4.2.1—Wood Sheathing

Wood sheet piles are constructed from wood planks 2 to 4 in. thick, 8 to 12 in. wide, with lengths varying up to 24 ft. In their simplest form, the planks are driven with the narrow edges abutting. The connections may consist of mill-cut tongue and grooves or the planks may be staggered and nailed together to form lapped joints. Wakefield type sheeting is constructed by nailing together three rows of planks, with the center row offset to obtain lapped joints. These various schemes for constructing wood sheeting are illustrated in Figure 4.2.1-1.

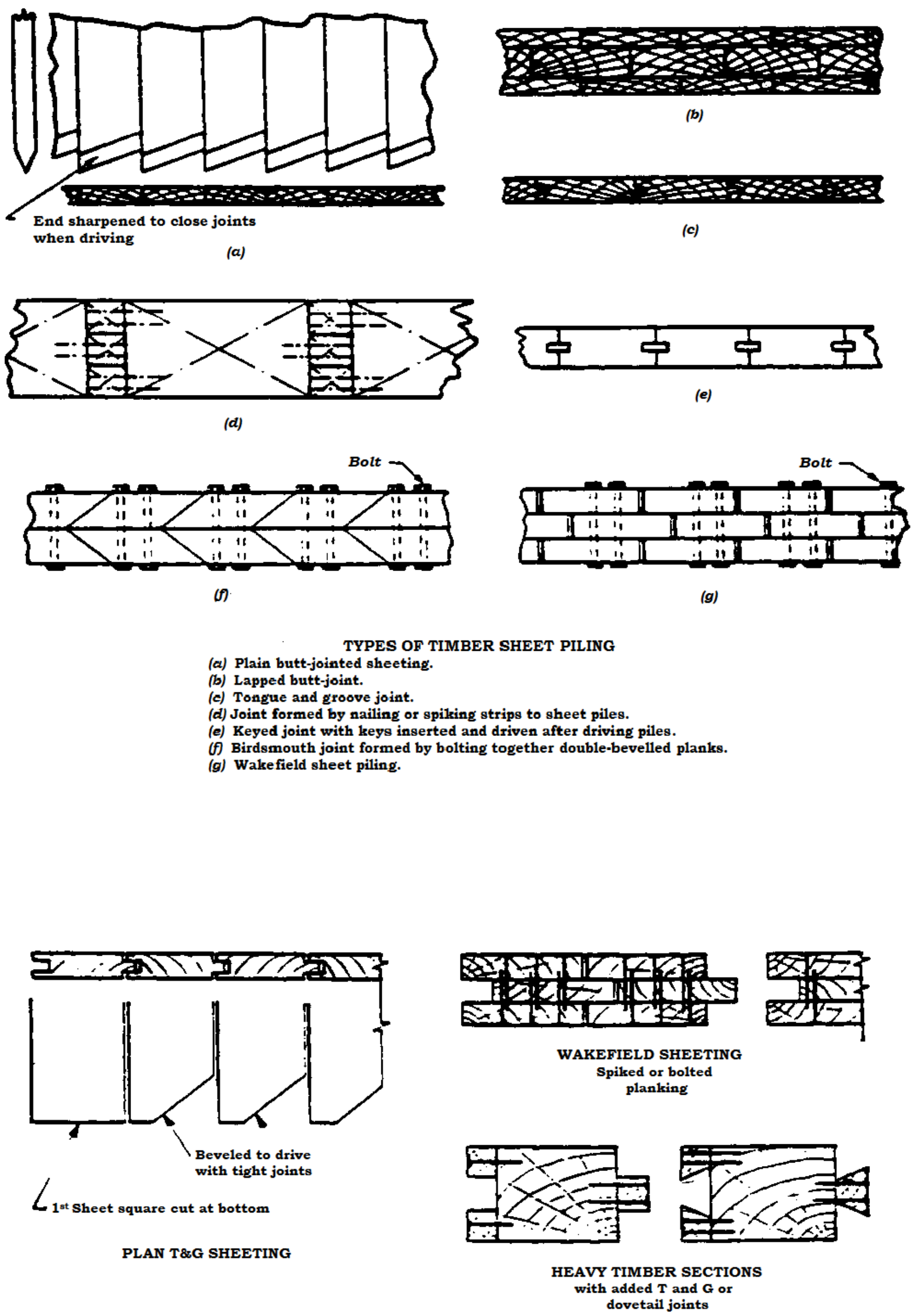


Figure 4.2.1-1—Types of Wood Sheet Piling [32]

In order to drive wood piles into soil, the lower end of the piling is beveled and provided with a driving shoe made of $^{1}/_{16}$ to $^{1}/_{8}$ in. thick metal. Even so, this type of sheeting is hard to drive into very stiff and dense formations. Also, wood sheeting can span only limited lengths and therefore requires fairly cumbersome bracing. When a single plank 3 to 4 in. thick is used, bracing is required at a 4 to 7 ft spacing. Bracing may be spaced at larger intervals if heavy or built-up members are used.

