

Montana Department of Natural Resources

Dam Safety Program

Technical Note 4

**Chimney Filter/Drain Design and Construction
Considerations**

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Prepared for:



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1. Introduction

This technical note is intended to provide practical guidance for use by dam owners and engineers for the design and construction of chimney filter and drainage features for embankment dams, particularly small embankment dams. This technical note is not intended to be an all-inclusive guide for design of filter and drain systems. In many instances, the document directs readers to other references that provide more detailed information. In addition, an extensive list of references on the topic is provided at the end of this technical note.

This document was prepared by URS Corporation, under contract to the Montana Department of Natural Resources and Conservation (DNRC). URS' work was directed by Mr. John W. France, P.E., and the technical note was reviewed for Montana DNRC by Ms. Michele Lemieux, P.E.

At the time of preparation of this technical note, an extensive document titled *Filters for Embankment Dams, Best Practices for Design and Construction* had been drafted for FEMA under the National Dam Safety Program and was awaiting final approval for publication. That document contains detailed treatments of the topics addressed in this technical note, as well as much other information related to filters and drains. The reader is encouraged to obtain that reference when it is available, to supplement the information contained in this technical note.

The remainder of this technical note is organized in the following sections:

2. Chimney Drains – General Information – a discussion of the dam safety benefits of chimney drains.
3. Filter Gradation Design – a brief discussion of filter gradation design procedures, followed by discussions of several practical aspects of filter gradation design.
4. Two-Stage Chimney Drains – a discussion of the benefits and applications of two-stage chimney drains.
5. Drain Pipes – a discussion of practical aspects of collector drain pipe design.
6. Conduits and Structural Penetrations – a discussion of the relationship of filters to conduits and other structural penetrations.
7. Some Construction Considerations – a discussion of selected construction considerations.
8. References – a list of selected useful references concerning chimney filters.

2. Chimney Drains – General Information

Although there are many existing dams that were constructed without chimney filters and which have performed satisfactorily, a chimney filter offers substantial benefits with respect to dam safety.

A well-designed chimney filter provides protection against possible defects in an embankment core. If a core should contain pervious layers or through-going transverse cracks, a chimney filter will safely collect seepage through these defects and prevent piping of the core, as illustrated in Figure 1.

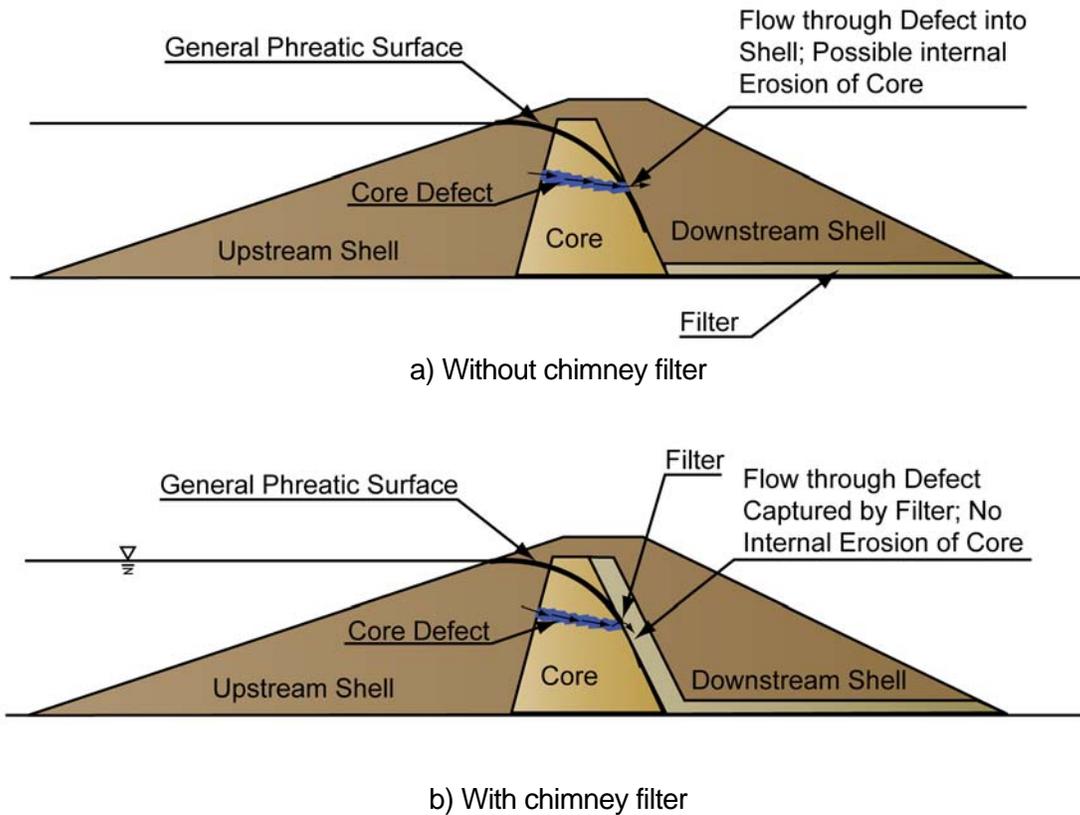


Figure 1 - Chimney Filters Provide Protection Against Core Defects

For dams with high horizontal to vertical permeability ratios, phreatic surfaces can approach and perhaps even reach the downstream face of the dam. A well-designed chimney filter provides positive control to produce a phreatic surface that is well within the embankment, as illustrated in Figure 2.

Risk analyses are becoming more common in the evaluation of dam safety. In its application of risk analyses for dams, the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) ascribes substantial benefits in risk reduction to the presence of a well-designed filter. The presence of such a filter results in the

assignment of a probability of 0.01 or less (very unlikely or less) to the event tree node for presence of an unfiltered exit.

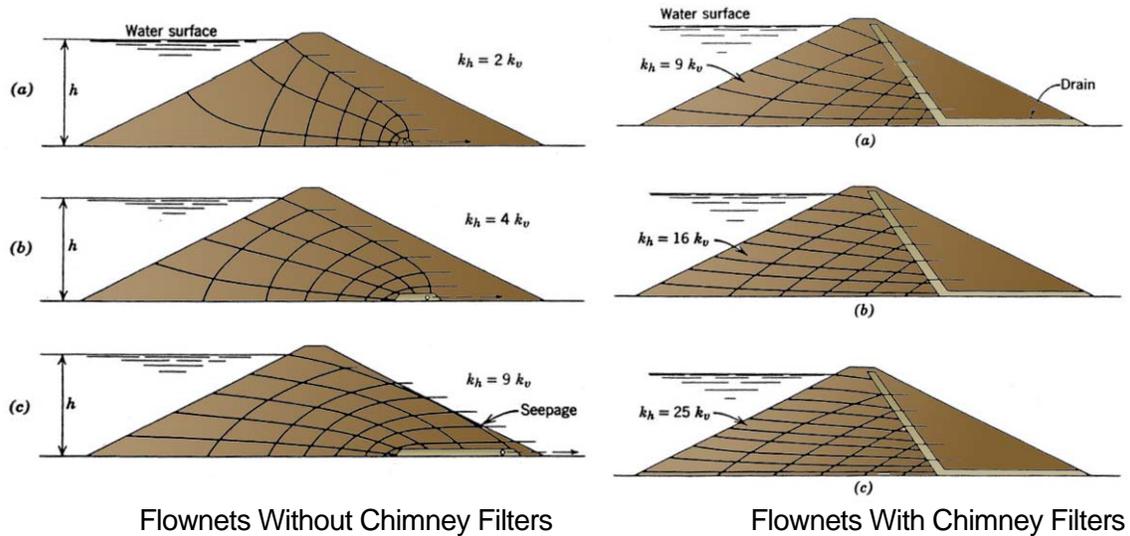


Figure 2 - Chimney Filters Provides Positive Phreatic Surface Control for Anisotropic Permeabilities

Considering the substantial benefits of a chimney drain, it is recommended that this feature be included in the following cases:

- All new dams over 25 feet high.
- Existing dams with evidence on the downstream face of seepage above the toe.
- Existing dams with likely defects through the core.
- Existing dams in seismic areas with likelihood of cracking under seismic loading.
- Outlet works replacements for existing dams.

3. Filter Gradation Design

Detailed guidance documents for gradation design for soil filters are readily available from three federal agencies: the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) [NRCS (1994)]; the U.S. Department of the Interior, Bureau of Reclamation (Reclamation) [Reclamation (2007)]; and the U.S. Army Corps of Engineers (USACE) [USACE (2004) and USACE (1993)]. This technical note does not include a repetition of the detailed guidance included in the three documents referenced above, all of which are readily available. Rather, this section of the technical note presents a general discussion of the guidance included in the three documents, highlighting some of the important practical aspects of the guidance.

