

Chapter 10

Marine Installations

Introduction

Since the early 1960's, just a few years after its first introduction, polyethylene (PE) piping has been increasingly used for various marine applications such as effluent outfalls, river and lake crossings, and fresh and salt-water intakes. Immunity to galvanic corrosion is a major reason for selecting PE. The combination of air and water, but particularly seawater, can be very corrosive to ordinary metallic piping materials. But other beneficial features, as follows, combine to make PE piping particularly well-suited for marine applications:

Light weight – For a given pipe diameter and equivalent performance requirements, the weight of PE pipe is around one tenth of the weight of concrete pipe and less than one half that of cast iron. Handling of PE requires a minimum of heavy equipment.

It floats – Because PE's density is about 96% of that for fresh water, and about 94% of that for sea water, PE pipe floats even when full of water. Long lengths can be assembled on shore where the empty pipe may be weighted to an extent that allows air-filled pipe to be floated to its intended location, and in most cases, is also sufficiently weighted to keep it anchored at its final submerged location after the air has been replaced with water.

Integral, "bottle-tight" joints – By means of the butt fusion method, continuous lengths of PE pipe can be readily assembled without the need of mechanical fittings. The resultant heat fusion joints are as strong as the pipe, and they eliminate the risk of joint leakage.

Flexibility – The flexibility of PE pipe allows it to be gradually sunk and to adapt to the natural topography of underwater surfaces. This results in a more simplified sinking procedure, and it also means that the flexible pipeline can normally be placed directly on the natural bottom without any trenching or other form of preparation of continuous level support.

Ductility (strainability) – Because of its relatively high strain capacity, PE piping can safely adjust to variable external forces generated by wave and current action. High strain capacity also allows the PE piping to safely shift or bend to accommodate itself to altered bedding that can result by the underscoring that may sometimes occur with strong wave and current actions.

Conventional, non-flexible materials such as concrete or iron pipe can only afford relatively small deformations before risking leakage at, or structural failure of, the joints. As the exact magnitude of the maximum forces that can act on rigid pipes is difficult to predict, installations using piping that only allows relatively small deformation at the joints, or limited bending strain in the pipe, requires a large “safety factor,” such as a relatively heavy loading to stabilize the pipe against movement, or the trenching of the pipe into sea bed sediments so as to stabilize it against movement that can result from heavy sea action. Such construction techniques tend to be more difficult, time-consuming and relatively expensive. In contrast, the flexibility and ductility of PE allows it to adapt to unconsolidated river and sea bottoms, and also to safely shift or bend under the forces resulting from occasionally strong currents or other actions. For most marine installations, PE piping needs only to be sufficiently weighted to keep it at the intended location and to prevent it from floating. This results in easier and less costly installations and in a submerged piping system that is capable of delivering very reliable and durable service. By choosing PE pipes, many projects have been accomplished which would not have been economically realistic with traditional piping materials. The lower overall cost of PE piping installations allows for the option of installing several small outfalls rather than one large one. Multiple outfalls can achieve greater environmental protection by the discharging of smaller quantities of effluent at separated points of discharge, and their use often results in lower onshore pretreatment costs.

A marine pipeline installation may involve considerable risk to the pipeline integrity both during installation and while in service. Guidance provided herein on the design and installation of PE piping is limited to those issues that are specific or are related to this

material. It is not the intent of this chapter to cover the many other design, construction and safety issues that need to be considered in a marine installation.

The primary focus of this chapter is the design and installation of underwater lines by the “float-and-sink” method that is made possible through the use of the light-in-weight and flexible PE pipe. Under certain conditions – such as when it is not possible to delay navigation long enough to launch and sink a pipeline – it may be necessary, or it may be more practical, to use a variation of the “float-and-sink” method that is herein described. In one variation, one or more separate long-segments of the pipeline with a flange at each end are assembled and floated. These segments are then sunk, properly positioned and bolted together by divers. Another alternative method is the “bottom-pull” method, which is briefly described at the end of Step 8. However, regardless of which method is used, the general design and installation principles that apply to the “float-and-sink” method also apply to alternate methods.

Other marine applications for which PE piping has proven to be very suitable include temporary water surface pipelines, lines installed over marshy soils and lines used in dredging operations. These are described briefly. Design and installation for these marine applications are conducted in accordance with essentially the same criteria and principles as described for the “float-and-sink” method.

