CHAPTER 7

FLOATING DOCKS, PIERS AND WHARVES

Floating docks, piers, or wharves are those that rely on their buoyancy for support. They are the major alternative to fixed or pile-supported structures intended for the berthing of small craft. While the application of either the "fixed" or "floating" type to a particular location depends on many site specific factors, floating slips are generally favored for water level variations greater than about 4 ft (1.2 m) and for basin depths greater than about 20 ft (6.1 m). Large water level changes are common on flood control lakes, rivers, and tidal inlets on the coast. Under such conditions secure mooring of a small craft to a fixed dock is difficult and boarding may be hazardous. Since pile costs are responsible for a large portion of the overall cost of a fixed dock, factors that increase pile costs such as great depths, very soft bottoms, or very hard (ledge rock) bottoms all favor floating berths.

Cost comparisons between fixed and floating docks, piers, and wharves are very risky in today's economy. Dunham (1969) notes that while fixed docks appear to be less expensive, there is an increasing trend toward the use of floating berths for all small craft harbors. In a later report, Chamberlain (1977) also finds the floating systems preferable while stating that costs are competitive between the two types.

In an effort to protect moored small craft better, floating and covered berths have been designed (Dunham, 1969). Two types are prevalent, differing in the method of supporting the roof. When the maximum water
level fluctuation is less than about 6 ft (1.8 m), the anchor piles of the float system may be extended up to support the top. In this type, pole shed construction is used that is identical to fixed-pier covered berths (See Chapter 6). The second type of floating-covered berth is suitable for water level variations in excess of 6 ft (1.8 m). Each floating pier is incorporated in a covered structural unit as illustrated in Figure 7.1. The superstructure consists of a continuous, truss-framed roof supported by columns from each side of the main walk and the outboard ends of the fingers. According to Dunham (1969), the superstructure is markedly different than a similar roof on land since it must provide structural rigidity for the entire float system that limits differential flexing to a small fraction of that which occurs in an open berth arrangement. Substantial bracing is required to achieve acceptable rigidity which leads to very large dead loads. The large above-water profile area causes high, wind-induced lateral loads that must be resisted by the anchorage system. Excepting very calm and protected waters, it is questionable whether floating covered berths are practical in light of their considerable cost for minimal benefits. As with fixed-covered berths, dry stack storage is suggested as an alternative (New York Sea Grant, 1978).

Floating dock, pier and wharf systems are well-suited to modular construction, and several manufacturers are marketing complete berthing systems. In general, their approach has been to develop float units that can be fastened together in various arrangements appropriate for different sites. The float unit usually consists of a number of pontoons attached to a framework that supports the deck. A mixture of plastic,
Figure 7.1 Floating Covered Berths
(Dunham, 1969, p. 112)
timber, steel, aluminum, and concrete materials is common for a well-designed system.

This chapter begins with a discussion of structural geometry of floating docks, piers, and wharves. Next, foam flotation is addressed, followed by the various types of pontoons differentiated by shell material. The selection of float type and design considerations for floating docks concludes this second section. Anchoring systems comprise the third section, including control piles, pile yokes, pipe struts, and cable anchors. The final section consists of the design considerations concerned with decking and framing for floating docks, piers, and wharves.

7.1 STRUCTURAL GEOMETRY

The structural geometry of floating docks, piers, and wharves is in a sense similar to the fixed structures described in Chapter 6. Vertical support is provided by flotation elements or pontoons which replace the pile bents and are arranged under a deck superstructure which acts to distribute the deck loads. The pontoons are most often rectangular (parallelepipeds or cylinders and may be placed transversely or longitudinally under the superstructure (PIANC, 1976). If placed transversely, the pontoon should be as long as the dock is wide to ensure maximum transverse stability. Stability is also a major concern when the longitudinal arrangement is used. Chaney (1961) notes that stability is maximized by concentrating the flotation elements under the edges of the dock, even for asymmetrical loading.

The deck superstructure of a floating dock or pier usually consists of a set of stringers that supports a deck that rides 15 to 20 in (380 to 510 mm) above the water with no live load (Figure 7.2). Other structural
Figure 7.2  Floating Dock Indicating Suggested Freeboard
(Ayers and Stokes, 1976, p. 37)
types include a metal truss system supporting the deck, a glued-laminated
marina plank, or a concrete deck that is monolithic with the floats
below (Figure 7.3). Along the perimeter of most of these systems lies
a heavy timber rub rail or waler.

Short float sections or modules are generally assembled on shore,
launched, and then connected end to end to form the berthing system.
The main walkways of the piers extend outward from fixed or floating
marginal wharves. Small craft are berthed at finger floats attached
at right angles to the pier. Nonorthogonal connections in finger float
and walkway alignment should be avoided since they are subject to stress
concentrations that cause damage and increased maintenance (Curry, 1979).
Knee braces are commonly provided at the finger float/main walk junction.
The knee brace area is a good location for anchor piles, locker boxes,
and utility risers. Access to the float system is gained by means of
hinged gangways that slide along the deck as it rises and falls with
changes in water level. Anchorages in the form of guide pile or cable
systems are used to restrain floating berths against lateral loads.

7.2 DESIGN CONSIDERATIONS FOR FLOTATION ELEMENTS

According to Dunham (1969), the earliest known flotation is the
ordinary timber log. While logs are very economical on a first cost
basis, they have two main disadvantages. First, they tend to become
saturated with time and will sink after a few years. Secondly, they
are susceptible to marine borers and, if treated against biological
attack, they retain little of their original buoyancy. Except in unusual
circumstances, wood is not recommended as a flotation material. A suitable
replacement should be inexpensive, light, and impermeable to water.
To be durable in the marine environment, it should also be resistant to petroleum products, easily fastened to the deck structure, flame retardant, and resistant to ice damage in cold climates (Koelbel, 1979). Satisfactory float types include lightweight solids, hollow shells, or combinations of these. Several types of closed-cell foams qualify as acceptable lightweight solids. While there are many types of hollow shells that could be used as flotation devices, most are now being replaced with foam-filled shells (Dunham and Finn, 1974). Problems with leakage, internal condensation of moisture, impact damage and vandalism are largely responsible for the change. Combinations of shells and foam cores are therefore the primary float type to be addressed.