The filter gradation design guidance provided by the documents from the three federal agencies is generally similar. Differences among the documents produced by the three agencies were highlighted in a technical paper prepared by Talbot and Pabst [Talbot and Pabst (2006)], and the reader is referred to that paper for details.

Filter Gradation Design Procedure – Two important terms used in the filter gradation design documents are “base soil” and “filter.” These two terms refer to the two soils on opposite sides of a boundary where flowing water has the potential to move soil particles, causing “piping” or “internal erosion.” The base soil is the material on the upgradient side of the boundary, which is to be protected against particle movement, and the filter is the material on the down gradient side of the boundary, which will prevent movement of the soil particles in the base soil, as illustrated in Figure 3.

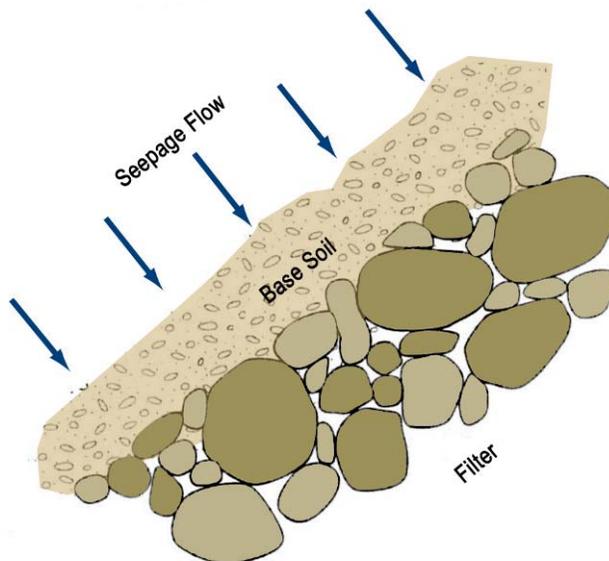


Figure 3 - Base Soil and Filter Definitions

The filter gradation design procedure included in the three federal agency documents is illustrated in Figure 4 and can be summarized in the following 11 steps taken from the NRCS document [NRCS (1994)]:

Step 1: Plot the gradation curve (grain-size distribution) of the base soil material.

Step 2: Proceed to step 4 if the base soil contains no gravel (material larger than No. 4 sieve – 4.75 mm size).

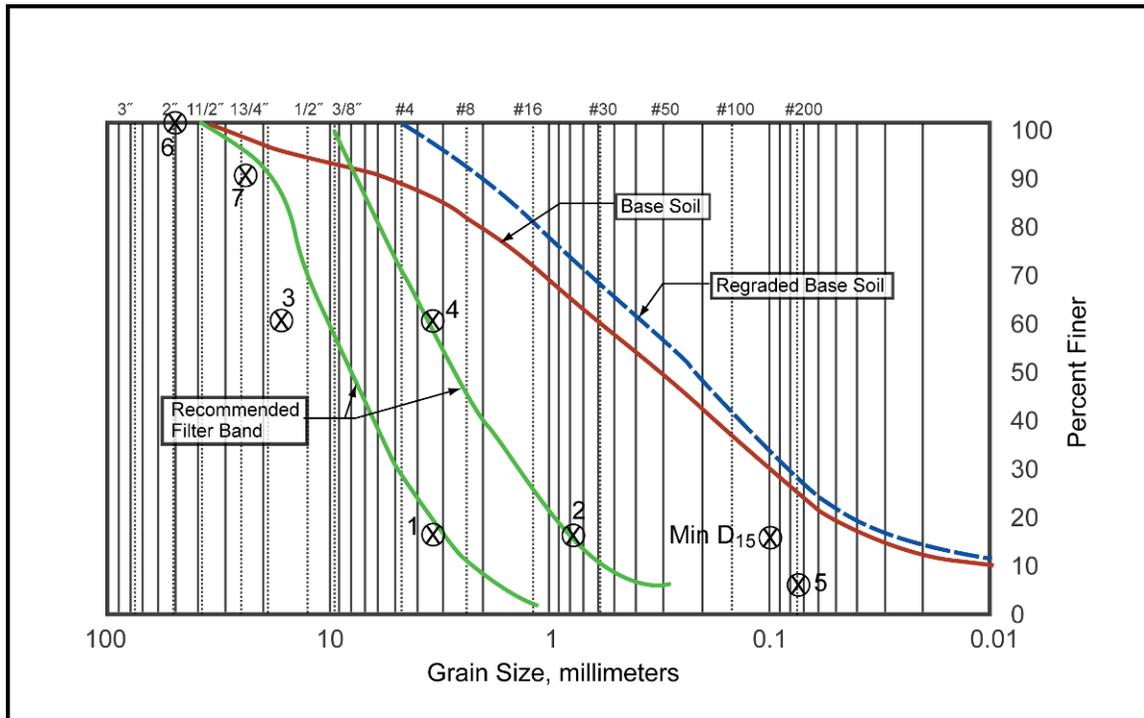


Figure 4 - Example of NRCS Filter Design Application

Step 3: Prepare adjusted gradation curves for base soils that have particles larger than the No. 4 sieve by mathematically removing the particles coarser than the No. 4 sieve.

Step 4: Place the base soil in a category determined by the percent passing the No. 200 (0.075 mm) sieve from the regraded gradation curve data – the NRCS document identifies four base soil categories.

Step 5: To satisfy filtration requirements, determine the maximum allowable D15 size for the filter in accordance with a table provided in the NRCS document – Max D15 point in Figure 4.

Step 6: If permeability is a requirement, determine the minimum allowable D15 in accordance with another table provided in the NRCS document – Point 2 in Figure 4.

Step 7: The width of the allowable filter design band must be kept relatively narrow to prevent the use of possibly gap-graded filters. Adjust the maximum

and minimum D15 sizes for the filter band determined in steps 5 and 6 so that the ratio is 5 or less – Point 1 in Figure 4.

Step 8: The designed filter band must not have an extremely broad range of particle sizes to prevent the use of possibly gap-graded filters. Adjust the limits of the design filter band so that the coarse and fine sides have a coefficient of uniformity of 6 or less. The width of the filter band should be such that the ratio of maximum to minimum diameters is less than or equal to 5 for all percent passing values of 60 or less – Points 3 and 4 in Figure 4.

Step 9: Determine the minimum D5 and maximum D100 sizes of the filter according to another table provided in the NRCS document – Points 5 and 6 in Figure 4.

Step 10: To minimize segregation during construction, the relationship between the maximum D90 and the minimum D10 of the filter is important. Calculate a preliminary minimum D10 size by dividing the minimum D15 size by 1.2. (This factor of 1.2 is based on the assumption that the slope of the line connecting D15 and D10 should correspond to a coefficient of uniformity of about 6.) Determine the maximum D90 using another table provided in the NRCS document – Point 7 in Figure 4.

Step 11: Connect Control points 4, 2, and 5 to form a partial design for the fine side of the filter band. Connect Control points 6, 7, 3, and 1 to form a design for the coarse side of the filter band. This results in a preliminary design for a filter band. Complete the design by extrapolating the coarse and fine curves to the 100 percent finer value.

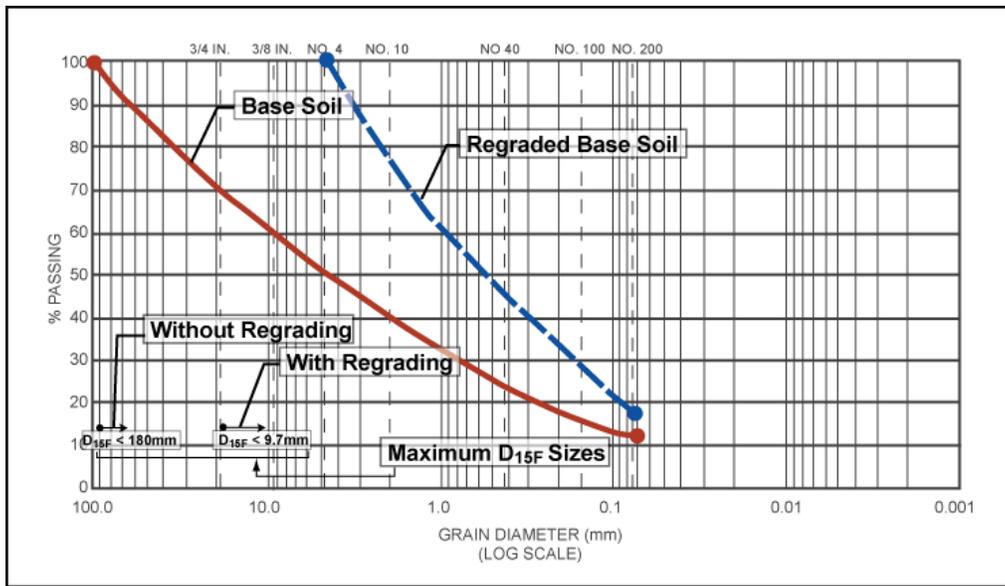
Steps 1 through 5 of the procedure establish the criteria that must be met to provide a filter that will prevent movement of soil particles from the base soil into the filter – the filter function.

