United States
Department of
Agriculture

Part 645 Construction Inspection
National Engineering Handbook

Chapter 11 Drains and Filters

Issued July 2016

Chapter 11 Drains and Filters

Contents

Figures

645.1100 Introduction

The purpose of drainage associated with 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 compaction of the materials.

Drainage systems generally 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.

Many small and midsized dams constructed prior to 1980 were constructed without engineered filters. Many of those 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. Few mid- to large-sized dams are now constructed without internal drainage systems.

How drainage systems operate—Seepage water will always follow the path of least resistance. Sometimes, that might be a pervious foundation or embankment. Drainage systems are designed to intercept seepage water before it reaches a downstream outlet in the embankment slope or beyond the downstream toe. The drain will then convey the filtered water to a safe outlet.

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 migration of particles. Each component of the drain is sized to prevent buildup of hydrostatic pressure.

The gradation of the fine filter must be compatible with the base soil. Figure 11–1 shows a poorly designed or poorly installed filter. The base soil material is transported by water and migrates into the filter material. This soil ultimately 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, possible failure of the drainage system, and potential failure of the structure.

Figure 11–2 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 a cause of concern unless the filter cake is such that the drain ceases to have adequate capacity to serve its intended purpose.

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 make pipe connections.

The contractor is ultimately responsible for the safety of its workers, but the inspector should be thoroughly familiar with OSHA trench safety requirements found in part 1926, subpart P. This contains the maximum allowable depth and side slopes for different soils and different loading conditions. In no instance does the allowable depth for a worker to be in a trench exceed 5 feet without appropriate protection. Figure 11–3 illustrates a worker in a trench that is not considered safe and does not meet OSHA trench safety requirements. The contractor in figure 11–4 is staging the excavation of the trench for this drainage system so that it does not exceed safe working depths.

Any excavation can be dangerous because of the possible presence of underground utilities. Many States have laws that require that contractors to call a statewide “one-call” system prior to digging. This effort, along with personal observation and interviewing local landowners, are positive steps to hopefully eliminate the chance that a contractor will encounter a utility.

NEH645.04 of this handbook has further information on the duties and responsibilities of the inspector as it relates to safety and health on a construction project. Appendix A contains checklist 4.1, which includes a section on excavation, trenches, and shoring, among other valuable safety checklists.

Figure 11–1 Poorly designed or poorly installed filter

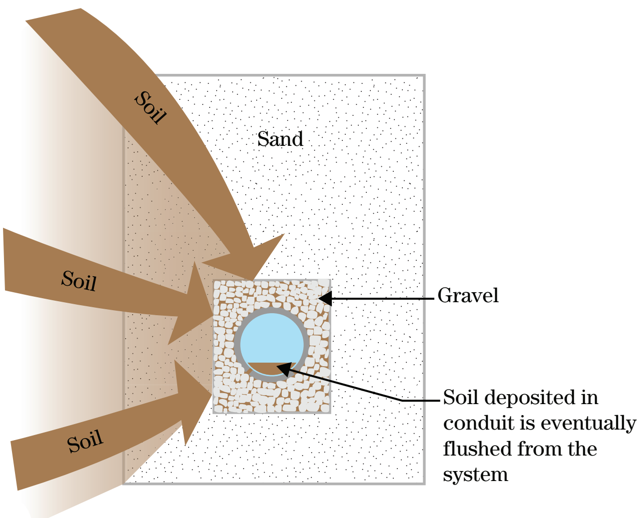


Figure 11–2 Properly functioning filter

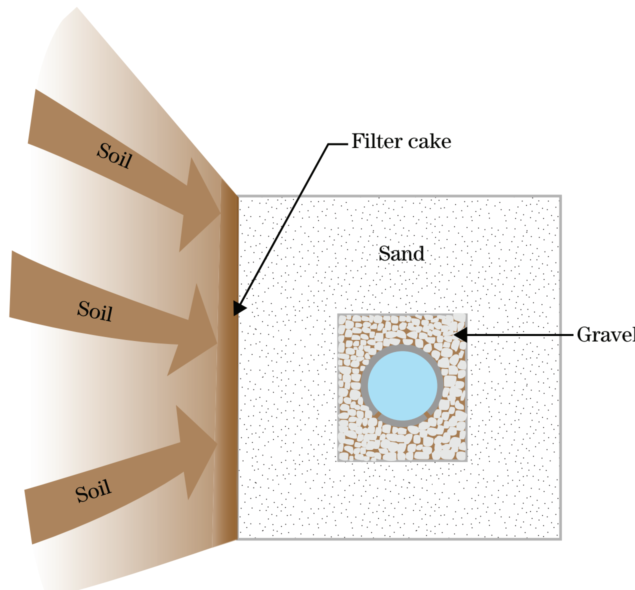


Figure 11–3 Hazardous trench excavation

Figure 11–4 Proper trench excavation

The inspector's responsibilities related to trench safety include verifying that:

- The contractor has scouted the area for underground utility markers.
- The landowner has been asked about possible underground utilities in the work area.
- The contractor has notified the appropriate utility or "one-call" system.
- The contractor is complying with the trench depth and sloping requirements of OSHA 1926.
- Appropriate changes to depth and sloping requirements are made when soil or moisture conditions change.
- Equipment and stored materials are being kept away from the trench walls.
- Trench shoring and bracing is complete before allowing personnel access to trenches.
- Trench boxes are installed properly and workers are not working outside of the protective limits.

