Technical Manual: Plastic Pipe Used in Embankment Dams


November 2007
Chapter 4
Drainpipes and Filters

Most modern embankment dams designed since about the mid 1970’s include drainage and filter zones that are sized to protect against seepage-related failure modes without relying solely on a system of drainpipes. Drainpipes provide extra capacity in drain systems and provide added conservatism and redundancy to the design of these important features. Collecting and measuring seepage flows through and under embankment dams is an integral part of safe and reliable monitoring of embankment dam performance. This flow is typically collected and conveyed through filters and drainpipes as part of a embankment drain collection system. Collected seepage can be measured to detect changes in seepage flows that may indicate changes in the condition of the dam or foundation, or possible clogging of drains. Collected seepage can also be inspected for the presence of sediments that may indicate a possible loss of soil materials.

This chapter will present methodology for the structural design of the drainpipe and hydraulic design for the collection of water into the drainpipe. This chapter will also discuss the relationship between soil backfill and the drainpipe. Types of backfill are separated into several groups, including backfill for perforated and nonperforated pipe as well as impervious caps to prevent surface water infiltration. In the discussion for perforated pipe backfill, the issue of single versus two-stage filters is addressed including the recommended minimum thickness for those materials.

Placing drainpipes beneath embankment dams in inaccessible locations should be avoided. Drainpipes system designs should include inspection wells or cleanouts to allow easy access for inspection, cleaning, and maintenance. These features should be accessible without disruption of the embankment. Each drainpipe segment should be accessible from both ends.

Example A-4 in appendix A demonstrates the principles involved for drainpipe and filter design.

4.1 Drainpipes

Drainpipes as described in this document are structural pipes used to convey seepage water collected in a drain system to a discharge at some point downstream of the
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dam. The materials used for these pipes have changed over time. Early dam construction typically used rigid pipe (i.e., clay tile) with flexible plastic pipe becoming more popular since the 1980’s. This section will address structural and hydraulic design for these flexible pipes. Figure 53 shows an example drainpipe construction using flexible plastic pipe.

A variety of materials and pipe cross sections are available for use as drainpipes. The most common materials are HDPE and PVC as described in other sections of this document. Commonly available cross sections include solid wall, corrugated single wall, and corrugated profile wall as described in section 1.2.1. Single wall corrugated plastic pipe is easily crushed during typical construction installations and should not be used. Solid wall pipe is available in PVC and HDPE materials. Solid wall PVC pipe should be a minimum schedule 80 gauge (schedule refers to the thickness of the pipe wall). While solid wall HDPE pipe offers sufficient strength, it is the most costly. Since quality of construction can vary, CCTV inspection should be performed to verify possible deficiencies within these pipes. The manufacturer’s recommendations for installation should always be consulted. Improper installation can result in a number of deformations, punctures, etc. Good installation practice should always be used.

Corrugated metal pipes were commonly used in drainpipe systems at one time, but deterioration and subsequent piping of surrounding filters into the pipes has caused these materials to be regarded as a poor choice. Asbestos cement pipe was also used in many drainpipe systems, but the hazard from asbestos in manufacturing has caused this product to no longer be available.

4.1.1 Structural design

Drainpipes should be structurally designed by the design procedures described in chapter 3. The soil and hydraulic loadings on the pipe should be determined by the methods described in chapter 2. Drainpipes beyond the footprint of the embankment are typically trench conduits while those beneath the embankment are typically positive projecting conduits. For guidance on evaluating drainpipe configurations to accommodate CCTV inspection equipment, see section 6.2.

4.1.2 Hydraulic design

Determining the anticipated seepage that will be collected by a drainpipe and back-calculating the size of pipe required to carry that flow can be complicated. The Bureau of Reclamation has developed simple rules-of-thumb for sizing drainpipes based on the size of embankment and type of foundation soils in which the drain is embedded. Table 11 summarizes those recommendations. Smaller pipes can be justified by more detailed flow compilations. Drainpipes should be sized to maintain a piezometric surface below the top of ground in most situations.
While the load-carrying capacity of nonperforated pipe is well documented, the strength of perforated pipe is less commonly addressed. Since the corrugations carry the majority of the load for both single-wall and profile-wall HDPE pipe, perforations through the corrugation valley have negligible effect on pipe strength (less than 1 percent). However, for all types of solid-wall plastic pipe (PVC, HDPE, etc), perforations will reduce the load-carrying capacity (loss in strength proportional to perforation percent open area). Additional research (PM-3) is needed as proposed in chapter 8.

Solid and profile wall corrugated pipe have the additional benefits of a smooth interior, which increases flow capacity, and no interior corrugations to collect and trap soil particles (which should be trapped at the measurement point sediment trap). Joints for corrugated pipe are typically bell and spigot with a gasket. Solid wall
HDPE pipe has become popular recently for drainpipe applications due to its strength and leakproof butt fused joints. The two major limitations in using this type of pipe in drainage applications are its cost and lack of factory produced perforations (perforations have to be drilled or cut in the field).

