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 underscouring 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) $$F_B = [W_P + W_C] - W_{DW}$$

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

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) $F_B = W_{DW}$ ["K"]

WHERE

W_{DW} **= 0.00545** $D^2_0 \rho_w$

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).

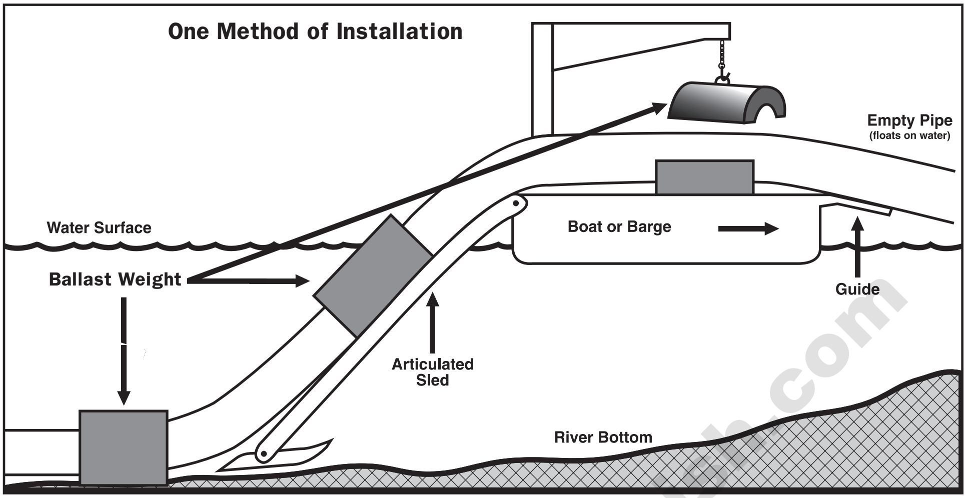

Figure 1 Submerging a heavily weighted pipe from a barge

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.

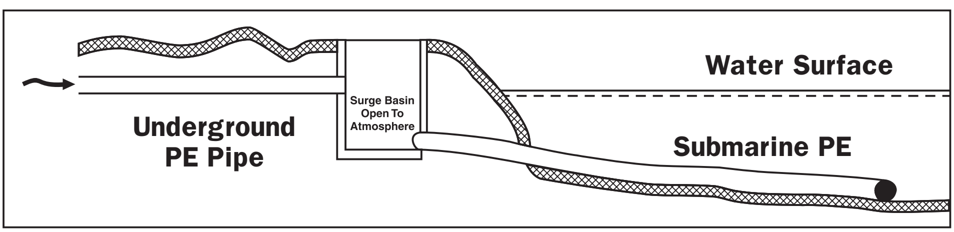

Figure 2 A surge chamber may be used to prevent air from entering a pipeline

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) $$B_W = W_S \ x \ L$$

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

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

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 1/8-in thick rubber sheet or approximately ¼-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.

Figure 3 Two-piece Concrete Anchors in Storage at Marine Job-Site

Step 4 Selection of an Appropriate Site for Staging, Joining and Launching the Pipe

The site for staging, joining and launching the pipe should preferably be on land adjacent to the body of water in which the pipeline is to be installed and near the point at which the pipe is to enter the water. Also, the site should be accessible to land delivery vehicles. If these requirements are not easily met, the pipe may be staged, joined and weighted at another more accessible location and then floated to the installation site. Long lengths of larger diameter PE pipe have been towed over substantial distances. However, considerable precautions should be exercised for insuring the stability of the towed materials in light of marine traffic, prevailing currents or impending weather considerations.

To facilitate proper alignment of the pipe-ends in the fusion machine and to leave enough room for the attachment of the ballast weights, the site near the water should be relatively flat. It is best to allow a minimum of two pipe lengths between the fusion joining machine and the water's edge. The site should also allow the pipe to be stockpiled conveniently close to the joining machine.

The ground or other surface over which the pipe is to be moved to the water should be relatively smooth and free of rocks, debris or other material that may damage the pipe or interfere with its proper launching. When launching a pipe with ballast weights already attached, provision should be made for a ramp or a rail skidway arrangement to allow the ballasts to move easily into the water without hanging up on the ground. As elaborated under the launching step, the end of a pipe that is moved into the water needs to be sealed to prevent water from entering and, thereby, compromising its capacity to float freely.

Step 5 Preparing the Land-to-Water Transition Zone and, When Required, the Underwater Bedding

At some point in time before the start of the submersion procedure, usually before the pipe is launched, a trench needs to be prepared in which to place the pipe between the point where it leaves the shore and the first underwater location beyond which the pipe is completely submerged without the need for external protection. The trench needs to be deep and long enough to protect the pipe from wave action, tidal scour, drifting ice and boat traffic. Special care should be employed in the design and construction of the land-to-water transition in ocean outfalls where occasional rough seas can result in very strong waves and in the scouring of the material below and around the pipe.

Unless weighted to a relatively high extent, say to at least 40% of the pipe displacement, a pipe lying in a land-to-water transition trench that has been filled with fine silt or sand could float up when that zone is subjected to strong wave action. One method of controlling this tendency would be to utilize increased weighting via enhanced ballast design. Alternatively, the submerged pipe could be placed on a bed of prepared backfill and subsequently surrounded by graded material in accordance with ASTM D2774, Standard Practice for Underground Installation of Thermoplastic Pressure Pipe. This ASTM standard provides that plastic pipe installed underground will be bedded and backfilled using material with a particle size in the range of ½″ to 1 ½″ depending on the outside pipe diameter. However, it may be necessary to place a layer of even larger particle sized fill (1 ½″ to 4″) over the graded material to avoid movement of the stone backfill in some tidal zones or areas of strong current activity. Protection and stabilization of the pipe installation may be further enhanced by the placement of a 1 to 2 foot cover of blast rock over the completed installation.

With regard to the preparation of the underwater support generally, no dredging of filling needs to be carried out because the ballasts act to keep the pipe above the bottom material. The principal requirement is that the pipe should not rest or come in contact with large stones. To this end, larger stones that project above the bottom and that could come in contact with the pipe should be removed, as well as those that lie within about 3 pipe diameters on either side of the pipe.

Step 6 Assembly of Individual Lengths of PE Pipe Into Long Continuous Lengths

The butt fusion of individual lengths into a long string of pipe should be conducted by trained personnel and by means of appropriate equipment. The heat fusion parameters – e.g., temperature, interfacial pressure, heating and cooling times – should be as recommended by the pipe manufacturer for the particular pipe material and the joining conditions, including outdoor temperature and wind. (See Chapter 9 on PE Joining Procedures.)

Upon the completion of the heat fusing of an added individual length to the pipeline, the resultant longer pipe string is further moved into the water. As discussed elsewhere, the pipe should always be moved to the water using suitable mechanical equipment that will cause no damage to the pipe or to the pipe ends.

Ballast weights can be mounted before the pipe string reaches the water. If circumstances make it more practical, the ballasts can also be attached on the floating pipe from a floating barge by a scheme such as illustrated in Figure 4.

Step 7 Mounting the Ballasts on the Pipe

Since the process of heat fusing a new pipe section on a string of pipe usually takes less time than the attaching of ballasts, the later procedure can be quickened by increasing the number of work stations. It is also helpful to stockpile the ballasts adjacent to each work station. Adequate lift equipment needs to be on hand to move the ballasts from the stockpile to the pipe location and to lift the pipe to allow the ballasts to be positioned under it. This equipment can also be used to lift and pull the pipe into the water. A suitable ramp or skidway should be provided to move weighted pipe into the water with a minimum of drag. (See discussion on launching the pipeline.)