Step 6 establishes criteria to assure that the filter is significantly higher in permeability (hydraulic conductivity) than the base soil – the drainage function.

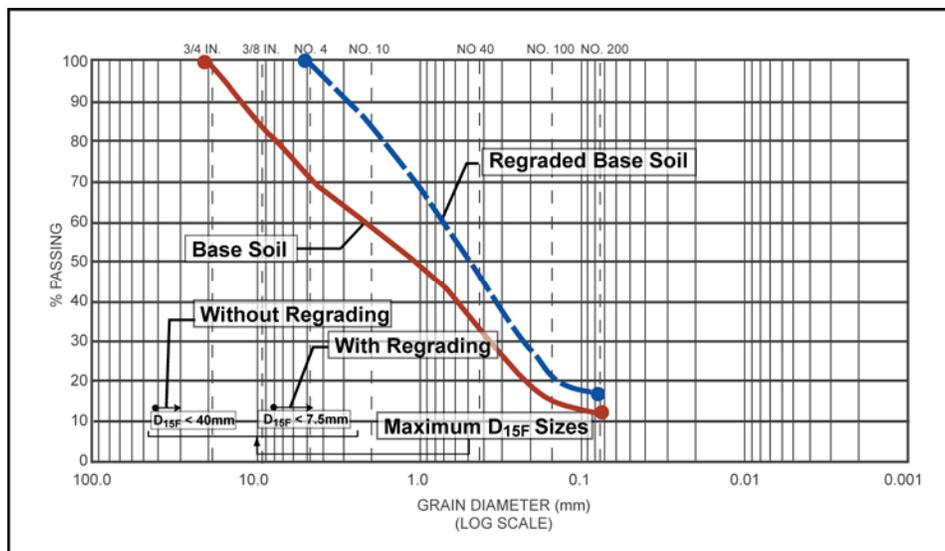
Steps 7 and 8 are intended to prevent the filter from being gap graded. A gap graded filter has a soil composed of particles of two different gradation ranges, e.g, gravel and fine sand, with very little if any of the intermediate grain sizes, e.g. coarse and medium sand. Gap graded soils can be internally unstable; that is the coarse fraction does not serve as a filter to the fine fraction, and the fine fraction can be piped out through the coarse fraction.

Steps 9 through 10 are intended to produce a filter gradation that will limit the likelihood of particle size segregation during placement of the filter. Segregation of the filter into coarser and finer zones can result in coarse zones which do not provide the required filter function.

Regrading of the Base Soil – Mathematical regrading of the base soil, Step 3 above, is critical to proper application of the filter design procedure. Figure 5 illustrates how failing to complete the mathematical regrading can result in a filter that is too coarse, and, therefore, would not provide the critical filter function.



a) Example 1



b) Example 2

Figure 5 - Effect of Using Mathematical Regrading in Filter Design

Applications Not Requiring Drainage – If the design requires that the filter not necessarily meet permeability requirement, the permeability criterion, Step 5, Point 2, can be relaxed, as long as the filter criterion, the gap graded criteria, and the segregation criteria are met. An example of where this might apply would be a filter for a core, with a very permeable, filter compatible shell downstream of the filter. In this case, the downstream shell would serve the drainage (permeability) function, lowering the phreatic surface immediately downstream of the filter.

Fines Contents for Filters – It is typically desirable that filters have high permeabilities (hydraulic conductivities). It is recommended that filters have less than 3% nonplastic fines (material finer than the No. 200 sieve size), in place, after compaction, and at most 5% nonplastic fines, in place, after compaction. Permeability of the filter decreases dramatically as the fines content increases above this level.

Difficulties With Use of Natural Materials – It is very rare to find a case where natural materials can satisfactorily serve as filters, without significant processing. Natural materials are typically not suitable as filters for the following reasons:

- The required gradations requirements for filters are relatively narrow, and the variation in gradations in natural deposits is typically too great to be confident that all of the material obtained from a natural source would be within the specified narrow limits.
- It is generally desirable for filters to have very low fines contents, less than 3 to 5 percent, as discussed above. It is very unusual to find natural deposits that reliably have such low fines contents.
- Natural deposits often have sufficient coarse particles that they do not meet the filter requirements to prevent segregation during placement.

Use of Standard Gradations – It is not necessary that the exact gradation limits resulting from the filter calculations be used in the project specifications. Rather, the calculated gradations can be used to select and specify readily-available, commercially-produced aggregates. Use of readily available materials can significantly reduce project costs. It is very unusual when readily-available commercial materials cannot be found to meet filter requirements. Typical readily-available commercial materials include ASTM, AASHTO, and state transportation department standard gradations. After the required filter gradations are calculated, gradations of readily-available materials should be reviewed for compliance. The availability of local suppliers producing the desired gradations should be verified before the gradations are specified.

For most mixtures of sands, silts, and clays found in dams and foundations, ASTM C33 fine aggregate will meet filter requirements, as illustrated in Figure 6. As illustrated in the figure, ASTM C33 fine aggregate meets the filter requirements for all Category 2 soils and many Category 1 soils. It is only for very fine, Category 1 base soils, with d_{85} less than about 0.035 mm, that ASTM C33 fine aggregate will not meet filter criteria. Even in that case, if the particular ASTM C33 fine aggregate is toward the fine side of the specified gradation band, it will meet the filter requirements for the very fine Category 1 soils, as shown in Figure 6. ASTM C33 fine aggregate will also meet filter requirements for many Category 3 soils. Although, ASTM C33 fine aggregate is a suitable filter for a wide range of soils, the filter calculations should always be completed for the particular base soils being protected, to verify the suitability of the specified filter.

It is noted that the gradation table included in the ASTM specifications includes gradation limits down only to the No. 100 sieve size. Gradation limits for the No. 200 sieve size should always be added to the specification for the filter if ASTM C33 fine

aggregate is selected, as illustrated by the blue “tail” on the gradation range shown in Figure 6.

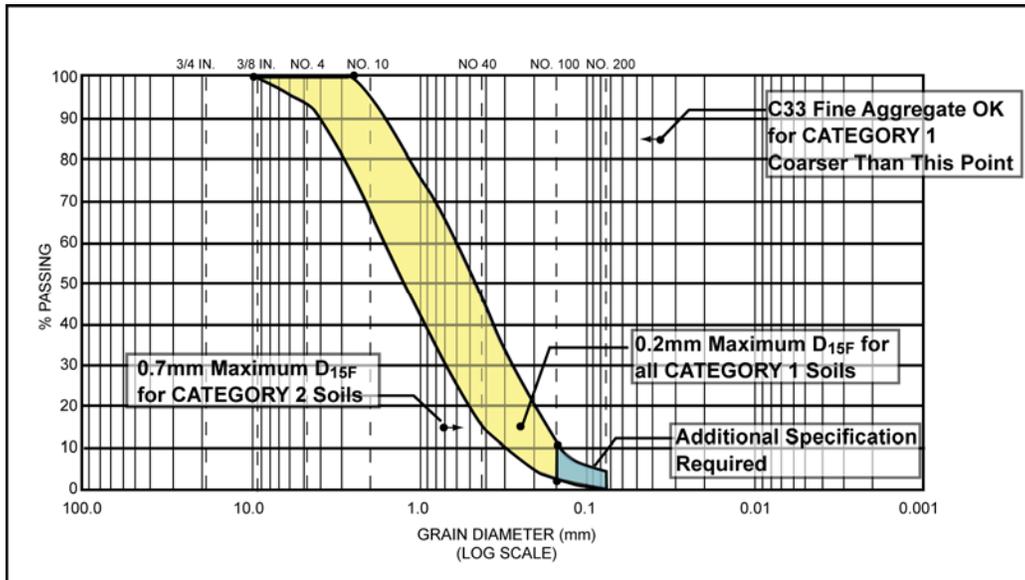


Figure 6 - ASTM C33 Fine Aggregate as a Filter

If ASTM C-33 fine aggregate is suitable as a filter, then ASTM coarse aggregate gradation No. 8, AASHTO coarse aggregate gradation No. 8, or a similar transportation department specification is a suitable, filter-compatible drain material.

Drainage Pipe Slot/Perforation Sizes – If a drain pipe is included in the filter and drain system, the slots or perforations in the pipe must be sized to be filter-compatible with the soil material that surrounds the pipe. The guidelines published by the three federal agencies referenced above provide criteria for appropriately sizing pipe slots or perforations, although there are some variations among the three documents in this regard.

Geotextiles – Currently, the guidelines and policies of the principal federal agencies involved in dam design, construction, and operation indicate that geotextiles are not to be used for critical filter functions in dams and at locations that could not be relatively easily accessed for replacement.