Typically, perforations in drainpipes are available in three geometries:

- Circles, which are drilled
- Slots, which are made with a saw blade or furnished from a factory
- Well-screen configuration

A fairly wide range of slot widths can be chosen to meet filter criteria related to either surrounding drain material or constructed filter zones. For slot-shaped perforations, the controlling dimension is the slot width. Typically, the slot length is a function of the slot width since the size of the tool used to make the slot is a function of the desired width. The slot length is also a function of how far the manufacturer advances the tool into the pipe to make the perforation. The manufacturer will select a slot length that satisfies desired strength and inflow requirements for a particular pipe product. Slotted pipe has considerable higher capacity than pipe with circular perforations (see figures 54 and 55). Corrugated slotted HDPE pipe is readily available in a variety of pipe diameters (see AASHTO’s M252 and M294). If desired, perforations can be drilled into solid wall HDPE pipe to provide a perforated pipe. PVC pipe is available with circular perforations as well as slots (figure 56). The use of geotextile socks surrounding perforated drainpipes should not be used (see section 4.2.1 for additional discussion).

Figure 54.—Profile wall corrugated HDPE pipe with slotted perforations.

Figure 55.—Profile wall corrugated HDPE pipe with circular perforations.
Drainpipes can also be constructed using plastic well screen products. These pipes have the largest unit open area and highest capacity of the available products, and consequently have the lowest strength. They are usually more expensive than other pipe types.

Consideration should also be given to the amount of inlet open area of perforation for a unit length of pipe. As a rule, perforations should be used that incorporate the entire pipe circumference (AASHTO Class II Perforation, M252). These patterns typically consist of perforations on a 45- or 60-degree pattern (8 or 6 equally spaced perforations around the drainpipe, respectively). Perforation patterns that only utilize half of the pipe circumference (AASHTO Class I Perforations, M252) should not be used due to reduced collection capacity.

Another consideration is the percent of the openings that will be blocked by the surrounding filter material. NRCS Soil Mechanics Note No. 3 (1971, p. A-4) recommends that the effective open area for circular perforations be considered as 30 percent of the total perforation area in computing inflow capacity. For rectangular slots, the recommendation is to use 60 percent of the total area of slots as the available flow area. The rate of flow into any given pipe per foot can be obtained from the manufacturer literature.

Flow capacity and pipe size of drainpipes can be calculated using Manning’s equation or Hazen-Williams equation, or obtained from table B-3 in the Bureau of Reclamation’s Design of Small Dams (1987a). The depth of flow in the pipe is typically no more than a maximum 75 percent full so that flow does not become pressurized. Pressurization limits the effectiveness of the drain. The amount of flow into a plastic pipe is a function of the opening size and the number of openings per foot of pipe. Perforations or slots in drainpipes are sized to prevent surrounding drain materials from passing through them, which would result in a piping condition. If the size and number of perforations and slots limits capacity, a well screen type product should be considered. Since the requirement for soil retention is to prevent particles from
passing through a perforation, care should be taken to not use slot length values as the maximum dimension. An inability to install the pipe uniformly (i.e., no sags within segments or from segment to segment) will reduce the flow capacity of the pipe (the pipe may flow full through sags). Even correctly installed pipes can develop sags after construction due to differential settlement.

Calculating the amount of water that can be collected from a foundation or embankment is not as simple as calculating flow in a pipe. Seepage analysis and collection prediction is complicated by lack of data and understanding of geologic conditions. Depending on site conditions and the complexity of the foundation, seepage analysis can be quite complicated, although lack of data in a small, simple foundation can be just as problematic (see USACE’s Seepage Analysis and Control for Dams, 1993).

Depending on the site conditions and the complexity of the foundation, seepage analysis can be subject to significant errors. For instance, if high permeability lenses are ignored or not detected in an investigation, errors can be dramatic. In simple foundations with few strata, computations of flow quantities are more accurate.

The simplest way of calculating foundation flow contribution into a drainpipe is by using Darcy’s Law:

\[ Q = k i A \]  

where:

\( Q \) = rate of flow into a drainpipe, ft\(^3\)/yr  
\( k \) = coefficient of permeability of the surrounding filter or foundation, whichever is greater, ft/yr  
\( i \) = hydraulic gradient, head loss outside the pipe divided by the distance over which that head loss occurs, ft/ft  
\( A \) = filter or foundation area through which flow passes, ft\(^2\)

The coefficient permeability may be estimated from empirical relationships, presumptive values, laboratory tests, or field tests. Units for the coefficient of permeability should be consistent with other terms in the equation.

Empirical methods for estimating the permeability for filter materials and coarse-grained foundation soils with no fines are available. These methods are usually based on the grain-size distribution curve of the materials. Most empirical estimates use the effective grain size, or \( D_{10} \) size from a soil or filter’s gradation curve. Some estimates use the \( D_{15} \) size, which is obtained similarly. The \( D_{10} \) and \( D_{15} \) sizes represent the particle size diameter (in millimeters) of the 10\(^{th}\) and 15\(^{th}\) percentile respectively, passing grain size of a material.

