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 walers, 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, walers, 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.
Figure 7.5 Timber Frame and Bearing Boards above Premolded Styrofoam Floats
(Chaney, 1961, p. 139)
Pontoon 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 mainwalk 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
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 overstress 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 \( \times \) 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 \( \times \) 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 \( \times \) braces should be installed in the opposite direction for a cross-bracing effect.

Strut systems and torque pipes, unlike \( \times \) 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 Crossties 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 7.11 Floating Dock Gangway (Dunham and Finn, 1974, p. 282)
Figure 7.12 Wheel Guided Gangway with Apron Plate
(Dunham and Finn, 1974, p. 159)
Figure 7.13 Gangway Counterbalance System (Dunham and Finn, 1974, p. 257)
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 pre-
sent ed 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 re-
spect 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 bawser s,
Figure 7.16 Hinge Connectors (Marine Docks, pp. 6, 7)
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
"T" Head

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
Figure 7.19 Pile Yokes (Marine Docks, p. 10)
(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
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 7.23 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

Rode

Danforth type anchor

Sinker

8°

Soft Bottom Material
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.
CHAPTER 8

UTILITIES AND SPECIAL SERVICES

Utilities are an essential part of the successful modern marina. According to Dunham (1969) the marina should be provided with all the utilities called for in any standard community development. For the purposes of this report, utilities are taken to be the services commonly supplied to the public by a municipal system. These services include electrical power, sewage disposal, telephone communications, and freshwater. Most marinas do not provide telephone connections to the berth and instead combine the telephone service with the public address as a subset of the electrical service. The most important special services of a marina with respect to dock, pier, and wharf systems are fire fighting facilities and the fuel dock.

For proper performance, utility sizing, location, design and construction should conform to methods of accepted practice. This chapter is intended to stress the practical aspects of utility design to insure that the designer does not overlook any of the key items peculiar to the marine environment. Utility subsystems must not be considered "add-ons," but instead should be integrated into the dock design from the planning stage. In addition to accepted practice, however, utilities must also conform to applicable codes. Local regulations are only the first step, as Blanton (1979) notes that many local agencies are not familiar with marina design. To protect against liability, the marina owner/builder should meet national standards as well, providing they are representative of accepted good practice.

While there are some areas of overlap, the electrical, sewage,
water, fire and fuel services are addressed separately in the following pages. The codes or regulations pertaining to each are presented, followed by the design considerations and location details that define accepted good practice.

8.1 ELECTRICAL SERVICE

The electrical system for a dock facility provides support for the slips, dock lights and a communication network. It may well be the most critical of marina utilities for the following reason. While a leaky water or sanitary system is an inconvenience and a health hazard, a leaky electrical system is potentially deadly. Fatal accidents that occur when a well-grounded person (water is an excellent ground) contacts a live electrical circuit are all too common. In the case of the electrical service for docks, piers, and wharves, these accidents can be avoided through attention to design details, and adherence to appropriate codes.

Regulations

While it is recommended that a competent electrical engineer be consulted to design the electrical system of any large marina (Dunham and Finn, 1974), owners of smaller operations may obtain construction permits to allow them to do the work themselves. Their work is then subject to local inspection to see that it satisfies both local and national electrical codes. The State of California (1980) recommends using the more conservative code in case of a conflict.

In the marina environment, only codes for outdoor or damp locations are appropriate. The National Electrical Code (National Fire Protection Association, 1980) is generally accepted as the national code of record for electrical systems not controlled and
maintained by the public utilities (Bernstein, 1979). According to Bernstein (1979), this code has no basis in law unless it is adopted by local jurisdictions. The Code is prepared and revised every three years by the National Fire Protection Association with the latest revision being the 1981 edition. Article 555 of the National Electrical Code is of primary interest since it applies to marinas and boat yards. Two other relevant publications are the "National Electrical Code Handbook" (McPartland, McPartland and McPartland, 1981) and the "Fire Protection Standard for Marinas and Boatyards" (NFPA 303-1975). While the Handbook is based on the current National Electrical Code, it provides additional discussion and illustrations to clarify ambiguous sections. Chapter 5 of the National Fire Protection Association Standard 303-1975 presents information pertaining strictly to marina electrical systems.