4.2.2—Soldier Piles

Soldier piles are isolated vertical elements, usually spaced at 5 to 10 ft, and driven or set in predrilled holes and backfilled with lean grout or concrete. The soil between the piles is supported by lagging, shotcrete, or cast-in-place reinforced concrete. The soldier piles must carry the full earth pressure, while the lagging must resist earth loads that are relatively minor due to the soil arching effects. Because of this soil arching phenomenon, lagging is designed empirically for a soil pressure reduced by 50 percent or more. The design of the lagging may also be based on experience for the type of soil and span. A table giving recommended lagging thicknesses is included in Appendix C.

The most common soldier piles are rolled steel shapes, bearing piles, or H-sections. However, soldier piles can be formed from precast sections, steel pipes, rails, double channels, or even sheet piles. Wood lagging, usually 2 to 4 in. thick, is the most common element used to span between the soldier piles. Lagging can also consist of light steel sheeting, corrugated metal, or precast concrete planks. Lagging can also be placed behind the back flange. However, this reduces the soil arching effects and is therefore not a desirable method. Some schemes for attaching the lagging to the piles, such as Contact Sheeting, are patented. Lagging placed behind the front or back flange stays in position by soil pressure. Various soldier pile shapes and methods for attaching lagging are shown in Figures 4.2.2-1 through 4.2.2-3. Other schemes can be devised to suit a particular field situation. Spacers are often placed between the lagging boards to allow drainage of seepage and backpacking of overcut zones. The space is sometimes filled with excelsior, hay, or a geotextile to prevent soil washout.

In hard clays, shales, or cemented materials, lagging can be omitted or only a skeleton system provided (widely spaced lagging), if the soldier piles are spaced sufficiently close. Spalling of the soil can be prevented by attaching wiremesh to the soldiers. Soil raveling can also be controlled by spraying a bituminous compound or shotcrete.

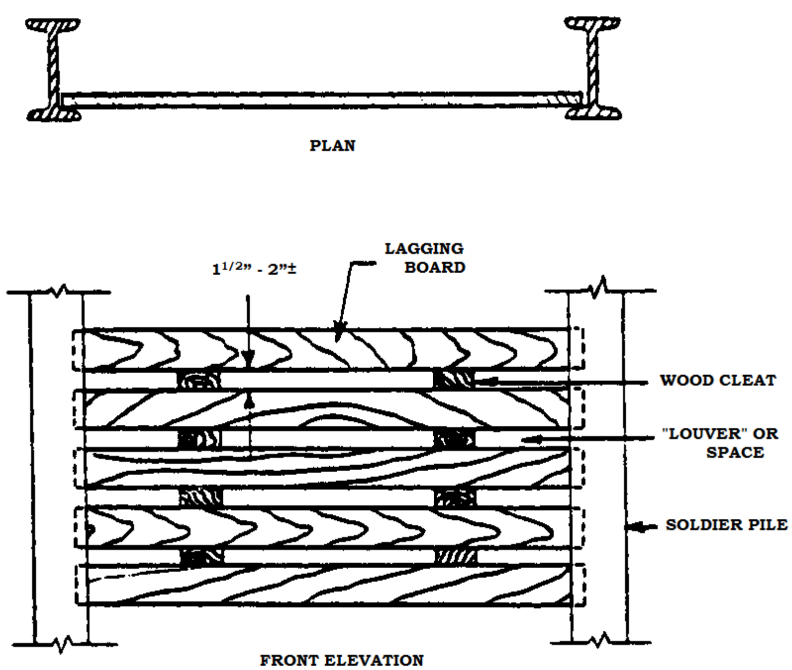
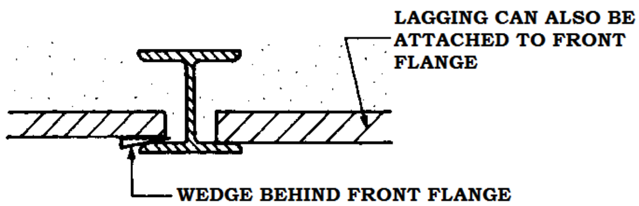
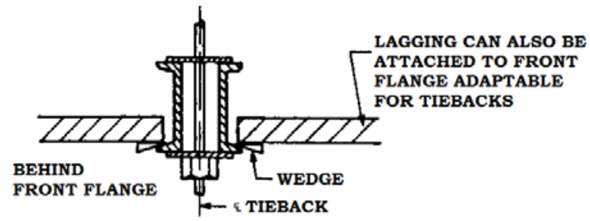