For mounting ballasts on the floating pipe it is necessary to have low-profile equipment such as a barge or raft that is of sufficient size to accommodate the required lifting equipment and to carry sufficient ballasts to allow for efficient operation. In this method the barge is brought alongside the floating pipe, the pipe is lifted to install one or more ballasts, and after their installation the pipe is returned to the water and a new section is moved onto the barge or the barge is advanced along the floating string of pipe. In either case, the working surface or platform of
the barge should be as close as possible to the water to reduce the need for a high lifting of the weighted pipe.

The steps involved in the mounting of ballasts include the following:

1. The placing of the protective/friction inducing material around the pipe. This can be done by first placing a pad over the lower half of the ballast and then placing a similar pad over the top of the pipe before the upper half of the ballast is lowered into position.

2. Lifting the pipe and positioning the lower half of the ballast under the pipe

3. Lowering the pipe so that it sits in the lower half of the ballast

4. Positioning and then lowering the upper half of the ballast so it sits on top of the pipe
5. Applying the strapping or tightening the bolts so that the ballasts are held fast to the pipe. (Note: before submersion, retightening of the bolts may be necessary to overcome any loss of gripping that may result from the stress-relaxation effect).

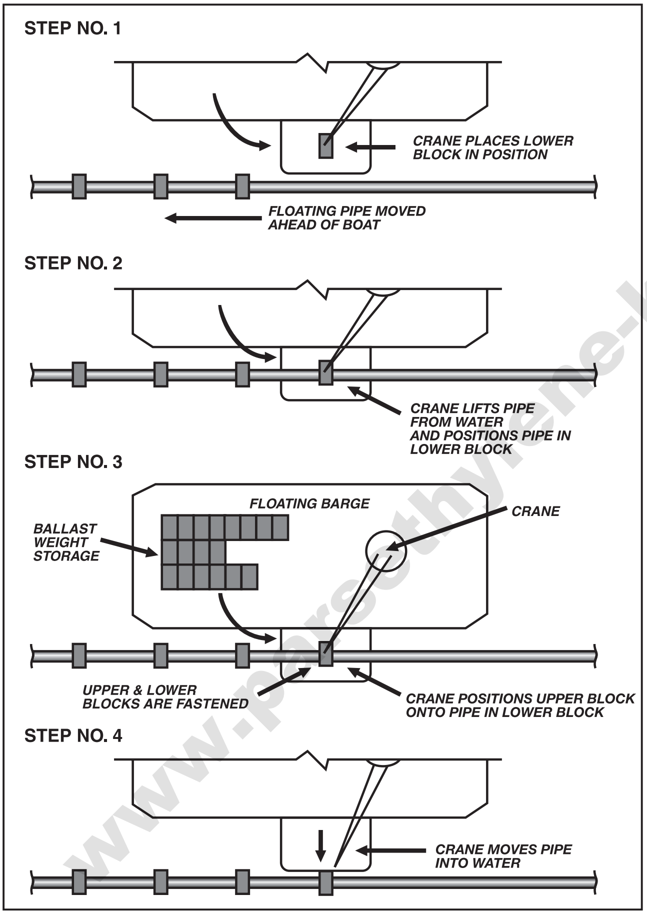

Figure 4 Installation of ballast weights from a raft or barge

Step 8 Launching the Pipeline into the Water

As previously cautioned, pipe that is launched into the water needs to have its ends closed, or its outlets located sufficiently high above the water, to prevent any water from entering the pipe. When the pipe is launched in the form of shorter strings of pipe that will later be joined to each other to produce the required overall length of submerged pipe, each separate section needs to have both ends sealed to prevent water from entering. In this respect, effluent outfall lines require special consideration.

Effluent outfalls usually terminate in one or more diffuser sections. Diffusers can be of different designs such as a “Y” or “T” outlet, a pipe length in which holes have been drilled on top of the pipe within 10 and 2 o’clock, or a pipe length onto which vertical risers consisting of short sections of smaller diameter PE pipe have been fused. Diffusers are often designed for connection to the pipe by means of flange assemblies. The connection can be made prior to launching, or by divers after the pipeline has been submerged. When a diffuser is attached prior to launching, it is necessary to float the diffuser higher up over the water by means of some additional buoyancy. This is necessary to prevent water from entering the pipe through the diffuser openings. This additional buoyancy is released as the pipe is sunk into position.

Extreme care should be taken in the submersion of a marine line with an engineered diffuser attached to the pipeline which is being sunk in place. The sinking process can create considerable stresses on the fittings that may be inherent to the design of the diffuser itself such as flanges, tees and/or other mechanical connections. A preferred method when placing a highly engineered diffuser into an HDPE marine pipeline is to first sink the flanged effluent pipe and then submerge the diffuser separately in easily controlled segments which may be connected to the main effluent pipe underwater using qualified diving contractors.

A pipe end that does not terminate in a diffuser section is best closed against entering water by attaching a blind flange assembly. The flange assembly consists of a PE stub end that is butt fused to the pipe end on which has been bolted a slip-on metal flange. A number of required tapped holes are drilled on the blind flange so as to allow for the installation of valves and other fittings required to control the sinking operation. (See the section on submersion of the pipeline.)

Figure 5 Unballasted PE Pipeline Being Floated Out to Marine Construction Barge Where Ballast Weights are Installed

Pipe with attached ballast weights should be moved into the water by means of a ramp or skidway arrangement that allows the ballasts to move easily into the water without hanging up on the ground. The ramp or skidway must extend sufficiently into the water so that when the pipe leaves this device the ballast weight is fully supported by the floating pipe. Pipe without ballast weights may be moved over the ground provided it is free of rocks, debris or any other material that may damage the pipe. When this is not practical, wooden dunnage or wooden rollers may be placed between the pipe and the ground surface.

The pipe should be moved using suitable equipment. The pipe may be moved by lifting and then pulling it using one piece of equipment while using another piece of equipment to simultaneously push the pipe from its inboard end. PE pipe should only be lifted using wide-band nylon slings, spreader slings with rope or band slings, or any other means that avoids the development of concentrated point loading. Under no conditions should the flange assemblies be used to pull the pipe.

Prior to the launching of the pipe into the water, a strategy should be worked out to control the floating pipeline as it moves into the water and to store it away from navigational traffic until such time as the entire length is ready for submerging. For this purpose, suitable marine equipment – such as boats that have adequate tugging power and maneuverability – may need to be on hand. Other means for controlling the pipe can be a system of heavy block anchors that are positioned on either side of the proposed site into which the pipe will be submerged. In the case of river crossings, a system of guide cables that are anchored on the opposite shore can serve to control the position of the pipeline, particularly when the pipeline is subject to strong river flow.

In the case of river crossings when navigational traffic prohibits the float-and sink procedure, a "bottom-pull" procedure, illustrated in Figure 6, has been successfully used. When using this procedure, only sufficient ballast is added to the pipe to ensure that the pipe follows the river bottom as it is winched from one shore to the other. After the completion of the "bottom-pull," additional ballast can be added or the pipeline can be adequately backfilled to produce the required anchoring and to offset any lift that may be created by currents or river flow.