McCook (2002, p. 5) obtained an empirical relationship for coefficient of estimating the permeability of a soil based on its \( D_{10} \) size and porosity. The equation is:
\[ k(\text{cm/s}) = 0.01047 e^{9.3071 \times \frac{\eta}{100} D_{10}^2} \]  

(4-2)

where:

- \( k \) = coefficient of permeability, \( \text{cm/sec} \)
- \( \epsilon \) = base of the natural logarithms, 2.7183
- \( \eta \) = porosity, percent of void volume, \( \% \)
- \( D_{10} \) = particle size diameter in millimeters of the 10th percentile passing grain size

Empirical methods for estimates for the coefficient of permeability for granular filters are also available from extensive testing performed by the Soil Conservation Service (now NRCS) Soil Mechanics Laboratories, reported in Sherard, et al. (1984). The study concluded that for clean sands and gravels in the tests, the \( D_{15} \) parameter from the grain size curves provided the best empirical estimate of permeability. The empirical relationship for that study is:

\[ k(\text{cm/s}) = CD_{15}^2 \]  

(4-3)

where:

- \( k \) = coefficient of permeability, \( \text{cm/sec} \)
- \( C \) = constant ranging from 0.2 to 0.6, averaging 0.35
- \( D_{15} \) = particle size diameter in millimeters of the 15th percentile passing grain size

The range for the \( C \) value is between 0.2 and 0.6, with an average value of 0.35. The range in values is based on the scatter in the data and the differences in materials tested. Generally, sands with rounded particles were slightly more permeable than those with angular shapes and have higher \( C \) values. See NRCS Soil Mechanics Note No. 9 (1984) for more details on this relationship.

A number of sources present presumptive values for soil permeability, such as table A1 in the Bureau of Reclamation’s Design Standard for Seepage Analysis and Control (1987b), NRCS’s Soil Mechanics Note No. 9 (1984), figure 7.6 in Holtz (1981), table 2.1 in Peck et al. (1974), and Sherard et al. (1984).

Common laboratory permeability tests can be found in ASTM D 2434, the Bureau of Reclamation’s Earth Manual (1989) and USACE’s Laboratory Soils Testing (1986). Foundation field testing can be done in single or multiple drillhole arrangements. While field tests give the most accurate prediction, they are also the most expensive. Typical testing methods are described in geotechnical engineering textbooks as well as the references previously mentioned.
Caution should be applied when using empirical, presumptive, and laboratory testing estimates of permeability. These methods tend to predict higher than actual permeability values, so actual seepage flows will be less because stratification and heterogeneity of foundation material are not considered. Naturally occurring soil deposits also almost always have greater horizontal permeability than vertical permeability. Estimates for $k$, $i$, and $A$ should be on the high side in order to calculate a larger $Q$ in the interest of not undersizing the pipe. Requiring drainage capacities 10 times greater than the calculated values is common.

Seepage analysis using computer software permits more detailed calculations, although the limitations of selecting permeability values described above also pertain to this method. Computer modeling allows the designer to utilize anisotropy in the calculations, which can have a significant effect on seepage calculations. If instrumentation data exists for an existing dam, model calibration should be done. This calibration consists of modeling known conditions for the existing structure. Once the model is constructed, analysis is made for a given reservoir elevation. The measured pressures in the instrument are compared to those produced by the model. If there is disagreement, permeabilities are adjusted until there is agreement. This trial and error method can be time consuming, and it should be noted since the number of unknowns exceeds the number of knowns, there are multiple valid solutions for any given model. Engineering judgment is required to discern whether a valid solution has been found. This calibration scheme aids in reducing uncertainty about the permeability and thus the flow.

The next design issue for drainpipes is determining perforation size. The U.S. Army Corps of Engineers (2004, p. B-4) recommends the following criterion:

$$\frac{\text{Minimum 50 percent size } (D_{50}) \text{ of filter material}}{\text{maximum opening of pipe drain}} > 1$$  \hspace{1cm} (4-4)

The Bureau of Reclamation has adopted two criteria for grain size of filter materials in relation to perforation openings in drainpipes (Bureau of Reclamation, 2007, p. 14). The first is for use with uniformly graded materials:

$$\frac{D_{85} \text{ of the filter nearest the pipe}}{\text{maximum opening of pipe drain}} > 2 \text{ (uniformly graded)}$$  \hspace{1cm} (4-5)

This criterion applies to multistage filter/drain combinations surrounding the drainpipe.

The second criterion is based on recent studies by the Bureau of Reclamation (1997, p. 24) that indicate that single stage broadly graded sand and gravel filter combinations should have a smaller slot size to prevent plugging. The following criterion may be used:
\[
\frac{D_{85} \text{ of the filter nearest the pipe}}{\text{maximum opening of pipe drain}} > 4 \quad \text{(broadly graded)} \quad (4-6)
\]

Note: The maximum opening of drainpipe in equations 4-4, 4-5, and 4-6 is the diameter for hole perforations and the width for slot perforations.

The NRCS recommends the following criterion which is about two times larger than the previous two other criteria (NRCS, 1994, p. 26-5). For critical structure drains where rapid gradient reversal (surging) is probable, it is recommended that the \(D_{15}\) size of the material surrounding the pipe be no smaller than the perforation size.

\[
\frac{D_{85} \text{ of filter material}}{\text{perforation size}} > 1 \quad (4-7)
\]

### 4.1.3 Inspection wells and cleanouts

Drainpipes should be installed with inspection wells or provided with cleanouts, so there is easy access for inspection and maintenance, and reasonable access without compromising the dam for repair, if necessary.