**Foam Flotation**

The most "successful" of the foam flotation materials include extruded polystyrene, expanded-pellet polystyrene, and foamed polyurethane (Dunham and Finn, 1974). While foam blocks have been used successfully as flotation elements without any surface coating, they suffer from a lack of durability. One of the worst problems is somewhat indirect. Large quantities of marine growth rapidly accumulate on unprotected foam floats. The plant matter attracts small organisms which in turn attract birds and sea animals to feed. It has been reported that large pieces of foam have been torn out as these animals seek marine life burrowed into the underside of the foam surface (Dunham and Finn, 1974). In addition, some foams are susceptible to damage from petroleum or ice contact, and may be flammable. For these reasons, some form of external protection is now applied to all foam floats, especially in saltwater. Protection may be in the form of a brushed-on coating or a more substantial
shell of plastic, fiberglass, metal, or concrete.

There are two basic approaches to manufacturing foam filled pontoons. The first method is to use a block of foam as the internal form and construct the shell around it. The alternative is to finish the shell first and foam the core material in afterward. Extruded polystyrene (commonly called styrofoam) in the form of planks is most suitable for the internal form construction because of its low cost and uniform quality, and because it is completely impervious to water (Dunham and Finn, 1974). While the expanded-pallet polystyrene may be less expensive than styrofoam, it is subject to quality control problems. Overexpansion of the beads or non-uniform heating will produce a low quality friable foam that is permeable to water. Since polystyrene is a common flotation material, the following specification recommended by the California Department of Navigation and Ocean Development (State of California, 1971) is reproduced for potential buyers:

"(1) Materials: Cellular polystyrene may be formed by the expansion of high density beads or granules in a mold or directly from the base resin by extrusion. The material shall be firm in composition and essentially unicellular. No reprocessed materials shall be used.

(2) Dimensions: Unless otherwise specified, the manufacturers' standard size will be acceptable if incorporated into the design with a minimum of field cutting. The tolerance in each dimension shall be plus 1 inch or minus 0.5 inch.

(3) Color: As normally supplied by the manufacturers for the particular type of polystyrene. Variation in color indicative of damage or deterioration will not be accepted.

(4) Surface Finish: Surface shall be stressed, polished, free from pits, blisters, cracks, dents, waviness, heat marks, or deep scratches.

(5) Odor: The material shall be free from any objectionable odor."
(6) Exterior Coating: In all locations where the water-front is subject to infestation by marine borers which damage polystyrene, the flotation material shall be protected with an adequate material capable of resisting any anticipated attack by marine organisms.

(7) Physical Properties: Specimens from polystyrene planks shall conform to the requirements stated below:

(a) Density: 1.5 pounds per cubic foot (minimum).
(b) Compressive Strength: 20 pounds per cubic inch minimum at 5 percent deflection.
(c) Tensile Strength: 40 pounds per square inch minimum at break.
(d) Shear Strength: 25 pounds per square inch minimum at break.

(8) Moisture Absorption: The maximum water absorption shall be 0.12 pounds per square foot of skinless or rindless surface when tested by immersion method in accordance with U.S. Department of Defense, Military Specifications MIL-P-40619 (3 April 1962) 4.5.7.

(9) Hydrocarbon Resistance: Polystyrene planks to be used in the vicinity of gas docks or other areas subject to petroleum products floating on water shall be hydrocarbon resistant. The materials shall show no apparent softening or swelling when tested by the immersion method specified in the U.S. Department of Defense, Military Specifications MIL-P-40619 (3 April 1962) 4.5.10.

(10) Shape: Surfaces of the finished planks shall lie in normal planes so that the plank, when installed in final position in the floating dock, shall lie in a true horizontal plane with the water. Edges formed by molding or cut sections may be either rounded or square.

Polyurethane is often preferred over polystyrene when the foam is to be placed inside a finished shell. Of the two types of polyurethane available, only the monocellular variety is non-absorbent and should always be specified (Dunham and Finn, 1974). While polyurethane foams are naturally resistant to hydrocarbons, they are prone to oxidation and should be provided with a protective covering.

One final note regarding foam flotation has to do with polymer compatibility. Some coatings or adhesives will work well with one foam
but react with another. According to Dunham and Finn (1974), polyester resins are compatible with polyurethane but not with polystyrene. Most manufacturers have representatives available for technical advice should such a question arise with the use of their product.

Coated Lightweight Pontoons

Lightweight shell pontoons are those in which the coating is a form of protection only and does not add significant strength to the foam core. Common protective coverings include brush or spray coats of polyvinyl-acetate emulsion or dense polyurethane (Dunham and Finn, 1974), epoxy paint (Dunham, 1969), and fiberglass reinforced polyester (PTANC, 1976). These coatings all bond to the foam core and provide a tough flexible skin that attracts less marine life and is easily wiped off. Compatibility between the coating and core should be checked to ensure the two materials do not react. For example, if the protection of a fiberglass and resin shell is desired over a polystyrene foam core, an intermediate coating of epoxy that is compatible with the resin must first be applied (Dunham and Finn, 1974).

Concrete has also been used as a coating for light, foam core floats. Although it adds considerable weight which must be compensated for with more flotation material, concrete provides an armored surface that may prolong the life of the system (Dunham, 1969). Concrete coated floats are stable because of their increased mass, and are quite durable as long as they are protected from impact damage. Noble (1964) cites the use of a polystyrene pontoon coated with 3/8 in. (10 mm) of concrete troweled in place. PTANC (1976) recommends a coat of fiber reinforced
concrete about 3/4 in. (20 mm) thick. Shotcrete has also been used with some success as a coating material. These pontoons are similar in appearance to the concrete shell type but float much higher.

**Synthetic Molded Shells**

The most common molded synthetic shells are made of fiberglass-reinforced polyester resin or high density polyethylene. Material technology in the field of synthetics is rapidly evolving, however, and other shell materials that are equally acceptable may be available. An attempt should be made by potential users of these materials to investigate their service record with respect to durability.

Fiberglass and polyethylene shells tend to be more durable than the lightweight shells mentioned above because of their better quality and increased strength. Brushed or sprayed-on coatings are typically non-uniform in thickness and contain local defects such as air bubbles or contaminants. This leads to cracking, pinhole leaks, and general slow deterioration (Dunham, 1969). The fiberglass and polyethylene shells on the other hand, are pressure molded between matched dies to ensure uniform wall thicknesses. Controlled manufacturing and curing conditions eliminate the defects experienced with lightweight shells.