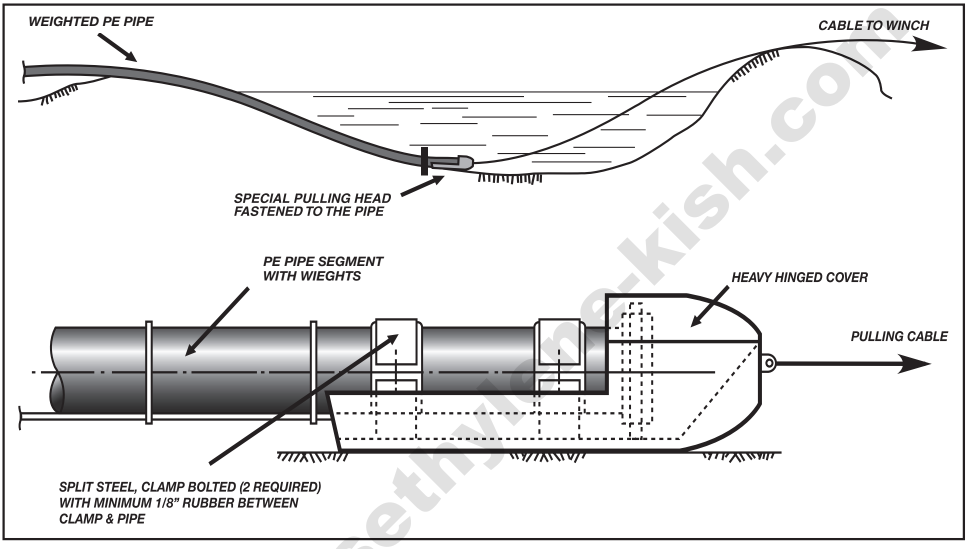

Figure 6 "Bottom-Pull" Installation of PE Pipe

Step 9 Submersion of the Pipeline Using the Float-and-Sink Method

To prepare the pipe for submersion, it is first accurately positioned over its intended location. The sinking operation basically consists of the controlled addition of water from the on-shore end of the pipe and the release of the entrapped air from the opposite end. The sinking is conducted so that it starts at the shore where the pipe enters the body of water and then gradually progresses into deeper waters. To achieve this, an air pocket is induced by lifting the floating pipe close to the shore. As the water is allowed to enter the pipe from the shore side, the added weight causes this initial air pocket to move outward and the intermediate section of pipe between the air pocket and the shore end to sink. As additional water is added, this pocket moves to deeper waters causing the sinking to progress to its terminal point in the body of water. This controlled rate of submersion minimizes pipe bending and it allows the pipeline to adjust and conform to the bottom profile so that it is evenly supported along its entire length (See Figure 7).

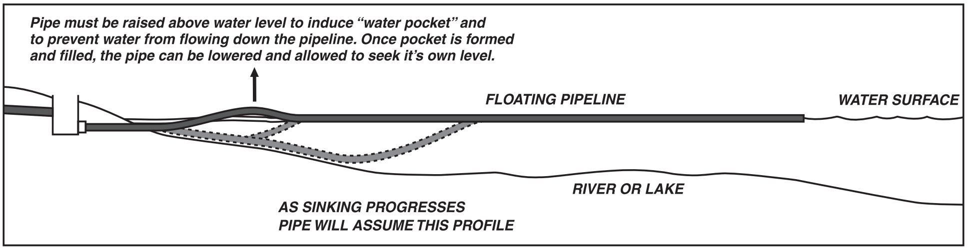

Figure 7 An induced water pocket initiates the submersion of the pipe and, as the pocket enlarges, it allows the submerging to gradually progress forward

A potential risk during the submersion operation is that, when the pipe sinking occurs too quickly, the bending of the pipe between the water-filled and air-filled portions may be sharp enough to risk the development of a kink, a form of localized pipe buckling. As a pipe is bent, its circumferential cross-section at the point of bending becomes increasingly ovalized. This ovalization reduces the pipe's bending moment of inertia, thus decreasing the bending force. Upon sufficient ovalization, a hinge or kink can form at the point of maximum bending an event that also leads to a sudden reduction of the bending force. Since the formation of a kink impedes the submersion process and can also compromise the pipe's flow capacity and structural integrity – in particular, the pipe's resistance to collapse under external pressure – it is essential that during submersion the bending of the pipeline be limited to an extent that will not risk the formation of a localized kink. The pipe bending radius at which buckling is in risk is given by the following expression:

(7)

$$R_b = D_o \frac{(DR-1)}{1.12}$$

WHERE

R_b **= bending radius at which buckling can be initiated, in**

D_o **= outside pipe diameter, in**

DR **= pipe diameter ratio = average outside diameter divided by minimum wall thickness, dimensionless**

Janson's relationship for determination of minimum buckling radius (Eq. 7) was derived on the basis of a maximum pipe deflection (ovalization) due to bending of the pipe of 7% and a maximum strain limit in the pipe wall of 5%. In actuality, the short term strain limit for modern polyethylene pipe materials is somewhat higher, on the order of 7-10%. Further, we know that these pipe materials are capable of long-term service at higher degrees of ovalization in buried pipe installations. (Please refer to Chapter 6 of this Handbook.) As a result, the values presented in Table 3 are considered conservative guidelines for the short-term bending radius of polyethylene pipe during submersion of most marine pipelines. The designer may want to utilize a higher minimum bending radius to compensate for additional factors such as extremely strong currents, tidal activity, prevailing marine traffic, frequency of ballast placement, or other installation variables associated with a specific installation.

TABLE 3
Pipe Diameter Multipliers for the Determining of Minimum Bending Radii

Pipe DR	Multiplier*
11	8.9
13.5	11.2
17	14.3
21	17.8
26	22.3
32.5	28.1

* The minimum buckling radius of a pipe, in inches, is equal to the pipe's outside diameter, in inches, times the listed multiplier

It is essential that the water be introduced into the pipe at a controlled rate. This is done to ensure that the submersion process occurs at a rate that does not result in excessive localized pipe bending that could buckle the pipe. It also allows the pipe to settle properly on the bottom – thus avoiding any bridging between high spots which may make the pipe more vulnerable to movement when subjected to strong currents. Experience has shown that submerging the pipe at a rate in the range of about 800 to 1500 feet per hour has been found to be adequate for most cases. While the pipe is in the bent condition, long stoppage of the submersion procedure must be avoided. Consult with the pipe manufacturer and design engineer for specific submersion techniques for individual installations.

The risk of buckling can be minimized by applying a suitable pulling force during the submerging, such as illustrated by Figure 8.

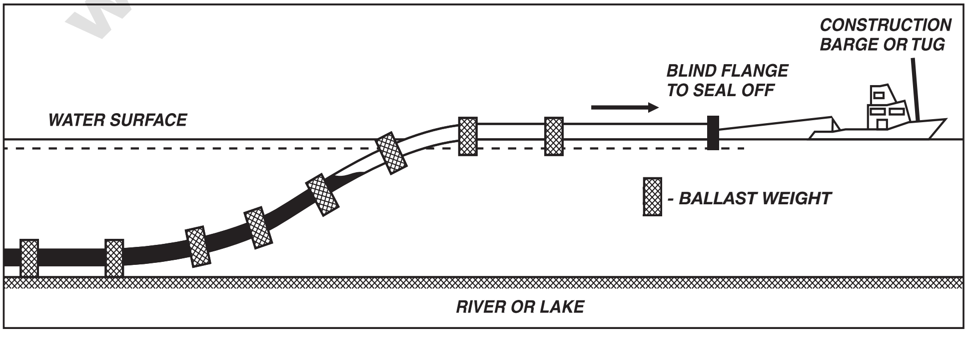

Figure 8 Pulling the pipe during submersion is a means for avoiding excessive bending that could risk buckling of the pipe

As water is being added at the shore-end of the pipe, air must be allowed to escape from the opposite end. In the case of outfall pipelines that terminate in one or more diffuser sections, the air is released through the diffuser outlets. When a pre-attached diffuser is used, it is necessary to support it with some additional buoyancy as a precaution against the water entering the pipe and causing that section of the pipeline to sink prematurely. Extreme care should be taken in the ballasting and submersion of elaborate diffuser systems that are sunk in concert with the main effluent pipe as the submersion process can create significant stresses on the tees, elbows or other fittings used in the design of the diffuser system. The preferred method is to submerge the flange or valved main effluent pipe and the diffuser separately and join the two sections underwater using qualified diving contractors.