Inspection wells are commonly used along or at the end of drainpipes. They typically serve three functions; access to the drainpipe, inclusion of a flow measurement device such as a weir or flume, and inclusion of a sediment or stilling basin that collects any sediment that may be included in the drainpipe flow.

Inspection wells are typically manufactured from precast reinforced concrete and range in size from 8 to 12 feet in diameter. The base can be a cast-in-place (figure 57), or precast and set in place. Combined slab/ring units should not be used due to poor strength and difficulty in installation. Experience has shown that handling of the combined units has resulted in separation issues. Precast rings come in standard lengths and several may be required to reach the desired surface elevation. Figure 58 shows the bottom ring of an inspection well. The inlet and outlet opening sizes should be supplied to the manufacturer prior to fabrication, so proper reinforcement and opening size can be included at the factory. Opening sizes are larger than the maximum outside diameter of the drainpipe, so that the pipe can penetrate the well and the annulus can be dry packed with a lean concrete. The invert of an inspection well is shown in figure 59. See section 4.3.3 for a discussion of backfill around inspection wells.
Figure 57.—Placement of a cast-in-place base slab for an inspection well.

Figure 58.—The first ring of a drainpipe inspection well.
When flow measurement and sediment traps are not required, a more economical cleanout type drainpipe access can be used. Cleanouts provide access for CCTV inspection equipment and cleaning tools and are used at the upstream end of drainpipes. These cleanouts consist of a “sweeping” end from its invert to the ground surface by two 22.5-degree bends. This results in the pipe daylighting at the ground surface at a 45-degree angle (figure 60). A protective encasement (typically CMP pipe) is placed around the plastic drainpipe to protect against vandalism and the elements. The encasement pipe should provide a minimum 6-inch free space between itself and the plastic pipe. The annular space between the two pipes is backfilled with gravel to provide support to the plastic pipe. The encasement pipe is embedded a minimum of 5 feet in the ground and a lockable protective metal cover is used to secure the end of the cleanout. Figure 61 shows an example of a cleanout.

Lateral cleanouts can also be used on long drainpipes. The layout of a lateral cleanout is the same as described above except the “sweep” consists of 22.5-degree bends that transition in both the horizontal (away from the drain alignment) and vertical (toward the ground surface) planes. An alternative to the sweep concept can be used for drainpipes of great length requiring intermediate cleanouts. A vertical riser consisting of nonperforated pipe of the same material and diameter is
Figure 60.—Cleanout designed to accommodate CCTV inspection in pipes with diameters of 8 inches or larger.

Figure 61.—A drainpipe cleanout with a steel encasement and lockable protective cover.

connected to the drainpipe. The top of the riser is protected by a CMP pipe, lid, and lockable latch similar to end cleanouts. This alternative can be used for drainpipes with diameters greater than 12 inches. See section 6.2 for additional guidance on the design of drainpipes to accommodate CCTV inspection equipment.

4.1.4 Renovation, replacement, and repair of drainpipes

Experience has show that CCTV inspection often reveals damaged or collapsed drainpipes. In many cases, the drainpipes appear to have failed during original
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construction due to equipment travel over the drain alignment, inadequate pipe support, pipe material defects, or other factors. In other cases, the drains are in a state of failure due to the deterioration of the drainpipe, differential settlement along the alignment of the drain. Replacement of the drainpipe may be an appropriate response in these situations. Considerations for repairing or replacing the drainpipe include:

- **Failure mode.**—If considering replacement of a drain, the designer should consider relocating the drain alignment, elevations, outfalls, etc. to better address seepage conditions at the dam or to reduce or eliminate potential failure modes associated with the drainage feature.

- **Address why the drain failed.**—In repairing or replacing the drainpipe, the designer should consider reasons why it failed, such as poor construction practice, reasons related to the pipe material, or drainpipe plugging due to problems with the drain envelope material. The repair or replacement should be designed to address these issues.

- **Design considerations.**—Drain repairs or replacements offer excellent opportunities to provide additional access to a drain system. If practicable and reasonable, access points should be added at least every 500 to 1,000 feet to facilitate inspection, cleaning, maintenance, and monitoring activities. Access points should include features for monitoring flow and material movement within the drain system, personnel safety features, and access for CCTV inspection and cleaning equipment.

- **Quality assurance.**—Many drainpipe failures are the result of construction activities. Drainpipe repair or replacement projects should include provisions for thorough inspection during construction and following completion of construction. A CCTV inspection of the drain alignment at the completion of construction is required. As-built drawings with accurate surveys must also be completed as part of the modifications.

When damaged or collapsed existing drainpipes are encountered, complete removal and replacement may not be possible due to a large amount of fill over the pipe or cost constraints. When met with such a situation it may be possible to slipline the existing pipe. The simplest way to perform this slining is to insert a new pipe into the damaged pipe. Since joint offset, deformation, and cracking can lead to a significant reduction in interior cross section of the existing pipe, the new pipe may have to be significantly smaller than the existing pipe.