The Float-and-Sink Method – Basic Design and Installation Steps

In nearly all underwater applications, the design and installation of PE piping is comprised of the following basic steps:

1. Selection of an appropriate pipe diameter
2. Selection of an appropriate pipe SDR (i.e., an appropriate wall thickness) in consideration of the anticipated installation and operating conditions
3. Selection of the design, weight and frequency of spacing of the ballast weights that will be used to sink and then hold the pipe in its intended location
4. Selection of an appropriate site for staging, joining and launching the pipe

5. Preparing the land-to-water transition zone and, when required, the underwater bedding
6. Assembly of the individual lengths of pipe into a continuous string of pipe
7. Mounting of the ballast weights (This step may be done in conjunction with the next step.)
8. Launching the joined pipe into the water
9. Submersion of the pipeline into the specified location
- 10. Completion of the land-to-water transition**

General guidance for the conduct of each of these steps follows. Since the specific conduct of each step can be affected by the choice of design and installation options discussed in other steps, the reader should review the entire chapter before deciding on the most applicable design and installation program.

Step 1 Selection of an Appropriate Pipe Diameter

Selection of an appropriate pipe diameter involves the estimation of the minimum flow diameter that is needed to achieve the design discharge rate. Guidance for doing this is provided in Chapter 6 of this Handbook.

A confirmation is then performed after the required pipe dimension ratio (DR) is determined in accordance with Step 2 which follows. Since the actual internal diameter of a pipe that is made to a standard outside diameter is dependent on the choice of pipe DR (see Table in the Appendix A.1 and A.2 in Chapter 6), the nominal pipe diameter/DR combination that is finally selected needs to have an actual inside diameter that is at least as large as the above determined minimum required flow diameter.

Step 2 Determination of the Required DR or SDR

The DR of the PE pipe, in combination with the pipe material's assigned maximum hydrostatic design stress, should allow the pipe to operate safely at the maximum anticipated sustained net internal pressure at the maximum anticipated operating temperature. Information, including temperature and environmental de-rating factors, for determining the appropriate pipe DR is presented in Chapter 6 and in Appendix, Chapter 3 of this Handbook. As an added "safety factor" it is common practice to pressure rate the pipe for the maximum anticipated operating temperature of either the internal or external environment, whichever is higher.

A check should be made to ensure that the selected pipe pressure rating is also sufficient to safely withstand any momentary pressure surges above normal operating pressure. Pressure surges tend to occur during pump start-ups or

shut-downs, and also during sudden pump stops caused by emergencies, such as loss of power. Guidance for selecting a PE pipe with sufficient surge pressure strength is also presented in Chapter 6 of this Handbook.

A sudden pump stop can sometimes also result in flow separation, giving rise to a momentary reduction in pressure along some portion of the pipeline. Since underwater pipelines can be subject to relatively large external hydrostatic pressure, flow separation can sometimes lead to a significant net negative internal pressure. A check needs to be made to ensure that the pipe DR that has been selected based on maximum internal pressure considerations is also adequate to safely resist buckling, or pipe collapse, under the largest net negative internal pressure that could ever develop from whatever cause. Guidance for this design check is also provided in Chapter 6 of this Handbook. The ballast weights that are attached to PE pipe for purposes of its submersion also fulfill an important role as ring stiffeners that tend to enhance a pipe's inherent resistance to buckling. Common design practice is to accept this benefit as an added "safety factor," but not to directly consider it in the design procedure for selection of a pipe of appropriate ring stiffness.

Step 3 Determination of the Required Weighting, and of the Design and the Spacing of Ballast Weights

The determination of these parameters is made in accordance with the following sub-steps.

Step 3a Maximum Weighting that Allows Weighted Pipe to be Floated into Place

The buoyant or vertical lift force exerted by a submerged PE pipe is equal to the sum of the weight of the pipe and its contents minus the weight of the water that the pipe displaces. This relationship can be expressed mathematically as follows:

$$(1) \quad F_B = [W_P + W_C] - W_{DW}$$

WHERE

F_B = buoyant force, lbs/foot of pipe

W_P = weight of pipe, lbs/foot of pipe

W_C = weight of pipe contents, lbs/foot of pipe

W_{DW} = weight of water displaced by pipe, lbs/foot of pipe

Since the density of PE (~59.6 lbs/cubic foot) is only slightly lower than that of fresh water (~62.3 lbs/cubic foot) the pipe contributes somewhat towards net buoyancy. However, the major lift force comes from the air-filled inner volume of the pipe. Since, for a pipe of given outside diameter, the size of the inner volume is determined by the pipe's wall thickness – the greater the thickness, the smaller the

