Title 210 – National Engineering Handbook

Part 645 – Construction Inspection

Subpart K – Drains and Filters

Amended March 2025

645.110 Introduction

A. The purpose of drainage for dams and other engineering structures is to control seepage and prevent the buildup of excess hydrostatic pressures. It is often impractical to build a structure with a completely impervious barrier in the embankment or foundation. In these instances, the design engineer can specify a constructed drainage system to allow safe collection and passage of seepage water. The success of these systems is highly dependent on the material quality, storage and handling, placement, moisture content, and material compaction.

B. Drainage systems consist of a filter layer and a drainage layer. Such a system may be referred to as a drain, even though it contains both a filter and a drain.

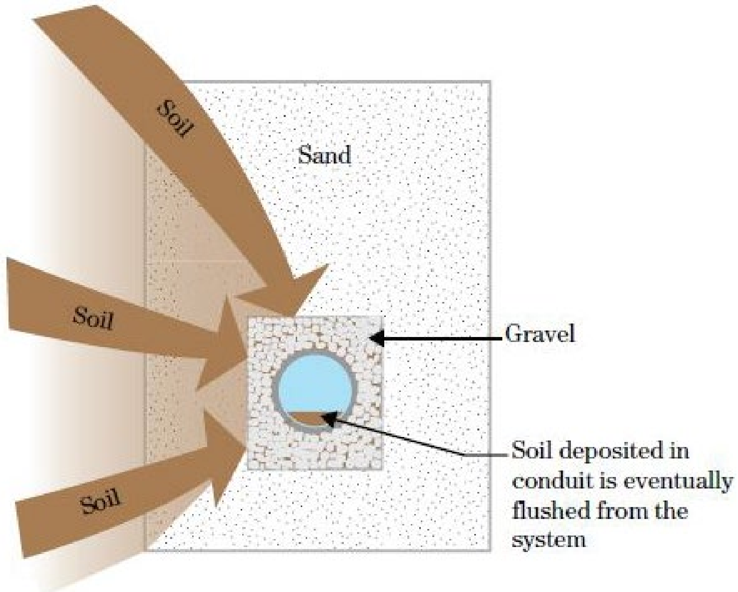
C. Many small and midsized dams constructed prior to 1980 do not have engineered filters. Many of those structures have operated for years and continue to operate without problems, but some have failed due to the lack of filters. Some of these failures resulted in extensive property damage and loss of life. Most mid- to large-sized dams today are built with internal drainage systems.

D. Function of drainage systems—Seepage water always follows the path of least resistance. This could be through a pervious foundation or embankment. Drainage systems intercept seepage water before it reaches a downstream outlet in the embankment slope or beyond the downstream toe. Then the drain conveys the filtered water to a safe outlet.

   1. A typical drainage system might be composed of a perforated or slotted pipe that is surrounded by a coarse drain material which is encapsulated by a fine drain material. The materials and the perforations in the pipe must be designed for filter compatibility to prevent particle migration. Each component of the drain is sized to prevent buildup of hydrostatic pressure.

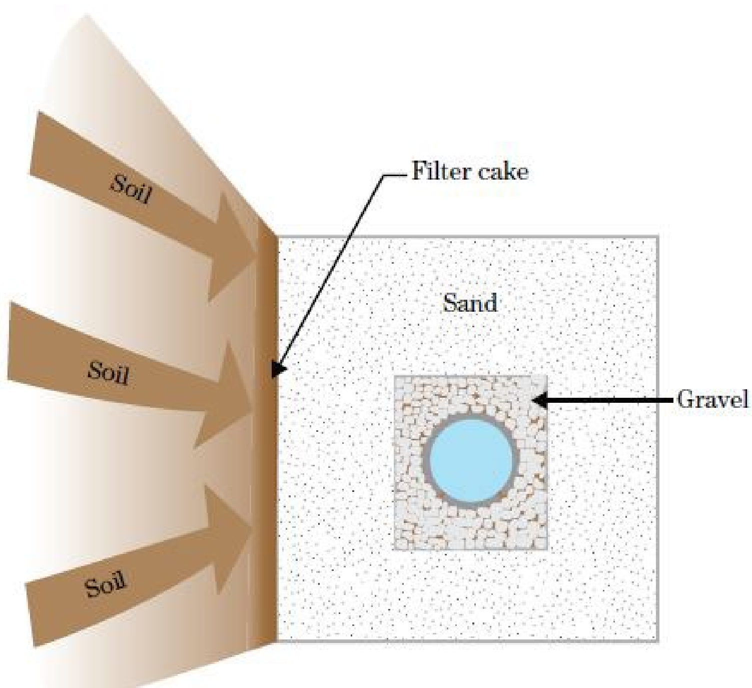
   2. The gradation of the fine filter must be compatible with the base soil. Figure 645K-1 shows a poorly designed or poorly installed filter. Seepage transports the base soil into the filter material. This soil enters the collection pipe and is flushed from the embankment. Fines occurring in the outlet water of a drainage system indicate an improper filter gradation, failure of the drainage system, and potential failure of the structure.

Figure 645K-1 Poorly Designed or Poorly Installed Filter



3. Figure 645K-2 shows a properly functioning filter. The gradation of the filter material is compatible with the base soil, and no fines are migrating into the drain to the collector pipe. A properly designed drain may develop a "filter cake" at the boundary between the base soil and the drainfill. This is not necessarily cause for concern unless the filter cake reduces the drain's capacity to serve its intended purpose.

Figure 645K-2 Properly Functioning Filter



E. Trench safety—The most common safety concerns associated with installation of drains involve trench excavation. Deep, narrow trenches are often necessary to construct toe drains and vertical embankment drains. Some of these drains require that workers enter the trench to place filter material and make pipe connections.

1. The contractor is responsible for worker safety, but the quality assurance (QA) inspector must thoroughly understand the trench safety requirements found in OSHA Construction Industry Standards 29 CFR Part 1926, subpart P. This standard contains the maximum allowable depth and side slopes for different soils and loading conditions. In no instance does the allowable trench depth for worker entry exceed 5 feet without appropriate protection. Figure 645K–3 shows a worker in an unsafe trench that does not meet OSHA trench safety requirements. The contractor in figure 645K–4 is staging the excavation of the trench for this drainage system so that it does not exceed safe working depths.
2. Any excavation can be dangerous because of the possible presence of underground utilities. Many states have laws requiring contractors to call a statewide "one-call" system prior to digging. This effort, along with personal observation and interviewing local landowners, helps reduce the chance that a contractor will encounter a utility.
3. Subpart D of this handbook has further information on the duties and responsibilities of the QA inspector as it relates to safety and health on a construction project. Appendix A contains checklist 4.1, which includes sections on excavation, trenches, and shoring.

Figure 645K-3 Hazardous Trench Excavation (NRCS-TX)

Figure 645K-4 Proper Trench Excavation (NRCS-OK)

4. The QA inspector's responsibilities related to trench safety include verifying that:
    a. The contractor has scouted the area for underground utility markers.
    b. The landowner has been asked about possible underground utilities in the work area.
    c. The contractor has notified the appropriate utility or "one-call" system.
    d. The contractor is complying with the trench depth and sloping requirements of OSHA 1926 Subpart P.
    e. Appropriate changes to depth and sloping requirements are made when soil or moisture conditions change.
    f. Equipment and stored materials are being kept away from the trench walls.
    g. Trench shoring and bracing is complete before allowing personnel access to trenches.
    h. Trench boxes are installed properly, and workers are not working outside of the protective limits.
5. For additional safety responsibilities see Appendix A, checklist 4.1.

F. Failures

1. Engineering structures sometimes fail because they lack a filter or have an improperly designed or installed filter.

2. The three common mechanisms of failure are:
    a. Piping—Piping is the movement of soil particles by percolating water leading to channel development. Signs of seepage leading to a piping failure are sand boils (figure 645K-6) or discolored or cloudy seepage water. These are signs that the seep water is carrying soil particles.
    b. Internal erosion—Internal erosion is the result of water flowing through cracks or holes in the soil mass or along interfaces between the soil and the principal spillway conduit or other embedded structures. Differential settlement, hydraulic fracturing, or drying can cause cracks. If cracks occur in highly erodible soils, considerable erosion can occur, and a failure can result. Burrowing animals can also lead to internal erosion. Failures from piping commonly take some time to develop, while failures from internal erosion often happen the first time the reservoir is filled or shortly thereafter. A seepage diaphragm can be installed around conduits to intercept cracks caused by differential settlement or other sources of internal erosion.
    c. Excessive pore pressure in soils—Soils can develop high pore pressures due to uncontrolled seepage flow, causing uplift forces destructive to embedded structures or structures downstream of an embankment. Foundation drains are one way that design engineers reduce hydrostatic pressure and intercept seep water before it surfaces.
    d. Figure 645K-5 shows an embankment with a typical piping failure caused by seepage from the principal spillway conduit installation.

