SMALL DIAMETER (HDPE) SUBMARINE OUTFALLS - 2002

Fred M. Reiff
PAHO/HPE

525 Twenty-third Street, N.W.
Washington, D.C., 20037
U.S.A.
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1. **HIGH DENSITY POLYETHYLENE SEWAGE OUTFALLS**

Deep submarine sewage outfalls until recent years have for the most part been limited to the medium to large size coastal cities primarily due to high construction costs associated with construction difficulties that required both expensive specialized equipment and skills generally not locally available. Now with the availability of modern plastic materials and construction methods it is often feasible for small communities to afford relatively long submarine outfalls utilizing for the most part local labor. The pipe material most commonly chosen* for these is high density high molecular weight polyethylene. When the term HDPE is used herein, it is meant to include high molecular weight, extra high molecular weight and ultra high molecular weight HDPE materials.

Pipe of these materials has the advantages that:

- **a)** It is light in weight and, thus, requires no specialized handling equipment (hand labor is sufficient in sizes up to 12 inches).

- **b)** An outfall pipeline can be quickly fabricated on shore by butt fusion*

- **c)** Correctly butt fused joints are stronger than the pipe itself essentially precluding future leaks at the joint due to settlement or movement.

- **d)** HDPE pipe is sufficiently flexible for it to be installed on a tortuous route if necessary, in order to avoid expensive removal of submerged rocks, reefs, etc.

- **e)** The butt fusion method of joining is sufficiently rapid to enable the fabrication of long ocean outfalls in only two or three days.

- **f)** Polyethylene is essentially immune to the corrosive effects of seawater and attack by marine organisms.

- **g)** The HDPE pipe is light enough, yet strong enough to be pulled and floated into place using a tugboat for towing and small boats for alignment of the outfall.

- **h)** If necessary, the pipe can be re-floated by injection of compressed air.

HDPE pipe is suitable for bottoms of sand, mud gravel and small rocks but requires external weights (usually concrete) or mechanical anchors to hold it in place and prevent it from floating or from moving due to hydrodynamic forces. It can also be placed on a seabed of rock as long as the pipe itself is not resting on a point or sharp ridge.

* PVC pipe continuously extruded on shore has also been utilized a few times for this purpose but not on a widespread basis and it is not covered in this manual.
Its major disadvantages are:

a) HDPE is a relatively soft material, which can be damaged by larger boat anchors that hook and pull the pipe. Its high impact resistance, however, will prevent the pipe from shattering or cracking when struck by an anchor.

b) In areas subject to the direct destructive hydrodynamic forces of severe storms, hurricanes or strong currents, additional protection through burial, encasement in concrete or rip-rap, or mechanically fastening the outfall to the seabed is necessary in the depths affected, as it is with all outfall pipe materials.

2. PLANNING A SUBMARINE OUTFALL

In planning a submarine outfall the first step should be to determine a suitable location for the diffuser. The determination of the location and design of the diffuser for a submarine outfall should be based on obtaining adequate distance from sensitive areas and sufficient depth, dispersion and/or die off of pollutants commensurate with the level of treatment prior to discharge to assure negligible environmental or health impact. This is a topic separate from this document, but the Visual Plumes, the 3-PLUMES, and the RSB for Windows computer programs are strongly recommended to carry out the analysis to determine the location and the basic design of the diffuser.

After the diffuser location is determined then the route that the outfall should follow to get there should be established, the necessary internal diameter to accommodate the flows anticipated throughout the useful life of the outfall should be determined, and the method for protecting the outfall against the hydrodynamic forces of the ocean should be designed. The oceanographic information and data that is required to carry this out includes but is not necessarily limited to the following:

a) Topography, hydrography, and geomorphology of the sea bed which is used to determine the route of the outfall,

b) Wave and current data which are used to determine the method of physically stabilizing the outfall, and

c) Current data and salinity temperature profiles of the water column. This is used to determine the location and design of the diffuser, the static hydraulic head, and to the physical stability of the outfall.

It is always a good idea to obtain as much information as early as possible. Nautical charts, bathymetric maps, oceanographic maps, SONAR charts and sounding, as bottom samples, meteorological records, oceanographic studies and reports of marine biology are sources of information that can be very useful in establishing a preliminary submarine outfall route. As such they should be sought out.

When this information is not available and the magnitude of the project warrants it, it may be necessary to conduct the following type of studies.

a) Sonar determined bathymetry with horizontal control linked to a global positioning system. Both the horizontal and vertical precision should be within one meter.

b) Side-scan sonar imaging to determine the geomorphology of the seabed. The sensitivity should be adequate to detect anomalies with dimensions as small as 50 cm and it should be capable of evaluating the class of seabed material.

c) Visual imaging of the possible outfall routes by use of video.
3. SUBMARINE ROUTE SURVEY

It is always recommended that a submarine route location survey be conducted by divers for all outfalls, because many features, which are too small to show up on the maps or the sonar screen, can still cause serious pipeline problems. It is important that the route avoid obstacles, hazards, and problem areas where possible. This includes reefs, environmentally sensitive areas, large rocks, cliffs, drop-offs, high points, areas used for ship anchorage, weak or unstable soils, and areas subject to erosion or deposition.

In the case of HDPE outfalls, this survey serves an additional purpose, which is to take fullest advantage of the pipe's extremely good flexibility so as to reduce installation costs. It is usually less expensive to go around obstacles, such as large rocks, reefs or problem areas such as ridges and sharp drop-offs, rather than to remove them. The time and money spent on determining the best route represents a good investment because it usually helps preclude a great number of problems that would otherwise arise during installation. The survey should not only designate the selected route, but should physically locate the obstacles and problem areas.

For almost all small diameter HDPE outfalls, skilled scuba divers (preferably one of the divers should be an engineer) should conduct a bottom survey. For the preliminary exploratory survey the divers can use compass bearings and dead reckoning from the point of entry of the outfall to the desired terminal point to carry out the survey. At this same time they should install numbered buoys at each problem area and then on the return swim estimate distance between problem areas by using a measuring wheel or a measuring tape. It is important that the diver keep a written log describing the problem area noting bottom conditions and materials along the route and correlating this with the respective buoy number. Videos of the route established and photographs of critical areas can be useful for planning and design. If the problem area is small, the buoys should be anchored or tied firmly in place at the center of the problem area; if it is large it should be marked at both the beginning and the end of the problem area.