inner volume – and since a pipe’s actual wall thickness can be expressed in terms of the pipe’s diameter ratio (DR), Equation 1 can be rearranged as shown in Equation 2. The resultant net buoyancy force can be determined from the pipe’s actual outside diameter, its DR (or SDR), the extent to which the pipe is filled with air, the density of the water into which the pipe is submerged, and the densities of the pipe and of the liquid inside the pipe:

$$(2) \quad F_B = \left[0.00545 D_o^2 \rho_w \right] \left[4.24 \frac{(DR - 1.06)}{(DR)^2} \frac{\rho_p}{\rho_w} + \left(1 - \frac{2.12}{DR} \right)^2 (1 - R) \frac{\rho_c}{\rho_w} - 1 \right]$$

WHERE

F_B = buoyant force, lbs/foot of pipe

D_o = external diameter of pipe, in

D_R = pipe dimension ratio, dimensionless

R = fraction of inner pipe volume occupied by air

ρ_w = density of the water outside the PE pipe, lbs/cu. ft

ρ_p = density of the pipe material, lbs/ cu. ft.

ρ_c = density of pipe contents, lbs/ cu. ft.

The derivation of Equation 2 is presented in Appendix A-1. The reader is advised that Equation 2 does not consider lift forces that can result from water currents; refer to Appendix A-2 for further assistance with this topic.

A more succinct way of expressing the principle embodied in Equation 2 is as follows:

$$(3) \quad F_B = W_{DW} ["K"]$$

WHERE

$$W_{DW} = 0.00545 D_o^2 \rho_w$$

Stated in words, the resultant buoyant force (F_B) is equal to the potential theoretical buoyant force (W_{DW}) times a buoyancy reduction factor (“K”) that takes into account inner pipe volume, degree of air filling and the densities of the pipe and the liquid inside the pipe.

The manner by which the buoyancy reduction factor “K” is affected by a pipe’s DR and the extent to which its inner pipe volume is filled with air, R, is indicated by the calculation results reported in Table 1. The values in this table have been computed based on the following densities: 62.3 lbs/ cu. ft for water both inside and outside the pipe, and 59.6 lbs/cu. ft for the PE pipe material. Using these K-values for approximation of the net buoyant force of a submerged pipeline in which a portion of the line is occupied by air greatly simplifies the calculations involved.

TABLE 1**Typical values of “K” in equation 3.0**

“K” is the fraction of maximum potential buoyancy. The exact value of “K” is determined by the particular combination of pipe diameter ratio (SDR), pipe material and liquid densities and the extent (R) to which a PE pipe is filled with air*

Pipe SDR	Value of “K” as a function of R, the fraction of inner pipe volume that is occupied by air					
	R = 0.10	R = 0.15	R = 0.20	R = 0.25	R = 0.30	R = 1.0 (100% Air)
9	-0.078	-0.107	-0.136	-0.166	-0.195	-0.604
11	-0.081	-0.113	-0.146	-0.178	-0.211	-0.667
13.5	-0.084	-0.119	-0.155	-0.190	-0.226	-0.723
17	-0.087	-0.125	-0.163	-0.202	-0.240	-0.776
21	-0.089	-0.130	-0.170	-0.210	-0.251	-0.817
26	-0.091	-0.133	-0.176	-0.218	-0.260	-0.850
32.5	-0.093	-0.137	-0.180	-0.224	-0.268	-0.879

* The “K” values in this table have been computed using Equation 2 and based on the following assumptions: a density of 62.3 lbs/cu ft for water outside and inside the pipe and 59.6 lbs/cu ft for the PE pipe material. The minus sign before each resultant value of “K” indicates a net upward, or buoyant force.