Figure 645K-5 Embankment Failure Caused by Seepage along Principal Spillway (NRCS-TX)

Figure 645K-6 Sand Boil Caused by Uncontrolled Seepage (NRCS-TX)

G. Types of Drains

1. Foundation or Toe Drain

    a. A foundation drain is sometimes called a toe drain because it is usually located near the downstream toe of an embankment dam (figure 645K-7). Foundation drains intercept any water traveling through porous foundation soils or rock before it surfaces downstream of the embankment. They are used on structures to reduce harmful hydrostatic pressure.
    b. Typically, the foundation drain is constructed in a vertical trench with a perforated pipe surrounded by coarse drain material that is then encapsulated by fine drain material (figure 645K-8).
    c. The design engineer will specify the required lower limits of the foundation drain based on the soil and geologic conditions of the site.
    d. The design engineer will specify the upper limits to a certain height or the existing natural ground surface.
    e. In some areas, the drain's slope may allow the design engineer to use the filter material alone to carry the anticipated flow. In those cases, the engineer will eliminate the perforated pipe. These are called blind drains.

Figure 645K-7 Typical Toe Drain Installation

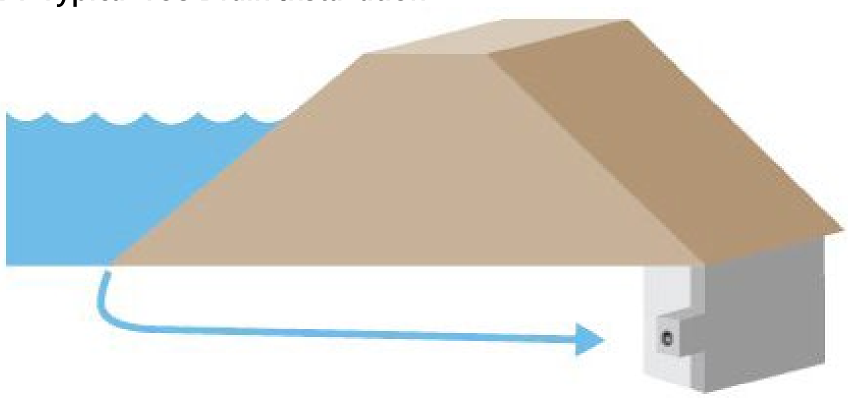
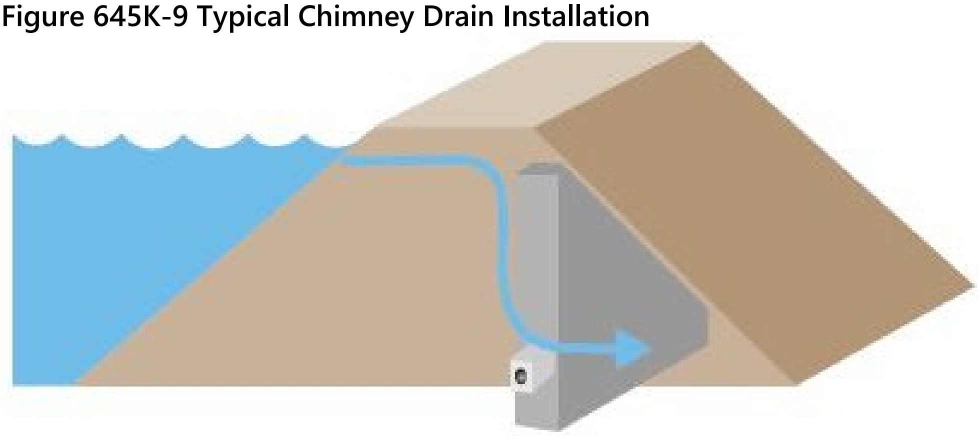


Figure 645K-8 Exposure of a Constructed Toe Drain (NRCS-TX)

2. Chimney Drain

   a. Over time, most earthen embankments that retain water will develop a phreatic surface. This represents the upper limit of the saturated material in the dam. If this phreatic surface intercepts the back slope, it can cause internal erosion or piping, which could jeopardize the embankment.
   b. Through investigation and analysis, design engineers can approximate the location of this phreatic line. If they determine it could intersect the back slope, they will design a chimney drain to intercept the seepage and provide a controlled release of water and pressure (figure 645K-9).

Figure 645K-9 Typical Chimney Drain Installation



3. Filter Diaphragm

    a. Moisture control and compaction of soil near or adjacent to the conduit is difficult. Movement in the foundation or embankment can open up cracks and fissures that allow the migration of seepage water along the interface between the outside of the conduit and the soil. The compactive effort in confined areas, such as in a conduit foundation excavation, is generally less than the compactive effort in areas where production compaction equipment has room to operate at normal speed. Therefore, the potential for differential settlement and hydraulic fracture is greater in those areas.
    b. The anti-seep collar (figure 645K-10) was used for many years to prevent seepage along the conduit but was ineffective at preventing internal erosion and piping. The anti-seep collar also made compaction around the conduit even more difficult
    c. The anti-seep collar was replaced with a filter diaphragm (figures 645K-11 and 645K-12), designed to intercept seepage along the conduit and any seepage path that might be caused by differential settlement associated with the installation of the conduit. During filter diaphragm installation, it must extend from each side of the pipe into natural ground where it will intercept that boundary. This will protect the confined area that was compacted manually or compacted by manually directed compaction equipment. The idea is to intercept any water that seeps through the portion of the earthfill received less compaction effort than the areas where the larger production compaction equipment could perform.

Figure 645K-10 Anti-seep Collar (NRCS-TX)