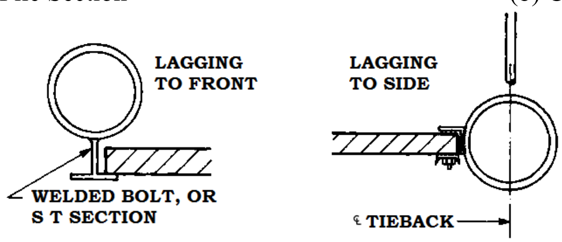
Figure 4.2.2-1—Louver Effect for Wood Lagging [33]



(a) WF Section of H-Pile Section

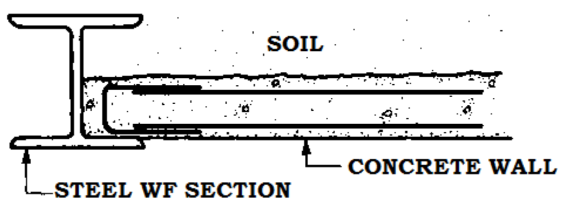


(b) Channel Section

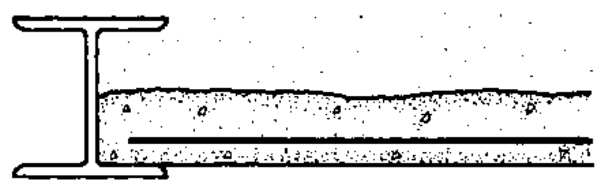


(c) Pipe Section

Figure 4.2.2-2—Steel Soldier Piles (33)

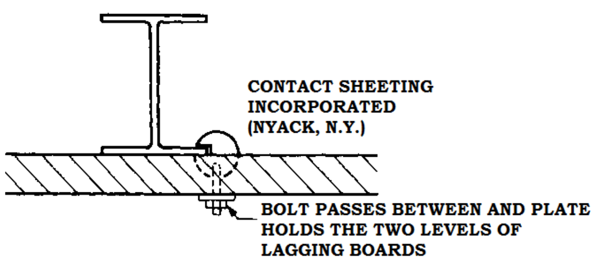


(a) Cast-in-Place

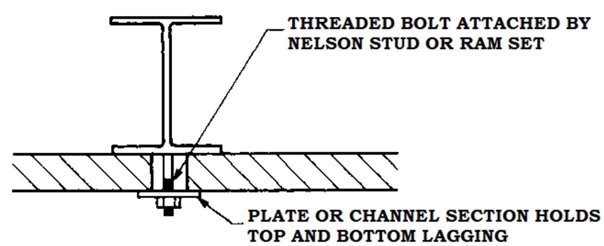


(b) Shotcrete

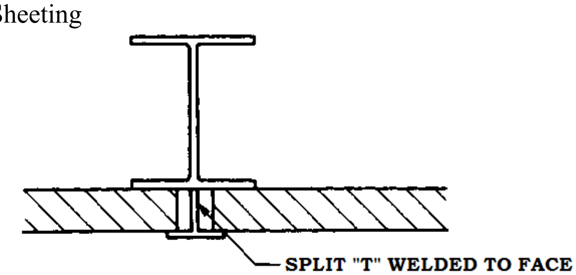
Figure 4.2.2-3—Concrete In-Fill between Soldier Piles (33)



(a) Contact Sheeting



(b) Bolt



(c) Split T-Section

Figure 4.2.2-4—Wood Lagging to Front Flange (33)

4.2.3—Steel Sheet Piles

Steel sheet piles are rolled Z-shaped or arch-shaped members, with interlockings to engage each other. A variety of steel sheet piles are available in different forms from various manufacturers. Hot-rolled and cold-rolled sections are manufactured with various types of interlocks. Generally, hot-rolled sections have stronger interlocks and tighter joints as compared with cold-rolled shapes. Pieces at corners and joints are fabricated by riveting, bolting, or welding. Common sheet pile shapes are shown in Figure 4.2.3-1, and section properties of some common sheet piles are included in Appendix D. Further information on specific sheet piles can be obtained from the manufacturers' catalogs. If sheet piles from various manufacturers or different shapes are mixed, their interlocking capability should be verified. If adjacent sheet piles are to be installed at an angle to one another, the maximum angular change that can be accommodated by the interlocks should be verified by the manufacturer. Straight sheet piling permits about a 10 degree angular change. For larger changes, bent sheet piling can be utilized. The arch-shaped sheet pile sections (PDA and PMA) interlock at the mid-line of the wall, whereas the Z-sections or the straight web sections interlock on the inside and outside line of the wall.