Step 3b Determining the Maximum Weighting That Still Allows PE Pipe To Float

When a PE pipe that is completely filled with air is weighted so that the submerged weighting is equal to W_{DW} (the weight of the water that is displaced by the outer volume of the pipe) times the appropriate value of “K” (e.g., the value given in the last column of Table 1), that pipe achieves neutral buoyancy – it neither sinks nor floats. Therefore, “K” represents the fraction of pipe displacement that, when counteracted by the placement of external weighting on the pipe, results in neutral buoyancy. With the objective in mind of facilitating a marine installation by the floating of a PE pipe so that it may readily be stored above water and then towed and maneuvered to its intended location, the weighting that is attached to the pipe needs to be limited to an amount that still allows an air-filled pipe to freely float on top of the water. To this end, the practice is to limit the weighting of an air-filled PE pipe to about 85% of the pipe displacement times the “K” value that corresponds to that pipe’s DR and the densities of the pipe material and the water, for example, the “K” values reported in the last column of Table 1. This practice results in the limiting of the weighting of an air-filled pipe that is to be installed by the “float-and-sink” method to a maximum that can vary, depending on the pipe’s DR, from about 57 to 75% of the pipe’s displacement.

Step 3c Determining the Required Minimum Weighting for the Anchoring of a Submerged Pipe in its Intended Location

Fortunately, as indicated by analysis and confirmed by experience^(1,2), in most cases

a weighting of 25 to 50% of the pipe displacement is quite sufficient to maintain a properly anchored submerged PE pipe after it has been filled with water. The lower weighting has been found satisfactory in cases, like in lake crossings, where current and wave action are relatively mild, while the larger weighting is used in sea installations where sea actions are stronger. However, even for pipes that are exposed to normal sea conditions close to the shore, it has been found that a weighting of about 70% of the pipe displacement is quite satisfactory⁽¹⁾. As indicated by the values shown in Table 1, this extent of weighting still allows most PE pipes to float when air-filled.

In an article summarizing the state of the art in utilizing plastics pipe for submarine outfalls, Janson⁽³⁾ reports that, based on past practical experience and theoretical studies, a 40-inch diameter PE ocean outfall line was installed in Sweden where, for depths greater than 40 feet, the pipe was weighted to 25% of its displacement; and in the surf zone, where the waves break and the water depth is about 10 feet, the loading was increased to 60% of the displacement. Closer to the shore, where wave action is at its strongest, it is common to protect the pipe by trenching it. In respect to trenched pipe, Janson also reports that, when a trench is refilled with fine-grained soil, the buried pipe can sometimes float from the trench, apparently a reaction resulting from the fluidization of the fill by strong wave action. This reference further reports that the possibility of floating from fine-grained backfill can be avoided by weighting the pipe to at least 40% of its displacement.

Calculation techniques have been developed for the determination of the required weighting of plastic pipes depending on anticipated current and wave action. A brief overview of the technical considerations upon which these calculations are based is included in Appendix A-2. References for further information are also provided.

In cases where it is indicated that the pipeline, or certain sections of the line, should be weighted to a greater extent than that which allows the pipe to float while filled with air, the attachment of the required ballast weights can be conducted in two stages: preliminary weighting is conducted so as to still allow the pipe to be floated into position, and then the additional required weights are added where required after the completion of the submerging of the pipe. Another option is to temporarily increase the pipe's buoyancy by the use of empty tanks or drums, or large blocks of rigid plastic foamed material that are then released as the pipe is being submerged. A further option, which is illustrated in Figure 1, is to attach the required ballast weights onto the pipe from a barge from which the pipe is slid to the bottom by means of a sled that has been designed to ensure that the bending of the pipe is less than that which might risk buckling (See the discussion on pipe submersion).