4. Two-Stage Chimney Drains

A two-stage chimney drain consists of a finer-grained filter layer and a coarser-grained drain layer, as illustrated in Figure 7. Two significant benefits of a two-stage chimney drain are its ability to address the effects of possible contamination of the filter layer and its ability to address concentrated seepage.

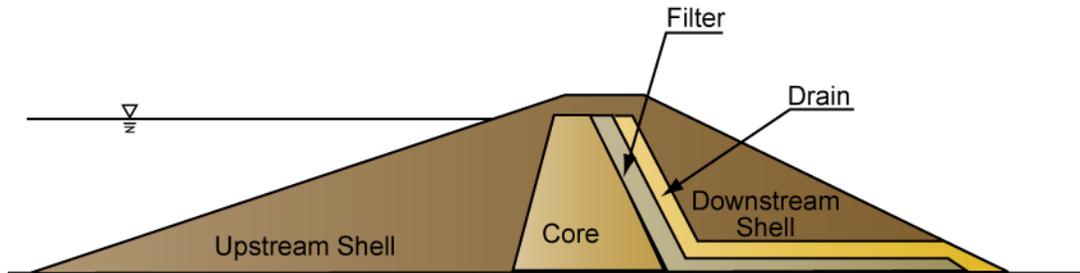
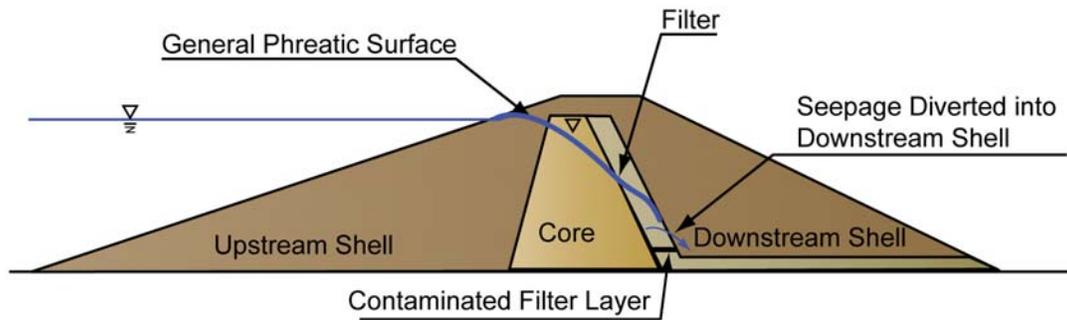


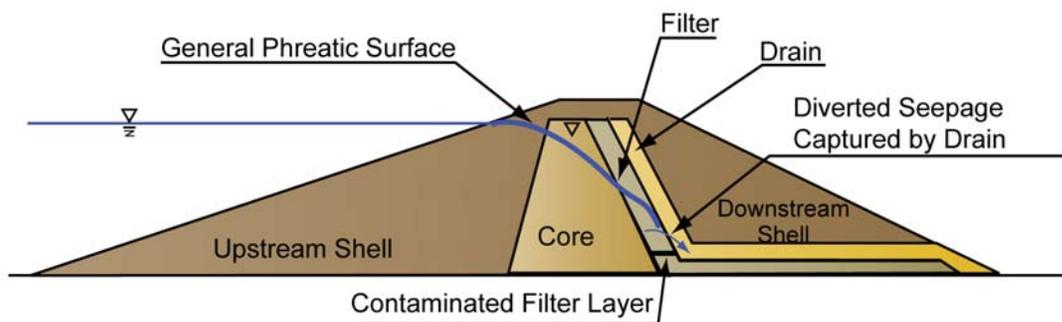
Figure 7 - Two-Stage Chimney Filter and Drain

It is possible for construction practices to result in contamination of a chimney filter. One potential type of contamination of a chimney filter layer is creation of a thin, horizontal or near horizontal layer of fine grained soil across the filter, possibly from runoff from an adjacent core layer during a precipitation event. This condition can result in drastically reduced vertical flow capacity in the chimney drain, resulting in diversion of seepage flow into the embankment zone downstream of the filter, as illustrated in Figure 8a. The additional flow into the downstream zone can cause elevated pore water pressures leading to instability or seepage flow in sections of the embankment where flow was not intended. A two-stage chimney drain addresses this condition by providing a high capacity, coarse-grained drain zone downstream of the filter to safely collect and convey the diverted seepage, as illustrated in Figure 8b.

If zones of concentrated flow exist, they can deliver more flow than a single-stage chimney filter can handle, resulting in 1) water “bleeding off” into the downstream zone, elevating pore water pressures, or 2) pore water pressures building up excessively upstream of the chimney filter, as illustrated in Figure 9a. A two-stage chimney drain addresses this condition by providing a relatively short path for the concentrated flow to pass through the filter zone into a high capacity drain zone, preventing the flow of seepage into the downstream zones and reducing the build up of pressures upstream, as illustrated in Figure 9b. The source of the concentrated flows could be a highly permeable zone in the foundation or large cracks through the core. The problems that developed at Washakie Dam in Wyoming [France (2004)] illustrate this potential problem. After dam safety modifications were constructed at Washakie Dam, including a single-stage chimney filter, excessive build up of pressures upstream of the chimney filter and a blowout at the downstream toe occurred, see Figure 10a. Fortunately, the dam was monitored very carefully during refilling of the reservoir after modifications, and the condition was discovered and addressed before the dam failed. It was determined that the problem resulted from