For additional safety responsibilities see NEH645.04, appendix A, checklist 4.1.

Failures—Failures of engineering structures sometimes occur because of the lack of a filter or an improperly designed or installed filter. The three common mechanisms of failure are piping, internal erosion, and excessive pore pressure in the soils. Figure 11–5 shows a typical piping failure of an embankment caused by seepage associated with the installation of the principal spillway conduit.

Piping is defined as the movement of soil particles by percolating water leading to the development of channels. Signs of seepage that might lead to a piping failure are sand boils (fig. 11–6) or seepage water that is discolored or cloudy. These are signs that the seep water is carrying with it soil particles. High pore pressures can develop in soils due to seepage flow that is not controlled. These can cause uplift forces that may be a problem with structures embedded or downstream of an embankment. Foundation drains are one way that design engineers use to reduce hydrostatic pressure and intercept seep water before it surfaces.

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. Cracks can be caused by differential settlement, hydraulic fracturing, or drying. If cracks occur in soils that are highly erodible, considerable erosion can occur and a failure can result. Burrowing rodents can also lead to internal erosion. Failures due to piping will commonly take some time to develop while internal erosion failures often oc-

Figure 11–5 Embankment failure caused by seepage along principal spillway

Figure 11–6 Sand boil caused by uncontrolled seepage

cur during the first filling of the reservoir or shortly thereafter. The seepage diaphragm installed around conduits is installed as a defensive measure to intercept cracks caused by difficulty of compaction in a confined space or differential settlement.

(a) Types of drains

(1) Foundation or toe drain

A foundation drain is sometimes called a toe drain because it is usually located near the downstream toe of an embankment dam (fig. 11–7). The purpose of the foundation drain is to intercept any water that might be traveling through porous foundation soils or rock so that it does not surface downstream of the embankment. Foundation drains are used on other structures to reduce hydrostatic pressure, which could damage the structure.

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. The design engineer will specify the required lower limits of the foundation drain based on the soil and geologic conditions of the site. The upper limits are set by the design engineer to a specified height or to existing natural ground surface.

In some areas, the slope of the drain may be such that the design engineer determines that the filter material alone has the capacity to carry the anticipated flow. In those cases, the perforated pipe is unnecessary and is eliminated. This situation is defined as a blind drain.

(2) Chimney drain

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.

Through investigation and analysis, design engineers are able to approximate the location of this phreatic line. If they feel that it could intersect the back slope, a chimney drain will be designed to intercept it and provide a controlled release of water and pressure (fig. 11–8).

(3) Filter diaphragm

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 water along the interface between the outside of the conduit and the soil. The compaction effort, which occurs in a confined area, such as in a conduit foundation excavation, is generally less than the compactive effort in areas where the production compaction equipment has room to operate at normal speed. Therefore, the potential for differential settlement and hydraulic fracture is greater in those areas.

The anti-seep collar (fig. 11–9) 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.

Figure 11–7 Typical toe drain installation

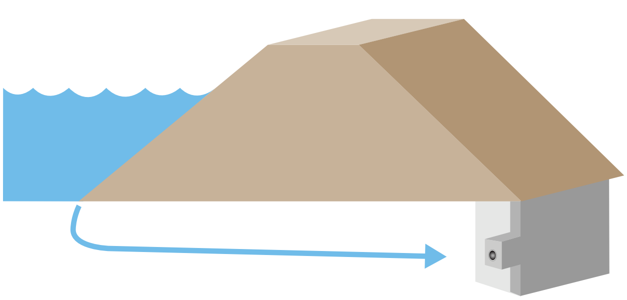
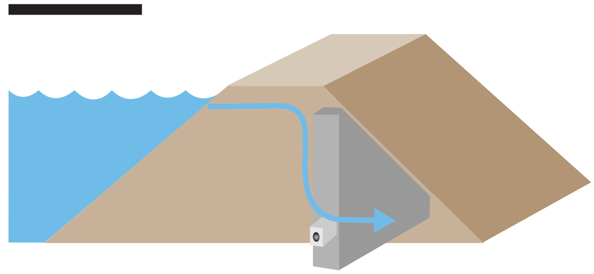


Figure 11–8 Typical chimney drain installation



The anti-seep collar was replaced with a filter diaphragm (figs. 11–10 and 11–11) 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. It is important in the installation of a filter diaphragm that it extend from each side of the pipe into natural ground where it will intercept that boundary. This will protect the confined area that has likely been compacted by manually directed compaction equipment or compacted by hand. The idea is to intercept any water that seeps through the portion of the earthfill that likely did not receive the same compaction effort as the less confined areas where the larger production compaction equipment could perform.

(4) Relief wells

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 a pervious foundation is overlain by an impervious strata.