Generally, it is not practical to design the replacement pipe to meet filter criteria. Usually the intent of slining repairs is to provide structural support to the existing damaged pipe. Flow measurement and a sediment trap should be installed at the
downstream end of sliplined drainpipe, so changes in flow and material movement can be monitored.

Introducing the new pipe into the existing pipe can be problematic. If both ends of the existing pipe are accessible this will make installation of the liner easier. Having to install the liner from one end will be much more difficult and if the amount of liner to be installed is large, it could be impossible.

Successful installation techniques when both ends of the drain are accessible include sending a fish line through the segment to be sliplined, attaching a torpedo to the fish, with the slipliner attached to the torpedo. The force required to pull this type of an arrangement may be large. Mechanical means may be required to make the pull, but care should be taken to not exceed the fish line or connection strengths of the apparatus. Breaking a fish line, or getting the torpedo stuck in the pipe can lead to a bigger problem than what was originally being corrected.

4.2 Filters

Properly designed filters adjacent to drainpipes serve two functions—allow foundation flow into the pipe, and prevent foundation and embankment soil from migrating into the pipe.

4.2.1 Zoning

Drainpipes have been designed in single and double stage configurations. A single stage system consists of one zone of filter material, usually sand, surrounding a drainpipe. The double stage system consists of a coarse drainage zone (gravel) surrounding the pipe and a filter (sand) zone surrounding the coarse element. Figure 62 illustrates these two types of design.

Single stage designs have been used on smaller jobs, such as low hazard potential dams in the interest of reducing costs and simplifying construction. Because the perforations in commonly available drainpipe are too large to meet infiltration criteria for typical sand filters, one of the following conditions must be met:

- The perforated pipe must be wrapped in a geotextile.
- Screen type pipe must be used.
- The trench must be lined with geotextile.
- A broadly graded filter must be used.

None of these approaches is entirely satisfactory. A geotextile used to prevent sand from infiltrating into perforations in the drainpipe can become clogged from ochre biofilm. Ochre formation results from microbial colonization by bacterial
consortia (biofilm) that may include various iron bacteria and its affinity to iron compounds (Mendonca, Ehrlich, and Cammarota, 2006, p. 34). Factors that influence the formation of ochre biofilm on geotextile include space between fibers, roughness of the fibers, and thickness of the geotextile. Geotextile wraps have also been known to clog when a filter seal forms caused by concentrated flow through the geotextile at perforations in the pipe. The concentrated flow transports (erodes) soil particles that concentrate on the face of the fabric. Clogging can more easily occur if the surrounding drainage medium contains some fines or the perforations are circular holes rather than slots. Most major design agencies, including the Bureau of Reclamation, Natural Resources Conservation Service, and the U.S. Army Corps of Engineers, do not permit use of geotextiles in critical drain applications due to the potential for clogging and particle migration around the edges of thin geotextile sections.

Poor performance of broadly graded filters have been noted in a number of case histories and laboratory tests. These filters may have small particle sizes that pass through the slots while larger particles may become lodged in the slots. Meeting the slot size requirements described in section 4.1.2 is difficult with broadly graded materials. Two stage filter/drain combinations have higher permeability and will be more efficient in collecting seepage than single stage filters. For these reasons, single stage filters should be avoided and high hazard potential dams and two stage filters are preferred by designers. However, for economy and simplicity, sometimes single stage drainage elements are used in low hazard potential dams. When considering this type of filter, consideration should be given to internal stability and plugging of perforations within the drainpipe. A number of methods are available to check for internal instability and are presented in the literature (Kenney and Lau, 1986; Laflaur, Mlynarek, and Rollin, 1989; Milligan 1986; Ripley, 1986). The designer should also
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be aware that a broadly graded sand and gravel filter has a lower permeability than a uniformly graded sand filter.

If single stage filters are used, slots should be no larger than the $D_{50}$ of the filter. This can lead to small slot size, which requires the use of screen type pipe or custom made perforation. Caution should be exercised in the use of screen pipe due to its low strength.

4.2.2 Determination of filter gradation limits

Determination of the required gradation limits for filter and drain material is a function of the “base” material it is protecting. The current state of practice for these limits is that the material performs two functions. The first is that it prevents the movement of the base material into the filter and the second is that the filter be sufficiently permeable that pore pressures do not build up as a result of the filter itself. For a single stage drain, the base material is the foundation soil. For a two stage drain, the base material of the outer filter is the foundation soil and the base for the inner filter (gravel) is the outer filter. The details for this design are covered in chapter 6 in FEMA’s *Technical Manual: Conduits through Embankment Dams* (2005). See example A-3 in appendix A for an illustration of required calculations. Guidance can also be found in the NRCS (1994) design standard.

In lieu of complete filter design, experience has shown that fine concrete aggregate designated in ASTM C 33 meets the design requirements for many foundation materials with between 40 and 85 percent passing the No. 200 sieve. The No. 200 sieve must be restricted to meet the permeability requirement of the filter design. Table 12 gives the gradation for this material, which is commonly referred to as “C 33 concrete sand.” Because foundation conditions differ from site to site, this filter should always be checked against the gradation of the base soil (foundation soil). Because foundation conditions differ from site to site, this filter should always be checked against the gradation of the base materials (foundation soil) before use.