On the second exploratory dive, the divers tries to determine and unobstructed route around both sides of each obstacle. If successful, the divers then mark the entire route with buoys of a different color from the obstacle problem area buoys in order to facilitate the determination of both the preferred route and the problem areas from the water surface as well as from the shore. In the neighborhood of the obstacles, the distance between the buoys may be as close as five meters, but on the straight-away a spacing of 50 meters is usually appropriate. It is important that the buoys be large enough and of bright color to be easily seen and that they be tethered with a sufficiently strong line and with a secure anchorage to prevent dragging from currents, wind or waves. It may also be advantageous to number them.

If the route in the vicinity of the obstacles does not entail curves with a radius smaller than 20 times the pipe diameter, the HDPE outfall can readily be bent into place. If extremely sharp curves are necessary, it might be necessary to install prefabricated bends. This will necessitate accurate measurement of angles and exact distance measurements between them. Although, the exact fabrication of an outfall line with accurate location of the bends along with exact placement may seem easy on paper, once on the ocean with seas rougher than expected, unanticipated currents, boat problems and many other unforeseen complications, the exact placement of three or four bends can become extremely difficult. If there is a choice between selecting a route requiring bends or a longer route which does not require prefabricated bends, it is usually preferable to opt for the latter.

By establishing two control points on shore, it is possible to use triangulation to the buoys to record the route with sufficient accuracy for future reference. The on-shore distance between the triangulation points should be no less than 1/4 of the length of the outfall.
4. PRESERVING THE ROUTING BUOYS

Usually the preliminary surveys are conducted before the design phase and there is a considerable lapse of time before construction gets underway. Thus, it is sometimes advisable to remove the buoys until the construction stage begins. When this is the case, easily visible and relocatable bottom markers, such as colored numbered concrete blocks, may be used to facilitate re-establishing the route with marker buoys. Most small diameter HDPE outfalls of less than 1,000 M length take no more than a few days to install. During this construction period it is necessary to prevent tampering with the marker buoys through whatever measures are necessary or are recommended by local authorities. Among them are warning notices printed in the buoys themselves, notices posted in small boat harbors, notification of boaters and fishermen to not only avoid fouling of the buoys, but also to stay clear of the pipeline construction when it is in progress. At this same time, it is a good idea to arrange for the outfall location to be added to nautical charts and coastal maps as soon as possible with a warning not to anchor in the vicinity of the outfall.

5. PIPE DIAMETER SELECTION

Selection of pipe diameter for HDPE outfalls is made through the same series of determinations as for other pipe material. This is usually done through a balancing of friction loss reduction against the flow velocities necessary to maintain sufficient scour to prevent deposition of suspended solids, or grease build up on the pipe wall. New HDPE pipe has excellent flow characteristics. Because of its exceptionally smooth its Hazen and Williams Formula coefficient of C = 155 but for outfalls that have been in use the C is usually estimated to be 140 due to build up of grease on the pipe wall.

For sewage outfalls utilizing HDPE, the flow velocity ranges that have proven satisfactory from both a friction and a cleansing standpoint usually fall within the ranges presented in Table 1. The amount of and characteristics of the suspended solids and grease in the effluent influences the necessary velocity for self-cleansing.

Table 1
Flow velocity ranges HDPE submarine outfalls

<table>
<thead>
<tr>
<th>Nominal Pipe Size (cm)</th>
<th>Satisfactory Velocity Ranges meter/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-30</td>
<td>0.7-2</td>
</tr>
<tr>
<td>25-50</td>
<td>1.0-2.5</td>
</tr>
<tr>
<td>40-75</td>
<td>2-3</td>
</tr>
</tbody>
</table>

It is important that cleansing velocities be achieved at least one time every day for a sufficient period of time to obtain complete flushing of the line. If this does not occur, depositions of solids and bacterial growth on the walls will occur and it will be necessary to send a cleaning plug (a pig) through the outfall at regular intervals to prevent pipe constriction or closure. When designing an outfall for a 25-year projected flow it is important to check the velocities at the present maximum flows to see if sufficient scour velocities are obtained during the first few years of operation. If not, then a maintenance schedule utilizing a cleaning plug should be implemented until such time that flows reach a level to obtain cleansing velocities. Facilities for the removal of grit and grease from the effluent prior to its discharge into the outfall will help minimize problems due to deposition and is recommended. This removal of grease along with floatables serves a second purpose of maintaining acceptable aesthetic conditions.
Computer programs can be used to develop a family of head loss-discharge curves for different diameters of pipe to facilitate the selection of an optimal diameter. In their absence the nomographs in Figures 1 (Metric Units) and 2 (English Units) based on the Hazen Williams formula can be used to determine the pressure losses and velocities for various flow rates in different internal pipe diameters.

HDPE plastic pipe is described by a specified exterior diameter and by a minimum wall thickness needed to obtain the pressure rating of the pipe. Tables 2 and 3 present the external and internal diameters, the unit weight of the pipe for various pressure ratings and the respective dimension ratio.

6. CONSIDERATION OF TIDES AND DENSITY OF SEA WATER

For small communities it is almost always important to keep operating costs as low as possible. This usually means that the designer of the outfall will try to use static gravity head and avoid pumping the sewage to be discharged. For this reason a few words of precaution are in order.

It must be remembered that the times of tidal fluctuations change daily and that the magnitude of tidal changes varies throughout the year as well as the lunar month. For this reason, it may well be assumed that the highest tide and peak sewage flow can probably occur simultaneously. The submarine outfall and appurtenances such as flow equalizers of pumps should be designed accordingly, so as to avoid undesirable surcharge of gravity sewers that have service connections.

The fact that seawater has a density that is approximately 2.5 percent greater that the density of sewage must also be taken into account. This static head must be overcome by the gravity head available or by the pumping facilities. This head can be significant, especially in deep outfalls. For example, an outfall 60 meters deep would have a "density difference" static head of one and one half meters.

7. SELECTION OF THE PIPE PRESSURE RATING AND DIMENSION RATIO (DR)

The pressure rating of the pipe is given by the formula

\[ P = \frac{2S}{(d/t) - 1} \]

in which...