**Electrical System and Outlets**

The general purpose electrical system used throughout the United States is the single phase, alternating current, 120/240V, 60 Hz system. 240V, 50 Hz is the electrical standard in Europe. A two-wire cable is used to transmit 120V while a three-wire cable is used for 240V service. The 240V service is preferred when transmitting over long distances because less energy is lost for a given conductor size, and smaller, lighter conductors may be used.

Power outlets are installed at each berth in a dock system as a convenience to the slip renter. Power demand will vary from 20-50 amperes per slip depending on the geographic location and the type
of boat in the berth (Dunham and Finn, 1974). Boat owners in colder areas often use small electric heaters to keep craft warm and dry, thereby using more power (Treadwell and Kycek, 1971). A minimum service of 20 Amperes is recommended by Dunham (1969) while a more recent source (State of California, 1980) suggests 120V/30A service for berths less than 50 ft (15.2 m) and 120V/50A service for berths greater than 50 ft (15.2 m). In the latter case, the boat manufacturers should be consulted since these larger craft may require 240V service (Dunham and Finn, 1974). The outlet selected for installation at a slip should be non-corrosive and waterproof, but not so shielded that the standard twist-lock plugs are hard to insert. Riser racks and locker boxes provide well protected and convenient outlet locations. In the interests of safety, outlets should be located such that an extension cord running to the boat in a berth will not cross a main walkway (State of California, 1980). In place of a fuse or circuit breaker, a ground fault circuit interrupter (GFCI) should be installed to protect each outlet. The GFCI acts both as a conventional circuit breaker and as protection against an accidental low current to a ground outside the circuit (Bernstein, 1979). Since the installation of meters at each slip is considered impractical (Treadwell and Kycek, 1971), the cost of unmetered electrical service should be included in slip rental fees. The charges should then be based on GFCI rating and average usage (Dunham, 1969).

**Lighting**

Dock lighting systems perform two important functions by providing safe access to berthed craft at night, and protecting these craft
and the harbor facilities in general from vandalism. While they may aid an incoming craft in locating the docks from the water, navigation and channel markers are usually furnished for that purpose. Dock lights are typically set on standards 8 to 12 ft (2.4 to 3.7 m) tall (Chaney, 1961). Some authorities, however, permit only low level (30 in. or 0.76 m above deck) lighting (Dunham, 1969). Lights must be carefully designed to provide uniform intensity over the dock without excessive glare on the water which could interfere with night-time navigation. Chaney (1961) recommends a minimum light intensity of 0.5 ft-candle and suggests that 300 watt lights, set on standards 10 ft (3 m) high and spaced 75 ft (22.9 m) apart, should be sufficient. A separate circuit should be used for dock lights, with switches located in the administrators office to control each pier independently. Red colored lights should be used to identify fire fighting equipment.

Communications

The communication systems used in marinas may range from a simple public address system to phone jacks installed at each pier. Communication lines carry very little current and are necessarily a separate circuit from lights or power outlets. Unlike lighting or power circuits, however, they can be installed after the berthing system is in service without much difficulty.