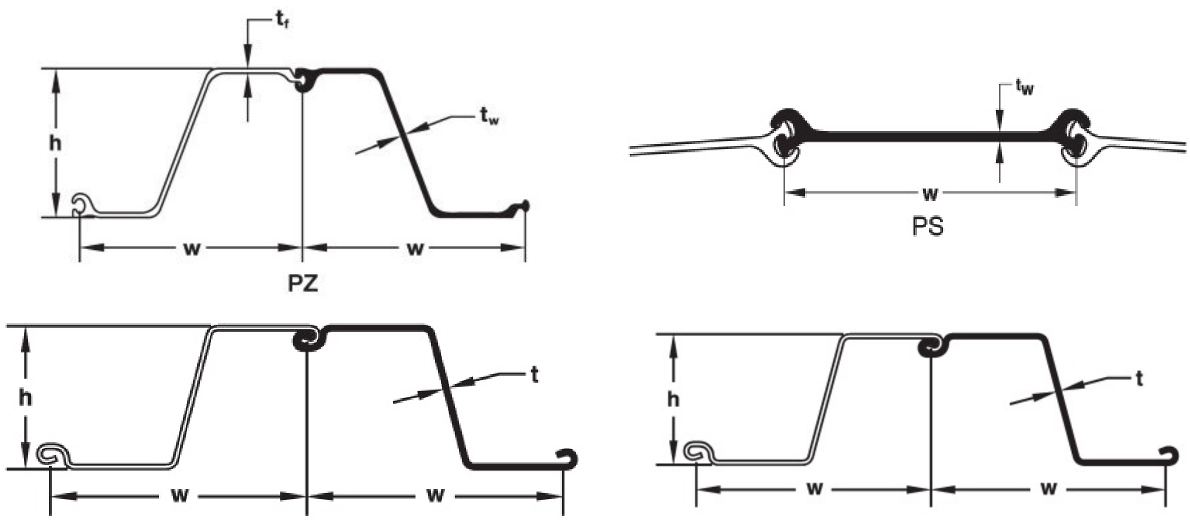


Figure 4.2.3-1—Typical Steel Sheet-Piling Sections [34]
Note: This figure was reproduced, with permission, from Skyline Steel Corporation.

4.2.4—Tangent Piles

Tangent or contiguous piles consist of a single row of tangentially touching piles. The piles are constructed by drilling and backfilling with concrete. In water-bearing soils, the hole may be drilled using bentonite slurry and the concrete placed by the tremie method. Reinforcement may consist of a cage of several rebars, a single bar, or a wide flange or I-beam section placed in the hole before concreting, or mucked in the wet concrete if no rebar cage is used. A watertight connection is not usually obtained because small gaps of up to a couple of inches could remain between adjacent piles. A closed joint can be achieved by constructing alternate piles, followed by intermediate ones that cut away a part of the first piles. This system is usually referred to as a "secant-pile" wall. Another method of achieving a tight system is to install a second row of smaller piles behind the first row (see Figure 4.2.4-1 for layout of piles).

A concrete diaphragm wall is a continuous concrete wall built downward from the ground surface. The wall may consist of precast or cast-in-place concrete panels cast within a trench that is stabilized with bentonite slurry as the excavation proceeds. The trench is usually 24 to 36 in. wide and is excavated using a clamshell bucket or by a rotary cutting system within guide walls that range in lengths from 10 to 20 ft. After an individual panel is excavated, the trench is cleared of sediments at the base and those suspended in the slurry by a desanding process. A reinforcing cage is then inserted in the trench. End stops are installed at the ends and concrete is placed by the tremie method. Soon after the initial set of the concrete, the end stops are removed. Slurry walls constructed by Hydromill do not require end stops. The Hydromill cuts into the adjacent panel to form the joint. Once the concrete is set and attains a specified strength, neighboring panels can be excavated. In one system, precast concrete panels are inserted in the excavated trench and the remaining bentonite slurry is replaced by bentonite-cement slurry. The slurry attains a strength of 200 to 600 lb/in.^{2}, which is better than the adjacent soil.