Figure 645K-11 Typical Installation of a Filter Diaphragm

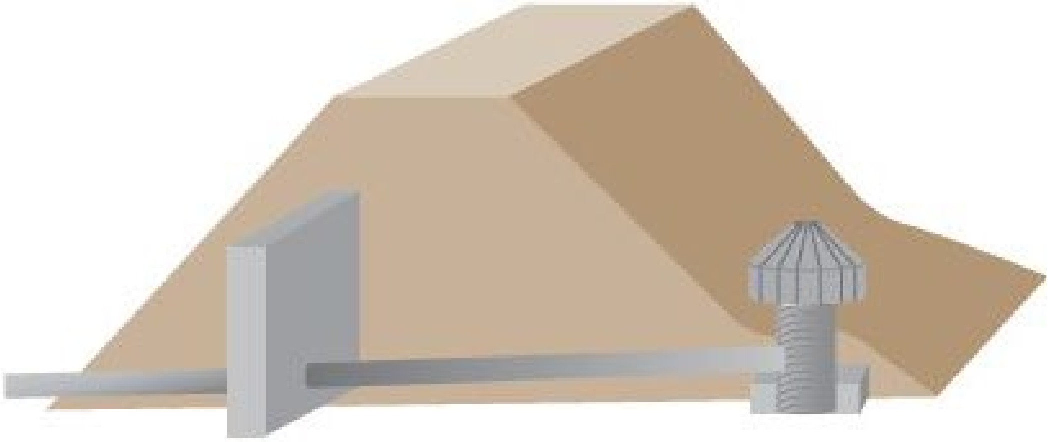
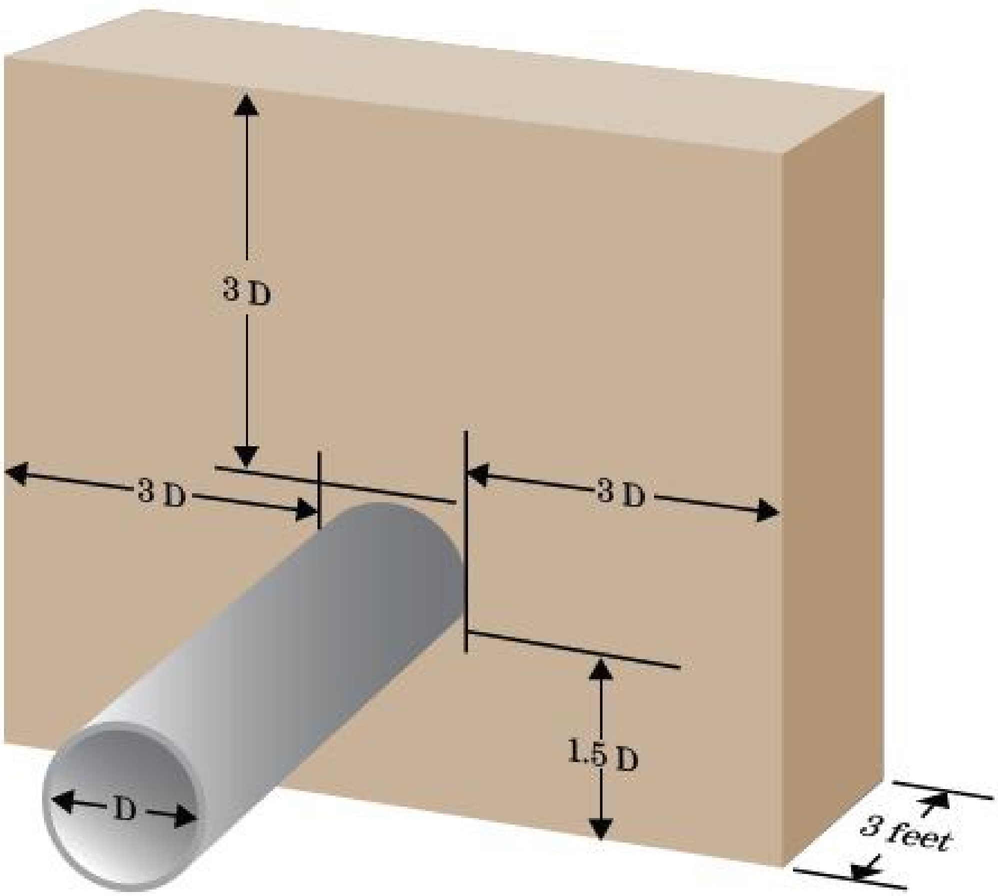


Figure 645K-12 Typical Dimensions of a Filter Diaphragm

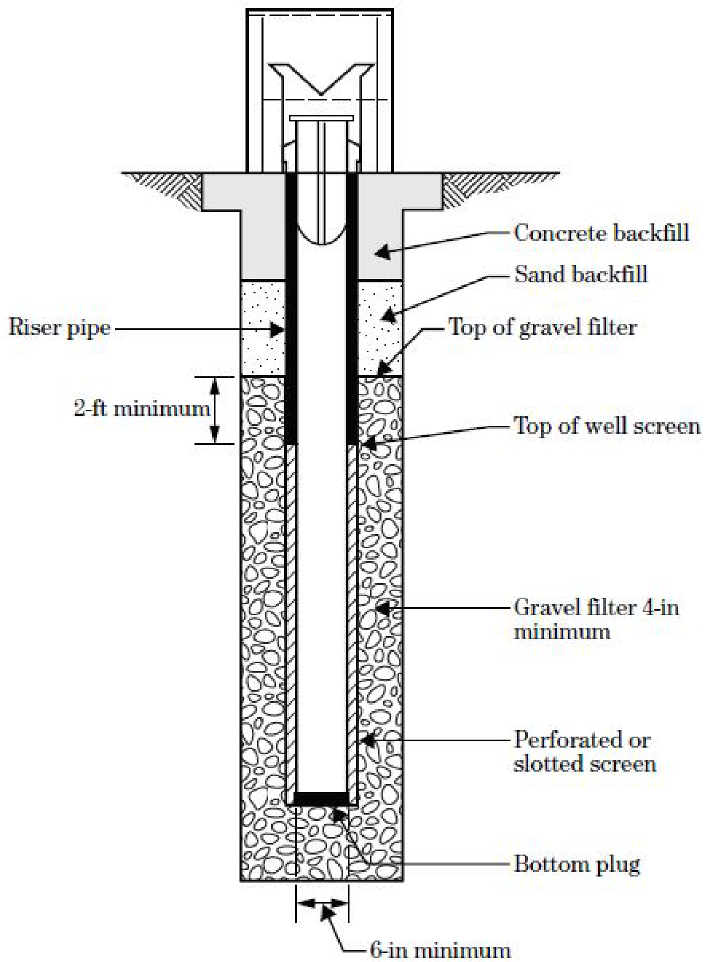


4. Relief Wells

    a. The purpose of a relief well or pressure relief well is to relieve the excess hydrostatic or uplift pressures that might jeopardize the integrity of a structure. Relief wells act as an artificial spring that reduce the uplift pressure to safe values. These conditions usually exist when an impervious stratum overlays a pervious foundation.

b. The relief well consists of a perforated or slotted pipe surrounded by filter material designed to prevent migration of the foundation material into the well. The well screen and riser pipe are commonly 6 to 18 inches in diameter. The design engineer specifies the size and depth of the relief well based on their review and analysis of the soils and geology. Figure 645K-13 shows a typical relief well design.
c. The U.S. Army Corps of Engineers publication "Design, Construction and Maintenance of Relief Wells" (EM 1110–2–1914) contains information on relief wells. NRCS Construction Specification (CS)-12, "Relief Wells," is also a useful reference for developing and installing relief wells.

Figure 645K-13 Typical Relief Well Design



5. Blanket Drain—A blanket drain is usually located at the interface between the embankment and the foundation. The purpose of the blanket drain is to collect seepage from the foundation and safely transport it to an outlet. The blanket drain is often installed when the foundation lies on coarse soils or bedrock. The gradation of the blanket drain filter material is critical because it must be compatible with the embankment soils and the foundation soils or bedrock when they might not be compatible with each other. Figures 645K-14 and 645K-15 show an installation of an embankment blanket drain.

6. Wall Drains—Wall drains prevent hydrostatic pressure buildup that could move, or damage constructed walls. The wall drain consists of a perforated pipe surrounded by a coarse drain material and encapsulated in a fine drain material. The conduit often outlets through the wall of the structure it protects. Figures 645K-16 and 645K-17 show typical wall drain locations and installations.
7. Subsurface Drainage Systems—Subsurface relief drains are installed to lower a high-water table to increase agricultural production, improve access, or allow the installation of structures. These commonly consist of a primary drain and outlet that is connected to lateral lines that may be randomly located or part of a regular pattern. The drain can be composed of a perforated pipe and one or more courses of drainage filter but is often installed with the perforated pipe enclosed in a geotextile "sock." When soil conditions allow, this system can be installed accurately and rapidly using a special trenching machine.

Figure 645K-14 Blanket Drain Location

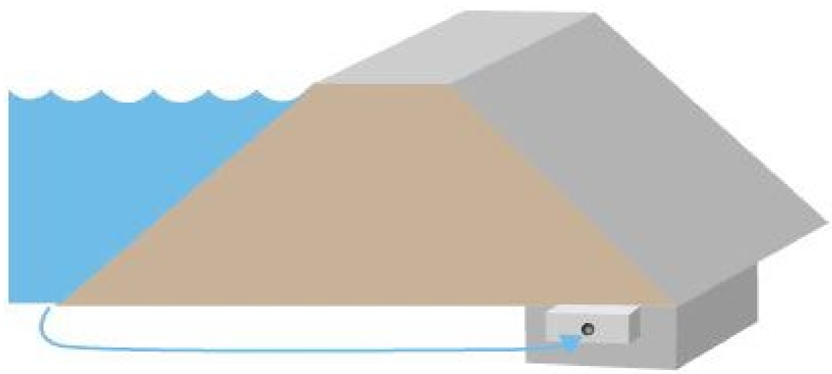


Figure 645K-15 Typical Blanket Drain Installation (NRCS-WV)