- \( P \) = pressure rating of the pipe
- \( S \) = hydrostatic design stress
- \( d \) = average outside diameter of the pipe
- \( t \) = minimum wall thickness
Figure 1
Nomograph for solution (metric units)
From F.E. Mc Junking, 1969
Figure 2
Nomograph for solution (English units)
From F.E. Mc Junking, 1969
Table 2
Dimensions and weight of HDPE pipe (ISO dimensions)

<table>
<thead>
<tr>
<th>EXTERIOR DIAMETER (mm)</th>
<th>WORKING PRESSURE IN kg/cm² (DR)</th>
<th>2,5 (40,8)</th>
<th>3,2 (32)</th>
<th>4,0 (26)</th>
<th>6,0 (17,6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVERAGE INTERNAL DIAMETER (mm)</td>
<td>AVERAGE UNIT WEIGHT (kg/m)</td>
<td>AVERAGE INTERNAL DIAMETER (mm)</td>
<td>AVERAGE UNIT WEIGHT (kg/m)</td>
<td>AVERAGE INTERNAL DIAMETER (mm)</td>
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<tr>
<td>NOMINAL DIAMETER (INCHES)</td>
<td>EXTERNAL DIAMETER (mm)</td>
<td>WORKING PRESSURE IN kg/cm² (psi) [DR]</td>
<td>AVERAGE INTERNAL DIAMETER (mm)</td>
<td>AVERAGE UNIT WEIGHT (kg/m)</td>
<td>AVERAGE INTERNAL DIAMETER (mm)</td>
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<td>1.282</td>
<td>178.14</td>
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</table>
The term dimension ratio is commonly used to describe and categorize various aspects of thermoplastic pipe. It is abbreviated by the acronym DR and is defined by the formula

\[ DR = \frac{d}{t} \]

in which…

- \( DR \) = dimension ratio
- \( d \) = outside diameter of the pipe
- \( t \) = minimum wall thickness

The ASTM F-17 hydrostatic pressure rating of pipes is based on the use of a service design factor of 0.5 of the results of a sustained long-term (1,000 hour) pressure test (ATSM D-2827) that must result in at least 1,600 psi. In addition a short-term pressure test must result in a 2,900 psi fiber stress before rupture. The design stress for HDPE is 800 psi or 56.24 kg/cm\(^2\) at 23\(^\circ\) C. In the ISO pressure ratings the allowable hydrostatic design stress (S) for HDPE resin is 50 kg/cm\(^2\).

All pipes of the same class of material and the same DR will have the same pressure rating regardless of pipe diameter. Table 4 summarizes the DR-pressure relationship for the more common ratings used in ocean outfalls.

**Table 4**

<table>
<thead>
<tr>
<th>Dimension ratio</th>
<th>41</th>
<th>32.5</th>
<th>26</th>
<th>21</th>
<th>17</th>
<th>15.5</th>
<th>13.5</th>
<th>11</th>
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</thead>
<tbody>
<tr>
<td>Pressure rating in psi and (kg/cm(^2))</td>
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<td>50</td>
<td>64</td>
<td>80</td>
<td>100</td>
<td>110</td>
<td>130</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>(2.8)</td>
<td>(3.6)</td>
<td>(4.5)</td>
<td>(5.6)</td>
<td>(7.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is very important to select the appropriate DR for HDPE pipe to be used in an ocean outfall in order to obtain a trouble free long useful life. Selection of the proper DR is dependent upon a number of factors.

- External hydrodynamic forces in the ocean
- Stresses imposed by construction and handling
- Internal hydraulic pressure
- Spacing of the ballast weights or anchors

Generally, the section of the outfall that is situated in the surge-surf zone is subjected to the greatest external punishment. It is also the area most subject to undermining. This zone is usually shallower than 15 meters when facing the open ocean but in locations subject to hurricanes it can be greater.

In some cases, the forces exerted at shallower depths are sufficiently great that the outfall must be buried and in others the outfall can be sufficiently anchored by use of ballast weights or mechanical anchors. The shallow entry area is usually the section the submarine outfall that sustains the greatest internal pressure. In addition, this area is frequently subject to impact stress from placement of rock ballast. For all of these reasons it is common practice to use a thicker pipe wall (a smaller DR) in the entry zone in order to offset the additional impact, flexing, shear, and hoop stresses. A DR of 11 to 21 is the range commonly used in the surge-surf zone and a range of 19 to 26 is commonly selected for the section outside this zone.

The section of the outfall that is exposed to the greatest external hydrodynamic stress should be determined by wave dynamics and current analysis. The hydrodynamic forces, especially the horizontal and vertical forces that are exerted by waves and currents, should be taken into consideration when selecting the dimension ratio and determining the method of stabilizing the outfall.


8 Classification of Polyethylene Resins

There are a number of classes of polyethylene resins that are used in the manufacture of pipe. Some of them are not appropriate for submarine outfalls because this use requires resins of particularly high quality with specific properties to assure that the pipe resists the physical forces during construction, the internal and external pressures to which it is exposed, the hydrodynamic forces of the ocean, as well as chemical and biological attack. For these reasons it is important that the pipe be manufactured of high density polyethylene resin with sufficiently high molecular weight. It is imperative that medium density polyethylene not be used for ocean outfalls. The American Society for Testing Materials (ASTM) has prepared a standard ASTM D3350 that describes a system of classification of polyethylene resins, known as cell classification. This system classifies the resins according to the results of standardized testing for the most important specific properties.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>CELL CLASSIFICATION ACCORDING TO ASTM D3350-84</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propiedad</td>
<td>Método de prueba</td>
</tr>
<tr>
<td>Densidad, (g/cm³)</td>
<td>D1505</td>
</tr>
<tr>
<td>Índice de fusión Condición E (gms/10 min)</td>
<td>D1238</td>
</tr>
<tr>
<td>Módulo de flexión Mpa, (psi)</td>
<td>D790</td>
</tr>
<tr>
<td>Esfuerzo a la tracción Mpa (psi)</td>
<td>D638</td>
</tr>
<tr>
<td>Resistencia al agrietamiento por esfuerzo ambiental Condición Duración (hr) Falla, max, %</td>
<td>D1693</td>
</tr>
<tr>
<td>Base de diseño hidrostático Mpa (psi), (23 °C)</td>
<td>D2837</td>
</tr>
<tr>
<td>Estabilizador UV y color</td>
<td>A Natural</td>
</tr>
</tbody>
</table>
The success of a submarine outfall is contingent upon the designer’s knowledge of the hydrodynamic forces of the ocean that are likely to be encountered by the outfall during the design life of the outfall. Failure to adequately assess these forces and take them into account during the design and construction of the outfall has probably been the leading cause of failure of submarine constructed of HDPE pipe and pipe of other materials as well. The prediction and analysis of the ocean’s forces that can be exerted on an outfall is a topic outside the scope of this manual but a summary of what information is needed and how it is applied is included in the following paragraphs.