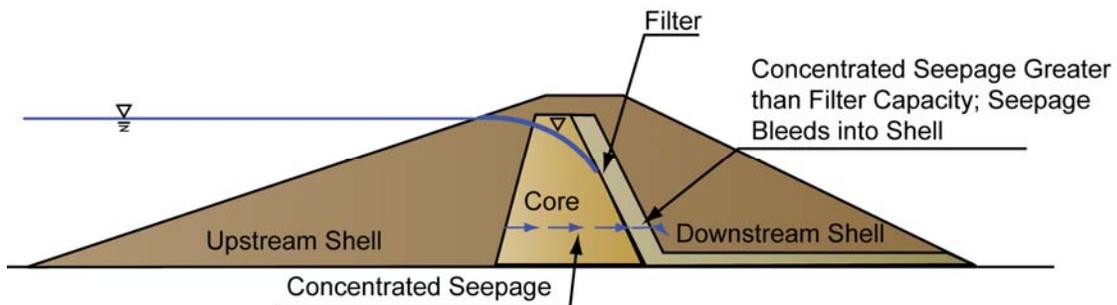


a) Single-stage chimney filter

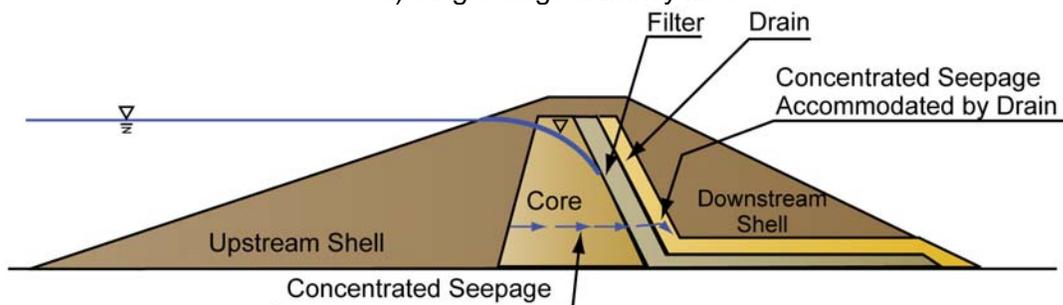


b) Two-stage chimney filter and drain

Figure 8 - Two-Stage Chimney Filter and Drain Addresses Filter Contamination



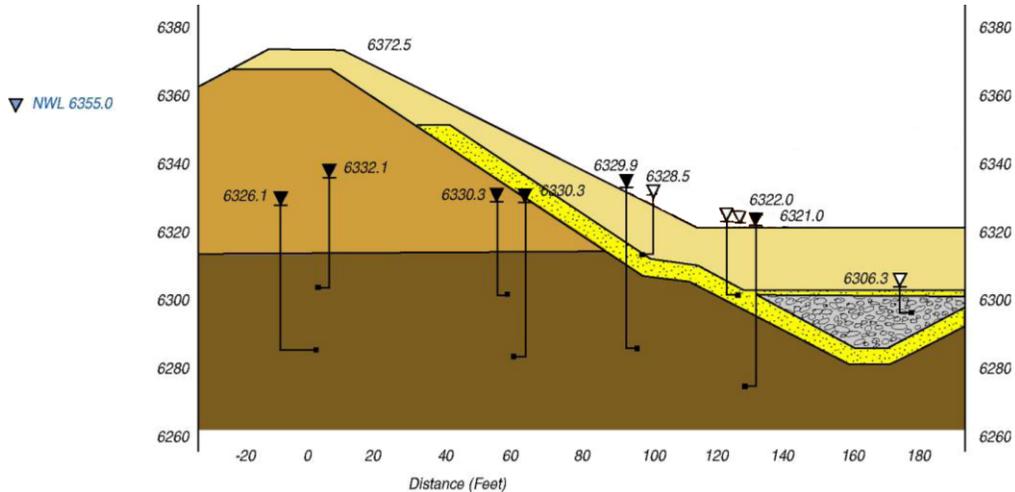
a) Single-stage chimney filter



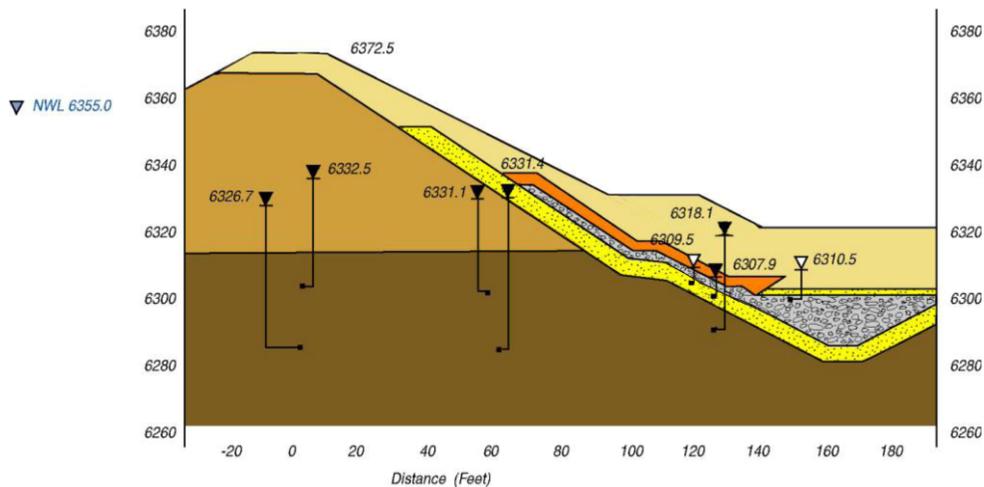
b) Two-stage chimney filter and drain

Figure 9 - Two-Stage Chimney Filter and Drain Addresses Concentrated Flows

concentrated flow through very permeable zones in the glacial foundations at the site. The problem was addressed by further modifying the dam, changing the single-stage chimney drain to a two-stage chimney drain, as illustrated in Figure 10b. The dam has performed satisfactorily since the additional modifications.



a) Original Modification – Single Stage Chimney Drain



b) Revised Modification: Two Stage Chimney Drain

Figure 10 - Chimney Drains for Washakie Dam, Wyoming

If the zone immediately downstream of the drain zone in the two-stage filter is relatively fine-grained and not filter-compatible with the drain material, the possibility of contamination of the drain at this boundary needs to be evaluated. Although seepage flow across this boundary would not be expected, contamination of the drain could occur during construction, or flow across the boundary from infiltration of precipitation could cause contamination. This could be addressed by designing the drain zone to be thick enough that some contamination could be tolerated. A more positive approach would be to provide a filter between the drain zone and the downstream zone. This second approach was used for Washakie Dam, as shown in

Figure 10b. In that case, the filter between the drain zone and the downstream shell was an aggregate base course material, which had a greater fines content than would typically be used in a filter. This material was judged acceptable in this case, because it was not necessary for this material to have high permeability since flow across this boundary was expected to be limited. This might also be a case where a geotextile could be used, because of the less critical nature of the filter at this boundary.

If the zone immediately downstream of a single-stage chimney filter both is much more permeable than the filter and provides filter protection for the filter material, the downstream zone would serve the same function as a drain zone, and, therefore, a separate drain zone would not be needed.

Based on the above discussion, use of a two-stage chimney drain is considered prudent for:

- High dams (higher than 100 feet), for which the likelihood of contamination may be higher because of longer construction time and more construction lifts.
- Dams of any height believed to be susceptible to concentrated flows, e.g. dams with foundations that likely contain highly permeable zones and dams with cores that are more susceptible to cracking.

5. Drain Pipes

Many chimney filter drain systems include drain pipes to collect drainage and convey it to locations where it can be monitored. The drain pipes consist of slotted or perforated pipes embedded in permeable materials.

Surrounding Soil – Experience with single-stage chimney drains with embedded pipes has been variable at best and poor at worst. Single-stage filter drain systems typically consist of sands or sands and gravels. When the pipes embedded in these materials are designed with slots or perforations sized according to the published filter criteria [NRCS (1994), Reclamation (2007), and USACE (2004)], it is not uncommon for the finer sand particles to partially or substantially plug the slots or perforations, severely limiting the entry of water into the pipes.

In the Washakie Dam case [France (2004)], the original system included 6-inch diameter, slotted, polyvinylchloride (PVC) drain pipes embedded in ASTM C33 fine aggregate. Video camera surveys of these pipes indicated that entry of water into the pipes was limited to small spurts of water, through small, unblocked segments of the slots, resulting in flow filling only a very small part of the pipe cross section, despite the chimney drain for several feet above the pipes being fully saturated with seepage water. These original pipes collected less than 100 gpm of flow. When these pipes were replaced with pipes embedded in the coarse-grained drain zone of the replacement two-stage filter, the collected flow increased to in excess of 500 gpm.

In another recent case, slotted PVC pipes embedded in a single stage filter were removed and replaced with pipes embedded in the coarse-grained zone of a two-stage filter, and it was found that the slots in the original pipes were almost completely plugged, as shown in the photograph in Figure 11.



Figure 11 - Plugged Drain Pipe Slots

It is recommended that, to ensure effectiveness, any drain pipes should be embedded within coarse-grained (gravel-sized) material, as illustrated in Figure 12. The coarse-grained material must be graded to provide filter protection for the filter soil, and the slots or perforations in the pipe must be sized to provide filter protection for the coarse-grained, drain soil surrounding the pipe. A combination of materials that works well for many applications is a filter and drain system consisting of an ASTM C33 fine aggregate filter; a drain material consisting of ASTM coarse aggregate gradation No. 8, AASHTO coarse aggregate gradation No. 8, or a similar transportation department specification; and pipe with 1/8-inch slots or perforations, although the Corps of Engineers guidelines would allow slots closer to 1/4 inch. As stated above, ASTM C33 meets filter requirements for many soils that are mixtures of sands, silts, and clays, in which case the combination of materials described in this paragraph can be used. Again, however, project-specific calculations should be completed to verify that the specific combination selected meets the desired guidelines.

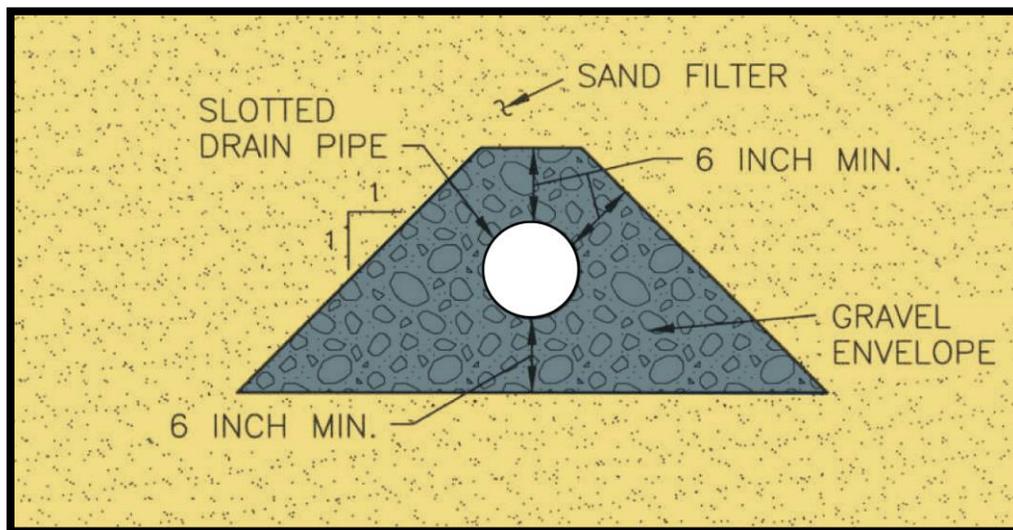


Figure 12 - Recommended Drain Pipe and Filter/Drain Configuration

The recommended configuration can be constructed relatively easily using a sequence similar to that illustrated in Figure 13.

To address the possible plugging concerns with pipes embedded in single-stage filters, some engineers have suggested using a geotextile “sock” around the drain pipe. The effectiveness of this approach is not fully proven, and it is not considered as reliable as the pipe embedded in a two-stage drain system recommended above.