As pontoon materials, fiberglass and polyethylene have many other advantages that are attractive to the marina designer and owner. Floats made of these materials are non-corrosive, non-conductive, resist marine life build-up, are not affected by petroleum spills, and have excellent impact strengths. In addition, one piece seamless construction is possible with provision for easy attachment to the deck framing.
Steel or Aluminum Shells

Metal shelled floats of steel or aluminum are another alternative for floating dock pontoons. Two shapes are common including a rectangular unit of folded thin gauge metal sheet with stiffener baffles, or a tubular one with end caps that resembles a corrugated drainage pipe. Used steel oil drums have been used as flotation units but should be considered only for short term or temporary projects because of their poor durability (Dunham, 1969). While fabricated steel and aluminum floats are also subject to rapid corrosion, they are commonly protected by manufacturer-applied preservative coatings both inside and out. In spite of this coating, most metals are not recommended for use on the sea coast because of their high corrosion rate in the saltwater environment (Dunham, 1969). Corrosion resistant alloys are available at some extra cost that may overcome this objection. Metal floats are nearly all foam-filled to provide extra protection against leakage, internal condensation, and internal corrosion (Dunham and Finn, 1974). Metal pontoons are particularly serviceable where ice formation and heavy floating debris is encountered.

Concrete Shells

Concrete has proven to be an excellent material for marina pontoons (Noble, 1964). Several manufacturers market floats with lightweight concrete shells around foam cores. The concrete usually used has a density of 100 to 110 pcf (15.7 to 17.3 kN/m³) significantly less than the 145 pcf (22.8 kN/m³) density of normal concrete (Curry, 1979). The primary advantage of lightweight concrete is that less buoyancy is required to support its dead weight. Pontoons of normal concrete
also require larger handling equipment and the resulting handling stresses are more critical because of increased size and weight (Noble, 1964).

Concrete floating dock systems are often cited for their stability and durability (Noble, 1964; Dunham, 1969). The heavier the pontoon, the greater its stability, providing the center of gravity remains low. Concrete pontoons tend to be more massive than other float systems and do not respond as quickly to load impulses or small waves. The mass of a concrete float system may work against it, however, in areas subject to long period waves or harbor surge (Curry, 1979). Considerable damage has been noted at locations where surge ran 10 to 18 in. (250 to 450 mm) at periods of 1 to 5 minutes. While concrete is very durable in the marina environment, it has three main weaknesses. First, reinforcement corrosion has led to deterioration of the walls of concrete shells. Since these must be thin-wall structures, it is difficult for the manufacturer to keep the reinforcing mesh in place at the center of the concrete section. For this reason, many designers do not use any reinforcement but instead design the float so that at no point will the tensile strength of the concrete be exceeded (Dunham, 1969). Second, concrete borers of the pholad family may damage concrete pontoons. Resistance to pholads depends on the quality and dispersion of the aggregate. Noble (1964) notes that ordinary rock and expanded shale aggregate have resisted attack while perlite aggregate, shotcrete without coarse aggregate, and plaster concrete coatings can be bored in 3 to 4 years. Finally, concrete pontoons are very susceptible to poor quality control and poor installation practices (Curry, 1979). Care must be taken during construction to use the proper quantity and quality of
foam core material, to locate the core correctly in the form, and to vibrate and finish the concrete shell properly. These steps will ensure that the floats are balanced and uniform, with walls, bottoms, and decks of the proper thickness and concrete quality. The best designed floats of the finest quality will still not function properly if poor installation procedures are used. Rough handling during transportation and launching will induce bending and impact stresses that lead to broken corners, cracks, and holes (Dunham, 1969). Rapid temperature changes and improperly tightened connections may also cause cracking.

7.3 SELECTION OF FLOAT ELEMENT TYPES

Of the decisions that must be made by the designer of a floating dock, pier, or wharf, the choice of flotation material may be the most controversial (Dunham, 1969). In some cases, the proper judgment is obvious. Logs, unprotected foam billets, and waste oil drums are acceptable only as temporary or short term float materials. On the other hand, the selection of a particular type of foam-filled shell may be based largely on the preference of the marina operator or patrons. Availability, durability, stability, and life cycle costs are factors to be considered in selecting a float type for a given marina installation. As in the case of fixed docks, piers, or wharves, appearance may also be an important criterion but will not be addressed here.

Pile foundations such as those used for fixed docks, piers, and wharves are also used to support other structures located on soft ground. For this reason, the various types of piles addressed in Chapter 6 are generally available regardless of location. Floats, on the other
hand, are not as readily available because of their narrower scope of application. The marina designer must first determine which float types may be obtained, followed by probable shipment and handling problems. In general, flotation elements are light and bulky, so all may be transported by land carriers. Lightweight and synthetic shell pontoons are easily handled manually while metal and concrete shell pontoons are heavy enough to require light machinery.

Durability is not a problem with any of the established float materials as long as they are used within their limitations. Lightweight shells are most suitable to calm, protected harbors where they will not be subjected to a lot of abrasion or impact. Metal shells, regardless of the coating applied, should not be used in saltwater because of their potential for corrosion. Care must be taken during the construction and launching of concrete shells to avoid tensile cracks that will lead to deterioration later on. The materials industry, especially in the field of synthetics, is rapidly evolving and has produced many new materials with potential application to float construction. The designer should be cautious in the use of these products, however, as they lack reliable data on fatigue, weathering, and wearing qualities (Dunham, 1969).

When used to describe a floating dock, pier, or wharf system, the term "stability" refers to how steady the structure feels underfoot. For a given deck superstructure, heavier floats will feel more stable to the user. Massive float systems do not respond as quickly to wave chop or dynamic live loads. Lightweight floats, however, tend to feel bouncy in the same conditions. The opposite is true in locations sub-
ject to long period (1 to 5 minute) surge, according to Curry (1979),
where concrete float systems have experienced considerable damage.

Life cycle costs should also be considered when selecting flotation
elements for a floating dock, pier, or wharf. Life cycle costs include
both the initial installation cost and maintenance costs over a standard
design life. Generally, lighter, less substantial floats will be less
expensive to purchase, but will require more maintenance. Heavier,
more durable floats may be preferable from an operators standpoint
since they minimize downtime during which maintenance is performed.