Current and wave-induced forces are the most important forces to be taken into consideration in the design of a submarine outfall. These forces have resulted in physical destruction of the pipeline by both the movement of the water itself or by the impact of objects such as submerged logs of trees being driven into the pipeline. Failure has also been associated with lateral sliding of the outfall from insufficient ballast anchor weight to withstand the horizontal and lifting forces induced by the current. Undermining of the seabed material from beneath an outfall by current induced differential erosion has resulted in failure by separation of pipe joints. (This is rarely a problem in HDPE outfalls pipe because of its superior flexibility but is a problem with pipe materials that utilize a compressed O-ring type of joint.) Mass movement of seabed material that has been caused by to storm induced waves and currents (and more rarely due to spontaneous liquefaction during earthquakes) has also resulted in outfall failure.

There are many areas in the ocean where tidally driven strong currents occur twice a day. Large fiords or bays with relatively narrow and shallow mouths can generate extremely strong currents especially in areas with large tides. Such currents have been measured in excess of 17 knots. Tidally generated movement of water through openings in barrier reefs can also reach high velocities on a daily basis. Frequently such areas have geomorphologically sheltered from the open ocean and are thereby protected from large waves. In such cases the currents are the critical factor in determining the method of stabilizing the outfall. An equation that is commonly used to evaluate the necessary ballast weight necessary to stabilize a submarine outfall against a current perpendicular to the centerline of the outfall is...

\[
W_B = \left( \frac{C_D + C_L}{\mu_s} \right) \frac{\rho}{2} (DL) V^2
\]

in which.....

- \( W_B \) = the buoyant weight (submerged weight of the outfall) of length \( L \)
- \( C_D \) = the drag coefficient
- \( C_L \) = the lift coefficient
- \( \rho \) = the mass density of seawater (the unit weight of seawater divide by acceleration of gravity)
- \( \mu_s \) = the static friction coefficient between the ballast anchor (or pipe wall) and the seabed
- \( D \) = pipe diameter
- \( L \) = length of pipe section considered (usually a length of 1 meter)
- \( V \) = the velocity of the current moving perpendicular to the pipe

It is important to note that \( W_B \) is the submerged weight of the outfall not the weight in air. This can be calculated by multiplying the weight in air by the (sink factor – 1). The sink factor is explained in the following sections. The friction factor \( \mu_s \) varies between about 0.6 and 1.4 for sand and between 0.2 and 0.7 for silt and clay. To obtain the aforementioned coefficients and for complete treatment of current induced forces on ocean outfalls, refer to the publication by Grace and the World Bank publication edited by Gunnerson both listed in the suggested references at the end of this document.
It is critically important to take into consideration the forces that are exerted by ocean waves on a submarine outfall, particularly where the outfalls extend from a coastline facing the open ocean, especially in regions that are frequented by hurricanes or other violent storms. The first step is to decide on a recurrence interval of a rare but possible deep-water wave that would travel to the outfall site during the useful life of the submarine outfall being planned. For ocean outfalls, a common recurrence interval (return period) is 50 years and sometimes a rather conservative interval of 100 years is used.

This is usually referred to as the design wave. The characteristics of the design wave that are used to calculate the resultant hydrodynamic forces on an ocean outfall are the deep-water period and the deep-water wave height. Unfortunately, wave measurements at specific stations cover spans of time much shorter than the recurrence intervals that are useful, and there are almost never stations that are strategically near the outfall site under consideration.

Typically, this is done by an Oceanographic/Ocean Engineering firm that incorporates into their analysis the historical database of storms and hurricanes that pass within a selected radial distance of the outfall site. A distance of 300 nautical miles is a common figure used for this purpose. One of a number of hurricane/tropical storm hindcast wind models is applied to each of the storms/hurricanes. These models incorporate into them such factors as the storms’s maximum wind speed, the speed that the eye of the hurricane travels, radius to maximum wind speed, and distance from the eye of the storm to the maximum wind speed. The model is used to determine the maximum deep-water wave height and period at the outfall location for each of the storms.

After this, a statistical analysis is used to determine wave heights and periods for different return periods. The results are usually presented in tabular form that correlates various return periods with the respective maximum wave height, wave period, standard deviation, and probability of exceedance. Return periods commonly presented are for 2, 5, 10, 20, 25, 50, and 100 years.

Now the person designing the submarine outfall must use the derived design wave to determine the hydrodynamic forces that this wave will cause to be exerted on the outfall. The first step is to determine the maximum velocity and maximum acceleration that the deep-water design wave would generate at the water depths in which the outfall is to be located. The Airy theory (otherwise known as the linear theory) and the Cnoidal theory are the two most common theories used to derive the maximum velocity and maximum acceleration. The CEDAS computer program from the U.S. Corps of Engineers allows the use of either theory. The maximum velocity is used to determine the drag force and the acceleration is used to determine the inertia force that the design wave exerts on the outfall as it passes over the outfall.

Entering the maximum velocity and maximum acceleration into any of several available computer programs or entering them into Morrison’s or Grace’s equations, the maximum horizontal and maximum vertical forces exerted by the design wave can be calculated. It is also necessary to adjust the coefficients of these equations to account for the angle of incidence of the design wave’s approach to the axis of the outfall pipe.

Knowing the maximum horizontal and vertical forces to which the outfall would be subjected during its design life is possible to make a decision on how to assure the stability of the outfall. It may be necessary to bury the outfall in the seabed up to a certain water depth to adequately protect it. It might be feasible to fasten the outfall to the seabed with mechanical anchors that are screwed or driven into an unconsolidated seabed. It also might be possible to stabilize the HDPE outfall by attaching sufficiently heavy ballast anchor weights onto the HDPE pipe to affix it to the seabed. Frequently, the outfall will be stabilized with a combination of these methods.
10 STABILIZING HDPE OUTFALLS WITH CONCRETE BALLAST ANCHORS (WEIGHTS)

Probably the most common cause of failure of small diameter HDPE outfalls is inadequate anchoring of the pipeline. This deficiency allows movement and damage due to waves, currents, surge and surf. Small diameter HDPE outfalls stabilized by concrete ballast anchors rarely fail because of undermining because the HDPE pipe and anchors tend to settle into the scour excavation without causing breakage of the pipe thanks to the flexible characteristics of HDPE. However when metal mechanical anchoring systems have been used to fasten the outfall to the seabed bottom, erosion has resulted in failure. HDPE can also tolerate movement better than almost any other submarine pipeline material.

Another cause of HDPE outfall failure has been due to the use of non-corrosion resistant metals to fasten the anchor collars to the pipe. Subsequent failure of the fasteners allows release of the anchors and since the pipe and its contents are lighter than seawater the pipe floats toward the surface.