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 size and depth of the relief well will be specified by the design engineer and are based on

Figure 11–10 Typical installation of a filter diaphragm

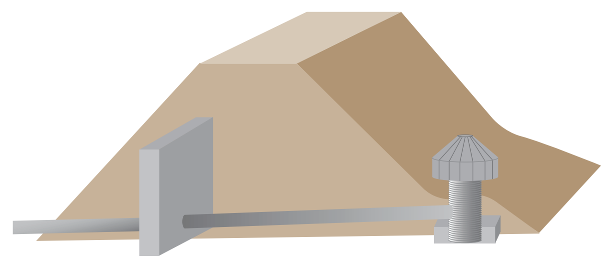
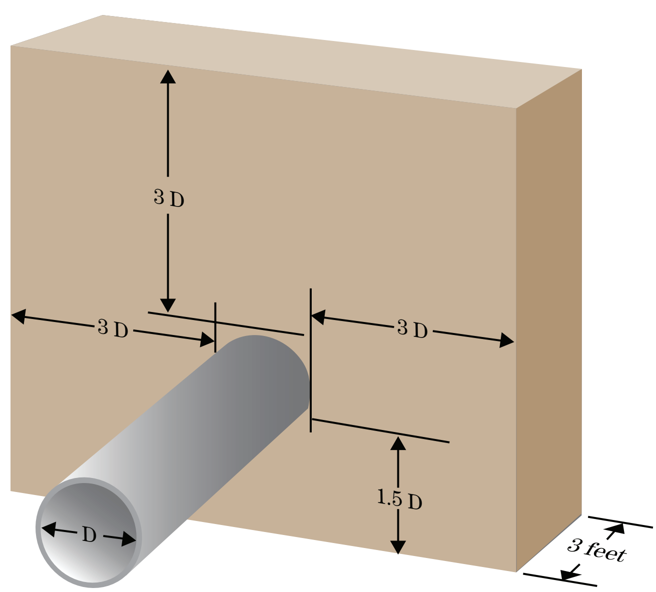


Figure 11–9 Anti-seep collar

Figure 11–11 Typical dimensions of a filter diaphragm



a review and analysis of the soils and geology. Figure 11–12 shows a typical relief well design.

The U.S. Army Corps of Engineers publication "Design, Construction and Maintenance of Relief Wells" (EM 1110–2–1914) contains a wealth of information on relief wells. NRCS Construction Specification 12, "Relief Wells," is also a useful reference for the installation and development of relief wells.

(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 often very 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 11–13 and 11–14 show a typical installation of an embankment blanket drain.

(6) Wall drains

Wall drains prevent the buildup of hydrostatic pressures that could lead to movement and damage of the walls. These drains are designed in ways similar to other drains. A perforated pipe is surrounded by a coarse drain material and encapsulated in a fine drain material. The conduit often outlets through the wall of the structure it is designed to protect. Figures 11–15 and 11–16 show typical wall drain locations and installations.

(7) Subsurface drainage systems

Subsurface relief drains are installed primarily to lower a high water table to increase agricultural production, improve access, or allow the installation of structures. These can be designed a multitude of ways but commonly consist of the installation 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 product can be installed accurately and rapidly using a special trenching machine.

