ligherage - Small craft designed to transport cargo or personnel from ship to shore. Ligherage includes amphibians, landing craft, discharge lighters, causeways, and barges. Based on the idea of using use hollow, sheet steel boxes as pontoons and pontoon-assembled structures.

Monopile Dolphin – A single pile dolphin usually consisting of a large diameter concrete or steel pipe pile filled with concrete. Monopile dolphins can be used as mooring or breasting dolphins. When used as a breasting dolphin, the monopile dolphin is faced with fendering elements.

Mooring Dolphin - A freestanding pile supported or solid filled structure used for mooring vessels. Mooring dolphins are usually placed at the bow or stern of a moored ship to provide mooring points to attach breasting lines, bow lines and stern lines.

Pier - A pier is a structure that projects out from the shore into the water. A pier is oriented either perpendicular to or at an angle with the shore. It may be used on both sides, although there are instances where only one side is used because of site conditions or because there is no need for additional berthing.

Port of Call - Any port where a ship stops along the way other than its homeport, or a stop at a fueling pier, an ammunition pier, a supply pier, or a repair pier. The only real requirements for a port of call would be that it has sufficient dredge depth and that it provides secure mooring. Ship does not go cold iron in port of call and uses its organic systems. However, local determinations and justifications can warrant adding specific features at ports of call. Many of the new classes of ships have concepts of operations and special mission requirements that have resulted in making accommodations at ports in forward operating areas that ordinarily would not be required, i.e. hotel services. These are handled on a case by case basis and driven by operational requirements.

Slip – The space between two approximately parallel piers or the space formed by a cut into the land that provides two approximately parallel mooring faces.

Wharf - A wharf is a structure oriented approximately parallel to the shore. Ships can only be moored at the offshore face of a marginal wharf. When water depths close to shore are not adequate to accommodate deep draft ships, the wharf, consisting of a platform on piles, is located offshore in deep water and is connected to shore along its length or at one or more points by pile-supported trestles, usually at right angles to the wharf.

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APPENDIX C HIGH MAST LIGHTING

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Safety Alert

Pier high mast lighting structural failure

DESCRIPTION/BACKGROUND:

High mast lighting systems are used for lighting on piers and other structures. Design includes a ring assembly at the "mast" or pole top to support fixtures facilitating lowering of the ring by an internal cable pulley/motor system to access/replace lights or bulbs.

CONCERN: Mast lighting systems at Naval Station Norfolk have experienced an apparent defect where the latching mechanism fractures at the top of the mast light assembly prematurely. These fractured latching arms can then fray associated support cables which support the light ring. Once the support cables fray to a critical point, the entire light ring assembly can fall catastrophically - which has occurred. A subsequent investigation at Naval Station Norfolk pier high mast lighting has revealed additional lights of various designs similarly affected by latching mechanism fracture and cable fray. Many of the latching mechanisms inspected were reported to have a clearly improved design however, and did not exhibit signs of wear or failure.



INDIRECT CAUSE: The cable was incorrectly tightened causing retraction of the cable.

LESSONS LEARNED/RECOMMENDATION: Inspect high mast light systems for latching mechanism fracture/cracking. Visually inspect support cables for signs of wear and fray. While not involved in the failure, it is also recommended that the inspection include (1) a visual examination of the internal master cable for signs of wear as it retracts/coils and (2) a visual examination of the high mast pole splice for any signs of cracking, particularly for systems that have been in operation for a number of years. Any latching mechanism or cable failures noted during inspection should result in the light ring being lowered to ground until repairs can be made (or if pole splice cracking is observed the pole taken down). In some case it may be acceptable to provide temporary safety strapping between the light ring and mast pole with engineering consultation to facilitate continued light use until permanent repairs can be made.

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RETROFIT: Where failures are discovered, repairs/retrofit of internal motor/cable assembly and top latching assembly can be performed. Contractor repairs are underway at Naval Station Norfolk. A manufacturer source experienced with retrofitting high mast lights is (www.eaglehighmast.com).





SAFETY ABSTRACT – HIGH MAST PIER LIGHTS



DESCRIPTION OF THE HAZARD:

- A high mast light support cable parted causing the light assembly to be partially suspended at the top of the pole which did not allow for the light to be lowered for maintenance. The plan was to use an aerial work platform and crane to lower the light for maintenance and inspection. The area immediately around the light structure was secured with caution tape and traffic cones. Before coordinated efforts could be made, the supporting mechanisms failed causing the lighting assembly to fall to the pier surface. There were no injuries or damage to property other than the light assembly.

SYSTEM INVOLVED:

- High mast lighting systems are used by the Navy to illuminate piers and other structures. They utilize a light ring assembly supported by a system of wire cables. This light ring is designed to be lowered to the ground mechanically via an internal pulley system so that maintenance can be performed from the ground level.

EVENT:

- The High Mast Light ring assembly fell at a NAVSTA Norfolk double deck pier causing catastrophic damage to the light ring assembly.

SAFETY CONCERN:

- Potential Life Safety Concern related to High Mast Lighting systems on Navy piers and elsewhere.
- Multiple designs at Naval Station Norfolk have been discovered to have a design defect where the latching mechanism fractures at the top of the mast light. These fractures can then cause fraying of the support cables which support the light ring. When the cables fray to a critical point, the light ring can fall catastrophically. Subsequent investigation has revealed additional lights of various designs similarly affected by latching mechanism fracture and cable fraying.

DIRECT CAUSE:

- Stress and fatigue caused the failure of the supporting cables and locking devices which caused the light assembly to fall.

INDIRECT CAUSE:

- Movement of the lighting assembly due to environmental conditions caused chaffing and wearing of the supporting system.

RECOMMENDATION:

- PWDs throughout NAVFAC inspect High Mast Lighting systems for fractures/cracking. Visually inspect support cables for signs of wear. The internal master cable should be inspected. Recommend that the high mast pole splice point be examined for signs of cracking, particularly for systems that have been in operation for several years. Any latching mechanism or cable failures noted should result in the light ring being lowered until repairs effected.