7.4 DESIGN CONSIDERATIONS FOR FLOAT COMPONENTS

The design of a floating structure is very complex, particularly
the connections between the float modules. Unlike a fixed structure,
the vertical support is not uniform and varies continuously with changes
in water level and deck loading. The deck and framing system must
be flexible enough to conform to the water surface while at the same
time having sufficient rigidity to distribute loads without the local
overstressing that leads to the development of an artificial hinge.
This tradeoff is a difficult one and, according to Chamberlain (1978),
the design of such systems is not safely left to amateurs. Two alterna-
tives are available to the designer of a floating dock. First, a
number of manufacturers are marketing float systems, some of which
have many years of performance records that show them to be successful.
Second, an expert with experience in the design of similar facilities
may be consulted. While it is difficult to equate the two approaches
in terms of cost, the prefabricated docks may be less expensive because
of volume production and lower design costs. Unfortunately, they
also more difficult to adjust to site specific conditions or owner preference.

The basic building block of a floating dock, pier or wharf is the float unit or pontoon. These pontoons are assembled with some members of the framing system on shore, launched, and then connected end-to-end to form the main walkways and finger floats of a berthing system. A floating dock consists of pontoons, stringers or wales, a deck, and bracing to make it sufficiently rigid. The following discussion presents the design considerations concerning each of these components as well as the connection and fastening details necessary to assemble the float system.

Pontoon

The first item in the design of pontoons is to determine their size and number required and how many pontoons are required for each module. According to the principles of buoyancy, an individual pontoon will support a total vertical load equal to the weight of water displaced when it is fully submerged. The vertical load as defined in Chapter 3 is the sum of the dead and live loads. The weight of the pontoons supporting a float module must be included in the dead load along with the weight of the stringers, wales, decking, and hardware. It follows that for the same live load capacity, concrete shelled pontoons must be larger than lightweight units. Manufacturers of commercial flotation elements produce standard sizes that have been found to be suitable for a range of deck and framing designs. The designer of a float module chooses a particular pontoon and determines the number required per module by dividing the total vertical load by the load capacity per pontoon.
Some floating docks are designed with continuous, shallow pontoons along their length, while others use a few large pontoons placed at strategic locations for stability. Dunham and Finn (1974) note that systems with continuous flotation elements will tend to trap surface debris, since no gaps exist for skimming or circulation. The use of large, discrete pontoons allows surface currents to flush debris through the gaps and results in a cleaner marina.

The attachment of the pontoons to the deck superstructure is another very important aspect of floating dock design. Attachment refers to the location of the pontoon within the framing members, as well as the methods of affixing the pontoon to these members. Figure 7.4 illustrates three different dock profiles to demonstrate the effect of pontoon placement on dock design. With respect to Figure 7.4, some definitions are in order. The distance labeled "dead load" is the depth to which the float system sinks without any live load acting on it. The "live load capacity" height remaining from the water line to the top of the pontoon when the dock is floating under its dead load only. This height corresponds to the amount of live load the dock can support just before the floats submerge and the whole dock begins to sink. Most floating docks have some height above the live load capacity line as indicated in Figure 7.4 which is defined as the "freeboard remaining with no live load capacity". Dock profiles (a) and (b) cause a false sense of security as the live load capacity is used up long before the deck reaches the water level. Koelbel (1979) cites several cases of boat shows where eager patrons crowded the docks until the pontoons became entirely submerged (with 6 to 8 in. or 152 to 203 mm freeboard remaining) followed by immediate submergence of the entire pier. Dock profile (c), on the
Figure 7.4 Floating Dock Design for Pontoon Location (Koelbel, 1979, p. 17)
other hand, provides increasing live load capacity to the point where the freeboard is virtually zero. The point to be made here is that freeboard is not a reliable indicator of live load capacity. A float design that minimizes the distance between the top of the pontoon and the deck surface is to be preferred for reasons of safety.

The height at which the deck of a floating dock rides above the water should be suited to the sizes and types of boats to be berthed. Dunham and Finn (1974) suggest that a range of 15 to 20 in. (380 to 508 mm) is appropriate for small craft docks floating under dead loading only. Koelbel (1979) recommends a freeboard of 18 in (460 mm) for the same condition. Some agencies also require that the dock settle no more than 8 to 9 in. (203 to 229 mm) under full live loading (Dunham and Finn, 1974).

Methods of affixing pontoons to the framing members of floating docks vary according to the float material. Unprotected foam blocks or lightweight shell pontoons do not have sufficient bending strength and must therefore bear on a flat surface under the deck superstructure (Figure 7.5). Bearing boards are attached to the bottom of the stringers and contact the top of the foam or lightweight floats. Contact pressures of about 5 psi (34.5 kN/m²) are acceptable for most foams, but the bearing boards should not be spaced more than 2 ft (0.61 m) apart and should be continuous along each edge (Dunham and Finn, 1974). The floats are then attached to the bearing board with skewed hardwood dowels driven into the foam, or nylon strapping that goes around the float. The strap method is preferable because repair or replacement of the floats is much easier.
Pontoons with stiffer shells of molded plastic, steel, aluminum or concrete have adequate strength to be bolted to the framing members of the deck superstructure. Molded shells usually have an integral tab that is provided for bolting while the metal pontoons can have brackets attached by welding. The most difficult attachment occurs for lightweight concrete shells since care must be taken to avoid tensile stresses that will cause cracking. Two basic methods are used to bolt up concrete pontoons to wood walers: inserts or through-bolts (Curry, 1979). Figure 7.6 illustrates both insert and through-bolt concrete pontoon assemblies. Curry (1979) recommends the use of through bolts since insert assemblies can be stripped or even pulled out of the concrete. Through bolts however are easily replaced if stripped or otherwise damaged.