When the end of a pipe that is being submerged terminates with a flange connection, air release can best be accomplished by installing a valved outlet in the blind flange outlet. To ensure that water will not enter through this outlet, a length of hose may be connected to the outlet, and the free end is held above water on a boat or by means of a float. After the completion of the submersion, a diver can remove the hose.

Should a problem be encountered during the submersion, the availability of a valved outlet on the outboard end of the pipeline allows the sinking procedure to be reversed. Compressed air can be pumped into the submerged line to push the water out and thus allow the line to be raised. Because compressed air packs a lot of potential energy – which, when suddenly released through a failure of a piping component, could present a serious safety hazard – the rule of thumb is to limit air pressure to not more than one-half the pipe's pressure rating for water.

Under certain methods, such as the bottom-pull method that is described above, the necessary ballast to offset floatation during the installation of a water filled PE pipe can be of a temporary nature – for example, steel reinforcing bars that are strapped on the outside of the pipe. This temporary ballast can be removed after the installation of permanent anchoring. Permanent anchoring can consist of an appropriate quantity of stable backfill that is placed on pipe that has been installed in a trench, or it can consist of tie-down straps that are installed by augering or other procedures that result in the permanent anchoring of the pipeline. However, when considering an alternate means for anchoring a pipeline, it should be kept in mind that, as discussed earlier, a pipeline lying on the sea or river floor is subject to greater lift action by currents or waves than a pipeline that lies even a short distance above the bottom.

Step 10 Completing the Construction of the Land-to-Water Transition

After the pipeline has been submerged, the portion of the pipeline that has been lowered into a land-to-water transition trench should be backfilled with specified material and to the required depth of cover.

Post-Installation Survey

Upon completion of the installation of a submerged pipeline, it is advisable to have the complete line surveyed by a competent diver to ensure that:

- The pipeline is located within the prescribed right-of-way
- The ballasts holding the pipeline are all properly sitting on the bottom contour and that the line is not forced to bridge any changes in elevation
- The pipe is not resting on any rocks, debris or material that could cause damage
- Any auxiliary lines, such as hoses, ropes, buoyancy blocks or any other equipment used during the installation has been removed
- Where required, the pipe has been backfilled and the backfilling was done properly
- All other installation requirements established by the designer for the subject application have been complied with.

Other Kinds of Marine Installations

Because of its flexibility, light-weight and toughness PE piping has also emerged as a choice material for other types of marine applications. The basic design and installation principles described above for the "float-and-sink" method are, with some modifications, also valid for other types of marine applications. A brief description of some other kinds of marine applications is presented in the paragraphs that follow.

Winter Installations

Where ice conditions permit, PE pipe may be submerged from the surface of a frozen lake or river. After a long pipe length is assembled by means of heat fusion it can be easily pulled alongside the right-of-way. The heat fusion process needs to be performed in an adequately heated tent, or other shelter, to ensure fusion joint quality. Once the heat fusion has been completed, the ballast weights can be mounted. An ice trench is then cut with a saw, the ice blocks are moved out of the way and the pipeline is pushed into the trench. The submersion is carried out in accordance with the procedure previously described.

Installations in Marshy Soils

Installation of pipe in marshy or swampy soils represents one of the most demanding applications for any design engineer. Generally, marshy soils do not provide the firm and stable foundation that is required by rigid, more strain sensitive traditional piping materials.

Due to its flexibility and butt fusion joining technology, PE piping can readily adapt itself to shifting and uneven support without sacrifice of joint integrity. As soil conditions vary, the PE pipe can accommodate these irregularities by movement within the fluid-like soil envelope. Of course, care must be taken to consider any line, grade or external hydrostatic design requirements of the pipeline based on the operating conditions of the system. However, with these design aspects in mind, it is possible to utilize the engineering features of PE pipe to design a cost-effective and stable piping system that can provide years of satisfactory service in this highly variable environment.

In certain situations, the high water table that is characteristic of these soils can result in significant buoyant forces that may raise the pipe from the trench in which it has been installed. When this possibility presents itself, a ballast system may be designed using the same guidelines presented in this chapter which can prevent or minimize pipe flotation.

Water Aeration Systems

Smaller diameter submerged PE pipe, with small holes drilled into the top of the pipe has been used for the de-icing of marinas. Compressed air that bubbles out of these pipes raises warmer water that melts ice that forms on the water surface. When the system is operating, the submerged pipe is full of air, and the ballast weight design should be adequate to prevent the line from floating. Ballast also needs to be spaced frequently enough to minimize the upward deflection that results from the buoyancy force.

Dredging

PE piping is a natural choice for use in marine dredging operations. Its flexibility, combined with its light weight, buoyant nature and overall durability, provides for a piping material which has been successfully used for years in the demanding rigors of dredging operations. Generally, these types of applications require that the HDPE pipe be fused into manageable lengths that can be easily maneuvered within the dredge site. These individual lengths are then mechanically joined together using flanges or quick-connect type fittings to create a pipeline structure of suitable length for the project. As the dredge operation proceeds, pipe segments may be added or removed to allow for optimum transport of the dredge material.

Dredging operations can vary significantly in type of slurry, scale or operation and overall design. As such, a detailed analysis of dredge design using HDPE pipe is beyond the scope of this writing. However, the reader should note that as the particulate size and nature varies from project to project, it is possible to ballast the pipe so that it still floats and can be managed from the surface using tow boats or booms. This is accomplished by analysis of the composition of the dredge material and the design and attachment of suitable floats to the HDPE discharge or transport pipe.

Temporary Floating Lines

PE piping has also been used for temporary crossings of rivers and lakes. Its natural buoyancy allows a PE pipeline to float on or near the water surface. The principal design and installation requirement for floating line applications is to work out a system to maintain the pipe in its intended location when it is subject to currents, winds and wave action. To this end, cable restraints are generally used. The cables need to hold the pipe by means of stable collars that do not slip along the axis of the pipe and that cause no damage to the pipe material.

Conclusion

Modern HDPE piping materials are a natural choice for marine installations. The overall durability and toughness of these products, combined with the innovative and cost-effective installation methods that they facilitate, are compelling reasons for their use in effluent discharge systems, water intake structures and potable water or sanitary sewer force main marine crossings, as well as more temporary marine systems such as dredging operations.

The dependable butt fusion system of joining PE pipe, supplemented by the availability of a wide array of mechanical fittings, means that the design engineer has an abundance of tools available by which to design a leak-free piping system that lends itself to the most demanding marine installations. This same system of joining allows for the cost-effective installation of long lengths of pipe via the float and sink method, directional drilling or pull-in-place techniques. Utilizing the unique features of the PE piping system allows the designer to investigate installation methods that minimize the necessity of costly pipe construction barges or other specialized equipment. These same installation techniques may minimize the economic impact associated with marine traffic disruption.

This chapter provides an overall design perspective for some of the more typical applications of HDPE pipe in marine environments. Its intent is to provide the designer with a basic understanding of the utility that PE pipe brings to the designer of these challenging installations. More elaborate design investigation and methodology may be required depending on the specifics of the project under consideration. However, through a basic understanding of the benefits of PE pipe in marine installations and a fundamental understanding of the installation flexibility that they provide, it can be seen that PE pipe systems are a proven choice for modern, durable marine piping structures.