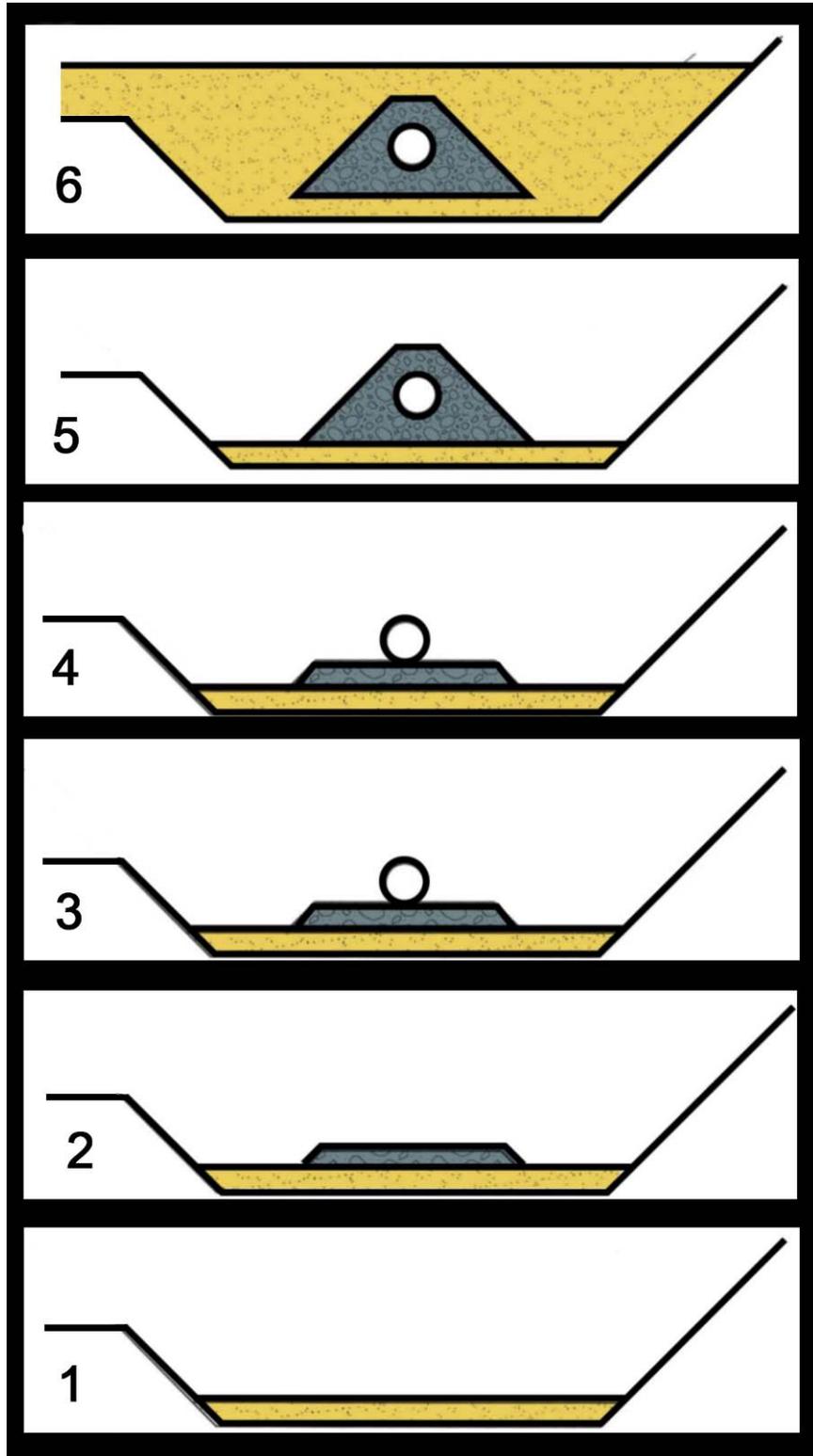


Figure 13 - Possible Sequence of Drain Pipe and Filter/Drain Construction

Drain Pipe Materials – Today, the most common material used for drain pipes is plastic pipe, typically either PVC or high density polyethylene (HDPE). The use of plastic pipe in embankments, including use in drain pipes, is covered in detail in a FEMA document produced for the National Dam Safety Program [FEMA (2007)]. All of the detail in that reference is not reproduced here, but rather some key aspects of the use of plastic pipe for drains are summarized. The reader is referred to the FEMA document for more detail.

For PVC pipe, gasketed, bell and spigot pipe is recommended. Non-gasketed pipe with glue joints can develop problems with induced pipe stresses caused by temperature changes that occur after installation, i.e. the pipe is laid and glued under hot conditions and cools and tries to shrink after burial. In addition, the glue joints are more rigid and subject to damage due to settlement or displacement than are the bell and spigot joints.

For HDPE pipe, corrugated pipes are most commonly used. Corrugated HDPE pipe is available in two types: single-wall corrugated pipe and profile pipe (double-wall, with a smooth inside wall and a corrugated outside wall). Camera inspections have identified a large number of single-wall HDPE drain pipe installations that have been badly damaged during installation or after installation. The reported damage has included large cross section distortion, severe cracking, and even pipe collapse. Because of the concerns regarding damage to the single wall HDPE pipe, this type of pipe is not recommended for drain pipes in seepage collection and control systems for dams. The HDPE profile pipes have been found to perform well and are recommended for drain pipes.

Butt-welded, solid wall HDPE pipe has also been found to be acceptable for drain pipe, but it is normally more expensive than the other alternatives discussed above.

Whatever type of plastic pipe is used, the load carrying capacity of the pipe should be reviewed to verify that it is suitable for the planned depth of burial.

Slots or perforations can be either completed during manufacture of the pipe or done in the field at the construction site. Obviously, the quality control (QC) for the slot or perforation sizes is better in the factory than in the field. If the slots or perforations are created in the field, the construction QC staff must verify the acceptability of the end product.

Drain pipes found in older dams constructed before the widespread use of plastic pipe include a variety of pipe types, including corrugated metal pipes (CMPs), open-jointed concrete pipes or clay tile pipes, and asbestos cement pipes, among others. None of these pipe types are recommended for drain pipes. Corrosion, degradation, and collapse has been a common problem with CMP pipes. Plugging with soil moved through the joints and collapse have been problems with the open-jointed pipes. And asbestos cement pipes constitute a hazardous material problem.

Access for Inspection and Cleaning – Drain pipes can be damaged during or after installation and slotted or perforated pipes can become compromised by biological or chemical fouling and require cleaning. Therefore, the drain pipe system should include access for video camera surveys and for cleaning.

Historically, the acceptability of installed drain pipes was verified by pulling a torpedo or “pig” through the entire pipe length to verify that the pipe was open for its entire

length. However, this method cannot reliably detect numerous types of defects – e.g. pipe damage, improperly constructed joints, or sags in the pipe alignment.

It is recommended that proper installation of drain pipes be verified with video camera surveys of the entire pipe length. It is further recommended that a video camera survey of the installed pipe be completed before the backfill over the pipe exceeds 3 to 5 feet. Surveying the pipe at this depth of burial allows for relatively easy repair of any problems identified, and, once the pipe is buried to this depth, damage with further burial is not likely. If the final burial depth of the pipe is greater than 3 to 5 feet, an additional camera survey should be performed with the pipe at final burial depth. Camera pipe surveys are relatively inexpensive, and they provide substantial assurance of a proper pipe installation.

To accommodate camera inspections, the drain pipe system needs to be designed with pipe diameters and bend geometries that accommodate video cameras. In addition, the drain pipe system needs to include access manholes or cleanouts at intervals that are not too far apart for reliable camera operation. Specific guidance on recommended pipeline configurations and access point distances can be found in the FEMA document referenced above [FEMA (2007)].

A pipeline configuration that is suitable for video camera access should also provide suitable access for maintenance.

6. Conduits and Structural Penetrations

Another FEMA document produced for the National Dam Safety Program [FEMA (2005)] addresses conduits through embankment dams in detail, including design features to address seepage along conduits. The reader is referred to that document for details, but again some key aspects are highlighted in this technical note.

Historically, structural cutoff collars around conduits were included to address seepage along the conduits. In recent years, the use of structural cutoff collars has fallen out of favor in the dam engineering profession. It has been concluded that, in many cases, the difficulty of compacting soil around the structural collars obviates the benefits of the cutoff collar, and the resulting condition with the cutoff collars is no better than the condition without them and in some cases is worse.

The preferred treatment for control of seepage is construction of a filter diaphragm entirely around the conduit, as illustrated in Figure 14. Details of the recommended filter diaphragm collar can be found in the FEMA reference [FEMA (2005)] and in an NRCS reference [NRCS (2007)].