Stringers and Walers

The stringers and walers of a float system form the framework that holds the deck together above its supporting floats. Walers are a special type of stringer in that they are visible on the face of the dock and can also function as rub rails. Depending on the rigidity of the connection between the finger floats and main walk, the stringers and walers in this area are subject to severe vertical bending stresses induced by wave action. Assuming a harbor depth of 10 ft (3.0 m), a design wave height of 2 ft (6.1 m), and a wave period of 5 seconds, a typical local wind wave will be about 80 ft (24.4 m) long from crest to crest (Dunham and Finn, 1974). Taking a wave approach along the axis of the main walk to be the worst case, the deck structure is loaded in bending with support points nearly (80 ft or 24.4 m) apart. Ordinary stringer systems supporting only the deadweight of the deck and floats cannot
2x8-in. facers
Continuous bar
Insert
Space

-Detail of facer attachment of a patented system

A. Insert Assembly (ACI, 1964, p. 111)

B. Through-Rod Assembly
(Winzler and Kelly, 1979, p. V-30)

Figure 7.6 Insert and Through-Rod Concrete Pontoon Assemblies
span such a distance, however, and Dunham and Finn (1974) note that resultant deflections will be about 1.5 ft (0.46 m) vertical in 45 ft (13.7 m) horizontal. Properly designed timber stringer systems can accommodate these deflections in flexure given adequate splice joints. If the joints are weak or allowed to loosen, the structure will form an artificial hinge at that point which leads to a rapid deterioration of structural integrity and major repairs.

Assuming the conditions mentioned above, a stringer system consisting of a 2 by 6 in. (51 by 152 mm) plank inside with a 2 by 8 in. (51 by 203 mm) plank outside, as shown in Figure 7.7, would be adequate for a 4 ft (1.2 m) wide finger float on lightweight shells (Dunham, 1969). Waler thickness is usually increased to a 3 or 4 in. (76 or 102 mm) nominal thickness to allow countersinking of the attaching hardware without reducing strength (Chaney, 1961). The thicker members are also found to be superior from a wood quality standpoint, with fewer checks and structural deficiencies (Curry, 1979). Dunham (1969) notes that stringer design based on the vertical stress criteria will normally be adequate for horizontal stresses, provided that adequate cross and knee bracing is installed. Another important consideration in the sizing of walers is the level of contact with the berthed craft. Walers should extend down to 8 in. (203 mm) above the water when the dock is subjected to a dead load only so that boats with low rub stakes will not be caught underneath (Dunham and Finn, 1974). At the same time, vertical fender posts may be necessary for boats with high gunwales. Floating dock fendering is addressed in more detail in a subsequent section of this chapter.
Figure 7.7 Stringer Detail on a Lightweight Shell
While timber stringers are the most common, lightweight metal truss systems have also been used (Figure 7.3). Since these proprietary systems are prefabricated and interconnected entirely by bolting, they may be rapidly installed, and easily expanded to create more berths. They are only suitable to rather calm, freshwater locations, however, according to Dunham and Finn (1974) since overstretch and corrosion problems are likely.

**Bracing for Floating Docks, Piers, and Wharves**

Braces are required in a floating berthing system primarily to transmit lateral loads into the anchorage points spaced throughout the installation. They also provide the structural integrity and sense of rigidity that Chamberlain (1977) claims is so important to a successful marina. The most obvious brace type is the knee brace located at the finger float/main walkway junction of most floating facilities. Other brace types include internal x braces, struts, and torque pipes.

Knee braces, sometimes called "fillets", are used with semi-rigid deck superstructures to augment the cantilever action of the finger and main walk stringer connection (Figure 7.8). A well designed junction with knee braces can accommodate the lateral loads of a finger float up to 40 ft (12.2 m) long (Dunham and Finn, 1974). Longer fingers should have an anchor pile located on the outboard end.

Knee brace configurations have traditionally been a 45° triangle for simplicity of design (Dunham, 1969), with a leg length equal to the width of the finger float. There is a trend however toward the use of a skewed knee with the longer leg on the finger side. The longer brace stiffens the finger by reducing its unbraced cantilever length...
Figure 7.8 Floating Dock Braces (Winzler and Kelly, 1979, p. VI-8)
and is favored for long fingers, large craft, and high wind load areas.

Metal and wood are the materials commonly used for knee braces. Metal knees are typically steel members consisting of angles of at least \( \frac{1}{4} \) in. (6.4 mm) thickness (Curry, 1979). Wood knees are usually constructed of the same size members as the waler on the outside of the pontoons. Both wood and metal knee braces are then covered over by the decking material. While anchor piles are frequently located inside the knee braces of a floating dock, the decking or cover plate should not be used to support the pile guides. The pile guides instead should be attached to additional framing members that transfer pile loads directly to the structural elements of the main walk. One disadvantage in the use of knee braces is that they encroach somewhat on berth space and are therefore subject to more frequent impact damage by boats. Also, larger commercial fishing vessels may not be able to berth with the stern close to the main walk for ease of boarding.

Internal x braces (Figure 7.8) are installed between the pontoons and stringers of the timber deck superstructure of some floating docks, piers, and wharves. The primary function of x bracing is to stiffen float systems in a horizontal plane to resist torsional and lateral loads better without large deflections. A secondary purpose of these members is to provide adequate bearing area for thin shelled foam flotation elements. When used with diagonal deck planking, the x braces should be installed in the opposite direction for a cross-bracing effect.

Strut systems and torque pipes, unlike x braces, are installed solely to resist torsional buckling stresses in the deck framework. Torsion is induced in a number of ways including eccentric deck loading, boat impact loads that are not applied at deck level, and various
combination loads because of waves and wind. Unbraced stringer and
deck arrangements are easily twisted because the high point of attach-
ment of the deck forms a "C" section that is relatively weak in torsion.
X braces are effective in resisting this torsional stress because of
their low plane of action. Strut systems (Figure 7.9) have also been
found very effective in resisting torsional buckling. Struts and cross
ties are placed at frequent intervals to reduce the clear stringer length
in which buckling can occur. Torque pipes typically consist of 3 to
3½ in. (76 to 89 mm) galvanized pipes with plates welded to each end
(Dunham, 1969). These plates are then bolted on one end to the main
walk stringer and, on the other, to the end partition of a finger
float (Figure 7.10). The finger float cannot twist then without exerting
a torsional stress on the pipe which resists this load essentially as
a very stiff spring.

As a final note on floating dock, pier, and wharf bracing systems,
it should be noted that the effectiveness of the braces discussed depends
on their connections being strong and tight. If braces are not properly
maintained, the structural integrity of the entire installation can
deteriorate rapidly, followed closely by the need for major repairs.