10.1 Determination of the spacing of anchor weights

The worst beam-stress condition usually occurs during installation and this is due to the weight of the anchors during the floating and towing of the pipeline. It may also occur from hydrodynamic forces due to currents and possibly from the sinking of the anchors into a soft seabed. It is important that distances between anchor collars not be too great. The stress exerted can be estimated as a uniformly loaded simple beam with a unit-loading equal to the unit buoyancy of the pipe. The greatest stress and deflection occurs during the sinking of the outfall during the installation on the seabed.

To limit the deflection to less than 5 percent or the strain to less that 1 percent, the chart shown in Figure 3 was developed to determine maximum spacing of anchors for various standard dimension ratios of HDPE pipe. It should be noted that for smaller dimension ratios, although the spacing between anchors can be large, it is often limited to no more than 5 or 6 meters because of construction practicality. This limit is a rule of thumb that has been established to avoid or at least reduce those problems encountered in handling and attaching inordinately large anchors. Generally, it is also better, from the standpoint of external hydrodynamic forces, to have more closely spaced smaller anchor weights than to have larger ones spaced at greater distances, because the closer the pipe is to the bottom the less the pipe is exposed to currents and surge forces.

10.2 Determination of anchor collar weight

There are two distinct considerations in determining the amount of weight to adequately anchor ocean outfalls of HDPE. One consideration is the ballast necessary to preclude flotation in areas outside of the surge-surf zone, the other is to prevent movement inside the surge-surf zone during worst expected storm conditions. Two altogether different approaches are used.

The term sink factor is used in HDPE submarine pipelines to describe the ratio of the total downward force to the total upward force of the pipeline system including pipe, pipe contents and anchor weights (collars). The sink factor is nothing more than the systems "specific gravity". It is used as an indicator of the pipeline's stability and resistance to the various hydrodynamic forces exerted by the ocean, and rules of thumb for appropriate use of sink factor values range between 1.1 and 1.5. The author has found that a great deal of caution should be used in applying the rule.
Figure 3
Maximum span between concrete weights
for underwater HDPE pipelines
of thumb for sink factors in the surge-surf zone in the ocean environment, especially when it is an installation facing the open ocean. However, experience shows it to be adequate for areas beyond the surge-surf zone with currents less than about 4 knots (0.72 m/sec).

The sink factor (K) can be expressed by the formula:

\[
K = \frac{\text{(weight of pipe + contents) + (weight of concrete anchor in air)}}{\text{(weight of water displaced by pipe) + (weight of water displaced by concrete anchors)}}
\]

If we let:

- \( W_A \) = Total weight of each anchor in Air (kilograms or lbs)
- \( W_s \) = Unit weight of pipe contents (kilograms/meter or lbs/ft)
- \( W_p \) = Unit weight of pipe (kilograms/meter or lbs/ft)
- \( W_m \) = Unit weight of pipe (kilograms/meter or lbs/ft)
- \( W_m \) = Unit weight of pipe (kilograms/meter or lbs/ft)
- \( S \) = Spacing selected for weights (meters or ft)
- \( V \) = External unit volume of pipe per unit length (m³/m of ft³/ft)
- \( W_c \) = Density of concrete (kilograms/m³ or lbs/ft³)
- \( K \) = A unitless constant (desired ratio of downward force to upward force often referred to as the sink factor)

We can rewrite the equation:

\[
K = \frac{S(W_p + W_s) + W_A}{SVW_m = W_A W_m / W_c}
\]

rearranging and solving for \( W_A \) results in the following equation:

\[
W_A = \frac{S(KW_m - W_p - W_s)}{1 - KW_m / W_c}
\]

For the portion of the pipeline through the surge-surf zone, it is a good idea to place as much anchor weight on the pipe which will still allow it to be floated into place when it is filled with air. For practical purposes, this means about 0.8 of that maximum weight. Under these conditions \( K = 1 \) and \( W_s = 0 \) and the equation simplifies to:

\[
W_A = \frac{0.8S(W_m V - W_p)}{1 - W_m / W_c}
\]

10.3 Ballast anchor design

Ballast anchors for HDPE submarine outfalls are usually made of reinforced concrete because of concrete’s suitable density and durability in seawater. There are many possible designs, but generally a trapezoidal or square design is used in the open ocean so that the ballast anchor will resist rolling when subject to lateral forces due to currents or wave action. A round collar design is often employed when the outfall will be buried in a trench or is intended to settle downward into a
seabed of loose sand or weak clay. In any case the specific design chosen should be based on:

a) Ease of fastening the anchors to the pipeline;
b) Fasteners resistant to salt water corrosion;
c) Ease of bending and placing the reinforcing steel and:
d) Ease of casting the concrete.

Figure 4 illustrates a common ballast anchor design for small diameter pipe that is illustrated in many plastic pipe. This common design has two rectangular collars constructed of concrete in a manner so that it can be clamped onto the outside of the pipe. It is herein referred to as the Type A design. This particular variation uses two bolts of saltwater corrosion resistant material. It is possible to also use fiberglass bolts, or polyethylene plastic pipe with heat formed ends as a means of fastening the halves together. It has two major shortcomings. 1) This design does not have a center of gravity that is lower than the systems center of buoyancy and it is therefore somewhat prone to rolling over in strong currents. 2) The bolts are long making them difficult to align with the top and bottom bolt holes during attachment to the outfall pipe and this also makes grouting of the annular space more difficult.

Figure 5 illustrates the Type B ballast anchor design that has been successfully used for HDPE pipelines up to 20 cm diameter. The spacing of this type of anchor is usually limited by the class of handling equipment available rather than the deflection or strain of the pipe itself. The major drawback of this ballast design is there is not much pipe surface area in contact with the bars that hold the pipe into place and this has resulted in kinking of pipe with larger dimension ratios during launching and sinking of the pipe.

Figure 5(A) illustrates the Type C ballast anchor, which is usually the easiest to install and has the least problems with corrosion because it requires no bolts to attach it to the outfall pipe. It is installed on the pipe by squeezing the HDPE pipe with two large clamps on each side of the pipe where the anchor is to be placed. The temporarily deformed pipe is then inserted through the narrow (0.7d) neck of the opening and then the clamps loosened to allow the pipe to snap back into the round shape. It may be necessary to rotate the clamps 90% to "encourage" the HDPE pipe to snap back completely. This is possible only with HDPE and polypropylene pipe. Larger anchors of this design should be constructed with lifting lugs cast into them, to facilitate their handling and fastening to the pipeline.

Concrete ballast anchors may be factory cast and hauled to the outfall assembly site or cast at the assembly site by the same labor crew to be used for installing and assembling the HDPE outfall. Since many installers elect to cast the ballast anchor themselves, some suggestions and precautions are included.