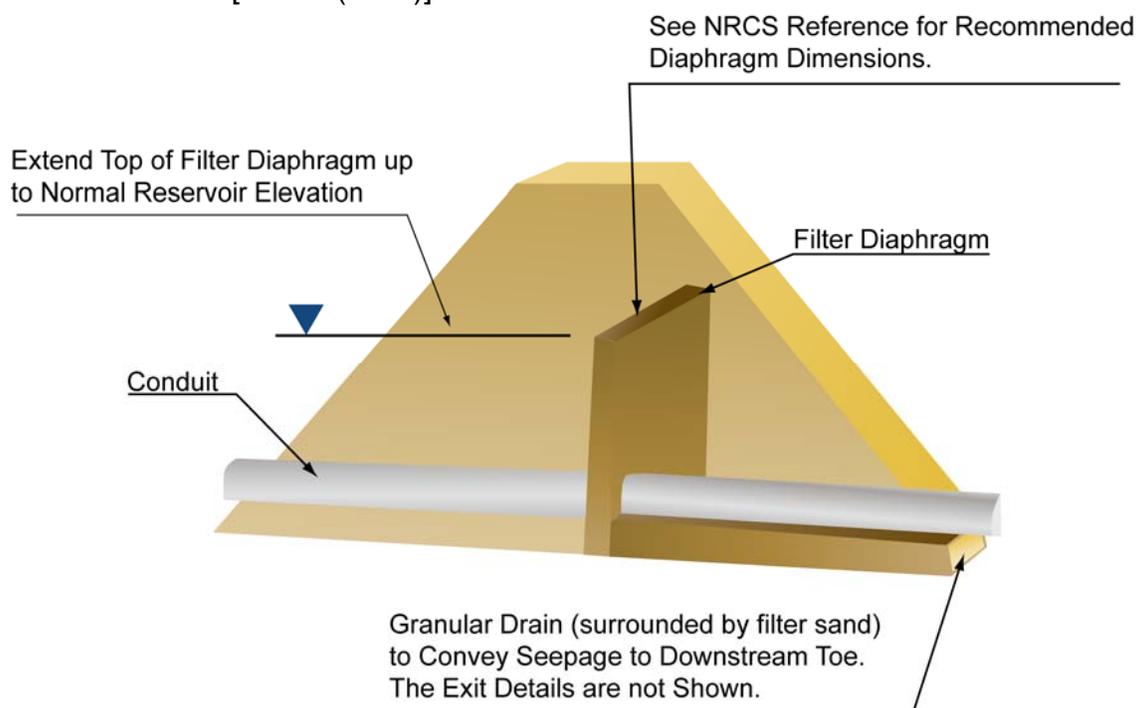


Figure 14 - Conduit Filter Diaphragm Collar

The diaphragm design should always include an outlet, so that water pressure cannot build up excessively in the filter diaphragm. An example outlet for the diaphragm is shown in Figure 14, although there are other acceptable outlet configurations.

The diaphragm should extend fully around the circumference of the conduit, if materials susceptible to internal erosion are present around the entire circumference.

Recommended dimensions for the diaphragm are given in the two references cited above.

If the dam includes a chimney filter that extends fully around the conduit, the chimney filter serves the purpose of the diaphragm, and a separate diaphragm is not required.

Compaction around circular conduits is very difficult in the quadrants beneath the springline, see Figure 15a. This should be addressed by the use of either full concrete encasement, Figure 15b, or use of a concrete cradle, 15c, to facilitate proper compaction. The sides of the encasement or the cradle should be battered from the vertical at least 10 vertical to 1 horizontal, so that as the soil settles over time it will maintain intimate contact with structure.

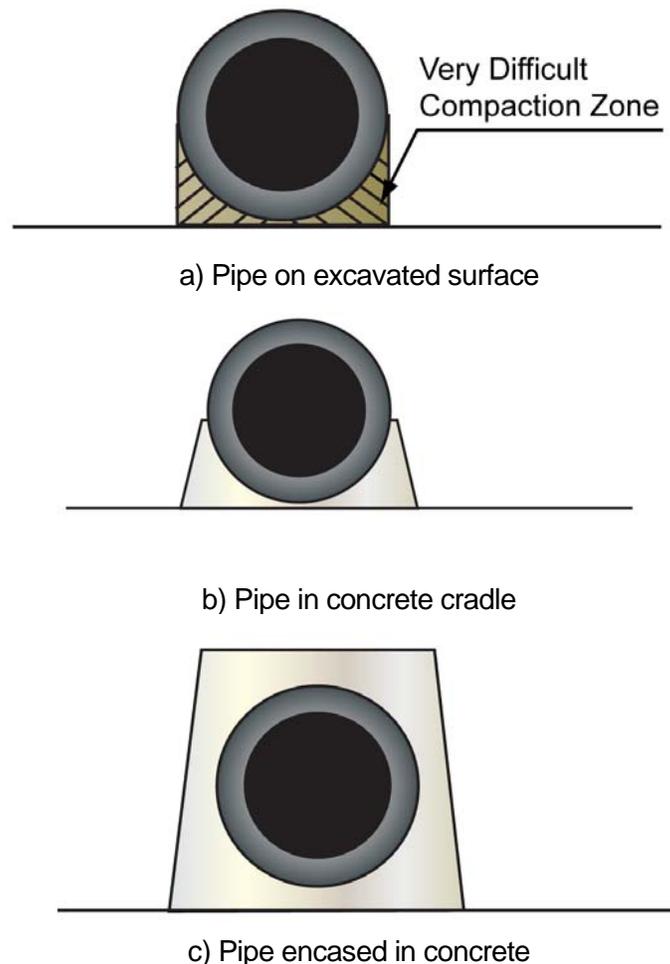


Figure 15 - Compaction Issues for Round Conduits

In some cases, spillway walls or other structures pass through the embankment. In such cases, the chimney filter system should be extended to contact the structure wall over its full height, and the outside wall of the structure should be battered from the vertical at least 10 vertical to 1 horizontal. If the dam does not include a chimney drain, a filter diaphragm should be constructed adjacent to the wall, in a manner similar to that recommended for conduits.

7. Some Construction Considerations

Filter and Drain Zone Widths – In design of a chimney filter drain, analyses are normally completed to determine the thickness of the filter and drain zones required to convey the estimated seepage flow rates. Normally these calculations result in relatively thin filter and drain zones and layers.

In reality, the design thicknesses of the filter and drain layers are normally controlled by consideration of constructability, not seepage flow capacity requirements. In considering constructability, the designer must address the question of how thick must each zone be to ensure that the zone is continuous, with no interruptions.

In typical filter and drain construction, the filter and drain materials are delivered to the dam in dump trucks and moved into the final location by loaders, dozers, or graders, after which they are compacted. Placement of chimney drains using this methodology is subject to what has been called the “Christmas tree effect,” as illustrated in Figure 16. In this example, an inclined chimney drain was being placed together with an upstream core and a downstream shell, with all three zones raised in unison. The photograph in Figure 16 shows a trench excavated through the chimney drain after placement of several layers. For each layer, a 5-foot wide layer of filter sand was placed and then compacted. As can be seen, the layer locations moved back and forth on subsequent layers, such that the 5-foot width placements resulted in sections of chimney drain as narrow as about 2 feet. If the chimney drain had been placed with layers 3 feet or less in width, it is reasonably likely that the continuity of the chimney drain may have been lost at some elevations. It is very difficult to avoid this type of variation in an inclined chimney drain location, unusually precise surveying methods are used.

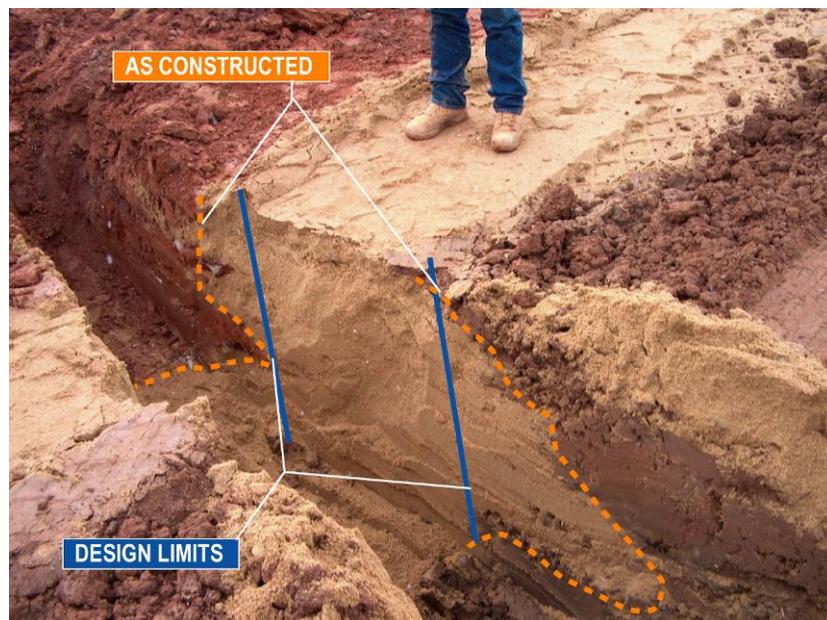


Figure 16 - “Christmas Tree Effect” in Chimney Filter Placement

As discussed earlier in this technical note, filter and drain materials are most commonly commercially-produced, processed materials, and, therefore, are expensive. As a result, there are always pressures to reduce the thicknesses of these materials and reduce cost. It is essential to resist any pressures to reduce filter and drain zone thicknesses to dimension less than those that will reasonably assure satisfactory construction.