Figure 645K-16 Typical Wall Drain Configuration

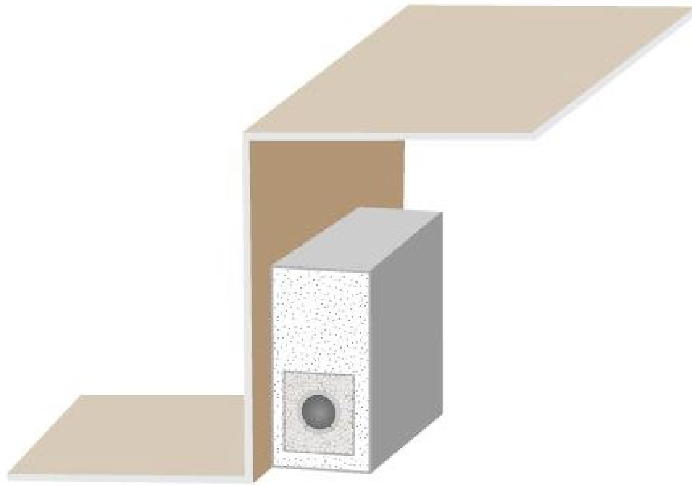


Figure 645K-17 Wall Drain Installation (NRCS-TX)

645.111 Installation

A. Material

1. Drainfill Material

a. The engineer is responsible to have tests performed and obtain the results or certifications to verify that the proposed drainfill materials meet specification requirements. The engineer must notify the QA inspector once those materials have been approved. The job diary contains a "Material Certification Record" section to document the approvals. Quality control and QA assurance tests may also be needed to verify that the delivered material is consistent with the approved material.

b. The quality of drainfill material is prescribed in CS-24, "Drainfill," and Material Specification 521, "Aggregates for Drainfill and Filters." Material quality concerns include the type of material used for drainfill, the gradation, the cleanliness, and the soundness.
c. Drainfill material generally consists of sand, gravel, crushed stone, or a mixture of these components. Material specification 521 discourages the use of crushed limestone as a fine aggregate. Fine particles of crushed limestone break down over time and cement together leading to performance issues. Crushed limestone may be used as a coarse drainfill, but it must be thoroughly washed and screened to remove limestone dust, limestone fines, and fine soil particles. Material specification 521 also states that the aggregates shall not contain organic material, clay balls, soft particles, or other substances that would interfere with the free draining properties of the aggregates. The cleanliness of material is very important because it could cause plugging of the drain and hinder its function.
d. A gradation for the filter and drain materials must be specified. The proper gradation is critical in ensuring that all filters are compatible with each other, the base soil, and the perforations of the drainage conduit. The proper gradation also ensures that the designed drainage capacity is achieved. American Society for Testing and Materials (ASTM) International C136 describes the mechanical analysis used to determine the gradation of an aggregate. ASTM C117 is a wet sieve procedure used to determine the number of fines in the sample. The gradation of the filter materials must be verified prior to delivery of the first load to the jobsite and intermittently during construction.
e. Obtaining a representative sample of an aggregate is often problematic. Aggregates dumped into piles tend to segregate, so special care must be taken when collecting a sample. ASTM D75, "Standard Practice for Sampling Aggregates," describes how to obtain a representative sample for gradation testing.
f. The durability of filter and drain material is referred to as soundness. This is a measure of how the material will respond over time to weathering and freeze-thaw. Drainfill materials must be sound enough not to dissolve in water during the life of the project. They must also be sound enough that they are not crushed under the design load. ASTM C88 describes sodium sulfate and magnesium sulfate soundness tests. In these tests, the particles are repeatedly soaked in a salt solution and dried. This results in the formation and swelling of salt crystals in the cracks and voids. The swelling of the salt simulates the destructive internal pressure caused by freezing water that is trapped within the aggregate particles. As the salt swells near the particle surface, some of the material flakes off. The more durable materials are less porous and tend to lose less flaked material. The materials are weighed at the beginning of each test. After each soaking, the materials are washed to remove any flaked-off materials and allowed to dry. After a set number of soaking and drying cycles, the material is weighed again to determine the amount of lost material. Material

specification 521 contains a maximum allowable loss. The allowable loss depends on the type of salt (sulfate or magnesium) used for the test.

2. Collector Pipe

   a. Most NRCS-engineered drainage systems that require a collector pipe use plastic (poly vinyl chloride, polyethylene, high density polyethylene, or acrylonitrile-butadiene-styrene) pipe, fittings, and joint materials according to material specification 547 and CS-45. The engineer will designate the material, wall thickness, and number and size of perforations or slots for the pipes and the QA inspector must verify they are used. The size of the pipe and the number, spacing, and size of perforations are related to the pipe's capacity and the gradation of the surrounding soil or filter material. The wall material and wall thickness are determined by the amount of earthfill over the drain.

3. Geotextiles

   a. Geotextiles (often called filter fabric) are a permeable synthetic material specifically designed to be used as a soil filter. Engineers will usually only specify geotextiles in easily accessible areas, in case the material must be repaired or replaced. They come as either woven or nonwoven and vary by composition, weight, opening size, and thickness. The design engineer specifies the geotextile material to be used. Material specification 592 covers the quality of geotextiles.
   b. Geotextile can be used as a single filter or combined with drainfill of a complementary gradation. Some applications use a geotextile (sock) enveloping a perforated collector pipe, but this is not recommended for a perforated pipe embedded in a drainfill. If the drainpipe is embedded in drainfill, it is best to install the geotextile around the drainfill to provide a greater filter surface area than if it were wrapped around the pipe.
   c. The QA inspector's responsibilities related to materials include verifying that:
      (1) The gradation and soundness of the drainfill materials have been verified before delivery.
      (2) The drainfill materials are delivered from the approved sources.
      (3) Gradation tests are conducted on the drainfill materials in accordance with the specification requirements, contractor's quality control plan, and NRCS QA plan.
      (4) The collector pipe meets all specification requirements for type, size, and perforations.
      (5) The collector pipe is protected from excessive Ultra-Violet (UV) radiation during storage.
      (6) The geotextile meets all specification requirements and is protected from UV radiation during storage.

B. Base Preparation

4. A clean, well-compacted foundation is desired so that contamination of drainfill does not occur. Organic matter, loose soil, and foreign substances

must be removed because they will also contribute to contamination and settlement. Unless accounted for in the design and installation procedures, all standing water must be removed. If the subgrade has been scarified, it must be recompacted prior to placement of drainfill. The QA inspector must document in the job diary that the subgrade was inspected and approved prior to placement.

5. The QA inspector's responsibilities related to base preparation include verifying that:
   a. Foundation surface and trenches are clean and free of organic matter, loose soil, foreign substances, and standing water when drainfill is placed.
   b. Earth surfaces upon or against which drainfill will be placed have not been scarified.

C. Placement

1. Storage and Handling
   a. Material specification 521 requires that aggregates conform to the specified gradation after being placed and compacted. Materials are approved contingent on the materials meeting the specified requirements for gradation and cleanliness after they have been placed. The material must be stored and handled in a manner that will prevent segregation of particle size and prevent contamination.
   b. Figure 645K-18 illustrates the importance of preventing segregation. Filter compatibility is based on well graded, non-segregated materials. If a filter material becomes segregated, the larger particles end up on the bottom and the smaller particles on top. Without the smaller particles, the openings within the large particles are too large to prevent migration of the base soil. Base soil particles will move into the lower portion of the filter and continue through the filter.
   c. When fine drain materials are moist, they tend to clump together. This clumping aids in preventing segregation. Fine drain materials that are dry will easily segregate. When depositing drainfill, especially coarse materials, care must be taken to keep the drop height and pile height and steepness to a minimum to guard against segregation (fig. 645K-19).
   d. The QA inspector's responsibilities related to storage and handling include verifying that:
      (1) Materials remain uncontaminated.
      (2) Materials are being handled in a manner that prevents segregation.