Figure 11–12 Typical relief well installation

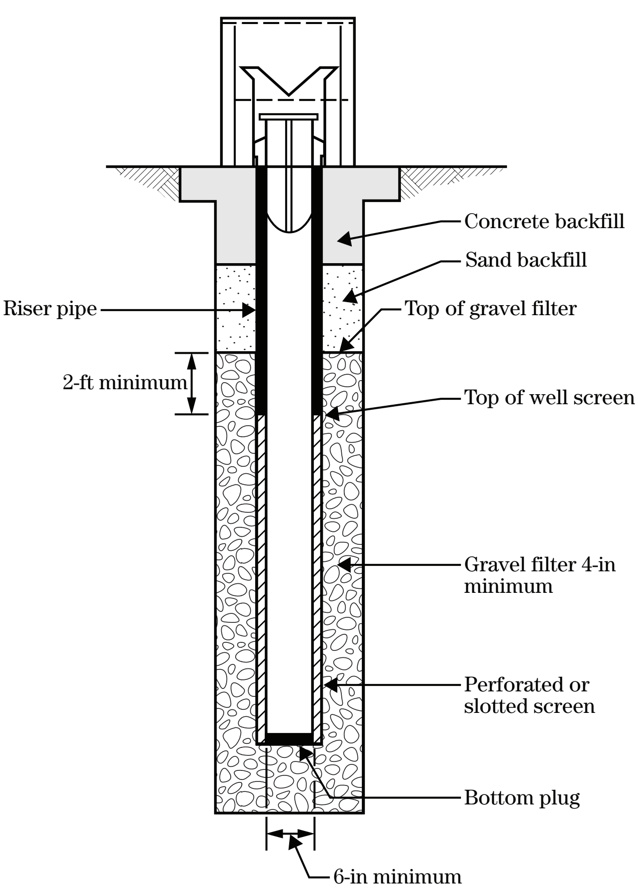


Figure 11–13 Blanket drain location

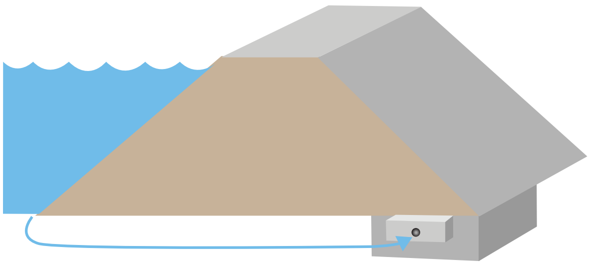


Figure 11–14 Typical blanket drain installation

Figure 11–15 Typical wall drain configuration

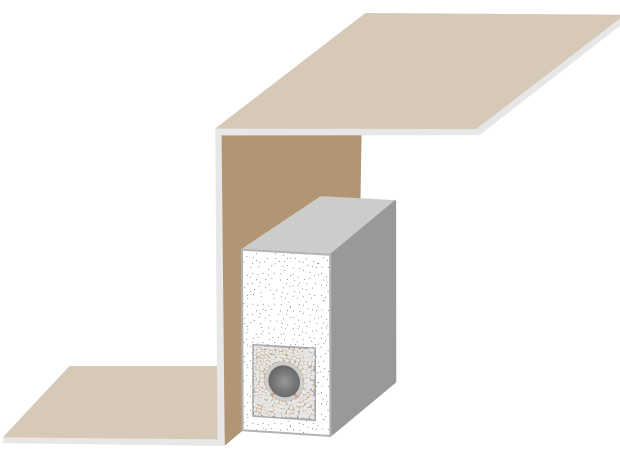


Figure 11–16 Wall drain installation

645.1101 Installation

(a) Material

(1) Drainfill material.

Usually the responsibility of the engineer is to have tests performed, obtain test results, or certifications to verify that the proposed drainfill materials meet specification requirements. The engineer should notify the inspector once those materials have been approved. The job diary contains a section entitled “Material Certification Record” to document the approval of materials. Quality control and quality assurance tests may be needed additionally to verify that the material delivered to the worksite is consistent with what was approved.

The quality of drainfill material is prescribed in construction specification 24, which refers to 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.

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 will break down over time and cement together which can cause several problems. 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 as it could cause plugging of the drain and hinder its function.

A gradation for the filter and drain materials must be specified. The proper gradation is critical in ensuring that all of the 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. ASTM C136 describes the mechanical analysis used to determine the gradation of an aggregate. ASTM C117 is a wet sieve procedure used to determine the amount of fines in the sample. The gradation of the filter materials should be verified prior to delivery of the first load to the jobsite and intermittently during construction.

Obtaining a representative sample of an aggregate is often problematic. Aggregates dumped into piles tend to segregate; therefore, special care should be taken when collecting a sample. ASTM D75, Standard Practice for Sampling Aggregates, is useful in describing how to obtain a representative sample for gradation testing.

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 to not dissolve in water during the life of the project. They also must be sound enough that they are not crushed under the design load. ASTM C88 describes sodium sulfate and magnesium sulfate soundness tests that are used to measure soundness. 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 generally less porous and tend to lose less flaked material. The materials are weighed at the beginning of test. After each soaking the materials are washed to remove any flaked-off materials and allowed to dry. After a specific number of soaking and drying cycles the material is again weighed to determine the amount of lost material. Material specification 521 contains a maximum allowable loss; the amount of material that can be lost is dependent on the type of salt (sulfate or magnesium) used for the test.

(2) Collector pipe

Most NRCS-engineered drainage systems that require a collector pipe use plastic pipe (poly vinyl chloride (PVC), polyethylene (PE), high density polyethylene (HDPE) and acrylonitrile-butadiene-styrene (ABS) plastic pipe, fittings, and joint materials) according to material specification 547 and construction specification 45. The designated material, wall thickness, and number and size or perforations or slots are factors that are specified by the engineer and should be verified by the inspector. 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

Geotextiles (often called filter fabric) are a permeable synthetic material specifically designed to be used as a soil filter. Engineers usually only specify geotextiles in areas that are easily accessed in case the geotextile has to 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.

Geotextile can be used as a single filter or combined with drainfill of a complimentary gradation. Some applications will see a geotextile (sock) completely 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.

The inspector's responsibilities related to materials include verifying that:

- The gradation and soundness of the drainfill materials has been verified before delivery.
- The drainfill materials are delivered from the approved sources.
- Gradation tests are conducted on the drainfill materials in accordance with the specification requirements, contractor's quality control plan, and NRCS quality assurance plan.
- The collector pipe meets all specification requirements for type, size and perforations.
- The collector pipe is protected from excessive UV radiation during storage.
- The geotextile meets all specification requirements and is protected from UV radiation during storage.

(b) Base preparation

A clean, well-compacted foundation is desired so that contamination of drainfill and foundation settlement does not occur. Organic matter, loose soil, and foreign substances should be removed as they will also contribute to contamination and settlement. Unless accounted for in the design and installation procedures, all standing water should be removed. It is important to document in the job diary that the subgrade has been inspected and approved prior to placement.

The inspector's responsibilities related to base preparation include verifying that…

- Foundation surface and trenches are clean and free of organic matter, loose soil, foreign substances, and standing water when drainfill is placed.
- Earth surfaces upon or against which drainfill will be placed have not been scarified.

(c) Placement

(1) Storage and handling

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 objective is to store and handle the material in a manner that will prevent segregation of particle size and prevent contamination.

Figure 11–17 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.

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 should be taken to keep the drop height and pile height and steepness to a minimum to guard against segregation (fig. 11–18).

The inspector's responsibilities related to storage and handling include verifying that:

- Materials remain uncontaminated.
- Materials are being handled in a manner that prevents segregation.