Based on the discussion above, the following recommendations are made, as illustrated in Figure 17:

- Inclined filter and drain zones which will be constructed at the same time as adjacent upstream and downstream zones should be designed with a minimum horizontal dimension of 5 feet.
- Vertical filter and drain zones which will be constructed at the same time as adjacent upstream and downstream zones should be designed with a minimum horizontal dimension of 3 feet.
- Inclined filter and drain zones which will be constructed against an excavated face should be designed with a minimum horizontal dimension of 3 feet.
- Horizontal filter and drain zones should be designed with a minimum thickness of 1 foot.

The smaller dimensions for the last three cases are a recognition of the improved ability to control the locations of the zones in those configurations. As a point of reference, it is interesting to note that Sherard et al, in their classic 1963 book *Earth and Earth-Rock Dams* [Sherard et al (1963)], state “For vertical and inclined filters ... a minimum horizontal width of 8 to 10 ft. is desirable for ease in construction, while 12 to 14 ft. is preferable.” Financial pressures have obviously caused the profession to move to much thinner filters, however, the pressure to move to impractically thin filters must be resisted.

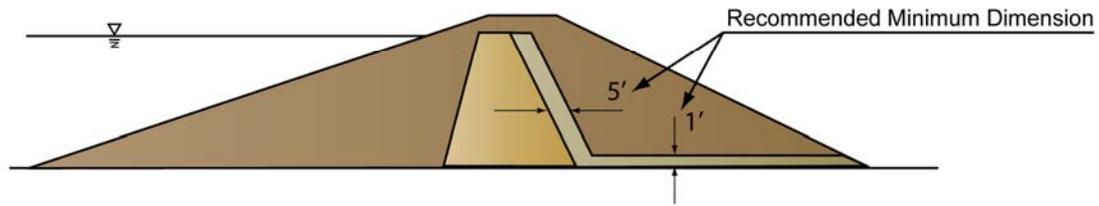
Filter and drain zones thinner than those recommended above might be considered in cases where exceptional placement control measures, such as atypical survey control and the use of spreader boxes, are used, however, it must be recognized in such cases that the satisfactory construction of the filters and drains is highly dependent on the correct application of these measures.

Filter and Drain Zone Compaction – Filter and drain materials are not particularly amenable to conventional earthwork compaction density control.

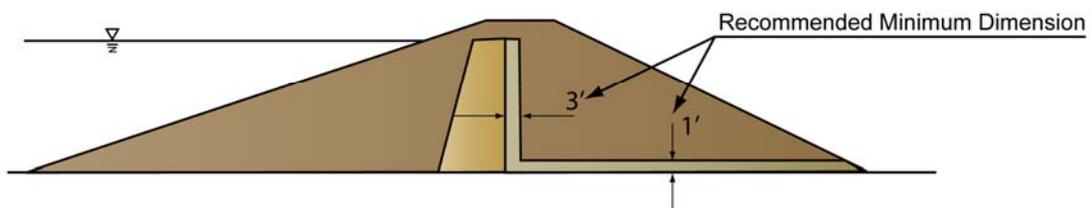
Typical filter sand materials do not exhibit the “standard” compaction curve shape, with a clear maximum dry density and optimum moisture content. Rather, these materials exhibit their maximum dry densities when either completely dry or nearly saturated.

Drain materials are typically uniform gravels, which are not suitable for conventional compaction testing nor for conventional field density testing.

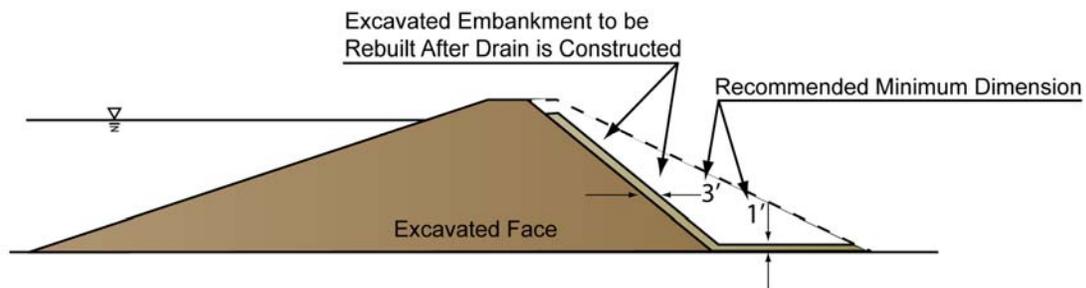
Conventional end product compaction specifications (e.g. percent compaction specifications) have sometimes been used for filter and drain materials, however, they are difficult to apply in the field, for the reasons given above.



a) Inclined chimney place together with adjacent zones



b) Vertical chimney placed together with adjacent zones



c) Inclined chimney placed against an excavated surface

Figure 17 - Recommended Filter and Drain Dimensions

End product compaction specifications based on relatively density requirements have also sometimes been used. However, the relative density test is notoriously difficult to apply in the field.

For most applications, it is desired that the filter and drain materials be compacted sufficiently to provide sufficient strength and to limit settlement. In locations subject to significant seismic loading, it is also necessary that the filter material be sufficiently dense to resist liquefaction if it is saturated. All of these requirements can be met by achieving densities that are greater than 70 percent relative density, which is not particularly difficult to accomplish with these clean materials. Further, it is desirable not to overcompact the filter material, because this can lead to excessive particle breakage and increased fines content, which is not desirable.

In general, it is easier to use a method specification for filter and drain materials, in which minimum compaction equipment and minimum compaction effort (e.g. number of coverages with the equipment) are specified. In addition to the compaction equipment and effort, it is also recommended that the placement specification for the filter include thoroughly wetting the material (to near saturation) as it is being compacted. There are a number of practical ways to accomplish this, including 1) covering the material with a water truck immediately ahead of the compactor, 2) applying water to the material with a hose immediately ahead of the compactor, and 3) mounting a water spreader bar on the compactor ahead of the compaction drum. Vibratory compaction equipment is the most appropriate equipment for compacting filter and drain materials.

A method specification requires close QC inspection during the work to assure that the method is being followed, but it is generally the easiest approach to use for these materials.

Prevention of Contamination – It is important to prevent contamination of the filter and drain materials during construction. To perform their functions as intended, the filter and drain materials must contain very limited amounts of fine materials. Contamination can occur if runoff carries fine-grained material into the filter and drain materials.

To prevent contamination, it is recommended that filter and drain materials be maintained at least one lift higher than the adjacent materials that contain fine-grained soils, and the adjacent materials should be sloped slightly to drain away from the filter and drain materials, as illustrated in Figure 18.

Should the filter or drain materials become contaminated despite efforts to prevent contamination, the contaminated materials should be removed and replaced.

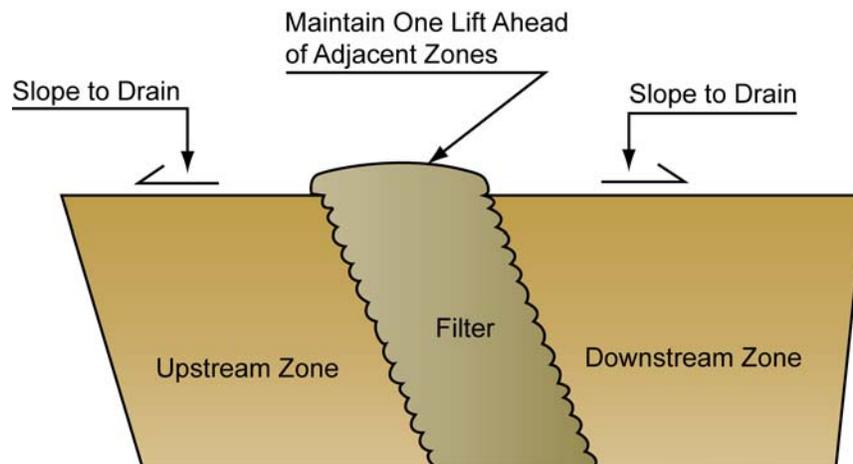


Figure 18 - Recommended Procedure to Prevent Contamination of Filter and Drain Materials

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