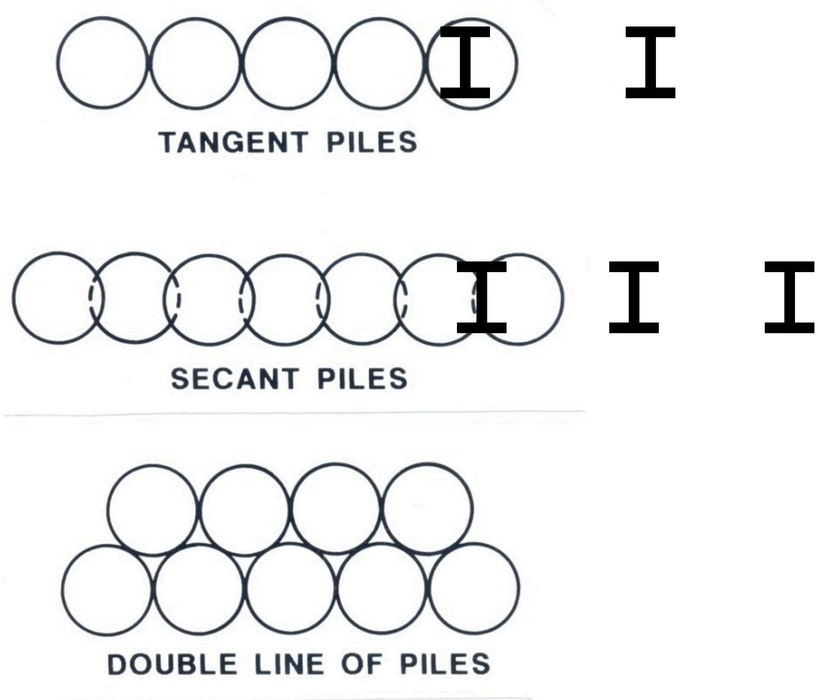


Figure 4.2.4-1—Typical Pile Arrangements

4.3—SELECTION OF COFFERDAM SCHEME

Size and layout of the cofferdam will depend on the shape and size of the foundation and the layout of the supporting piles and foundation seal, if any. The entire construction must be accommodated within the cofferdam, including any batter piles. Where space is available and soil conditions are suitable, a sloping cut can be made to the foundation level or to a higher level to reduce the depth of the cofferdam.

Factors that should be considered in the selection of a cofferdam scheme are listed below:

- Soil type and strength
- Ground water
- Relative cost of the system
- Available installation equipment
- Local experience
- Static or flowing water
- Tolerable movement
- Space available for benching and sloping cuts and external anchorage
- Environment and neighboring conditions
- Construction staging
- Duration of the work
- Interference with existing facilities and obstructions
- External loading (e.g. from railroad surcharge, barge impact, currents, etc.)
- Availability of materials
- Size of internal structure (foundation, batter piles, etc.)

Wood sheeting is suitable only for relatively shallow depths. It cannot be driven very hard and so it is often driven as the bottom is excavated, especially in stiff and dense soils. Some overdigging may occur behind the sheeting, and so wood sheeting is appropriate only in cohesive soils that can stand temporarily unsupported. As the sheeting is pushed down, it slides against the walers and the face of the excavation. It is necessary to backfill all voids soon after the sheeting is installed.

Soldier piles and wood lagging are suitable for use in cohesive soils, except when the soils are soft or loose and have a tendency to flow after exposure and before the lagging boards can be installed. Usually this system is not suitable for wet granular soils unless they are predrained. However, predraining may be difficult when the wet soils (silts, sands, gravel, etc.) overlay an impervious stratum or rock. Installation of wood lagging requires some overcut behind the lagging, which causes additional ground movements in the retained soil.

Interlocking steel sheet piles are most commonly used when a water cutoff is required. Although seepage through the interlocks will occur, the amount of ground water flow will be reduced. Sheeting is also used to provide a cutoff below the excavation level or to reduce seepage gradients below the bottom of the excavation. Where rock exists within the excavation, a tight seal may be difficult to attain between the toe of the sheeting and the top of the rock. The presence of boulders or obstructions can lead to ripping of sheet piles or jumping of interlocks, which will seriously impair the effectiveness of the sheet pile wall. Steel sheeting walls are most often used for water-retaining cofferdams built in soft clays, organic soils, silts, wet granular soils, and dilatant soils of low plasticity for which a soldier pile scheme is inappropriate. Hard driving conditions may preclude the use of sheet piles and suggest predrilled soldier piles, slurry construction, or tangent piles.

Cast-in-place diaphragm walls are suitable for virtually any type of soil. However, their use for temporary bridge construction is rare due to high costs and the permanent nature of this type of cofferdam. Their use would be more economically feasible if they could be combined with the permanent structure elements, such as abutments and wing walls, or counterweight pits or anchor pits for cable suspension bridges. Diaphragm walls with precast concrete elements are rarely used for bridge temporary works.

Contiguous or tangent piles are constructed by boring or drilling a circular hole (generally 12 to 36 in. in diameter), placing a reinforcing cage or a steel beam, and backfilling with concrete. Reinforcing elements may be placed in alternate piles or every third pile, depending on design requirements. This system is useful in dense or extremely dense wet granular soils in which it would be difficult to drive sheet piles. The system is, of course, more attractive if it is incorporated into the permanent structure for a load-bearing or retaining wall.