Figure 645K-18 Segregated Filter

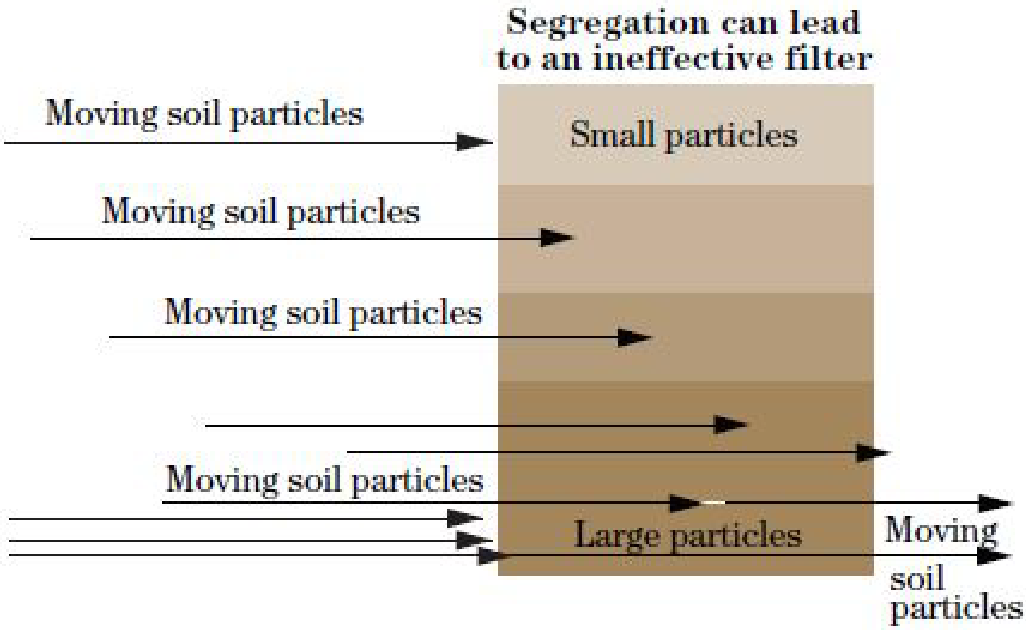
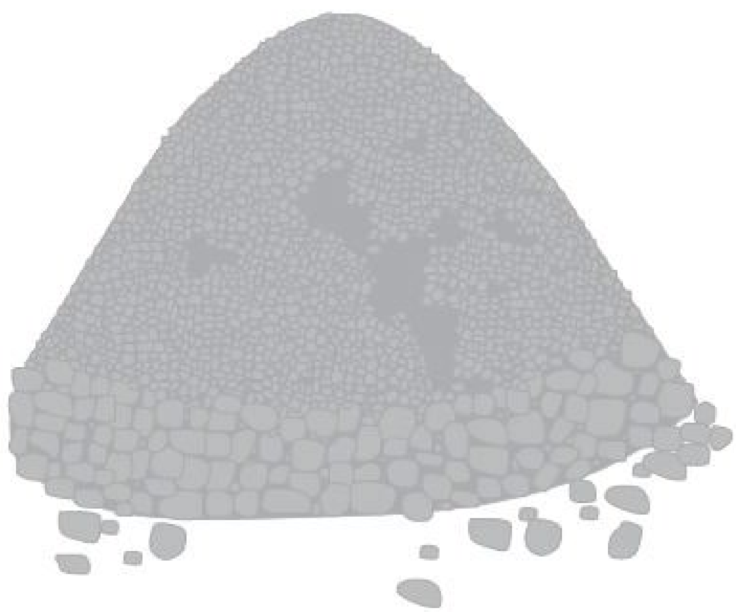


Figure 645K-19 Stockpile Height and Steepness Can Cause Segregation of Materials



Larger particles roll down the side of the pile

D. Location of Drains and Filters

1. Minor changes in the location of drains and filters may make them less effective. It is very important to make sure that the drain system is installed to the exact limits specified by the design engineer. Knowing the purpose of

the drain system and how it works helps to understand the importance of design adherence.

2. Figure 645K-20 shows a sand filter diaphragm that was installed to intercept any hydraulic fracturing that might occur in the vicinity of the conduit installation. The diaphragm stretches from one side of the excavation limits to the other.
3. Small variances in the location of the filter can hinder performance. The contractor may ask to move the conduit to one side of a conduit foundation excavation so that a concrete truck can travel down one side of the conduit. Thinking that it is important to center the diaphragm on the conduit, the field engineer may require the diaphragm be moved (fig. 645K-21). This would be an incorrect decision because the entire area subject to hydraulic fractures and the entire interface between the foundation and the backfill are no longer protected by the filter diaphragm. Anytime there are proposed changes in the location of a filter or any other component, the design engineer must agree to the change, and the QA inspector must document the change in the job diary.

Figure 645K-20 Properly Located Sand Filter Diaphragm

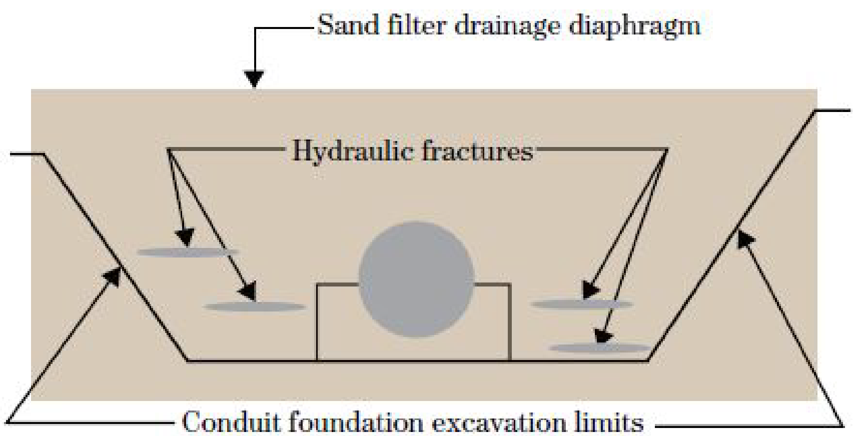
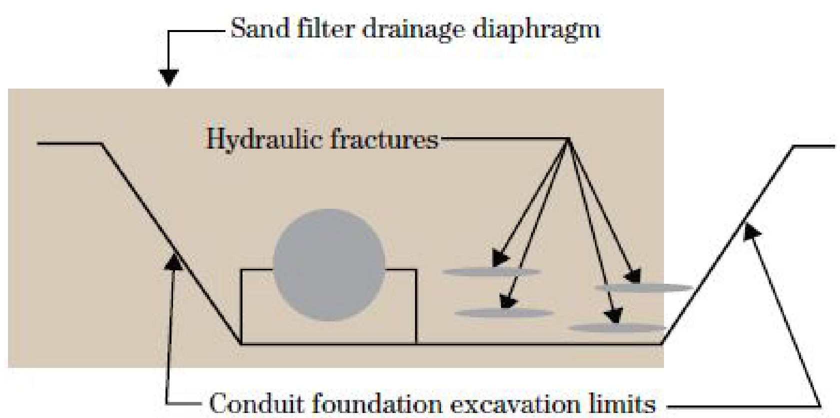


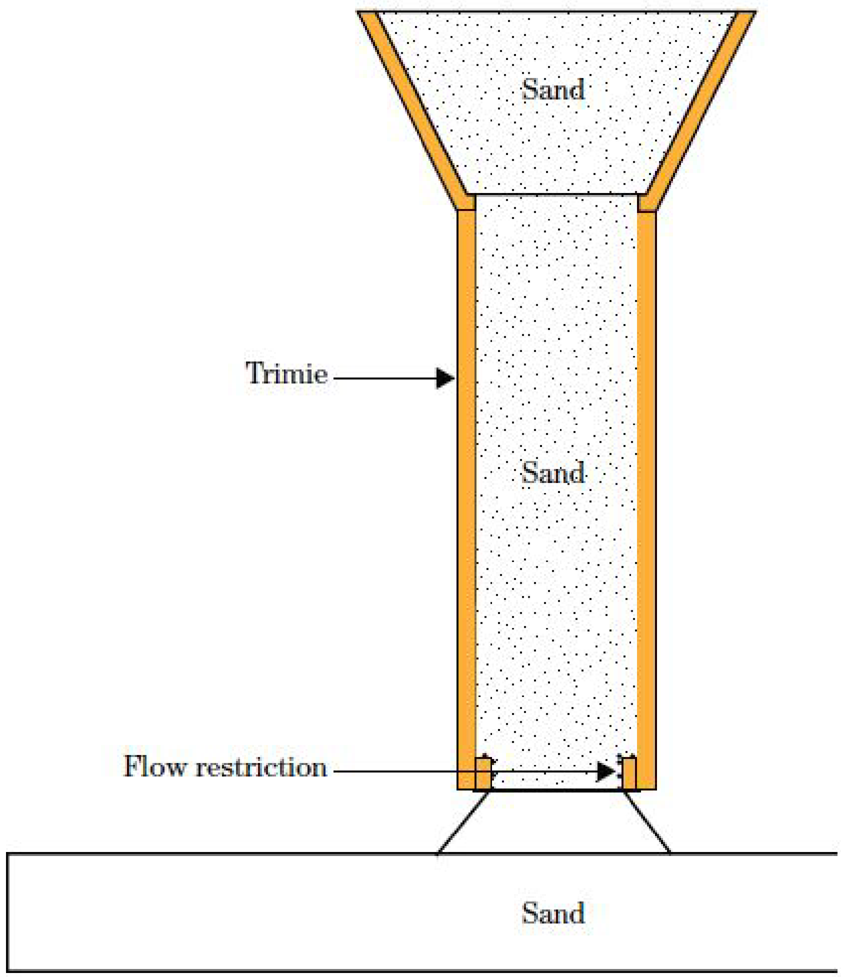
Figure 645K-21 Improperly Located Sand Filter Diaphragm