Figure 11–17 Segregated filter

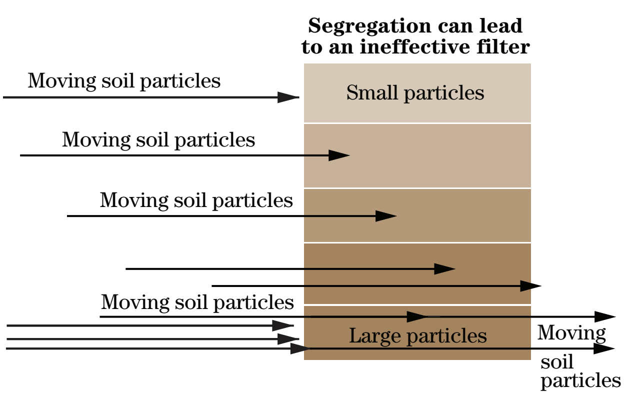
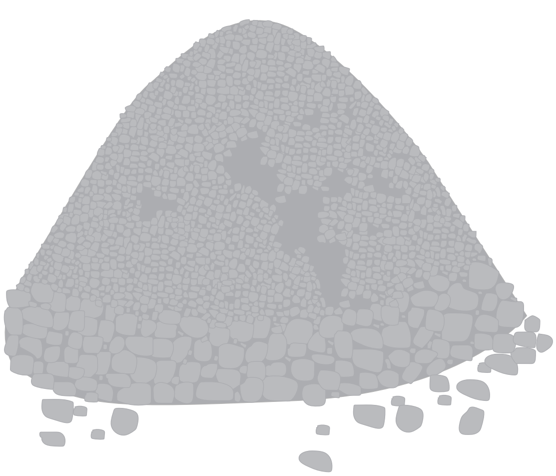


Figure 11–18 Stockpile height and steepness can cause segregation of materials



Larger particles roll down the side of the pile

(2) Location of drains and filters

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 not varying the location.

Figure 11–19 shows a sand filter diaphragm that was installed to intercept any hydraulic fracturing that might occur in the vicinity of the conduit installation. Note that the diaphragm stretches from one side of the excavation limits to the other.

Small variances in the location of the filter can greatly 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. 11–20). This would be an incorrect decision because the entire area

Figure 11–19 Properly located sand filter diaphragm

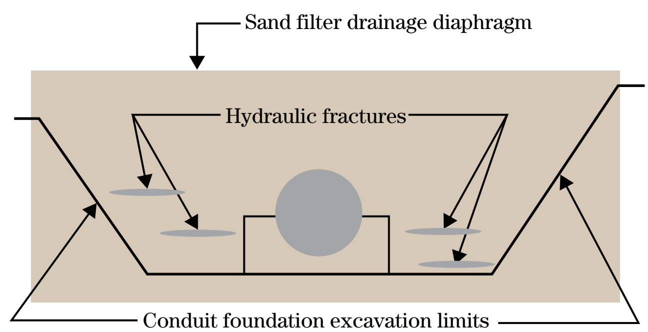
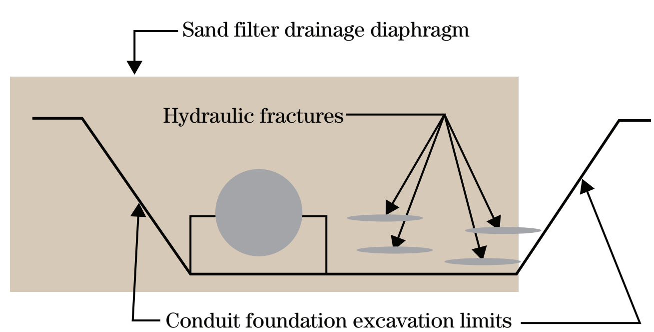


Figure 11–20 Improperly located sand filter diaphragm



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 concur in the change and the change be documented in the job diary.

(3) Placement

Granular materials tend to become contaminated and segregated when they are handled and placed. There are specific practices and handling methods that should be avoided to reduce contamination and segregation during placement. Construction specification 24 contains several requirements regarding placement.

Construction specification 24 limits the maximum free-fall to 5 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.

A tremie can be used to limit the free-fall distance (fig. 11–21). 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.

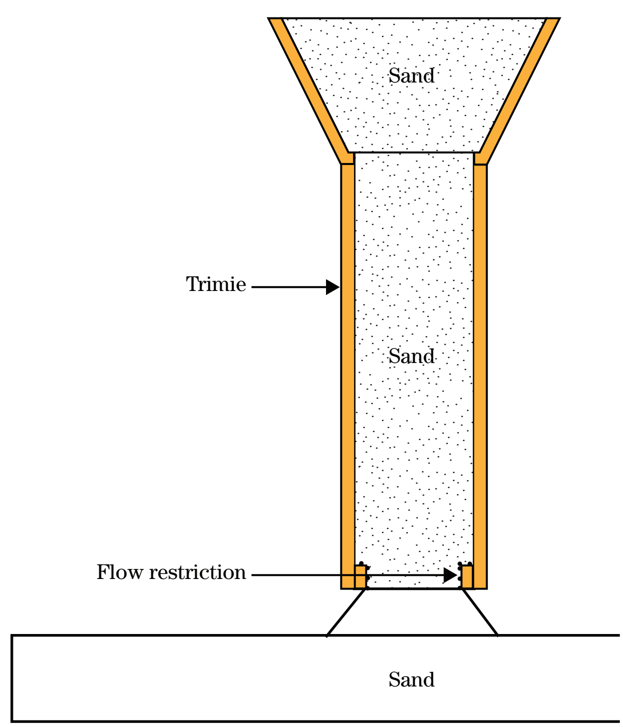
Placement in water is not recommended without special equipment. Allowing granular material to free-fall in water will result in significant segregation. According to Stoke's Law, the forces that control the rate of fall are weight, buoyancy, and resistance. Larger particles reach the bottom faster than smaller particles.