A true caisson is typically a prefabricated boxlike structure that is sunk from the ground or water surface to the desired depth. Its use is more common in marine construction where it can be installed in a predredged location and then sunk by removing soil from inside without dewatering. The most common shapes are circular and rectangular, with compartments for bridge piers of all sizes. For smaller sizes, the shell may be of steel, reinforced to prevent buckling. Larger sizes are made of reinforced concrete with a steel cutting edge consisting of angles and plates. After installation to the required stratum, it will typically form a permanent deep foundation or bridge pier. These are useful in relatively shallow [15 to 30 ft deep] foundations where the soil or rock is too hard for sheet pile driving, or in highly porous soil that cannot be dewatered by conventional methods. They are not suitable for very deep excavations, or where the skin friction on the walls of the caisson is excessive for sinking, or the foundation structure is a sloping rock surface. Great care is still required to ensure even sinking to the required depth to overcome friction and to prevent tipping which may be hard to correct. The caisson bottom will need to be properly sealed prior to dewatering by placing tremie concrete of sufficient thickness to withstand the hydrostatic pressure. A complicated marine installation of a caisson can sometimes be converted to a land job by creating a sand island at the pier site. The island is made by earth filling to a level above the high-water level. Thereafter, a more conventional cofferdam of driven steel sheet piles can be installed.

4.4—RELATIVE COSTS

Relative costs of the various cofferdam systems are typically in the following ascending order:

- Wood sheeting
- Soldier piles and lagging
- Steel sheet piles
- Drilled in soldier piles and cast-in-place concrete or shotcrete
- Contiguous or tangent piles
- Cast-in-place diaphragm walls
- Caissons

4.5—SELECTION OF SUPPORT METHOD

The simplest support system is a cantilever wall, where the wall element (sheeting, soldier pile, pile, or diaphragm wall) is installed to a sufficient depth in the ground to become fixed as a vertical cantilever. This type is suitable for a moderate height, generally less than 15 ft., where the embedding medium is sufficiently strong to restrain the wall. The embedment length should be designed to accommodate any scour or erosion in front of the wall.

For deeper cofferdams, or those with insufficient or inadequate subgrade soils, a bracing system is required. A conventional internal bracing consists of walers and struts. Various layouts of struts are possible to suit the shape of the cofferdam and desired open space. For a relatively wide excavation, the wall can be braced with inclined rakers reacting on a deadman or on one or more foundation units connected by grade beams. A circular cofferdam can be braced with compression rings of rolled-steel W-shapes or by cast-in-place reinforced concrete beams. These beams will require lateral support.

A self-supported system or an externally braced system provides an unobstructed working area. For narrow cofferdams, internal bracing is usually more economical although it may restrict working space. Grouted soil anchors are feasible in granular soils that are at least medium density and in cohesive soils with unconfined strengths of over 1.5 ton/ft^2 and where sufficient space is available for anchorage beyond a 45 degree slope from the bottom of the wall. For installation of grouted anchors, a bench about 50 ft wide is required for the anchor installation equipment.

Ground freezing can be used as a means of ground support, water cutoff, or a combination of both. However, the process of ground freezing is expensive and takes a fairly long time. Unless other systems cannot be used, this method may not be a viable scheme for bridge temporary works.

Ground stabilization using chemicals is also not a common method for cofferdams in bridge temporary works. However, grouting is utilized for minimizing seepage through sheet pile interlocks and where the sheet pile or other retention system has been damaged by obstructions or hard-driving resistance.

4.6—SEALING AND BUOYANCY CONTROL

When conditions are encountered that render it impractical to dewater a cofferdam for the construction of the structural unit, a foundation seal is usually placed under water to resist buoyancy, act as a lower support for the sheet piles, tie the driven piles together to resist uplift, and provide subsequent support for the construction of the pier footing. Foundation seal concrete is placed underwater by the tremie method. The size and thickness of the seal concrete should be sufficient to permit subsequent dewatering without the risk of buoyancy.

For tremie concrete, the mix selected should be highly flowable. A slump of 6 to 8 in. is desirable. Coarse aggregate should be under $^3/_4$ in. and preferably rounded for better workability. An appropriate mix design and trial batches should be prepared. Air entrainment is not necessary. Use of pozzolan as a partial replacement for cement improves flow and reduces heat of hydration.

Placement of tremie concrete is best initiated in a sealed tube or tremie pipe 10 to 12 in. in diameter. The bottom is closed by a plate with a gasket, tied to the pipe with twine. The plate is held in place tightly by the static pressure of water as the pipe is lowered. Concrete is placed into the pipe, just sufficient to balance buoyancy. The pipe is then raised about 6 in. off the bottom. This is usually sufficient to break the seal and the concrete flows out. Additional concrete is constantly kept flowing into the tremie pipe. The concrete continues to flow out and fill the cofferdam, maintaining a surface slope of about 6 (horizontal):1 (vertical) to 10 (horizontal):1 (vertical). The tip of the pipe must be kept immersed a depth of 3 to 5 ft in the concrete. If the tip is raised out of the concrete, the seal will be lost, the flow rate will increase, and water will be mixed with concrete, causing segregation and loss of strength.