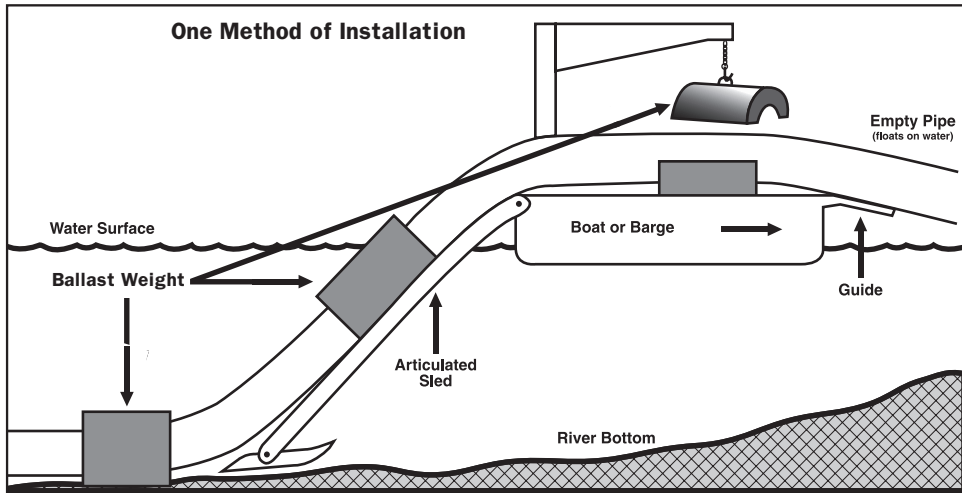


Figure 1 Submerging a heavily weighted pipe from a barge

Step 3d Ensuring that the Required Weighting Shall Not Be Compromised by Air Entrapment

As suggested by the “K” values in Table 1 that apply to pipes that are partially filled with air, even a modest amount of air entrapment can result in a lift force that can significantly reduce the quality of pipe anchorage. For example, if a pipeline is weighted to 25% of the water it displaces and in a section of that pipeline enough air accumulates to occupy just 10% of the pipe’s inner volume, the lift produced by that amount of air will reduce the effective weighting in that portion of the pipeline to about only 15% of the pipe displacement. Such reduction is sure to compromise the stability of that pipe section against wave and current actions. Accordingly, one important objective in the design of the piping system to prevent the entrance and accumulation of air in all portions of the submerged section. In outfall systems, one effective means for achieving this objective is to utilize a surge or “drop” chamber into the system design, as illustrated in Figure 2. Another precautionary measure is to ensure that there are no localized high points along the submerged pipeline that could accumulate air or gases, particularly during periods of low or no flow rate.

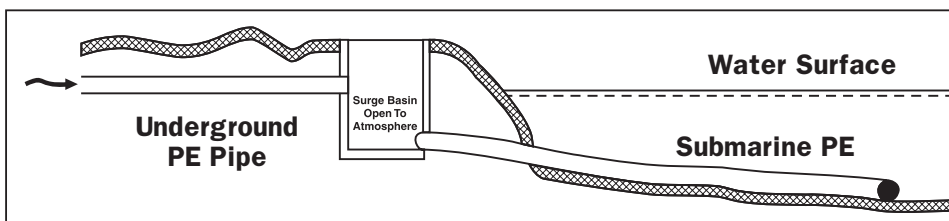


Figure 2 A surge chamber may be used to prevent air from entering a pipeline

In cases where the possibility of some accumulation of air or gas – which may be given off by chemical reactions – cannot be avoided, or where the line may at some time be emptied, it is necessary to add enough ballast weighting to offset the additional negative buoyancy so as to always hold the pipe in its intended location.

Step 3e Determining the Spacing and the Submerged Weight of the Ballasts To Be Attached to the Pipe

The objectives for limiting the spacing between ballast weights are essentially the same as those for establishing the support spacing requirements for above-ground suspended pipelines. In both cases the pipes are subject to a distributed loading – in the case of submerged pipelines, by the combined effect of current, lift and wave actions. The objective of the design is to limit resultant pipe deflection so that the resultant maximum fiber bending stresses and strains are within safe limits. An additional reason for limiting deflection in submerged pipelines is to reduce the chances of forming pockets in which air or gas can accumulate. The lift created by air-filled pockets can, if large enough, compromise the quality of the anchoring of the submerged pipe. Information on conducting the required calculations and on the appropriate limiting values for bending stress and strain is included in the chapter on design. Because of the concern of trapping air, support spacing for submerged pipes is normally delimited by allowable pipe deflection – considerably greater deflection would generally be permitted under the criteria of maximum bending stress or strain.

Listed in Table 2 are commonly used ballast spacings. To satisfy the objective for minimizing air entrapment, the spans in this table are somewhat shorter than for pipes that are suspended above ground. An added benefit of shorter spans is that they better distribute anchoring loads on the sea bottom, which often offers only moderate load bearing capacity. Additionally, these shorter spans minimize the chance of pipe shifting, help smooth out the submersion process and they lead to ballasts that are more manageable both in size and in weight.