E. Placement

1. Granular materials tend to become contaminated and segregated when they are handled and placed. Specific practices and handling methods that must be avoided to reduce contamination and segregation during placement. CS-24 contains several requirements regarding placement.
2. CS-24 limits the maximum free-fall to five feet. Chutes, clamshell buckets, skips, or other equipment can be used to place materials in deep excavations. Placing material against forms or pouring through obstructions can cause segregation. When placing materials in a trench, make sure the granular materials go directly from the bucket to the bottom. Materials that fall on the bank and then into the trench or bounce from the side of the trench tend to segregate more than if they go straight from the bucket to their final resting place.
3. A tremie will help limit the free-fall distance (fig. 645K-22). The bottom of the tremie must be kept as close as possible to the fill surface. Restrict the flow at the bottom of the tremie or control the rate of loading so that the tremie is full. This will prevent material from free-falling through the tremie.

Figure 645K-22 Tremie Used to Limit Free-fall Distance of Material



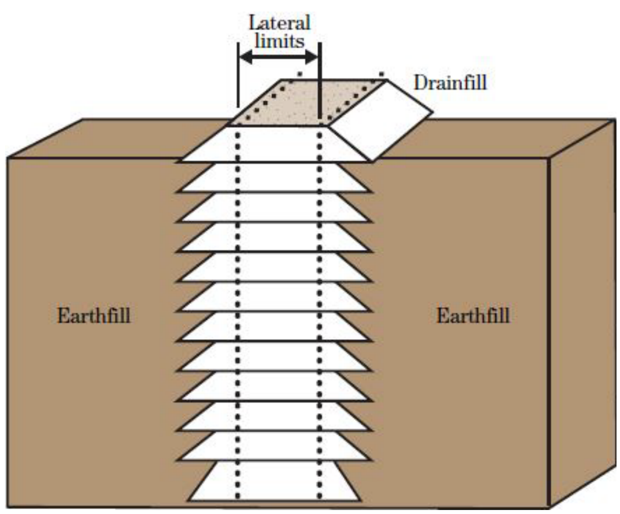
4. Placement in water is not recommended without special equipment. Allowing granular material to free-fall in water will result in significant segregation. According to Stoke’s Law, the forces that control the rate of fall are weight, buoyancy, and resistance. Larger particles reach the bottom faster than smaller particles.
5. Traffic crossing over drains must be minimized to prevent contamination. CS-24 contains provisions for limiting the number of crossovers and requires that the areas be cleaned of all contamination and inspected before placement of additional drainfill material.
6. CS-24 also requires the upper surface of drainfill, when constructed concurrently with adjacent zones of earthfill, be maintained at an elevation at least one foot above the upper surface of the adjacent earthfill to prevent contamination from surface runoff or sloughing of earthfill material. If the earthfill is trenched, it can be trenched every few feet to allow placement of earthfill. The drainfill must be placed in one-foot lifts; but, in this situation, the maximum allowable lift thickness would likely be eight inches because of the need to use manually operated compaction equipment. Compaction by flooding in a trench must be used with caution due to the potential for the trench to become unstable as the moisture conditions change. The instability may result in contamination of the drainfill or trench failure.
7. Figures 645K-23 and 645K-24 show the installation of a two-stage filter in a trench. The dog-house-shaped box allows for separate placement of each of the filters. With the top flaps open, the coarse drainfill is placed into the interior zone and around the pipe. With the flaps closed, the fine filter can be placed in the appropriate outer zone. The sand must be loaded equally on both sides of the box to prevent it from being pushed out of alignment.
8. Figure 645K-25 shows what is called a Christmas tree configuration. It requires more sand because it must be overbuilt to allow it to reach the specified limits. There will be some contamination of sand outside of the specified lateral limits, but that is acceptable as long as the sand within the lateral limits remains clean. The contractor may devise a method of drain installation that is not described here. Any method which accomplishes this goal is acceptable, but the engineer must review it prior to placement.
9. The QA inspector’s responsibilities related to placement of drains and filters include verifying that:
    a. Work is not started until the specified foundation depths, lines, and grades are attained.
    b. Drainfill is not placed until the subgrade has been inspected and approved by the engineer.
    c. Drainfill is not placed over or around pipe or drain tile until the installation of the pipe or tile has been inspected and approved.
    d. Drainfill is not placed in layers exceeding 12 inches thick before compaction or not more than 8 inches thick if manually controlled compaction equipment is used.

e. The material is placed in a manner that does not cause segregation.
f. The material is placed in a manner that ensures continuity and integrity of zones.
g. Perforations of the collector pipe are correctly oriented.
h. Drainfill is not contaminated with foreign material during placement.
i. Traffic is not allowed to cross over drains at random locations.
j. Equipment crossovers are established and approved before beginning of drainfill placement.
k. Crossovers are cleaned of all contaminated material and inspected by the engineer before placement of additional drainfill material.
l. Surface runoff is not allowed to enter the filter.
m. Any damage to the foundation surface or trench sides or bottom occurring during placement is repaired before drainfill placement is continued.
n. The upper surface of drainfill constructed concurrently with adjacent zones of earthfill is maintained at a minimum elevation of one foot above the upper surface of adjacent earthfill.
o. Drainfill over and around pipe or drain tile is placed to avoid any displacement in line or grade of the pipe or tile.
p. Drainfill is not placed adjacent to structures until the concrete has attained adequate strength as defined by the specification or approved by the engineer.
q. Geotextile is placed as specified.
r. Geotextile lap lengths meet specification requirements.
s. Soil surface is relatively smooth and free of protruding rocks and debris prior to placement of geotextile.
t. Damaged geotextile materials are repaired or replaced.

Figure 645K-23 Two-stage Filter Installing the Outer Zone of Fine Materials (NRCS Oklahoma)

Figure 645K-24 Placing the Inner Zone of Coarse Material around the Collector Pipe (NRCS Oklahoma)

Figure 645K-25 Christmas Tree Method of Installing Filter Material



F. Control of Moisture

1. The concern for moisture content only applies to fine drainfill. Coarse drainfill contains little moisture, which has very little effect on the segregation potential or the ability to obtain density. The moisture content of the fine drainfill, however, can reduce the segregation potential and greatly affect the ability to densify the material. Very dry fine drainfill can be effectively compacted to the desired density by complete saturation and drainage or flooding.

2. The problem with sands occurs in a certain moisture content range where a condition called “bulking” occurs. Bulking is caused when a film of capillary water on the surface of the sand particles holds the particles together. In this condition, the compactive equipment will likely not provide the energy to overcome the bulking forces.
3. Figure 645K-26 shows the sand at a moisture content that results in bulking. The particles are held together and not allowed to move independently of one another. By simply increasing the moisture content to the point where the bond is broken, the density of the sand increases. Figure 645K- 27 shows the same sand in a denser state after only adding water.
4. Bulking is not a concern if the sand is dry with a moisture content less than 2%, but care must be taken to prevent segregation while handling and processing dry sand. Bulking is also generally not a problem when the moisture content is at or above 10%. Although bulked sands can be densified by flooding, a greater density can be obtained by flooding and draining. Flooding involves supplying water at a great enough flowrate to completely saturate layers of the sand as the water moves downward through the sand. This breaks the bonds caused by bulking, and the downward movement of the water sets the particles in motion. The particles resettle in a denser state. Additional compaction can be achieved by mechanical vibration.
5. The QA inspector’s responsibilities related to control of moisture include verifying that:
    a. The moisture content of fine drainfill is appropriate for the method of compaction to be used.
    b. Fine drainfill in the bulking moisture range is saturated and drained to break the capillary bonds.
    c. When additional water is required, it is applied in a manner to avoid excessive wetting to adjacent earthfill.