The tremie pipe layout and sequence should be such as to maintain acceptable flow distances of about 25 to 35 ft and to prevent cold joints. The latter requires relatively high pour rates of about 50 to 100 yd^3/h. Retarding admixtures have been found to be helpful in preventing cold joints. The tremie concrete surface will be somewhat irregular, with a mound at the location of the tremie pipe. The valleys can be filled after dewatering, when any laitance is also removed. Horizontal lifts are not desirable in a tremie concrete placement as the surfaces will have laitance. If a large cofferdam is to be subdivided, it should be done with a vertical bulkhead.

Buoyancy is resisted by the weight of the seal concrete, the cofferdam elements (if they are anchored with the seal), and from uplift resistance of the foundation piles embedded in the seal. However, the weight of the cofferdam elements should not be included in the resistance of hydrostatic uplift pressures unless a positive means of connection with seal is provided. Also, since it is difficult to estimate the frictional resistance of sheet piles and to engage all of the sheet piles in the seal, the resistance of the sheet piles to buoyant forces requires conservative design assumptions and adequate safety factors. When conditions are encountered that render it impractical to place seal concrete of sufficient thickness to resist buoyancy, additional resistance can be provided by rock or soil anchors drilled to sufficient depth below the seal and embedded in the seal or anchored to it. Anchors can be installed through sleeves cast in the seal and grouted after the anchors have been preloaded.

Where the foundation is supported on the subgrade soils, it will be necessary to remove all disturbed soil from the excavated subgrade. In underwater excavation this is difficult to verify. Dry excavation is possible only in cohesive soils or in cohesionless soils if the water table is sufficiently depressed. Even if the disturbed soil is removed while it is dry, piping and sloughing can occur under any seepage head. Hence, the subgrade should be protected by placing a layer of clean gravel or crushed rock. Flooding of the cofferdam to a level equal to the outside water level will also ensure subgrade integrity.

4.7—SEEPAGE CONTROL

When the water level outside the sheeting is higher than the excavation level within the cofferdam, the water percolates through the soil behind the sheeting and then upwards in front of the sheeting. The upward seepage reduces the effective weight of the soil and consequently the passive resistance. Seepage forces per unit volume equal the unit weight times the seepage gradient. When the gradient is high, seepage forces can equal the buoyant weight, and sand boiling or piping can occur. Piping is controlled by dewatering outside the cofferdam (lowering the water table), by pressure relief using dewatering wells within the cofferdam, and by use of a cutoff (extending sheeting deeper to reduce gradients). Deepening of the cutoff is particularly effective if the toe is embedded in an impervious layer that will stop or reduce flow around the bottom of the cutoff. The design of sheeting penetration to control piping for various subsurface conditions is presented in Figures 4.7-1 and 4.7-2.