Traffic crossing over drains should be held to a minimum to prevent contamination. Construction specification 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.

Construction specification 24 also requires the upper surface of drainfill be 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 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 1-foot lifts, but, in this situation, the maximum allowable lift thickness would likely be 8 inches because of the need to use manually operated compaction equipment. Compaction by flooding in a trench should 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.

Figures 11–22 and 11–23 show the installation of a two-stage filter in a trench. The dog-house-shaped box used 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. Care must be taken to load

Figure 11–21 Tremie used to limit free-fall distance of material



the sand equally on both sides of the box to prevent it from being pushed out of alignment.

Figure 11–24 shows what is called a Christmas tree configuration. It requires more sand because it has to 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.

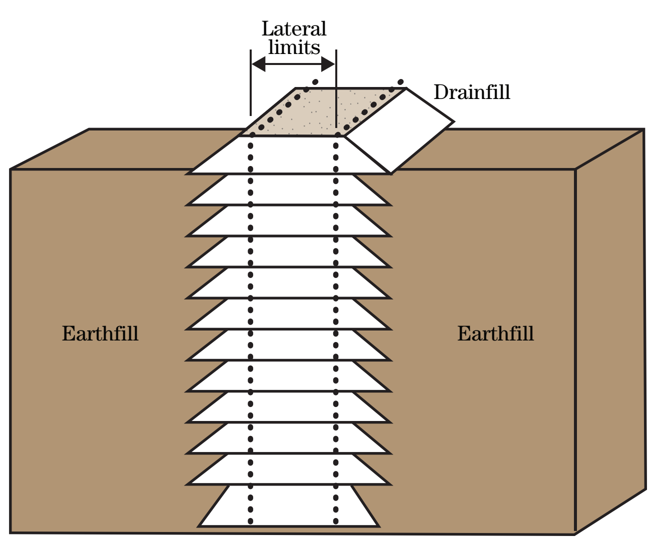
The inspector's responsibilities related to placement of drains and filters include verifying that:

- Work is not started until the specified foundation depths, lines, and grades are attained.

Figure 11–22 Two-stage filter installing the outer zone of fine material

Figure 11–23 Placing the inner zone of coarse material around the collector pipe

Figure 11–24 Christmas tree method of installing filter material



- Drainfill is not placed until the subgrade has been inspected and approved by the engineer.
- Drainfill is not placed over or around pipe or drain tile until the installation of the pipe or tile has been inspected and approved.
- 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.
- The material is placed in a manner that does not cause segregation.
- The material is placed in a manner that ensures continuity and integrity of zones.
- Perforations of the collector pipe are correctly oriented.
- Drainfill is not contaminated with foreign material during placement.
- Traffic is not allowed to cross over drains at random locations.
- Equipment crossovers are established and approved before beginning of drainfill placement.
- Crossovers are cleaned of all contaminated material and inspected by the engineer before placement of additional drainfill material.
- Surface runoff is not allowed to enter the filter.
- Any damage to the foundation surface or trench sides or bottom occurring during placement is repaired before drainfill placement is continued.
- 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.
- Drainfill over and around pipe or drain tile is placed to avoid any displacement in line or grade of the pipe or tile.
- Drainfill is not placed adjacent to structures until the concrete has attained adequate strength as defined by the specification or approved by the engineer.
- Geotextile is placed as specified.
- Geotextile lap lengths meet specification requirements.
- Soil surface is relatively smooth and free of protruding rocks and debris prior to placement of geotextile.
- Damaged geotextile materials are repaired or replaced.

(d) Control of moisture

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 compacted to the desired density and complete saturation and drainage or flooding are very effective methods for densifying this material.

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.

The first photo (fig. 11–25) 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 will increase. The second photo (fig. 11–26) shows the same sand in a denser state after only adding water.

Bulking is not a concern if the sand is dry with a moisture content less than 2 percent, but care should 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 percent. 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 bond 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.

The inspector's responsibilities related to control of moisture include verifying that:

- The moisture content of fine drainfill is appropriate for the method of compaction to be used.
- Fine drainfill in the bulking moisture range is saturated and drained to break the capillary bonds.
- When additional water is required, it is applied in a manner to avoid excessive wetting to adjacent earthfill.

(e) Compaction

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 could be caused by changes in the moisture condition, 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 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 and even failure.