References

1. Janson, Lars-Eric. (1990, Sept 10-13). Review of Design and Experience With Thermoplastic Outfall Piping, ASTM STP 1093, Compendium of papers presented at the Buried Plastic Pipe Technology Symposium, Dallas, TX.
2. Berndtson, B. (1992, Sept 21-24). Polyethylene Submarine Outfall Lines, Paper presented at Plastics Pipes VIII, a symposium held in Koningshof, the Netherlands, and included in the Book of Proceedings for this symposium as published by The Plastics and Rubber Institute, London.
3. Janson, Lars-Eric. (1986). The Utilization of Plastic Pipe for Submarine Outfalls—State of The Art, *Water Science and Technology* ,Great Britain, Vol. 18, No. 11, pp 171-176.
4. Janson, Lars-Eric. (1996). *Plastics Pipe for Water Supply and Sewage Disposal,* published by Borealis, Sven axelsson AB/Affisch & Reklamtryck AB, Boras, Sewede.

Appendix A-1

Derivation of the Equation for the Determining of the Buoyant Force Acting on a Submerged PE Pipe (Equation 2 in the Text)

The first bracketed term in Equation 2, namely $[0.00545D^2_0\rho_W]$, is one commonly used form of the formula for obtaining a numerical value for the term W_{DW} in Equation 1, the weight of water that is displaced by the submerged PE pipe. This displaced weight is equivalent to the lift force acting on a submerged pipe that has an infinitely thin wall and that is completely filled with air. The sum of the three terms within the second set of brackets expresses the reduction of this potential lift force in consequence of the weight of the pipe (the first term) and that of its contents (the second term). As is evident from inspection of Equation 2, the extent to which the inner volume of a pipe is occupied by air (represented by the fraction R) exerts the more significant effect on resultant pipe buoyancy. Since a decrease in pipe DR (i.e., an increase in pipe wall thickness) results in a decrease in potential air volume space, a lower DR tends to reduce the potential buoyancy that can result from air filling.

1. The net buoyant (upward acting force) acting on a submerged PE pipe is:

(1) $F_B = [W_p + W_c] - W_{DW}$

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 the water displaced by the pipe, lbs/foot of pipe**

2. W_p, the weight of pipe is:

$$W_p = V_p P_p$$

WHERE

V_p = volume occupied by pipe material per foot of pipe

P_p = density of pipe material, lbs/ cu. ft

Since
$$V_p = \frac{\pi}{144} D_m t_a$$

WHERE

D_m = mean pipe diameter of the pipe, in

t_a = average wall thickness, in

And since
$$DR = \frac{D_o}{t_m}$$

WHERE

D_o = outside pipe diameter, in

t_m = minimum wall thickness, in

Then, by assuming that the average wall thickness (t_a) is 6% larger than the minimum (t_m), it can be shown that:

(2)
$$W_p = \frac{1.06\pi}{144}\left(\frac{D_o}{DR}\right)^2 (DR - 1.06)\rho_p$$

3. W_c, the weight of the pipe contents is equal to the volume occupied by the liquid inside the pipe times the density of the liquid:

$$W_c = V_L \rho_L$$

WHERE

V_L = the volume occupied by the liquid, cu ft/linear ft

P_L = the density of the liquid inside the pipe, lbs/cu ft

If the fraction of the inside volume of the pipe (V_I) is expressed as R and as the formula for the inside volume is as follows:

$$V_I = \frac{\pi D_I^2}{4}\frac{1}{144}$$

WHERE

D_I = inside diameter of the pipe, in

And also, since $D_I = D_o - 2t_a$ **(where** t_a *is* $1.06\ t_m$, **as previously assumed) it can then be shown that:**

(3)
$$Wc = \frac{\pi}{144}\frac{\rho_L}{4}\left[D_o\left(1-\frac{2.12}{DR}\right)\right]^2(1-R)$$

4. W_{DW}, the weight of the water displaced by the pipe is determined by means of the following formula:

(4)
$$W_{DW} = \frac{\pi D_o^2}{4}\frac{1}{144}\rho_W$$

WHERE
ρ_W **= the density of the displaced water, lbs/cu ft**

5. By substituting Equations 2, 3 and 4 into Equation 1, and by simplifying the resultant relationship, the following formula (Equation 2 in the text) is obtained:

$$F_B = \left[0.0054 D_o^2 \rho_W\right]\left[4.24\frac{(DR-1.06)}{(DR)^2}\frac{\rho_p}{\rho_w} + \left(1-\frac{2.12}{DR}\right)^2(1-R)\frac{\rho_c}{\rho_w} - 1\right]$$

Appendix A-2

Water Forces Acting on Submerged PE Piping

The following is a brief introduction to the technology for the estimating of the magnitude of the lateral forces that can act on a submerged pipe in consequence of water currents and wave action. As this technology is relatively complex and it is still emerging, the objective of this introduction is to provide basic information and references that can provide initial guidance for the proper design of PE piping for submerged applications. It is the responsibility of the designer to determine the design requirements and appropriate design protocol for the specific anticipated conditions and design requirements of a particular project. In addition to the information and references herein provided, the reader should consult the technical staff of PPI member companies for further information, including references to engineering companies that have experience in the use of PE piping for submerged applications.

Submerged pipes can be subject to lateral forces generated by currents or by wave action. A principal design objective is to ensure that the resultant lateral forces do not subject the pipe to excessive deflection, nor to fiber stresses or strains that could challenge the pipe material's capabilities. Thus, the capacity to estimate with some reasonable accuracy the potential maximum lateral stresses to which a submerged pipe may be subjected is an important element for achieving a successful design.

Currents impinging on a submerged pipe can cause two principal forces: a drag force in the direction of the current; and a vertical force at right angles to the drag force. The magnitude of these forces depends on the angle between the direction of the current flow and the pipe. They are at their maximum when the current flow is at a right angle to the pipe. As this angle (Θ) is reduced, the resultant force is reduced by $\sin^2 \Theta$.

For the purpose of estimating the drag and lift forces that a current can exert on a submerged pipe, Janson developed the graphical solution that is herein reproduced as Figure A-2-1. This graph is applicable to the condition where the current velocity, expressed in feet per second, times the pipe diameter, expressed in feet, is equals to or is greater than 0.5 m^2/sec (2.7 ft^2/sec).

Janson's nomagraph is based on the assumption that certain design variables are known. These design variables are as follows:

D = **external diameter of pipe, in meters (feet)**
l = **distance from the bottom, in meters (feet)**
u_m = **mean velocity of water, in m/sec (ft/sec)**
h = **depth of water, in meters (feet)**
k = **hydraulic roughness of the water bed, meters (feet)**
Θ = **angle between the direction of the current and that of the pipe, degrees**
λ = **ratio of l/h, dimensionless**
= **0 for pipe placed on seafloor or bed of body of water**

Janson determined that for values of $D \times U_m > 0.50$ m^2/sec, a nomograph could be constructed which allowed for a relatively quick approximation of the drag and/or lift forces for which an underwater HDPE piping installation must be designed.