G. Compaction

1. Drainfill that is not adequately compacted during placement can lead to post-construction settlement. This might occur during the remaining construction period or at some point in the future when conditions are favorable. Post-construction settlement is caused by changes in moisture, loading, vibration, or a combination of these factors. Material that is bulked during placement and later becomes saturated is likely to settle considerably. Post-construction settlement can cause differential loading within the fill, which can lead to cracking in the fill or failure of embedded structures. It could also lead to a large void in the drain system if the lower portion of a vertical drain settles while the upper portion bridges. This could lead to very serious consequences for the embankment, including failure.

Figure 645K-26 Sand at a Bulking Moisture Content Before Saturating (NRCS-TX)

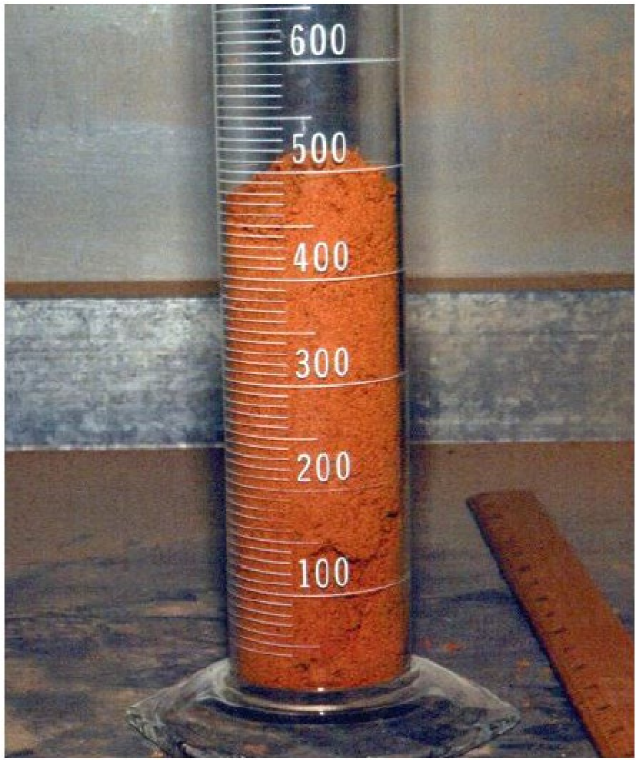
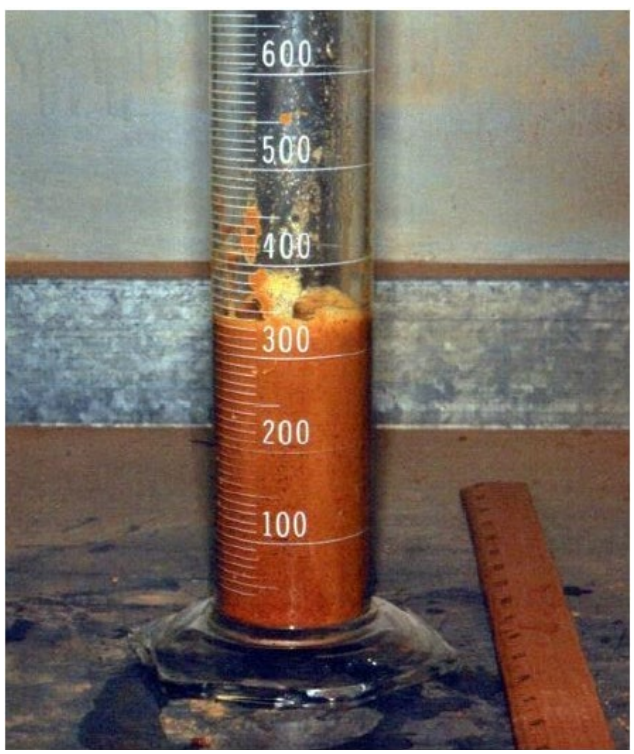
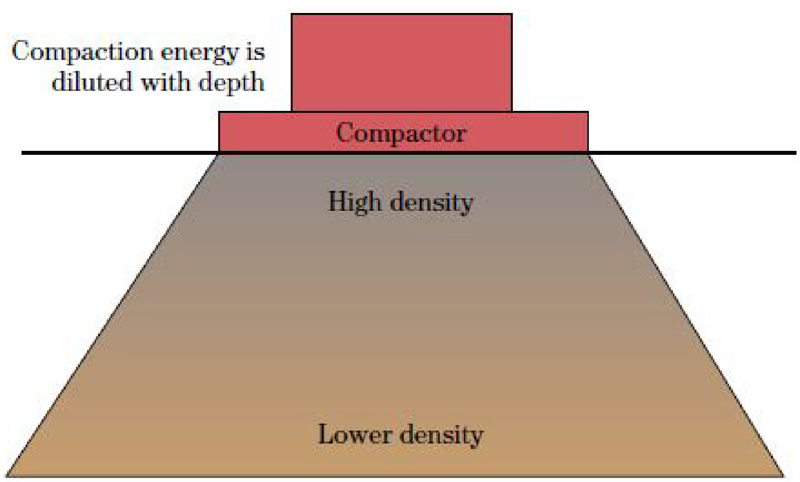


Figure 645K-27 Sand After Saturating (NRCS-TX)



2. CS-24 limits lift thickness to a maximum of 12 inches, or eight inches with manual compaction equipment. The energy supplied by compaction equipment is diluted with depth. If the lift is too thick, the compaction equipment may not be capable of supplying enough compaction energy to the lower limits of the lift to reach the specified density. Figure 645K-28 shows that as the compaction energy travels down through the soil, some of the energy is transferred to adjacent particles because of friction between the particles. The force per unit area is diluted with depth because, although the compactive effort remains the same, the area being compacted increases with depth. For this reason, it is important to check densities at different depths to ensure that the density requirement is met throughout the lift.
3. Compaction requirements for drainfill can be based on a performance specification or a method specification. In the performance specification, the drainfill must be compacted to a specified density. There are two methods of specifying the required density of fine drainfill. The first specifies a percent relative density based on maximum and minimum densities obtained from two ASTM procedures (D4253 and D4254). The second was developed by the NRCS Soil Mechanics Laboratory in Fort Worth, Texas. It is a modification of the ASTM D698 procedure for conducting a one-point test. CS-24 requires that the modified ASTM D698 procedure be used when more than 70% of the drainfill material will pass the three-quarter-inch sieve, and the relative density test be used when 70% or less pass the ¾ inch sieve.

Figure 645K-28 Showing How Compaction Energy is Dissipated with Depth



4. Method specifications describe a procedure to be used rather than a measured end result, such as a moisture or density requirement. CS-24 includes three method specifications. They are used where small quantities are involved, and the density of the material is not critical to the performance of the practice being installed. These method specifications are effective if the material is dry, or the moisture content is more than 10%. They must not be used if the drainfill material is within the moisture range where bulking is a problem. When method compaction is specified, full-time inspection is required to verify proper installation of the drainfill.

5. In a performance specification that specifies a required density, any equipment that can attain that density may be used, but some equipment will do a better job than others. A steel-drum vibrating roller is an excellent piece of compaction equipment for fine drainfill, as long as the lift thickness is 12 inches or less and the moisture content is not within the bulking range. Plate compactors, as shown in figure 645K-29, produce a stress wave that travels through the sand and sets particles in motion. Manually directed plate vibrators supply less compactive effort than the larger production compactors. CS-24 requires the lift thickness not to exceed eight inches. An impact type compactor, sometimes called a jumping jack, does a poor job of compacting filter sands. To attain significant compaction, this type of equipment requires very thin lifts.
6. It is difficult to ensure compaction of drainfill under a conduit such as the principal spillway pipe. It is recommended that the drainfill in this area be placed a little above the pipe subgrade before it is installed and then trimmed to match the exact subgrade elevation just prior to laying the pipe.
7. Bulked sands can be densified by flooding and draining. Flooding involves supplying water at a great enough flowrate to completely saturate the layers of sand as it moves downward through the sand. The saturation of layers breaks the capillary bonds that cause bulking, and the downward movement of water sets the particles in motion. The particles resettle in a denser state. This method of compaction requires adequate flow and drainage. Lift thickness is important, too. If the lift is too thick, the drainfill material near the bottom of the lift may not be saturated and remain bulked.
8. Often flooding isn't adequate to meet the required density. In these cases, the addition of mechanical compaction and vibration may be required. The flooding and draining breaks the capillary bonds between particles where they are free to move independent of one another, and the mechanical vibration allows the drainfill to become denser than it will attain with just flooding.
9. The QA inspector's responsibilities related to compaction include verifying that:
    a. Fine drainfill is compacted according to the method specified in the applicable specification.
    b. The density of the drainfill material meets specification requirements, or the specified compaction process is followed.
    c. Heavy equipment is not operated within two feet of any structure, and vibrating rollers are not operated within five feet of any structure.
    d. There is no compaction by means of drop weights operating from cranes, hoists or similar equipment.