Figure 11–25 Sand at a bulking moisture content before saturating

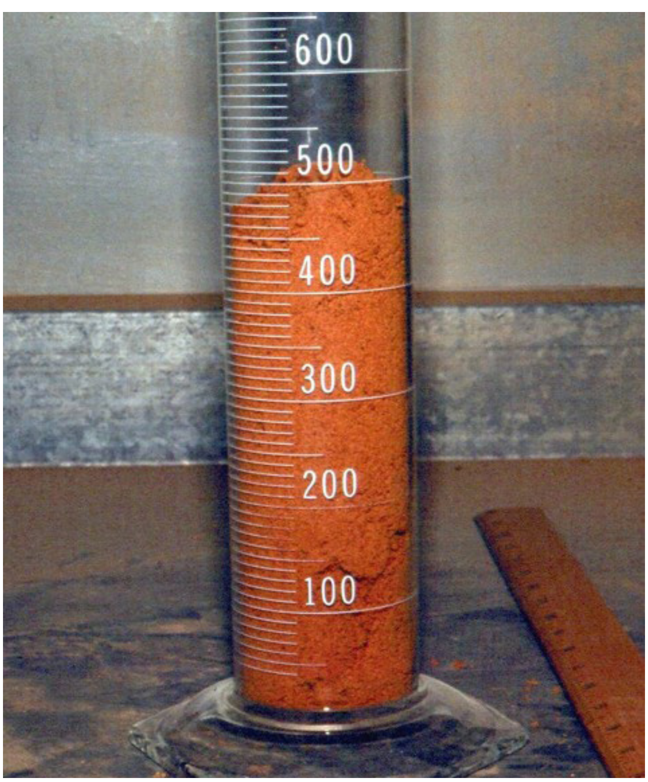
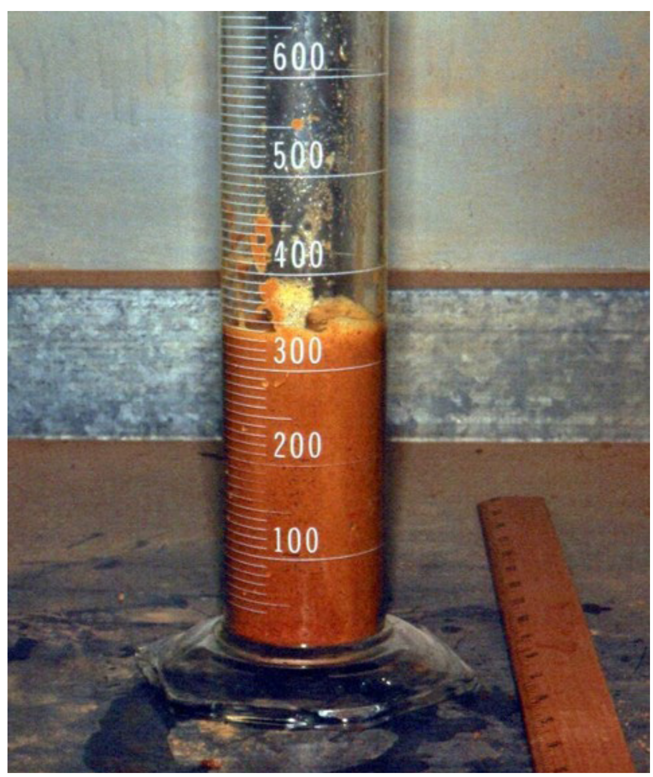


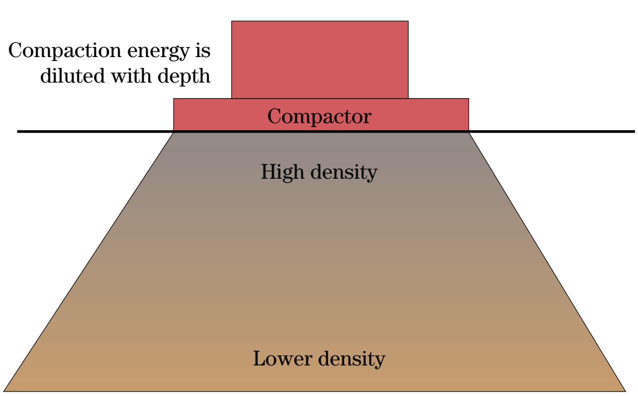
Figure 11–26 Sand after saturating



Construction specification 24 limits lift thickness to a maximum of 12 inches or 8 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 11–27 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.

Compaction requirements for drainfill can be based on a performance 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 conduction a one-point test. Construction specification 24 requires that the modified ASTM D698 procedure be used when more than 70 percent of the drainfill material will pass the three-quarter-inch sieve and the relative density test be used when 70 percent or less pass the three-quarter-inch sieve.

Figure 11–27 Showing how compaction energy is dissipated with depth



Method specifications describe a procedure to be used rather than an end result, such as a moisture or density requirement. Construction specification 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 percent. They should 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.

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 11–28, 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. Construction specification 24 requires the lift thickness to not exceed 8 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.

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.

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.

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 to one another and the mechanical vibration allows the drainfill to become denser than it will attain with just flooding.

The inspector's responsibilities related to compaction include verifying that:

- Fine drainfill is compacted according to the method specified in the applicable specification.
- The density of the drainfill material meets specification requirements or the specified compaction process is followed.
- Heavy equipment is not operated within 2 feet of any structure and vibrating rollers are not operated within 5 feet of any structure.
- There is no compaction by means of drop weights operating from cranes, hoists or similar equipment.