10.4 Ballast anchors cast at worksite

In casting the two halves of the Type A design, the form shown in Figure 6 is usually constructed so that both halves of the collar can be cast at the same time, using a short piece of the HDPE outfall pipe to achieve an exact fit. The two halves are separated by 1/2 cm (1/4 inch) plywood. This provides sufficient play to insure a tight fit when the two halves are bolted together when the anchor collar is attached to the pipe. The holes for the bolts are formed using thin wall PVC pipe with an internal diameter 50 percent larger than the diameter of the bolts to be used. They are held in place by a rod extending through the form so as to help assure bolt alignment.
Figure 4
Type A. Concrete anchor collar for pipe diameters smaller from 20 cm.
Figure 5
Type B. Concrete anchor blocks for HDPE submarine outfall
Type C. Reinforced concrete anchor blocs for HDPE submarine outfall
Figure 6: Typical form for casting type A concrete anchor collars.
Figure 7: Typical Form for Casting Type B Concrete Anchor Blocks.
Figure 7 presents the typical form used for casting type B concrete anchor blocks.

It is important to schedule casting of concrete anchor collars to be completed at least one month in advance of outfall installation to allow adequate time for curing. Consideration should be given to casting the anchor collars at the outfall shore line site to avoid unnecessary handling and transportation.

It is also a good idea to number the matching halves when they are removed from the form to assure compatibility of bolt holes. In any case, a little extra care in form precision will pay for itself many times over during the attachment process.

The concrete used in the ballast weights should have a minimum cement content of 375 kg/m$^3$ and a 28 day strength of 300 kg/cm$^2$ so as to be resistant to the salt water environment and reduce the potential for corrosion of the reinforcing steel. High early strength cement may be used to allow early removal from the forms, thus, reducing the number of forms needed over the casting period. The type of cement used should be for marine use.

It is always a good idea to cast a sufficient number of extra anchor collars to allow for possible breakage.

11 JOB SITE FOR BUTT FUSION AND ANCHOR COLLAR ATTACHMENT

Every site is somewhat different, but careful planning of the butt fusion and concrete ballast anchor attachment operations is always time well spent. The primary objective is to get the outfall constructed properly and into the water as quickly and as easily as possible. The strategy to accomplish this should include the following components:

a) Material storage in a convenient, easily accessibly location.

b) Adequate size and number of pieces of heavy equipment to handle material.

c) Selection of butt fusion equipment that is adequate for the diameter and DR of the outfall pipe and which automatically records the essential details of the fusion of each joint. Retain the services of an experienced fusion equipment operator.

d) Protection of the butt fusion process from wind, dust, rain, snow. If necessary provide an enclosed or semi-enclosed shelter for this operation. Carefully follow the pipe manufacturer’s recommendations for the fusion process. Assure adequate time (at least 35 seconds for each cm of diameter) for the newly fused joint to cool sufficiently before the pipe is removed from the clamps of the fusion machine and an additional 20 minutes before the joint is subjected to traction or flexure.

e) Provide adequate temporary facilities on which to fabricate the outfall and from which to launch the outfall into the ocean. The temporary facilities should be designed to require as little motion and as little handling of materials as possible, especially the ballast anchors.

f) The system for attaching the ballast anchors should enable the ballast anchors to be accurately spaced at the designated intervals on the outfall.

g) The temporary facilities should enable the completed outfall assembly to be moved into the ocean as efficiently and quickly as possible with as little handling as possible.

h) Doing all this in a safe manner.
There are two main approaches to fabricating and launching HDPE outfalls into the ocean. One is to butt fuse the pipe and attach the ballast anchors at the same time that the pipe is being pulled into the ocean. This is only suitable for pipe diameters of 25 cm or smaller and it is usually limited to outfalls that are shorter than 500 meters long.

A better approach that can be used for all diameters of pipe is to construct a temporary facility (usually a small rail system) on which butt fuse and fabricate the entire outfall with the ballasts, end plates, and pulling heads securely attached. After pressure testing the outfall it is then pulled and towed down the rail system to launch it into the ocean. The entire outfall is then towed into place and carefully submerged by releasing air and allowing water to enter the outfall. It is guided into the desired seabed route by divers that instruct the boats for direction of pull and advise a person at the terminal end when and how much air to release.

Even though the second method necessitates more extensive temporary facilities than the first method it has several major advantages.

a) It enables a shorter interval of time between commencing of launching and placement and submergence of the outfall. This can be very important when sea conditions are subject to change.

b) It enables pressure testing of the completed outfall while it is still on land and can readily be inspected for leaks or defects. This virtually eliminates the possibility of defective butt fused joints and the extreme difficulty of repairing them once the launching process has begun.

c) The butt fusion process and attachment of the ballast anchors can be accomplished under less pressure for speed and this greatly reduces the likelihood of defective joints or misalignment of the ballast anchors.

d) It greatly reduces the time that boats and divers will have to be available.

e) It can be utilized for all diameters of HDPE pipe.

f) It can be utilized for pipe made of other materials that are suitable for installation by floating and submergence.

A variation of this method is to fabricate the outfall, with ballasts attached, in 2 or 3 long sections and then launch the sections consecutively and butt fuse them together during the launching process.

It is important that the methodology chosen for ballast anchor installation make the job as easy as possible. For larger ballast anchors it is important to have adequate equipment to move and manipulate the anchors when they are moved from the casting area to the area to attach them to the outfall. The anchors should be attached after the joint has adequately cooled. It is a good idea to leave several hours for the joint to cool before the anchors are attached to the pipe.

The simultaneous butt fusion, anchor attachment, and launching method is limited to use only for smaller diameter outfalls, where tidal variation is not too great, and sea conditions are relatively calm. When this method is used it is common practice to install a temporary working platform at the waters edge (see Figure 8) so the concrete anchor collars can be attached immediately before the pipe is dropped into the water. A gantry with block and tackle is installed at this platform for handling and attaching the concrete anchors. Typically a system or rollers is used to guide the pipe from the butt fusion area to the platform and facilitate the forward movement of the butt fusion area to the platform and facilitate the forward movement of the pipe.

Another arrangement that has been used instead of rollers is to construct a temporary track (see Figure 9) from above the high water line down to below the low tide and to make simple dollys to run on this track to carry the concrete anchor collars and pipe down to the water. After the dolly enters the water and the pipe begins to float the dolly is removed and placed under another anchor. In this arrangement the gantry or the tripod usually straddles the upper end of the track. This method can be used in situations with more tidal fluctuation than the small working platform can.
To accelerate pipe fusion during the installation process, it is a common practice to fuse every other two lengths of pipe together two or three days before the outfall installation. This reduces by half the number of joints to be fused during the installation process.