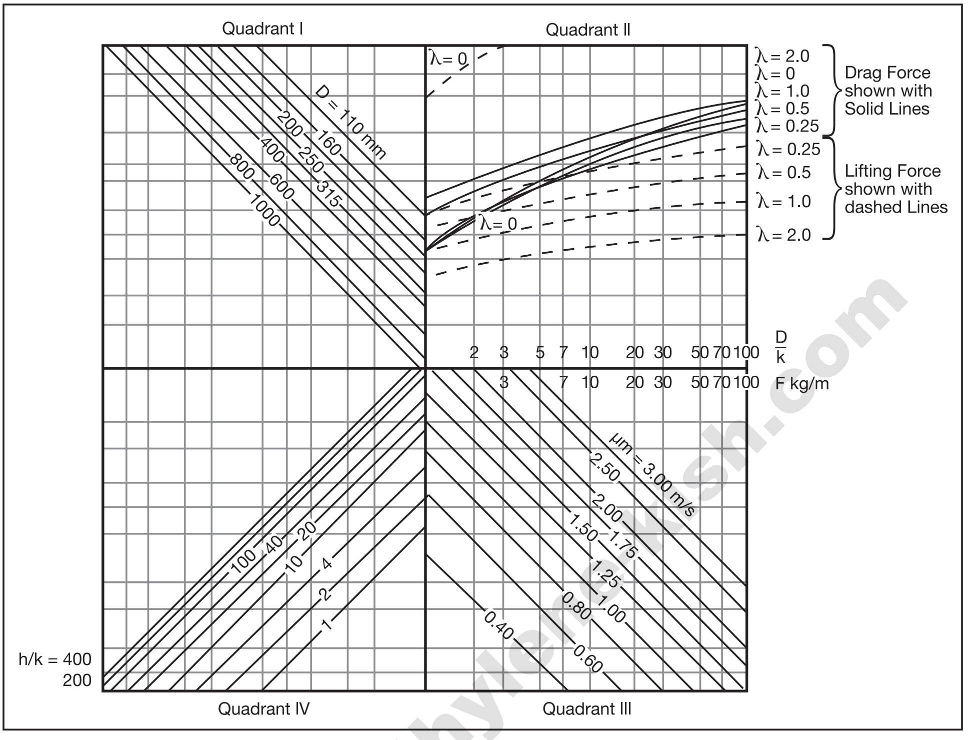

Figure A-2-1 Graph for the estimation of drag and lifting forces on underwater pipes when the flow rate of the current times the pipe diameter is 0.5 m^2/sec, or greater [4]

Consider the following example:

A 315 mm HDPE pipe is to be placed directly on the floor of a body of water that is flowing at approximately 3 m/sec and at 90 degrees to longitudinal axis of the pipe. The depth of the water is 10 meters and the pipe will be placed directly on a bed of gravel for which we will assume a hydraulic roughness of 10 cm.

Step 1 First, check to see if the nomograph is applicable

$$D \times u_m = 0.315 \text{ m} \times 3 \text{ m/sec} = 0.96 \text{ m}^2\text{/sec}$$

So, the nomograph can be utilized.

Step 2 Determine the two key dimensionless design ratios, D/k and h/k

GIVEN THAT

D **= 315 mm = 0.315 meter**

and

k **= 10 mm = 0.10 meter**

Then

D/k = **0.315 m / 0.10 m = 3.2**

h/k = **10 m / 0.10 m = 100**

Step 3 Determine the Drag Force

Utilizing the nomograph in Figure A-2-1, start at the horizontal axis between quadrant II and III. On the D/k axis locate the point 3.2 from the calculation in step 2. Draw a line vertically up to the solid curve (drag force) for $\lambda = 0$ (the pipe will rest on the bed of the body of water). Now draw a horizontal line from quadrant II into quadrant I to the line for diameter, in this case 315 mm. At the point of intersection with this line, draw another line downward to the line for h/k = 100 shown in quadrant IV. At that point of intersection, then draw another line horizontally back across to quadrant III to the line for flow velocity, in this example 3m/sec. From this point draw a line upward to the original axis and read drag velocity directly from nomograph. The result is 20 kg/m.

Step 4 Determine the Lift Force

Generally speaking, the lift force for a pipe laying on the floor of a body of water is eight times that of the drag force. In this case, the lift force generated is approximately 160 kg/m.

Alternatively, the lift force could have also been approximated from the nomograph by starting on the same axis between quadrant II and III and proceeding up to the dashed line for $\lambda = 0$ in quadrant II. The dashed line represent the curves for lift force relationships. From the intercept with the dashed curve for $\lambda = 0$, the procedure of is the same as that described for determination of the drag force from the nomograph.

Consider another example:

Now, using the scenario outlined in the preceding example, assume that the pipe is oriented in the water such that the angel of impact, θ, is 60 degrees.

Solution:

The revised angle of impact suggest that the drag force may be reduced by a factor, $\sin^2\theta$.

$$\text{Sin}^2\theta = \sin^2 60^\circ = 0.75.$$

Using this, we get a net drag force as follows:

$$\text{Drag Force}_{(90)} \times \text{Sin}^2\theta = 20 \text{ kg/m} \times 0.75 = 15 \text{ kg/m}$$

English Units

Janson's nomograph was originally published in metric units. However, the curves presented in quadrants II and IV are dimensionless. By converting quadrants I and III and the horizontal axis to English units then the nomograph may be used for pipe sized and installed accordingly. For ease of reference, Janson's nomograph is recreated using English units in figure A-2-2 below.

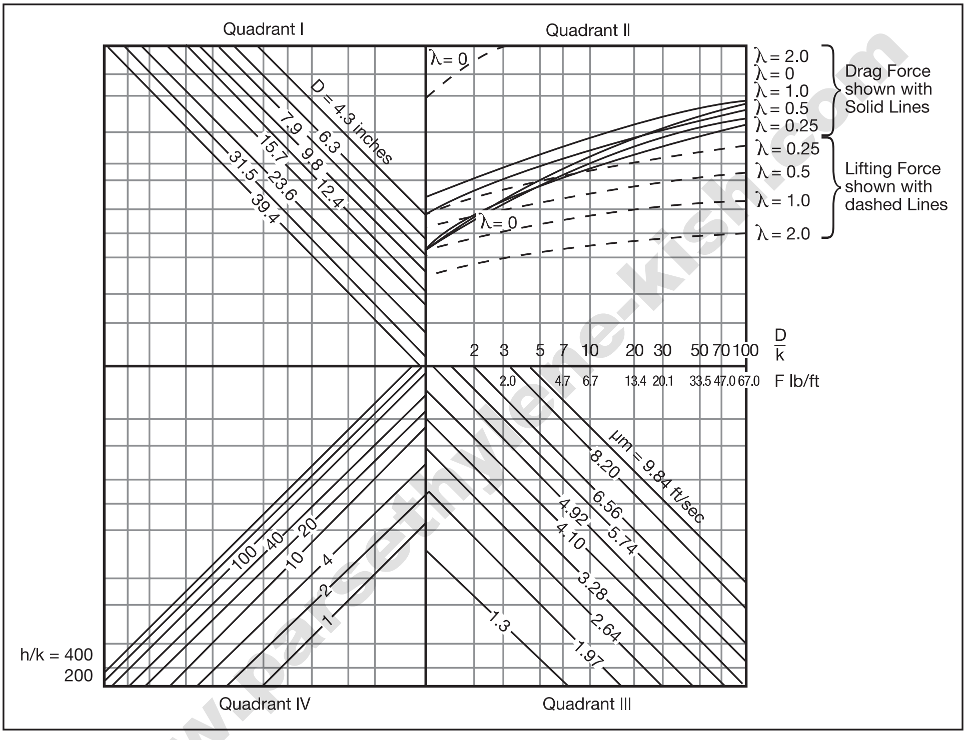

Figure A-2-2 Graph for the estimation of drag and lifting forces on underwater pipes when the flow rate of the current times the pipe diameter is 2.7 ft²/sec, or greater

Consider the previous example restated in English units

A 12" IPS HDPE (325 mm) pipe is to be placed directly on the floor of a body of water that is flowing at approximately 9.8 ft/sec (3 m/sec) and at 90 degrees to longitudinal axis of the pipe. The depth of the water is 33 feet (10 meters) and the pipe will be placed directly on a bed of gravel for which we will assume a hydraulic roughness of 4 inches (10 cm).