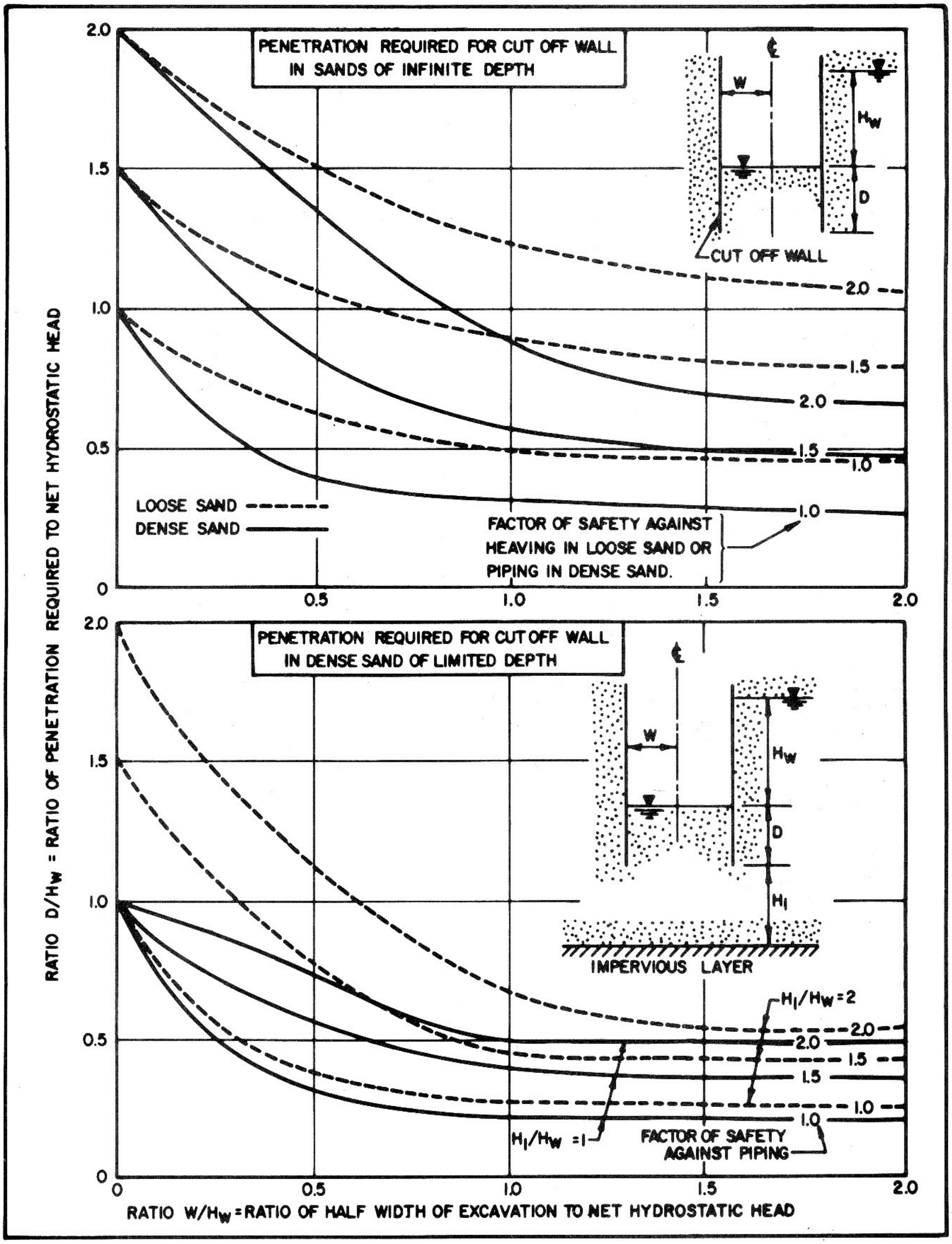


Figure 4.7-1—Penetration of Sheeting Required to Prevent Piping in Isotropic Sand [20]

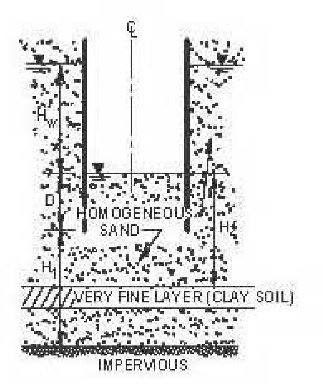


Figure A

FINE LAYER IN HOMOGENEOUS SAND STRATUM

IF THE TOP OF FINE LAYER IS AT A DEPTH GREATER THAN WIDTH OF EXCAVATION BELOW CUT OFF WALL BOTTOM, SAFETY FACTORS OF FIGURE 4.7-2B APPLY, ASSUMING IMPERVIOUS BASE AT TOP OF FINE LAYER.

IF TOP OF FINE LAYER IS AT A DEPTH LESS THAN WIDTH OF EXCAVATION BELOW CUT OFF WALL TIPS, PRESSURE RELIEF IS REQUIRED SO THAT UNBALANCED HEAD BELOW FINE LAYER DOES NOT EXCEED HEIGHT OF SOIL ABOVE BASE OF LAYER.

IF FINE LAYER LIES ABOVE SUBGRADE OF EXCAVATION, FINAL CONDITION IS SAFER THAN HOMOGENEOUS CASE, BUT DANGEROUS CONDITION MAY ARISE DURING EXCAVATION ABOVE THE FINE LAYER AND PRESSURE RELIEF IS REQUIRED AS IN THE PRECEDING CASE.

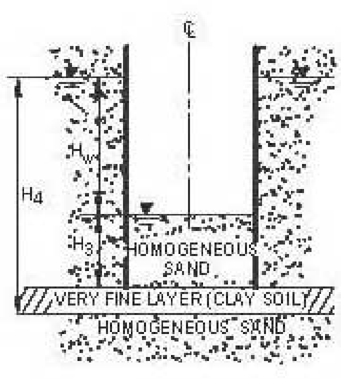


Figure B

TO AVOID BOTTOM HEAVE, Y_T x H_3 SHOULD BE GREATER THAN Y_W x H_4.

Y_T = TOTAL UNIT WEIGHT OF THE SOIL

Y_W = UNIT WEIGHT OF WATER

Figure 4.7-2—Penetration of Sheeting Required to Prevent Piping in Stratified Sand [20]