Decking

The design considerations regarding decking for floating docks,
piers, and wharves are similar to those pertaining to fixed structures
as addressed in Chapter 6, and will not be repeated here. One factor
that becomes important with floating systems, however, is weight.
Heavier decks feel and sound more secure under foot, but indirectly
boost overall costs because of the extra flotation required.
Figure 7.9 Crossovies and Struts Used to Strengthen Floating Pier Decks (Dunham and Finn, 1974, p. 149)
Figure 7.10  Deck Framing Stiffened with a Torque Pipe  
(Dunham, 1969, p. 111)
Gangways

Gangways for floating docks may be identical to those of fixed structures with the notable exception being the end connections. Since the float system must move up and down relative to the wharf it is attached to, rigid connections cannot be used. Gangways for float systems anchored by means of pipe struts or stiff arms can be hinged both top and bottom (Figure 7.11). In most cases, however, the floats are anchored by guide piles which require that one end of the gangway be free to slide in and out as the deck rises and falls. While simple metal guides are adequate for light gangways, wheels are commonly used to reduce the sliding friction for heavier gangways (Figure 7.12).

The design of the floating dock under the lower end of a gangway must compensate for its concentrated weight. Two methods are commonly used, including adding additional pontoons to pick up the load, or using a pile supported counterbalance system as in Figure 7.13.

Gangways are most often designed as lightweight decks supported by truss systems combined with the side handrails. In this manner, adequate length can be achieved without weight that would be associated with simple beam design. Examples of gangways are illustrated in Figure 7.14. The deck of these ramps should be covered with a non-skid surface, or have cleats affixed to it on 1 ft (0.3 m) centers (State of California, 1980). A maximum slope of 3:1 is allowable at extreme low water.

Connections and Hardware

The connections of floating docks, piers, or wharves are perhaps the most critical areas the designer must address. The two basic approaches
Figure 7.12  Wheel Guided Gangway with Apron Plate
(Dunham and Finn, 1974, p. 159)
Figure 7.13 Gangway Counterbalance System (Dunham and Flinn, 1974, p. 227)
Figure 7.14 Truss Supported Gangways (Chaney, 1961, p. 143)
to connection design are to use rigid junctions that transmit stresses between connected members, or to provide hinges that allow displacement of the joint under load. Dunham (1969) states that rigid connections provide for long life with respect to the deck framing of most floating piers. Actually, the term "rigid" is probably inaccurate in describing float system superstructure, and instead Dunham and Finn (1974) suggest "semirigid". It was noted earlier that stringer systems may be subjected to deflections of 1.5 ft (0.46 m) vertical in 45 ft (13.7 m) horizontal. Included in this stringer system are both stringer-to-stringer splices, and finger float/headwalk junctions that must be designed to accommodate these large deflections in flexure. Figure 7.15 illustrates one example of a semirigid crosslocked connection of finger and headwalk stringers.

The most efficient framing is obtained when fingers lie opposite each other along the headwalk and provide balanced loading conditions. When they do not, header framing is difficult and may lead to torsion in the mainwalk. It is very important for the durability of semirigid connections that they not be allowed to loosen enough to form an artificial hinge. Bearing this in mind, the designer must be careful to specify fasteners that do not overstress and crush the wood fibers and create a "working joint" (Dunham, 1969).

Hinged connections between float sections and at the finger float/headwalk junction may be necessary for stiffer stringer materials, heavier pontoons, or excessive environmental loading conditions. Monolithic concrete floats, being of great dead weight and low tensile strength, are a prime example. Since vertical bending stresses from a concrete finger float cannot be transmitted to the header, a hinge must be pro-
Figure 7.15 Crosslocked Connection of Finger and Headwalk Stringers (Dunham and Finn, 1974, p. 150)
vided (Dunham, 1969). Where necessary, hinges should be massive, with large diameter pins that are closely fitted. Poorly maintained hinges wear rapidly, however, soon becoming loose and noisy (Dunham and Finn, 1974). Curry (1979) notes that hinges should be avoided whenever possible since they allow too much movement and "tear up" the pontoons. Hinge fittings are illustrated in Figure 7.16.

The fasteners used in floating dock, pier, and wharf construction are in most cases identical to those used in fixed structures as presented in Chapter 6. For this reason, no further discussion of fasteners will follow.

7.5 FLOATING DOCK MOORAGE

Moorage design for floating docks is essentially the same as for fixed docks. The fundamental difference is that floating docks move vertically with the berthed craft in response to tides or long period surge, while fixed docks are stationary. The most common mooring system is the double berth with cleats, tie lines, and tie piles as shown in Figure 6.27. Traveling Irons (Figure 6.28) are used on the tie piles for large water level fluctuations (Chaney, 1961). Section 7.6 should be consulted for general small craft mooring design considerations.

7.6 FLOATING DOCK FENDERS

Fenders for floating docks are less complex to design than fixed dock fenders because the docks remain at approximately the same level with respect to the berthed small craft. Floating dock fenders generally take the form of a rubrail affixed to the face of the dock in such a manner that it contacts the boat hull first. The various materials used have included wood rub strips, old rubber tires, discarded fire hose, or hemp hawsers,
but these fender types are unsightly and not particularly durable (Dunham and Finn, 1974). Special synthetic extrusions or molded shapes (Figure 7.17) are now being manufactured that solve these problems. Butyl rubber and neoprene are durable synthetics that are used for fender materials when reinforced with metal strips through the attachment points.

7.7 ANCHORAGE SYSTEMS

Floating docks, piers, and wharves must be provided with some form of anchorage system to maintain their position when subject to lateral loads. The anchorage system must allow vertical movement with all fluctuations of the water level while restraining horizontal movement because of wind, water current, and boat, ice, or floating debris impact. The magnitude and proper combination of these loads is addressed in Chapter 3. There are two general groups of anchorage systems for floats. The first consists of various types of guides that attach the floats to piles or other fixed support. The second group includes cable and sheave systems that work in conjunction with bottom and shore anchors. The choice of a system depends primarily on the depth of water in the basin, and the amount of water level fluctuation that must be accommodated. A third group that pertains to the anchorage of covered berths will also be addressed briefly.

The restraint methods of the first group include anchor piles with pile guides, anchor piles with traveling irons, traveling irons attached to other fixed structures such as bulkheads or breakwaters, and stiff arms or pipe struts. Water level fluctuations of approximately 10 ft (3.0 m) can be safely accommodated by most of these systems (Chaney, 1961). The simplest and most common are the anchor piles which are suitable for water depths up to 30 ft (9.1 m) according to Dunham (1969).
Figure 7.17 Floating Dock Fender (Dunham and Finn, 1974, p. 179)
Piles are intended to resist lateral loads at the water surface through cantilever bending. This requires that they be firmly fixed in the harbor bottom. If the basin depth is too great, or the substrata too soft, the anchor pile must be very large to be sufficiently rigid (PIANC, 1976). In such cases, pile costs soon become prohibitive and cable anchorage is more economical.