12 FLOATING, SUBMERGING AND PLACING THE OUTFALL

The HDPE submarine outfall is designed to be buoyant with the anchor collars attached and the pipe filled with air and to be strongly negatively buoyant when it is subsequently filled with water. Air is contained in the pipe by means of a sealed and plug or plate securely attached to the end of the pipe. The plate or plug is fitted with an air release/inlet valve and then it is attached to the terminal end of the pipe. By gradually releasing air from this valve and allowing water to enter the outfall at the shore end. The rate of descent is controlled through the release of air at the terminal end and the controlled entrance of water at the shoreline. It is important that the pipe be sunk from the shore progressing to the terminal end so as to preclude entrapment of air in a high spot.

A number of small boats are needed to tow the pipeline out from shore as it is fused together and the anchor collars are attached and to tow it into place for submergence. A general rule of thumb for the number of boats required is one boat for every 100 meters of pipe. Fewer or more may be applicable depending on water conditions.

Several boats are stationed at intervals along side the pipe on the up current side of the route pulling the pipe into place. During the sinking, the boat at the terminal of the pipe operates the air release valve. The boat at the terminal end of the pipe does not have to be in place until the final length is sent into place. Three placement boats are usually required in the vicinity of the section being sunk. It is usually easier to allow the pipe to flex with the current gradually pulling it into place along the route as it is sunk.

Divers on the pipeline communicate with both the three or four placement boats, which are towing the pipe into place, and the boat on the terminal end releasing the air. The divers advise the placement boats to move the pipe to right or left, or hold, so as to keep the pipe on alignment as it reaches the bottom and also advise the air release operator when to release the air to obtain descent of the pipe. Air is released in a series of short bursts with sufficient time between bursts to receive communication from the divers. It is better to release the air too slowly than too quickly.
Figure 9: SCHEMATIC OF A TYPICAL TRACK AND DOLLY METHOD FOR ATTACHING ANCHOR BLOCKS TO HDPE SUBMARINE PIPELINE
Figure 11: PROFILE OF TYPICAL SUBMERGING PLACEMENT PROCESS FOR HDPE SUBMARINE OUTFALL
Figures 10 and 11 schematically depict the plan view and the profile of this process, respectively.

Several words of caution are in order here. The air pressure that develops at the terminal end plate will be equivalent to the pressure of water at the depth of submergence. The end plate (or plug) must be securely fastened to the terminal end. If it dislodges it can be almost as dangerous as a cannon to the nearby workers. In addition, the pipe will sink rapidly greatly endangering the divers. When this happens the pipe usually does not sink evenly, it will probably drape over the reefs, rocks or other obstacles that were to be avoided and it will usually be necessary to replace the plug/plate under water and pump air into the pipe from the terminal end to refloat and resubmerge the outfall. This is a costly and time-consuming situation that surely should be avoided.

It is, therefore, recommended to use specially fabricated strong pulling head that can be very securely fastened to the end of the outfall to be towed into the ocean. The pulling head should be fitted with a check valve and a quick connect coupling to permit attachment to an air compressor if needed. It should also be fitted with a strong, corrosion resistant air release valve of a diameter appropriate for the diameter of outfall. Also, the terminal/air release boat should have a small gasoline driven air compressor with a hose at least 50 percent longer that the depth of the end of the outfall to allow refloating and adjustment if necessary.

The shoreward end of the HDPE outfall should be fitted with a butt fused flange adapter and with a bolted plate with an air-tight gasket. It should also be fitted with a water valve of sufficient diameter to allow water to enter the pipe at a reasonable rate for submergence of the outfall.

In addition, all boats should be fitted with two-way radios or supplied walkie-talkies. A communication system to enable the divers to give instructions directly to the boats is very helpful.

All divers should be instructed to stay above the pipe at all times. The divers should have available several large air lift bags with lifting straps each capable of lifting 400 lbs. so, if necessary, to make minor adjustments in the pipe without having to refloat it. There should be a sufficient number of divers on hand to enable shifts so as to avoid the necessity for decompression, otherwise a decompression chamber should be on hand.

If proper precautions are taken and the workers are careful, methodical, and well organized with good communication between the divers and the crews in the boats will not be a need for this equipment, but it should be available and ready to use just in case a mistake is made.

13  COSTS

Figure 12 presents the unit cost of HDPE submarine outfalls including their diffusers en relation to the nominal diameter of the pipe in centimeters. This figure is intended for use in making the first crude costs estimates. The graph is based on actual costs of HDPE outfalls in different countries and conditions that vary from tropical to arctic.

The costs are generally limited to the costs associated with fabrication of the outfall, ballast anchors, testing of the outfall, launching the outfall into the ocean, and floating and towing the outfall to the desired location, and submerging it in to place. It also includes trenching and burial in the ocean floor when that was necessary.
Figura 12

COSTO UNITARIO DE CONSTRUCCIÓN DE UN EMISARIO
SUBMARINO DE HDPE
This graph does not include the cost of sewage treatment prior to discharge. It also does not include the cost of pumping facilities. The range of costs varies considerably within the limiting conditions described as favorable or difficult. The unit cost fluctuation is to be expected for the following reasons.

a) Some outfalls are located in situations where it is necessary to bury much of it in the seabed in order to protect it from hurricanes and tropical storms.
b) Other outfalls are located in protected areas with more favorable weather conditions and a suitable seabed so that stabilization of the outfalls requires nothing more than ballast weights and a relatively low sink factor.
c) The transition from the land to the sea can also influence the cost greatly. Extensive rock excavation or other difficulties can elevate the costs significantly.
d) Another factor in the complexity of the geomorphology of the ocean floor. This can affect the difficulty of placing the pipe as well as require expensive efforts to modify unfavorable conditions such as obstacles, sudden drop offs, etc.
e) The diffuser location and depth also have a strong influence on unit costs.
f) Construction site accessibility can have a significant influence on costs. Proximity of harbors and ports and the general transportation infrastructure are also import factors.

The total cost of an outfall is not only dependent on unit costs but also to a great degree the length and diameter of the outfall. The length can be dictated by the location of environmentally sensitive areas such as shellfish harvesting areas, beaches and water sport areas, the slope of the ocean floor, the predominant direction of the wind, and the direction and velocity of currents. The salinity temperature profiles of the water column has a significant influence on the design and cost of the diffuser.