In a similar manner, when modified ASTM C 33 concrete sand is used as a filter, there are standard materials that can be used as the gravel drain that surrounds the pipe. Several coarse aggregates in ASTM C 33 have been checked against modified C 33 concrete sand and are included in table 13. When using modified C 33 concrete sand, the coarse aggregates does not have to be checked since the filter size is fixed. Six materials have been included since not all materials will be available at all locations.

Based on the $D_{85}$ size of these materials, the maximum slot size can be calculated as described in section 4.1.2 using the Bureau of Reclamation criteria (equation 4-4, 4-5, and 4-6, respectively). Table 14 summarizes the resulting perforation sizes.
### Table 12.—Gradation of ATSM C 33 fine aggregate with additional requirement

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Percent passing, by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾-inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>95-100</td>
</tr>
<tr>
<td>No. 8</td>
<td>80-100</td>
</tr>
<tr>
<td>No. 16</td>
<td>50-85</td>
</tr>
<tr>
<td>No. 30</td>
<td>25-60</td>
</tr>
<tr>
<td>No. 50</td>
<td>5-30</td>
</tr>
<tr>
<td>No. 100</td>
<td>0-10</td>
</tr>
<tr>
<td>No. 200(^1)</td>
<td>0-2(^2)</td>
</tr>
</tbody>
</table>

\(^1\) Note qualifications of No. 200 sieve.  
\(^2\) 2% stockpile, 5% in-place. For discussion of material breakdown, see section 4.3.2.

### Table 13.—Gradation for ASTM C 33 drain materials (percent passing by weight)

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>No. 467</th>
<th>No. 57</th>
<th>No. 67</th>
<th>Blend 579(^*)</th>
<th>No. 8</th>
<th>No. 89</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-in</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1½-in</td>
<td>95-100</td>
<td>100</td>
<td>-</td>
<td>100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1-in</td>
<td>-</td>
<td>95-100</td>
<td>100</td>
<td>90-100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>¾-in</td>
<td>35-70</td>
<td>-</td>
<td>90-100</td>
<td>75-85</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>½-in</td>
<td>-</td>
<td>25-60</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>¼-in</td>
<td>10-30</td>
<td>-</td>
<td>20-55</td>
<td>45-60</td>
<td>85-100</td>
<td>90-100</td>
</tr>
<tr>
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<td>0-10</td>
<td>0-10</td>
<td>20-35</td>
<td>10-30</td>
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<td>-</td>
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<td>0-5</td>
<td>5-15</td>
<td>0-10</td>
<td>5-30</td>
</tr>
<tr>
<td>No. 16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
<td>0-5</td>
<td>0-10</td>
</tr>
<tr>
<td>No. 50</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-5</td>
</tr>
</tbody>
</table>

\(^*\) This gradation is a blend, in equal parts, of gradations No. 5, 7, and 9 and is not an ASTM standard aggregate.
Plastic Pipe Used in Embankment Dams

Table 14.—Maximum perforation dimension for ASTM C 33 Drain Materials*

<table>
<thead>
<tr>
<th></th>
<th>No. 467</th>
<th>No. 57</th>
<th>No. 67</th>
<th>Blend 579</th>
<th>No. 8</th>
<th>No. 89</th>
</tr>
</thead>
<tbody>
<tr>
<td>USACE (mm)</td>
<td>0.53 in.</td>
<td>0.41 in.</td>
<td>0.35 in.</td>
<td>0.28 in.</td>
<td>0.23 in.</td>
<td>0.16 in.</td>
</tr>
<tr>
<td>Bureau of Reclamation (mm)</td>
<td>0.53 in.</td>
<td>0.38 in.</td>
<td>0.35 in.</td>
<td>0.37 in.</td>
<td>0.19 in.</td>
<td>0.18 in.</td>
</tr>
</tbody>
</table>

* The minimum dimension should be used. For circular perforation, that is the diameter; for slots, the width measurement should be used.

While some design standards allow for \(D_{15F} \leq 9 \times D_{85B}\), in this instance (Bureau of Reclamation, 2007), other standards only allow \(D_{15F} \leq 4 \times D_{85B}\) (NRCS, 1994). Table 13 illustrates which materials meet each standard. The Blend 579 material is a blend of the No. 5, No. 7, and No. 9 gradations from the C 33 specification. Although it is not a standard ASTM gradation, it is included since it allows a greater pipe perforation size as shown in table 14.

4.2.3 Flow capacity

When designing drainpipes or other drainage collection systems for pervious foundations where seepage is expected to be significant, consideration should be given to the permeability of the filter in relation to the permeability of the foundation. In situations where the foundation consists of interbedded silts, sands, and gravels, design criteria require sizing the filter for the silt sizes. This can result in a filter composed primarily of sand sizes being placed over the gravel layers that carry the majority of seepage. This filter then acts as a barrier to the flow in the gravel, resulting in poor seepage collection and high pore pressures. If this issue cannot be resolved by adjusting the filter design, additional water barrier elements upstream of the centerline of the dam (i.e., cutoff wall, upstream blanket, or reservoir liner) may be required. Figure 63 illustrates an existing (old) drain that produces a large flow, although it does not meet modern filter criteria. Figure 64 illustrates the barrier situation that can arise for a replacement drain when filter criteria are followed.