Conduit and Circuit Design Considerations

Shoreside utility lines are almost always buried. Over-the-water electrical lines may either be run overhead on insulated supports, or in conduits under the deck. Overhead lines are less
costly to install and repair, but they are unsightly. On the other hand, under deck wiring must be encased in waterproof conduits to minimize damage in case of flooding. While the under deck location is more expensive, it provides good protection for the wires and is more attractive (Chaney, 1961). Electrical conduits should be non-corrosive, waterproof, and located for ease of repair (Dunham and Finn, 1974). They should also be large enough in diameter so that the wires are easily "fished" through them without sticking. Common locations for conduits are in a covered utility trough down the center of the deck, a central chase with pull-boxes, or hung under the walers on the outside of the structure (Figure 8.1). Curry (1979) states that deck troughs are the "best solution" and are worth the extra cost. Grounding plates that hang in the water have been used in the past to avoid running a ground wire back to a suitable land ground. These should be avoided since they may cause electrical currents in the water that damage propellers and other metal parts (Dunham, 1969).

Conductor size is one of the most important aspects of electrical circuit design. Conductors that are too large are needlessly expensive while undersized conductors are a potential fire hazard. Conductor size depends on the electrical load it must carry (measured in amperes), the circuit length, and the allowable energy losses. The National Electrical Code (National Fire Protection Association, 1980) and Wiring Simplified (Richter, 1977) are recommended references for the design of marina electrical systems (Bernstein, 1979).

8.2 Sewage Pumpout and Disposal Service

Sewage pollution in the marina has been called a "topic suffering
A. General (State of California, 1980, p. 19)

B. Electrical Plan (Dunham, 1969, p. 123)

Figure 8.1 Location of Electrical Utilities
from overkill" (Ross, 1976) and "the greatest non-issue that has ever been raised" (Chamberlain, 1979). Theoretically, small-craft could cause a serious pollution problem by discharging toilets or "heads" within the confines of the marina, thereby raising the level of fecal coliforms and the potential for disease carrying pathogens (Chmura and Ross, 1978). In fact, recreational marinas are little more than parking lots for empty boats, and when these boats are in use (i.e., engines running and toilets flushing), they are out of the marina and their pollutants are dispersed in ratios of billions-to-one (Ross, 1976). Nixon, Oviatt and Northby (1973) report that with respect to raw sewage from pleasure craft, "No impact on the marinas could be detected". Cited as evidence is the case of the city of Newport Beach, California, where water samples are taken twice a week, year-round. While its harbor accommodates 8,000 pleasure craft, the beaches have never been closed because of boat sewage. Nixon, Oviatt and Northby also state that in some areas the background levels of coliforms resulting from land-based sewage input were so high that no boat-related impact could be detected.

For better or worse, environmentalists and concerned health officials have lobbied for and achieved regulations requiring contained systems or chemical toilets. Contained systems require support facilities to remove and dispose of the wastes they collect. Chemical toilets release physically and chemically treated sewage, and according to Chmura and Ross (1978), the environmental impact of the chemicals used may be more harmful than raw sewage. Chamberlain (1979) suggests that the sewage problem should be a part of site evaluation since marinas may be required to meet water quality standards that are not
achievable because of existing problems. The discussion that follows presents the marina designer with the regulations that pertain to sewage pumpout facilities, design considerations concerning the facilities themselves, and finally factors affecting the recommended location of such facilities.

Regulations

On the federal level, the Coast Guard and the Environmental Protection Agency now require that boats with permanently installed toilet facilities be equipped with marine sanitation devices (Chmura and Ross, 1978). These marine sanitation devices (MSD’s) are separated into three type categories. Type III devices are designed to prevent any discharge of sewage (i.e., holding tanks) and are required on inland waters since these waters are used for drinking supplies. Chemical toilets (Type I and II MSD) are required on marine and navigable waters. The treated sewage released by these toilets must meet state and local water quality regulations as well as the Department of Interior Federal Water Pollution Control Administration standards (Quinn, 1972). As a result of these stringent requirements, the modern marina must provide pumpout facilities to handle and dispose of waste from boats. Chmura and Ross (1978) report that such facilities are very limited and marina operators should be encouraged to provide more of them. A minimum of one shoreside pumpout station is recommended for each marina (State of California, 1980).

Pumpout and Disposal Systems

The marina planner has a number of options concerning the sewage