Step 1 First, check to see if the nomograph is applicable

$$D \times u_m = 1 \text{ ft} \times 9.8 \text{ ft/sec} = 9.8 \text{ ft}^2\text{/sec} = 0.91 \text{ m}^2\text{/sec} > 0.50 \text{ m}^2\text{/sec}$$

So, the nomograph can be utilized.

Step 2 Determine the two key dimensionless design ratios, D/k and h/k

GIVEN THAT

D **= 12.75 inches = 1.06 foot**

and

k **= 4 inches = 0.33 foot**

Then

D/k **= 1.06/0.33 = 3.2**

h/k **= 33/ 0.33 m = 100**

Step 3 Determine the Drag Force

Utilizing the English version of the nomograph in Figure A-2-2, start at the horizontal axis between quadrant II and III. On the D/k axis locate the point 3.1 from the calculation in step 2. Draw a line vertically up to the solid curve (drag force) for $\lambda = 0$ (the pipe will rest on the bed of the body of water). Now draw a horizontal line from quadrant II into quadrant I to the line for diameter, in this case 12 inch. At the point of intersection with this line, draw another line downward to the line for h/k = 100 shown in quadrant IV. At that point of intersection, then draw another line horizontally back across to quadrant III to the line for flow velocity, in this example 9.8 ft/sec. From this point draw a line upward to the original axis and read drag velocity directly from nomograph. The result is 13.5 lbf/ft. The reader should keep in mind that this is only an approximation and is not intended to displace a more detailed engineering analysis of a specific marine installation design.

Step 4 Determine the Lift Force

As with the previous example, the lift force for a pipe laying on the floor of a body of water is eight times that of the drag force. In this case, the lift force generated is approximately 108 lbf/ft.

The lift force may be approximated from Figure A-2-2 by starting on the same axis between quadrant II and III and proceeding up to the dashed line for $\lambda = 0$ in quadrant II. The dashed line represent the curves for lift force relationships. From the intercept with the dashed curve for $\lambda = 0$, the procedure of is the same as that described for determination of the drag force from the nomograph.

APPENDIX A-3

Some Designs of Concrete Ballasts

Concrete ballast designs may take on a variety of different sizes, shapes and configurations depending on job-site needs, installation approach and/or availability of production materials. Table A-3-1 below provides some typical designs for concrete ballasts and details some suggested dimensional considerations based on pipe size, density of unreinforced concrete at 144 lb/ft^3 and per cent air entrapment in a typical underwater installation. The reader is advised to consider these dimensions and weights for reference purposes only after a careful analysis of the proposed underwater installation in accordance with the guidelines presented in this chapter.

TABLE A-3-1
Suggested Concrete Weight Dimensions (All dimensions in inches)

Nominal Pipe Size	Mean Outside Diameter (inches)	Spacing of Weights To Offset % Air (feet)			Approx. Weight of Concrete Block (pounds)		Approximate Block Dimensions (inches)						Bolt Dimensions (inches)	
		10%	15%	20%	In Air	In Water	"D"	"X"	"Y"	"T"	"S" (min)	"W"	Dia.	Length
3 IPS	3.50	10	6 ¾	5	12	7	4	9	3 ¾	2 ½	1 ½	2 ½	¾	12
4 IPS	4.50	10	6 ¾	5	20	10	5	11	4 ¾	2 ½	1 ½	3	¾	12
5 IPS	5.56	10	6 ¾	5	30	18	6	12	5 ¼	3 ½	1 ½	3	¾	12
6 IPS	6.63	10	6 ¾	5	35	20	7 1/8	13	5 ¾	3 ½	1 ½	3	¾	12
7 IPS	7.13	10	6 ¾	5	45	26	7 5/8	13 ½	6	4 ¼	1 ½	3	¾	12
8 IPS	8.63	10	6 ¾	5	55	30	9 ¼	15 ¼	6 7/8	4 ¼	1 ½	3	¾	12
10 IPS	10.75	10	6 ¾	5	95	55	11 ¾	19 ¼	8 5/8	4 ½	2	4	¾	12
12 IPS	12.75	10	6 ¾	5	125	75	13 ¼	21 ¼	9 5/8	5	2	4	¾	13
13 IPS	13.38	10	6 ¾	5	175	100	13 7/8	24	11	5 ¼	2	5	¾	13
14 IPS	14.00	15	10	7 ½	225	130	14 ½	24 ½	11 ¼	6 ½	2	5	1	13
16 IPS	16.00	15	10	7 ½	250	145	16 ½	26 ½	12 ¼	6 ½	2	5	1	13
18 IPS	18.00	15	10	7 ½	360	210	18 ½	28 ½	13 ¼	8 ¼	2	5	1	13
20 IPS	20.00	15	10	7 ½	400	235	20 ½	30 ½	14 ¼	8 ¼	2	6	1	13
22 IPS	22.00	15	10	7 ½	535	310	22 ½	34 ½	16 ¼	8 ½	2	6	1	13
24 IPS	24.00	15	13 ½	7 ½	610	360	24 ½	36 ½	17 ¼	8 ¾	2	6	1	13
28 IPS	28.00	20	13 ½	10	900	520	28 ½	40 ¼	19 ¼	11 ¼	2	6	1	13
32 M	31.59	20	13 ½	10	1140	660	32	44	21	12 ¼	2	6	1	13
36 IPS	36.00	20	13 ½	10	1430	830	36 ½	48 ½	23 ¼	13 ½	2	6	1	13
40 M	39.47	20	13 ½	10	1770	1020	40 1/8	52	25	15 ¼	2	6	1	13
42 IPS	42.00	20	13 ½	10	1925	1125	42 ½	54 ½	26 ¼	15	2	6	1	13
48 IPS	47.38	20	13 ½	10	2500	1460	48 ¼	60 ¼	29 1/8	17	2	6	1 1/8	13
55 M	55.30	20	13 ½	10	3390	1980	55 ¾	68	33	18 ¾	2	6 1/8	1 1/8	15
63 M	63.21	20	13 ½	10	4450	2600	63 ¾	78	38	18 ½	2	7 1/8	1 1/8	15

Notes to Table A-3-1

1. Suggested underpad material: 1/8" black or red rubber sheet, 1/4" neoprene sponge padding width to be "T"+ 2" minimum to prevent concrete from contacting pipe surface.
2. Concrete interior surface should be smooth (3000 psi – 28 days).
3. Steele pipe sleeves may be used around the anchor bolts (1" for 3/4" bolt, etc.). Hot dip galvanize bolts, nuts, washers and sleeves.
4. A minimum gap, "S", between mating blocks **must** be maintained to allow for tightening on the pipe.
5. To maintain their structural strength some weights are more than the required minimum.
6. Additional weight may be required for tide or current conditions.
7. Weights calculated for fresh water.
8. All concrete blocks should be suitably reinforced with reinforcing rod to prevent cracking during handling, tightening, and movement of weighted pipe.
9. See Table II for alternative weight design and suggested reinforcement for use with 28" to 48" HDPE pipe.