4.3 Backfill

The following sections address two types of backfill around drainpipes. The first describes backfill around nonperforated drainpipe, and the second describes backfill around perforated drainpipe. ASTM D 2321 also provides guidance on backfill for drainpipes installed in trenches with vertical sides.
4.3.1 Backfill for nonperforated drainpipe

For ease of construction and placement, backfill should be a material composed of natural gravel and sand, and free of silt, clay, loam, friable or soluble materials, and organic matter. Table 15 gives the gradation requirements for an acceptable material, although other granular gradation may also be satisfactory.

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Percent passing, by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾-inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>50-75</td>
</tr>
<tr>
<td>No. 50</td>
<td>10-25</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-5</td>
</tr>
</tbody>
</table>

No backfill materials should be placed in the drain when either the materials or the foundation on which it would be placed is frozen or flooded. No brush, roots, sod, or other organic or unsuitable materials should be placed in the backfill.

Backfill should be carefully placed and spread in uniform layers. Backfill should be placed to approximately the same elevation on both sides of the pipe to prevent
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unequal loading and displacement of the pipe. The difference in elevation of the backfill on both sides of the pipe should not exceed 6 inches at any time. Adequate earth cover (minimum 2 to 4 feet) should be provided over the pipe to prevent damage to it from construction equipment loads. Figure 65 shows equipment passing over a pipe with a 4-foot cover of material, with no damage to the pipe.

4.3.2 Backfill for perforated drainpipe

Durability and material quality go hand in hand. Concerns with these characteristics are associated with material breakdown during construction. Once they leave the processing plant, the aggregate particles can break down during handling and placing procedures. Typically, loaders and possibly dozers place these materials in stockpiles in order to build larger piles. Then the materials are loaded into trucks, dumped onto the fill, bladed to a uniform lift thickness, and compacted. Each of these operations can cause individual aggregate particles to break down. This breakdown will lead to a change in gradation between the material produced at the sieving plant and what is in place in the dam. Typically, filters are required to have no more than 5 percent fines measured in the fill. Breakdown between the stockpile and fill is 1 to 2 percent, thus requiring 3 percent limit on the fines when measured in the stockpile.

While it is beneficial to specify measurement in the stockpile for construction operations, testing of the fill should also be done in accordance with ASTM C 117 and ASTM C 136 to measure the amount of breakdown caused by placement operations. The amount of breakdown is a function of the durability of the raw material and the amount of handling between the plant and the fill. Breakdown is usually a greater concern for smaller grain sizes used for filters than it is for larger grain sizes, which are used for drain material.

As a minimum, the filter material should meet the durability requirements of concrete aggregate as defined in ASTM C 33 class designation 1N. In addition to the quality requirements of ASTM C 33, the material should be nonplastic. Since it is desirable that filter materials “flow” or self heal, adhesion such as plasticity or cementing is undesirable. Plasticity can be determined in accordance with ASTM D 4318 on material passing the No. 40 sieve. Nonplastic material is defined as having a plasticity index (PI) of zero as per the previous procedure. Additionally, the material should be free of cementing agents, such as, but not limited to, carbonate minerals, gypsum, sulfide minerals, and sand-sized volcanic (pyroclastic) ash. Cementing is indicated by cohesive behavior of granular material. Cementing agents can be detected by checking for reaction of the material to hydrochloric acid.

McCook (2005, p. 3) suggests performing compressive strength tests on samples of fine filter materials to determine if undesirable cementitious properties may be present in a given sample. The “sand castle” test proposed by Vaughan and Soares (1982, p. 29) may also be helpful for evaluating self-healing properties of sand filters. For small projects, it may not be feasible to determine aggregate quality by laboratory
testing. In this instance, the designer should consider the mineralogy of the parent material. Aggregates that are derived from metamorphic and igneous based rocks will usually have higher quality than aggregates that come from sedimentary rocks.

For materials obtained from commercial sources, stockpiles should be examined for slope uniformity. Piles with irregular slopes or portions of near vertical surfaces indicate high fines content or possibly binders or cementing agents in the material.

4.3.3 Zoning design

Filter and drainage materials surrounding the drainpipe should have a minimum thickness equal to 12 inches. The ease of placement and inspection of the filter and drainage material around a drainpipe should serve as a guide to the designer on setting the thickness of these materials. The thickness may need to be increased for more difficult placements and inspection conditions. For two stage filters, care must be exercised to ensure the gravel stage is completely surrounded by the sand stage to ensure the foundation does not erode into the gravel stage.

A capping layer of relatively impervious material (>12% fines) should be used to differentiate groundwater and surface water flows in order to more completely understand the performance of an embankment dam. For this reason, only groundwater flow, or seepage through the dam, should be collected and measured. Drainpipes should be designed to isolate the surface flow (by use of drainage ditches) and infiltration by the use of a surface cap. Therefore, the drainpipe filter envelope
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should be capped with a relatively impervious layer to prevent precipitation from entering the drainpipe.

Relatively impervious material should also be used as backfill around inspection wells. This relatively impervious material, or “underground dam” acts as a barrier to flow in surrounding drainage materials. This barrier directs this flow into the drainpipe and through the measurement device in the inspection well.