All of the various types of piles, with the exception of cast-in-place concrete, are used for anchorage. While treated timber is the most common, prestressed concrete, structural steel shapes, and railroad rail have all been used. Timber is popular because of its low cost and flexibility. Prestressed concrete piles are preferred over conventionally reinforced concrete because of their greater bending strength and durability. Small diameter metal pipe such as well casing may be used in well protected areas, but the system must be carefully designed to avoid overload (Dunham, 1969).

The design and layout of an anchor pile system may be approached from two different outlooks. First, given the pile geometry (diameter and length), the penetration depth, and the soil properties of the substrata, an allowable load for each pile may be calculated. Dividing the allowable load per pile into the total horizontal load on the float system will determine the number of piles necessary for safe anchorage. The alternative is to locate piles for uniform stress distribution in the deck members, thereby determining the number of piles to be used. The necessary capacity of each pile is then calculated and it determines the pile geometry and embedment depth, given the soil properties of the harbor bottom. The spacing of piles is a matter
of judgment that depends on the rigidity of the dock in the horizontal plane, and the magnitude of the lateral loads to be resisted (Dunham and Finn, 1974). Efficient structural design would dictate that the anchor piles be located at the finger ends and the knee braces of the slips as illustrated in Figure 7.18. Additional piles are usually provided at the "T" head of main piers under the assumption that it will be used as a breasting dock for large cruisers.

Cheung and Kulhawy (1981) should be consulted for the design procedures for lateral loads on individual piles. Anchor piles are generally designed as free-headed members with the exception of a sleeve-guide that has been used to fix effectively the head of the pile against rotation. Sleeve-guided anchor piles are addressed in a subsequent section. The load applied to an anchor pile must be introduced at the highest possible point of application which is assumed to be the expected maximum still water elevation plus the design wave height plus the height of the pile guide over the water (Dunham, 1969). While the pile guides of a float system will rarely contact all the anchor piles simultaneously, it is commonly assumed that the piles are sufficiently flexible to permit even distribution of load (Dunham and Finn, 1974).

The installation of the anchor piles for a floating dock, pier, or wharf presents a potential problem. Pile driving equipment is often too big to drive the piles after the floats are in place. Instead, the float system is moved into place after the piles are carefully driven at predetermined positions using shore control (Dunham and Finn, 1974).

Dunham (1969) suggests that anchor piles placed in sandy soils should be jetted in to obtain more precise positioning and minimize driving damage to the pile. Jetting should not be used with cohesive
Figure 7.18 Anchor Pile Location
substrata, however, since the soil will not properly fill the voids around the pile and form a good bond. Anchor piles so placed will have a low capacity and may work loose under frequent stress reversals. In hard rock substrata, anchor piles have been grouted into predrilled or blasted holes (Dunham, 1969). Although this provides excellent fixity for high capacity anchor piles, the procedure is expensive and cable anchorage is probably indicated. While float systems have been designed that place the anchor pile in the middle of the deck, a location on the float perimeter or in the knee brace is to be preferred (PIANC, 1976). In this manner, over-water construction may be minimized, and a clear deck is left for pedestrian traffic.

Pile guides are used to transmit the lateral loads of a floating dock or pier to the anchor piles that resist these loads. While slack or free play should be minimal, the guide must not be so tight that it abrades the anchor pile or damages the structural member of the float deck to which it is attached. Guides that surround the pile are preferable since open sided guides do not carry any load in one direction and therefore cause unusually high loads on other piles (Dunham and Finn, 1974).

The various types of pile guides may be separated into two general groups: pile yokes and pile rollers. There are yokes as well as roller systems, and yoke and roller combinations are also available. Pile yokes are typically fabricated of wood and/or steel and are illustrated in Figure 7.19. Note that for the purposes of this report, rectangular wood collars that are framed into the deck of a float are considered yoke guides. The most common pile yokes according to Curry (1969) are metal hoops. These guides work well with wood piles, but Curry
(1979) has observed that 50% of a pile cross-section has been worn away in the tidal zone of severe surge areas. Steel yokes perform acceptably well on steel piles with the main objection being that they are noisy. Dunham (1969) recommends the use of metal or hardwood bearing strips attached to the pile to reduce pile damage and noise. Curry (1979) suggests wood or rubber wear strips and notes that 4 by 4 in. (102 by 102 mm) oak has been observed to work well for many years. Sleeve guides are used on some float systems in conjunction with small diameter pipe piles. Given that the deck structure is very stiff in torsion, a sleeve that fits closely will fix the pile head against rotation. Theoretically, the load capacity of a sleeve-guided pile is increased significantly when compared to a free-headed pile of the same diameter. While a pile fixed against rotation at the top is apparently more rigid, the analysis is made complex by the flexibility of the pile and the float components. Furthermore, any wear in the pile sleeve or loosening of the float connection can lead to a reduction in the degree of head fixity which results in lower anchor stiffness and greater deflections. Cheung and Kulhawy (1981) should be consulted for the design of sleeve-guided anchor piles.

Pile rollers are illustrated in Figure 7.20. They are generally made of hard rubber with axles of stainless steel. Rollers are more expensive than wear strips and yokes but look more "clean" and modern (Curry, 1979). They are also more quiet since they do not subject the pile to scraping and wear. Wear of the roller itself may be a problem however. Rollers do not generally work well against round piles (especially concrete) and the rubber wears out prematurely in the middle. The State of California (1980) recommends octagonal concrete piles which
Figure 7.20 Pile Rollers (Marine Docks, p. 10)
offer the appearance of a round pile but still provide flat bearing surfaces for the roller guides. Square concrete piles are the least expensive of the concrete piles and, while they work well with roller guides, they often rotate during driving and present an unattractive appearance.