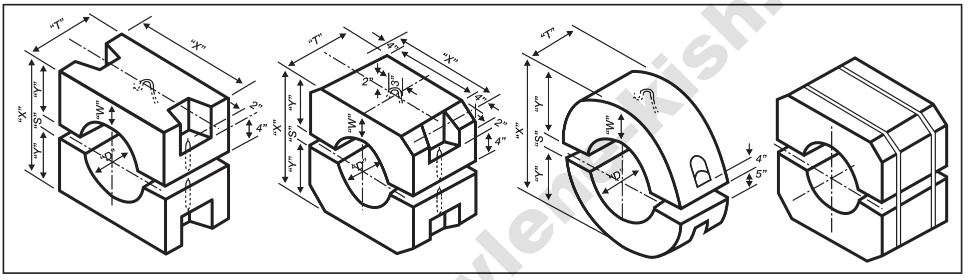

Figure A-3-1 Schematics of Concrete Ballast Designs

TABLE A-3-2
Suggested Dimensions and Reinforcing for Bottom-heavy Concrete Weights (For Extra Stability)
All dimensions in inches

Nominal Pipe Size	Mean Outside Diameter (inches)	Spacing of Weights To Offset % Air (feet)			Approx. Weight of Concrete Block (pounds)		Approximate Block Dimensions (inches)						Bolt Dimensions (inches)	
		10%	15%	20%	In Air	In Water	"D"	"X"	"Y"	"Z"	"R"	"T"	Dia.	Length
28 IPS	28.00	20	13 ½	10	900	520	28 ½	44	19 ½	26 ½	48	7 ½	1	54
32 M	31.59	20	13 ½	10	1140	660	32 1/8	48	21	28	51	8 ½	1	57
36 IPS	36.00	20	13 ½	10	1430	830	36	52	23	30 ½	55 ½	9 3/8	1	61 ½
40 M	39.47	20	13 ½	10	1770	1020	40 1/8	56	25	33	60	10 ¼	1	66
42 IPS	42.00	20	13 ½	10	1925	1125	42 ½	59	26 ½	34 ½	63	10	1 1/8	69
48 M	47.38	20	13 ½	10	2500	1460	48 ¼	64	29	39	70	11 ½	1 1/8	76
55 M	55.30	20	13 ½	10	3390	1980	55 ¾	72	33	43	78	12 ¾	1 1/8	84
63 M	63.21	20	13 ½	10	4450	2600	63 ¾	80	37	47	86	14 ½	1 1/8	92

Notes to Table A-3-2

1. Minimum cover of rebar to be 2 ½".
2. Rebar to be rail steel or equivalent.
3. Anchor bolt material to be ASTM A307.
4. It may be desirable to increase the amount of reinforcing used in the 55" and 63" pipe weights.
5. See recommended bore detail on the following page.

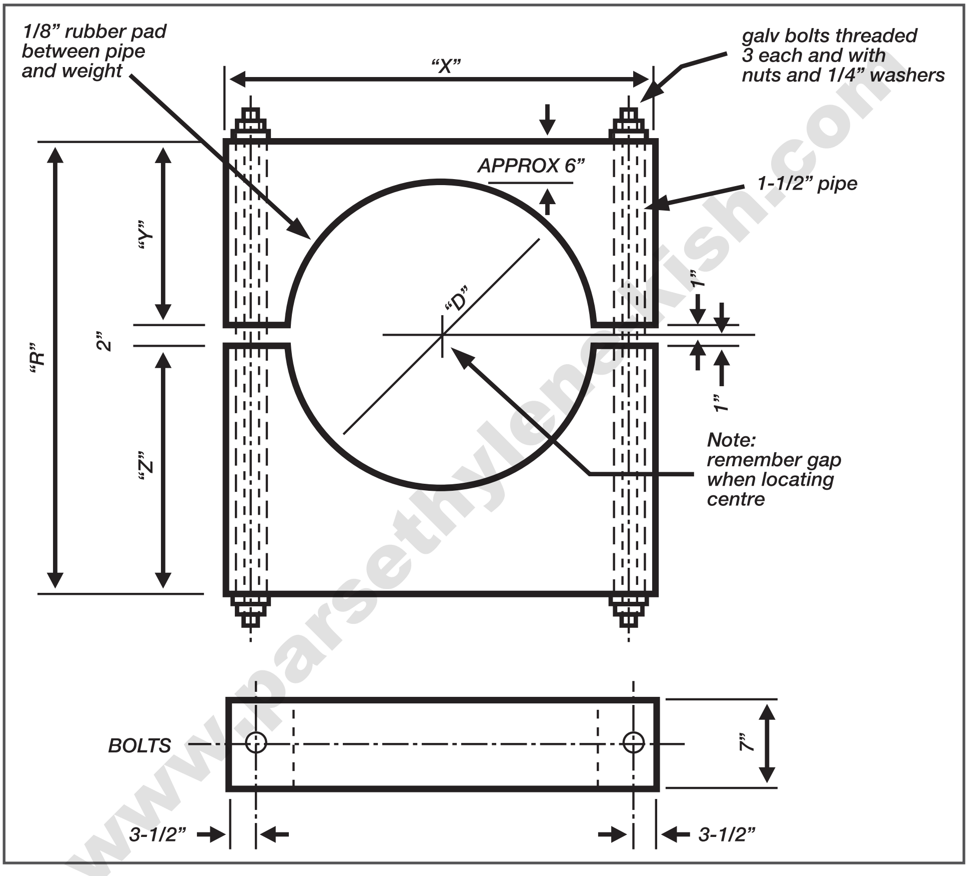

Figure A-3-2 Typical Detail of Concrete Ballast Showing 1-inch Gap Between Ballast Sections

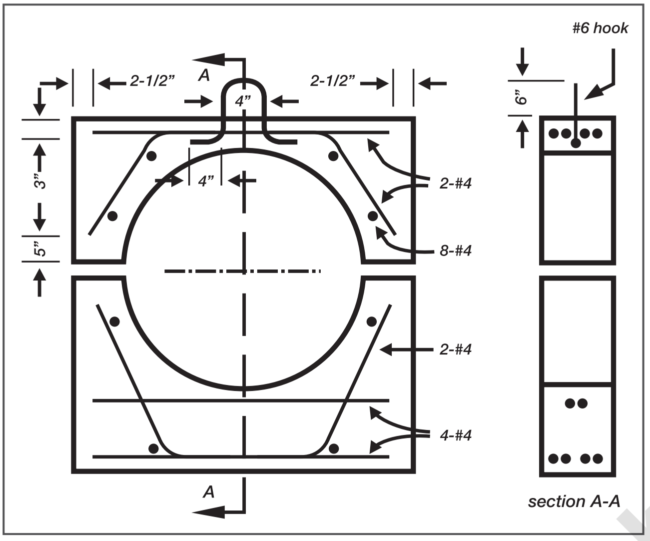

Figure A-3-3 Typical Rebar Detail in Concrete Ballast Design

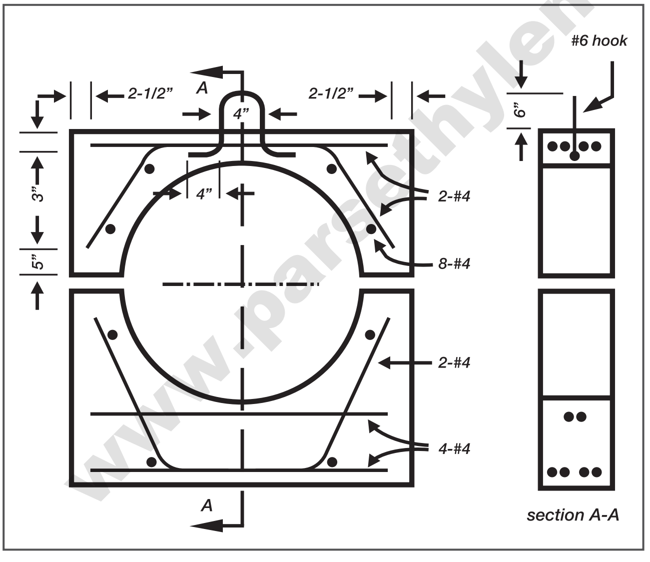

Figure A-3-4 Bore Detail for Concrete Ballast Design