4.3.4 Improving access

CCTV inspection equipment is sometimes limited by the length of cable tether and by sharp bends in the drainpipe. The same is true of drain cleaning equipment. In general, CCTV inspection equipment and cleaning equipment can travel up to about 1,000 feet from the access point (under ideal conditions), depending on the grade of the pipe and its smoothness. Some selected equipment may have extended capabilities, but 1,000 feet is a good rule of thumb. Some existing embankment dams have very long sections of drainpipe with no intermediate access points. Access is further complicated by sharp bends in the drainpipe alignment. Sediment accumulation, roots, organic debris, or damaged pipes can further limit access to the drainpipes. These problems may limit the possibility for inspection, monitoring, cleaning, or maintenance of significant portions of the drainage feature. For additional guidance on inspection and cleaning of drainpipes, see section 6.2.

The cost and feasibility of improving access to drainpipes warrant careful consideration of the need for such access. When evaluating the need to improve access to the drain system, the following factors should be considered, in addition to those considerations discussed in the previous section:

- **Constructability.**—Constructability has a major influence on the decision to provide additional access to an existing drain system. The location and configuration of drainpipes vary from dam to dam. Drain alignments near the downstream toe of embankments are generally much easier to access than alignments deeper under the dam. Some drain systems have multiple alignments parallel to the crest of the dam, possibly necessitating multiple access points. Others are constructed as a grid under the embankment. Access constructability considerations include:

  1. Potential to cause harm
  2. Depth of excavation
  3. Disruption to the embankment and foundation
  4. Need for unwatering and dewatering
5. Need for reservoir restrictions or need to schedule the work during the normal reservoir filling and drawdown schedule to facilitate construction

6. Number of access points needed

- **Alternatives for providing access to drainpipes.**—The selection of an alternative should be based upon evaluation factors listed under *Constructability* above. Possible alternatives include:

1. *Construct or expose embankment drain outfall.*—Many structures have drainpipes with buried outfalls. If the embankment drain is located as a result of exploration, constructing an outfall would be considered the minimum access necessary to provide monitoring capability. This may be appropriate in cases where little or no history of flow is apparent in the pipe or surrounding area.

2. *Construct access at junction of drain and outfall.*—Construction of an access point at the juncture of the outfall and drain can be accomplished either by casing the excavation, which may be appropriate if the junction is located well within the embankment, or by normal excavation if the junction is located near the downstream toe of the embankment. Once this access is established, additional inspection can be conducted, and intermediate access points can be located, if necessary.

3. *Locate access at upstream terminal points of drains.*—The upstream end of the drainpipe can be utilized as an access point to the drainpipe. The advantages of constructing access at the upstream end can include:

   a. Shallower excavation

   b. Less reservoir loading at the point of excavation

   c. Once established, can be used to locate intermediate points of access

   Disadvantages include difficulty in locating the upstream end of the drainpipes. Generally, as-built drawings that accurately locate the elevation or alignment of the drainpipe do not exist. Locating the drainpipe often requires extensive exploratory excavation.

- **Other considerations.**—When implementing recommendations to provide improved access to drainpipes, the following items should be considered:

1. *Flow and sediment monitoring.*—Access points should include provisions for measuring flow and monitoring sediment movement through the system.
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The access points should include sediment traps and flow measurement devices.

2. *Material sampling.*—Collect and analyze samples of surrounding embankment, foundation, and drain envelope material when installing new access points to assess their erodibility and determine if filter criteria are met.

3. *Personnel safety.*—The access points should include provisions for safe entrance and egress for personnel to measure flow and sediment accumulation.

4. *Configuration.*—The design of improved access must take into consideration the size requirements needed to accommodate use of CCTV inspection equipment.

### 4.3.5 Abandonment/grouting of the drain system

Abandonment may be an appropriate alternative in cases where the drainage is not considered a critical feature in the performance of the dam, where historic flows have been small or nonexistent, and where the results of the examination reveal damage or failure of the drain system that could lead to a future “incident,” and abandonment cannot cause harm.

Abandonment would likely be most appropriate in those cases where there is not a likely failure mode that would lead to failure of the embankment. Rather, this alternative could be selected to prevent development of an “incident,” such as development of a depression over the alignment of the drain, and may also be an appropriate alternative when replacing a drain system.

When making the decision to abandon or grout the drain, the designer should consider temporary measures to evaluate the impact of plugging the drainpipe. The designer should assess all sections of the drain to make sure that plugging would not cause detrimental pressures to rise. One alternative would be installation of a packer to temporarily plug one or more sections of the drainpipe. This would allow evaluation of changes in seepage conditions prior to implementing permanent measures to plug the drains. An adequate length of time should be allowed for any changes in seepage to be monitored.

Options for plugging the drain system include filling the drain and outfall pipes with sand or grouting the drains. The sand alternative would have the advantage of being a less permanent measure, in that the sand could be jetted from the drain if changing conditions warrant such an action. However, grout may be easier to place and assure...
complete filling of the drain. The existing conditions within the drainpipe, as observed with CCTV inspection, may govern the alternative selected.