Figure 645K-29 Photos of a plate vibrator and impact compactor (Photos used with permission of Wacker Neuson USA)

645.112 Sampling and Testing

A. Sampling

1. Sampling fine and coarse drainfill materials for gradation testing can be problematic. These materials tend to segregate when handled, and the best place to obtain a representative sample is off the belt where they are being produced. If this is not possible, then great care must be taken to obtain a representative sample. ASTM D75, Standard Practice for Sampling Aggregates, may be used as a reference but it is not required by CS-24.

B. Index Density Tests

1. The minimum index density (ASTM D4254) and the maximum index density (ASTM D4253) are performed in the laboratory, with the design engineer specifying the minimum relative density for compaction of the fine drainfill. In general, 70% relative density is normally specified in areas of high seismic activity or in embankments over 40 feet high, and 50% relative density is specified for embankments less than 40 feet high. Figures 645K-30 through 645K-33 show the test process for the index density tests.

2. The tests to determine index densities are easy to perform but require special equipment. The tests will provide values for the maximum and minimum index density. The relative density can be computed with this formula:

$$D_r = \frac{(\gamma_d)_{max}}{\gamma_d}\left(\frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}}\right) \times 100$$

where:

- D_r = relative density of the filter material
- $(\gamma_d)_{max}$ = maximum index density
- $(\gamma_d)_{min}$ = minimum index density
- γ_d = measured dry density of the filter material

C. Modified One-point Test

1. Relative density determination is not conducive to field testing on small jobs because the vibratory table needed for the test is not normally available in the field. To aid in completing in-field testing, NRCS has adopted a modified one-point Proctor test.
2. This test uses the standard Proctor effort described in ASTM D698 on dry sand. Laboratory tests have shown that 100% of the standard Proctor density is approximately 70% of relative density, and 95% of the standard Proctor density corresponds to approximately 50% of relative density. This procedure is more conducive to field testing and effective to determine a target density. Figure 645K-34 shows the modified one-point test with drainfill material.

D. Moisture Testing

1. Moisture tests on filter materials may be conducted using any of the common procedures for testing moisture in soils, including ASTM standards for the carbide meter (D4944), nuclear moisture meter (D6938), direct heat (D4959), microwave oven (D4643), and the laboratory oven-dry moisture determination (D2216). When the material is not tested immediately, the drainfill sample must be sealed in a moisture-tight bag to prevent drying.

E. Compaction Testing

1. The nuclear moisture-density meter (ASTM D6938) is one method for determining in-place density of drainfill. The nuclear gauge measures wet density and moisture content and computes dry density. This method is no longer performed by NRCS for QA but is still a reliable device for contractors to use when performing quality control.
2. The sand cone method (ASTM D1556) is available if there is adequate moisture in the drainfill to allow the hole to remain open.
3. A new nuclear density gauge technology to measure soil density that doesn’t need licensing became available in 2015. This gauge is referred to as low-activity nuclear gauge (ASTM D8167). Licensing is not required because the Cesium source emits radiation below the Nuclear Regulatory Commission’s human safety limits and poses no danger to the operator. These gauges do not contain a system (nuclear or otherwise) for the determination of the water content of the material under measurement.

Figure 645K-30 Minimum Index Density of Clean Sand is that Resulting from Very Loosely (No More than 1 in. Drop) Filling a Steel Mold (ASTM D4254) (NRCS – TX)

Figure 645K-31 Minimum Index Testing of Clean Sand. After filling the mold, screed off excess sand. Knowing the weight of the sand and the mold volume, the dry density is easily determined. (NRCS – TX)

Figure 645K-32 Maximum Index Density is then determined by compacting the sand in the mold using a known weight and vibratory table (ASTM D4253). (NRCS – TX)

Figure 645K-33 Maximum Index Testing of Clean Sand. The densified sample is measured to determine the new volume and the maximum index density is determined.

Figure 645K-34 Modified One Point Test for Drainfill Material

4. A nuclear moisture and density gauge reads moisture in what is called backscatter geometry. The nuclear source and detector are both in the base of the gauge. Therefore, regardless of the depth of the probe, the moisture is being measured in the material directly underneath the gauge (fig. 645K-36).
5. When taking moisture readings in a trench, a trench correction must be made. The nuclear gauge measures moisture by sending out gamma particles that are thermalized (slowed down) by hydrogen in the soil. This assumes that the hydrogen represents moisture in the soil. The gauge is calibrated to measure moisture in the soil below the gauge. The gauge sends out particles in all directions and expects that the only particles that were thermalized were located under the gauge. It doesn't recognize that, in a trench, some of these thermalized particles are coming back from the walls of the trench. This leads to a higher moisture reading than is present in the drainfill. The owner's manual for each gauge will describe how to run a trench correction.

Figure 645K-35 Nuclear Moisture Density Gauge Measuring in Direct Transmission Mode

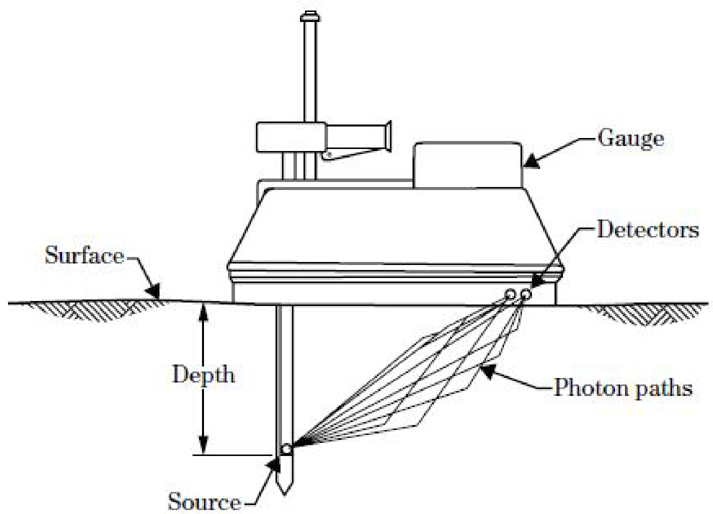
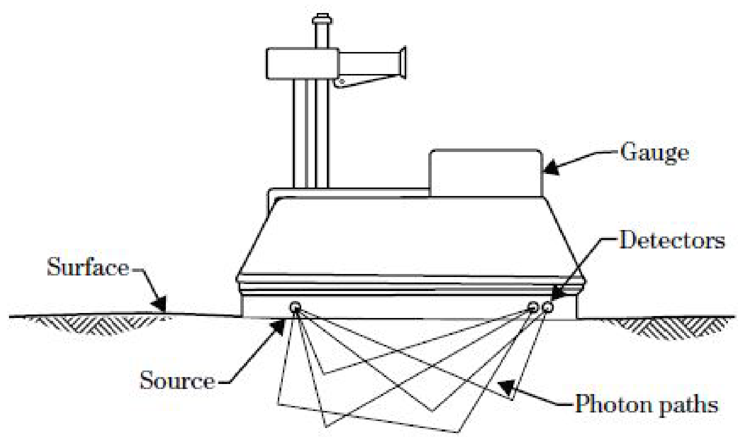


Figure 645K-36 Nuclear Moisture Density Gauge Measuring in Backscatter Mode



645.113 Records and Reports

A. The QA inspector uses the daily diary to record the day-to-day construction activities, including the drain and filter installation. See appendix C for an example of a daily diary example related to drains and filters.

645.114 References

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