14 EXAMPLE PROBLEM

Choose the pipe diameter and DR and determine the spacing and weight of concrete anchors for an HDPE ocean outfall for a community with a present population of 20,000 people which generates a sewage flow of 4,000 m$^3$/day and which has a projected population of 42,000 people and is projected to have a sewage flow of 10,000 m$^3$/day at the end of the 25-year design life of the outfall. The sewage receives primary treatment. The peak flow is 150% of the average flow. The surge-surf zone at the selected outfall site terminates at a depth of 7 meters, at a distance of 200 meters from the shore and the selected discharge area of the outfall is located an additional 700 meters offshore at a depth of 27 meters at high-high tide and 25 meters at mean low tide level. The bottom conditions are sand and gravel with random outcrops of rock. The surge-surf zone bottom is all sand and gravel. The outfall site is facing the open ocean. For this problem assume that 80% of the maximum floatable weight of the outfall pipe will be adequate to stabilize the pipe through the surge-surf zone. The available gravity head above the high-high tide level is 7.4 meters and 9.4 meters above the mean low tide level.

SOLUTION

10.1 Step I: Selection of Pipe Diameter

The strategy for designing an appropriate submarine outfall is to obtain cleansing velocities at least once a day under present conditions and still not obtain excessively high heads before the end of the design life (in this case 25 years). It is not always possible to attain both objectives and when this occurs one must refer to the shape of the projected population growth curves to determine whether it is better to favor the present, intermediate or design life sewage flows.
For this problem we shall attempt to keep the friction losses sufficiently low so as to eliminate the need for pumping during the life of the outfall and to obtain flow velocities during the initial years of operation within the cleansing range indicated in Table 1.

First it is necessary to calculate peak flows for both the present population and the design population so as to be able to determine the respective losses.

Present peak flow

\[
Q_{dpf} = 4000 \text{ m}^3/\text{day} \times 1.5 \times 0.0116 \frac{\text{liters/ sec}}{\text{m}^3/\text{day}}
\]

\[
Q_{dpf} = 69.5 \text{ rounded to 70 liters/second}
\]

Design peak flow

\[
Q_{dpf} = 10,000 \text{ m}^3/\text{day} \times 1.5 \times 0.0116 \frac{\text{liters/ sec}}{\text{m}^3/\text{day}}
\]

\[
Q_{dpf} = 174 \text{ rounded to 175 liters/second}
\]

Next the density head of seawater at high-high tide is derived. The density head of seawater \((h_d)\) is equal to the depth of submergence at high-high tide multiplied by 0.025. For mean level \(h_d = 27 \text{ m} \times 0.025 = 0.68 \) (rounded to 0.7).

The driving head available \((h_d)\) at high-high tide is the critical limiting condition. It is equal to the available gravity head of 7.4 m less the density head.

\[
h_d = 7.4 - 0.7 = 6.7 \text{ m}
\]

Next we will determine the diameter of pipe, which will give a cleaning velocity of 1 m/sec for present peak flow (70 l/sec). Using the Hazen Williams nomograph in Figure 1 we obtain a diameter of 30 cm. We now need to refer to Tables 2 and 3 to find an inside diameter close to 300mm that is actually available for a DR appropriate (between 15.5 and 26) for the surf zone. In Table 2 we can locate a pipe with an internal diameter of 314.8 in the column for DR of 17.6.

Now we check the head loss for this diameter and the design flow of 175 l/s and a Hazen Williams coefficient \(C=140\) using the nomograph in Figure 1. We obtain a friction head loss of 12.5 meters per 1,000 meter length. For a length of 900 meters this gives a head loss of 11.3 m which is well above the 6.7 meters available. Because only 6.7 meters of gravity head is available, it would be necessary to boost the head and additional 4.6 m by pumping to meet these flows. This could be an expensive proposition for a town of 20,000 people.

The next step is to check the results of using the next larger internal diameter of HDPE pipe, which is shown as 354.5 mm. Using Figure 1 again we obtain a head loss of 7 meters/1000 meter length which would reduce to 6.3 meters for the actual 900 meter length. This is within the available head of 6.7 meters. The velocity is found to be 1.77 m/s for the design flow.
However, this diameter would yield a velocity of only about 0.7 meters/sec for the present peak flow of 70 l/s. This slightly below the recommended self cleaning velocities indicated in Table 1, which means that a cleaning plug (pig) might have to intermittently be sent through the outfall during the initial years of operation until the peak flows increased sufficiently to create cleansing velocities.

10.2 Step II: Spacing of concrete ballast anchors in surge zone

For this problem we will elect to use the 354.5 mm inside diameter pipe with the 400 mm outside diameter and the DR of 17.5 (that is suitable for the surf zone). The density of concrete is 2,400 kg/m$^3$ and the weight of this seawater is 1,025 kilograms/m$^3$. The volume of seawater displaced by the external volume of this pipe would be 0.1257 m$^3$/meter of length. Table 2 gives the unit weight of this as 26.9 kg/meter of length.

Referring to Figure 3, for a DR 17.6, a spacing less than 8.6 meters should be used. In this situation, because of an interest in using as much hand labor as possible, a spacing of 4 meters will be used out through and beyond the surge surf zone.

Then the concrete anchor weights are calculated by equation (2) from page 16.

$$W_A = \frac{0.8S(W_m - W_p)}{1 - W_m/W_c}$$

$$W_A = \frac{0.8 \times 4m \times (1,025 \text{ kg/m}^3 \times 0.1257 \text{ m}^3/m) - (26.9 \text{ kg/m})}{1 - \frac{1,025}{2,400}}$$

$$W_A = 569 \text{ kg}$$

10.3 Step III: Spacing of concrete ballast anchors beyond surge zone

Beyond the surf-surge zone the ballasts can be spaced further apart. We try an interval of 8 meters for the same ballast anchors. This is less than the 8.6 meters permitted by the Figure 3 graph. Now we will check the sink factor that is obtained with this interval of spacing for ballast anchor weight of 569 kg to see if it is a reasonable figure. Using equation 1 found on page 16.

$$K = \frac{S(W_p + W_s) + W_A}{SVW_m + WAW_m/W_c}$$

and substituting the given values and obtained values for the variables we obtain the sink factor K for this interval of ballast spacing.
This is a reasonable sink-factor for the conditions outside of the surf-surge area,

\[ K = \frac{8(26.9 + 98.98) + 569}{(8 \times 0.1257 \times 1025) + 569(1025/2400)} = 1.24 \]
15 SUGGESTED REFERENCES