Figure 11–28 Photos of a plate vibrator and impact compactor. Photos used with permission of Wacker Neuson USA

645.1102 Sampling and Testing

(a) Sampling

The sampling of fine and coarse drainfill materials for gradation testing can be problematic. Due to the fact that these materials tend to segregate when handling, the best place to obtain a representative sample is off of 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 construction specification 24.

(b) Index density tests

The minimum index density (ASTM D4254) and the maximum index density (ASTM D4253) are performed in the laboratory. The design engineer will then specify the minimum relative density for compaction of the fine drainfill. In general, 70 percent relative density is normally specified in areas of high seismic activity or in embankments over 40 feet high, and 50 percent relative density is specified for embankments less than 40 feet. Figures 11–29 through 11–32 show the test process for the index density tests.

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

$$D_d = d_{d\,max} \frac{\left(d_d \times d_{min}\right)}{d\left(d_{d\,max} \times d_{d\,min}\right)}$$

where:

D_d = relative density of the filter material
δd_{max} = maximum index density
δd_{min} = minimum index density
δd = measured dry density of the filter material

(c) Modified one-point test

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. NRCS has adopted a modified one-point Proctor test.

This test is conducted using the standard Proctor effort described in ASTM D698 on dry sand. Laboratory tests have shown that 100 percent of the standard Proctor density is approximately 70 percent of relative density, and 95 percent of the standard Proctor density corresponds to approximately 50 percent of relative density. This procedure is much easier to conduct in the field and very effective for determining a target density. Figure 11–33 shows the modified one point test being conducted on drainfill material.

(d) Moisture testing

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

(e) Compaction testing

The nuclear moisture-density meter is the preferred method for determining in-place density of drainfill. The balloon method or sand cone method is available if there is adequate moisture in the drainfill to allow the hole to remain open. The balloon will yield erroneously low readings in sand if the balloon deforms the hole.

The nuclear gauge measures wet density and moisture content and computes dry density. The density measured is an average of all materials that are located from the end of the probe to the detector which is in the base of the gauge (fig. 11–34). Since the drainfill may be denser at the surface than at the bottom of a lift, it is good practice to take readings at various depths to ensure uniform top to bottom density throughout the lift.

Figure 11–29 Minimum index density of clean sand is that resulting from very loosely (no more than 1 in. drop) filling a steel mold (ASTM D4254)

Figure 11–30 After filling the mold, screed off excess sand. Knowing the weight of the sand and the mold volume, the dry density is easily determined

Figure 11–31 Maximum index density is then determined by compacting the sand in the mold using a known weight and vibratory table (ASTM D4253)

Figure 11–32 The densified sample is measured to determine the new volume and the maximum index density is determined

Figure 11–33 Modified one point test for drainfill material

A nuclear 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. 11–35).

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 is based on the assumption 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 actually present in the drainfill. The owner's manual for each gauge will describe how to run a trench correction.

Figure 11–34 Nuclear moisture density gauge measuring in direct transmission mode

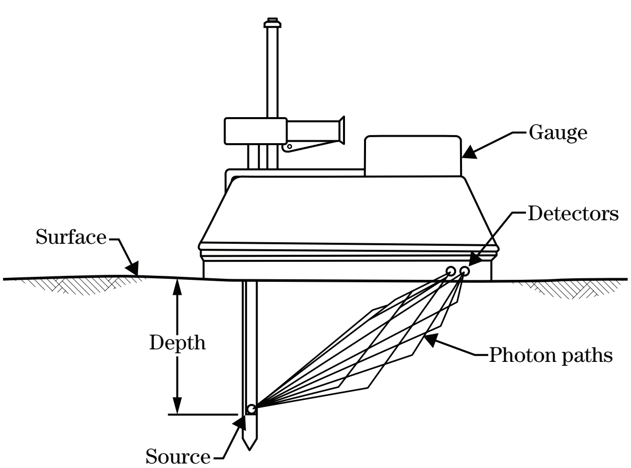
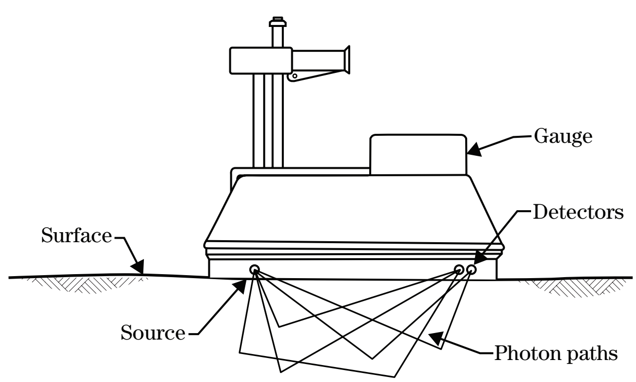


Figure 11–35 Nuclear moisture density gauge measuring in backscatter mode



645.1103 Records and Reports

The following record and report are related to drains and filters:

- Daily diary—Used to record the day-to-day activities of construction including drain and filter installation activities. See appendix C for an example of a daily diary example related to drains and filters.

645.1104 References

U.S. Federal Emergency Management Agency. 2011. Filters for embankment dams—best practices for design and construction. Washington, DC.

U.S. Army Corps of Engineers. 1992. Design, construction, and maintenance of relief wells. EM 1110–2–1914. Washington, DC.