TABLE 2
Commonly Used Values for the Spacing of Ballasts

Nominal Pipe Diameter, in	Approximate Spacing (L), ft
Up to 12	5 to 10
Over 12, up to 24	7.5 to 15
Over 24, up to 63	10 to 20

Source: AWWA M55, PE Pipe – Design and Installation, Chp 8: Installation, Denver, Colorado, USA

The required submerged weight of the ballasts can be determined from the following:

$$(4) \quad B_W = W_S \times L$$

WHERE

B_W = weight of ballast in water, lbs

W_S = required submerged weighting by ballasts, lbs per foot

L = center to center spacing between ballasts, feet

The resultant dry weight of the ballast depends on the density of the ballast material as compared to that of the water into which the ballast is to be submerged:

$$(5) \quad B_A = B_W \frac{\rho_B}{(\rho_B - \rho_W)}$$

WHERE

B_A = weight of ballast in air, lbs

ρ_B = density of ballast, lbs/cu. ft (~144 lbs/cu ft for plain concrete, ~ 150 for reinforced)

ρ_W = density of water, lbs/ cu ft (~62.3 lbs/cu ft for fresh water, ~64.0 lbs/cu ft for sea water)

Since the weight of a ballast cannot be closely predicted or readily adjusted, it is more practical to tune in the final weighting to the required value by adjusting the distance between ballasts of known weight. To this end the following formula, derived by combining Equations 4 and 5, may be used:

$$(6) \quad L = \frac{B_A (\rho_B - \rho_W)}{W_S \rho_B}$$

Step 3f Design and Construction of Ballast Weights

To prevent cracking of ballasts when handling, tightening and moving PE pipe, they are typically made of suitably reinforced concrete. Ballasts can be made to different shapes, although a symmetrical design such as round, square, or hexagonal is preferred to avoid twisting during submersion. Flat-bottomed ballasts are preferred if the submerged piping is likely to be subjected to significant currents, tides or wave forces because they help prevent torsional movement of the pipe.

Also, when such conditions are likely to occur, the ballasts should place the pipeline at a distance of at least one-quarter of the pipe diameter above the sea or river bed. The lifting force caused by rapid water movement that is at a right angle to a pipe that rests on, or is close to a sea or river-bed is significantly greater than that which acts on a pipe that is placed at a greater distance from the bed. This means that ballasts designed to give an open space between the pipe and the bed will give rise to smaller lifting forces.

For example, in accordance with the calculation procedure developed by Janson (See Appendix A-2), the lifting force that develops on a 12-in PE pipe that is resting directly on a sea bed and that is at an angle of 60° to the direction of a strong current that is flowing at a rate of about 10 feet per second is approximately 100 lbs per foot. When this pipe is raised above the sea bed so that the space between the bottom of the pipe and the sea bed is one-quarter of the pipe's outside diameter, the lifting force is reduced to about 25 lbs per foot.

The ballasts should comprise a top and bottom section that, when mated together over a minimum gap between the two halves, the resultant inside diameter is slightly larger than the outside diameter of the pipe. This slightly larger inside diameter is to allow the placement of a cushioning interlining to protect the softer PE pipe from being damaged by the hard ballast material. Another function of the interlining is to provide frictional resistance that will help prevent the ballasts from sliding along the pipe during the submersion process. Accordingly, slippery interlining material such as polyethylene film or sheeting should not be used. Some suggested interlining materials include several wraps of approximately $\frac{1}{8}$ -in thick rubber sheet or approximately $\frac{1}{4}$ -in thick neoprene sponge sheet.

The purpose of the minimum gap between the two halves of the ballasts is to allow the two halves to be tightened over the pipe so as to effect a slight decrease in pipe diameter and thereby enhance the hold of the ballast on the pipe.

Additionally, experience has shown that in certain marine applications where tidal or current activity may be significant, it is feasible for the pipe to "roll" or "twist". This influence combined with the mass of the individual ballasts may lead to a substantial torsional influence on the pipe. For these types of installations, an asymmetric ballast design in which the bottom portion of the ballast is heavier than the upper portion of the ballast is recommended. Typical design considerations for this type of ballast are shown in Appendix A-3.

Suitable lifting lugs should be included in the top and bottom sections of the ballasts. The lugs and the tightening hardware should be corrosion resistant. Stainless steel strapping or corrosion-resistant bolting is most commonly used. Bolting is preferable for pipes larger than 8-in in diameter because it allows for post-tightening prior to submersion to offset any loosening of the gripping force that may result from stress-relaxation of the pipe material.

Examples of various successfully used ballast designs are shown in Appendix A-3.