Traveling irons attached to anchor piles (Figure 7.21) are very similar in performance to anchor pile/roller guide systems. The traveler bar is connected to the floats by means of a metal ring which allows very little slack and results in a quiet, dependable system. Traveling iron anchorage systems are much stiffer when fastened to bulkheads or fixed piers since these structures cannot deflect as an anchor pile does. Chaney (1961) notes that while traveling irons can tolerate a maximum advisable water fluctuation of 9.5 ft (2.9 m), they become costly if this range exceeds 7 or 8 ft (2.1 or 2.4 m). A variation of the traveling iron that is suggested by Chaney (1961) is the T-bar (Figure 7.22). The T-bar is a more substantial member that is capable of withstanding greater horizontal forces and greater water level fluctuations. Note that no stops are provided on the top or bottom. In the event of extreme high or low water, the dock can then float free without damage.

The final group one restraint method to be addressed is the pipe strut or stiff arm system. This type consists of a series of rigid struts or ramps that are hinged at the top to a bulkhead or other fixed structure, and at the bottom to a row of floats (Figure 7.23). The water level fluctuations that can be accommodated by this system depend on the length of the strut. Chaney (1961) notes that a "dead water space" between the bulkhead and float line is a necessary product of
Figure 7.21  Traveling Iron Guide  
(Chaney, 1961, p. 143)

Figure 7.22  T-Bar Guide (Chaney, 1961, p. 135)
Figure 7.23 Pipe Strut or Stiff Arm Anchorage
stiff arm anchorage and longer arms waste more area. Regardless of
strut length, however, the entire float system will move toward and away
from the support point with changes in water level. This precludes
the use of anchor piles or cable systems as supplemental anchorage.

Cable and sheave anchorage are favored over the previously discussed
systems for water depths in excess of 30 ft (9.1 m) and water level
fluctuations greater than about 10 ft (3.0 m). Anchor piles of suitable
stiffness must be too large to be economical in deep water. Furthermore,
piles intended for water level changes in excess of 10 ft (3.0 m) are
too flexible at high water and unsightly at low water. Cable anchorage
may also be more practical at lesser overall depths and level changes
when ledge rock or very soft bottoms make pile driving difficult. Another
disadvantage of pile anchorage systems that is partially overcome by
cables is the hindrance to dredging operations (PIANC, 1976).

There are many variations of cable anchorage systems, and their
arrangement depends largely on site specific conditions. In general,
two anchor lines diverging at 45° are attached to the outer corners
of a float system, and two lines tie the system back to the shore
(Dunham, 1969). Larger installations require more lines and larger
anchors. Two examples of drawdown adjustable systems are illustrated
in Figures 7.24 and 7.25. The type of anchor used depends on bottom
soil conditions, profile, and the magnitude of the expected loads.
Common anchors for small installations are shown in Figure 7.26. Since
these anchors derive most of their resistance from embedment in the
bottom, the line pull should be kept as near horizontal as possible.
Dunham (1969) suggests that a "sinker" be attached to the midpoint of
Figure 7.24 Deepwater Cable Anchorage of Floating Pier (Dunham and Finn, 1974, p. 147)
Figure 7.25 Drawdown Adjustable Anchorage
(Chaney, 1961, p. 142)
a. Danforth-type Anchor 

b. Mushroom Anchor

c. Navy Standard Stockless Anchor

Figure 7.26  Soft Ground Anchor Types (Ehrlich and Kulhawy, 1982, p. 66)
the anchor line to flatten the lower part and steepen it near its float attachment point so as not to foul boats moving nearby. Fisher (1980) states that for optimal performance, the angle between the bottom and the anchor line or "rode" should not exceed 8 degrees (Figure 7.27). Concrete weights and large boulders are also used as anchors and rely on their mass to resist dragging. High capacity plate anchors that require direct embedment in soft bottoms have been developed recently. These anchors are inserted in the bottom sediments by means of explosive propellants (Figure 7.28) or vibration. Field test data of anchor capacity is available from the Naval Facilities Engineering Command for conventional anchors (Taylor, 1980; Taylor and Rocker, 1980) and plate anchors (Beard, 1980).

Anchors are connected to the docks floating above by means of cables or chains. An adjustment should be made in the amount of flotation at the attachment point because of the weight of the anchor line. Cables are lighter than chains for a given tensile strength, they are not as durable, and chains may be substituted to obtain a longer life. Wrought iron chains are preferable to those of mild steel in corrosive environments (PIANC, 1976). The upper portion of the chain or cable is most subject to corrosion and provisions should be made for splicing or repair. In very deep water, transverse chains may be hung from pier to pier with ground anchors only at the extreme side piers. These chains must be deep enough that they do not obstruct or foul boats moving around the harbor.

Covered floating berths generally require much more substantial anchorage than an open system because of the large side area presented to wind loading. An ordinary guide-pile arrangement may be sufficient
Figure 7.27 Cable Anchoring of a Floating Dock
Figure 7.28 Penetration and Keying of a Propellant-Embedded Anchor (Beard, 1980, p. 6)
in calm areas when the number of piles required is not too great. According to Dunham and Finn (1974), however, it is more common to use some other anchorage system such as a pile dolphin. Dolphins derive their strength by acting as a braced A-frame instead of through cantilever bending. Since a single dolphin may have the strength of 10 to 20 individual guide piles, fewer are needed (Dunham and Finn, 1974). The dolphins are then located at strategic points beneath the cover, and the structural framework of the roof is used to transmit the lateral loads. Submerged cross ties (Figure 7.29) may be used to strengthen the system further if the water is deep enough.

7.8 SUMMARY

Floating docks seem to be the most popular structural type in new marina projects. Their attributes include reasonable cost, neat appearance, and ease of access to berthed craft. The structural geometry of floating docks is very similar to fixed docks with the major exception that they rely on pontoons for vertical support instead of piles.

These pontoons include coated lightweight foam blocks, and shells made of molded synthetics, metal, and concrete. Virtually all of these shells are now filled with foam cores to minimize problems with internal deterioration, leaking, and vandalism. The selection of float material is based on availability, durability, stability, and cost. Except as a temporary float, oil drums and unprotected foam blocks are not recommended.

The design considerations relating to the components of the floating dock system have been presented in this chapter. These components include pontoons, stringers and walers, bracing, connections, fenders, and gangways. Lateral restraint of float systems is provided by anchorage
Figure 7.29 Submerged Crossties (Dunham and Finn, 1974, p. 145)
systems. There are two general categories of anchorage including fixed support or guide pile systems, and flexible support or cable anchorage.