United States Department of Agriculture

Part 645 Construction Inspection National Engineering Handbook

Chapter 9 Soil Modification

(210–VI–NEH, Amend. 74, October 2015)

Issued October 2015

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Chapter 9 Soil Modification

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Chapter 9 Soil Modification

645.0900 Introduction

Soil modification is the application of a soil amendment such as cement, pozzolan, lime, bentonite, or a dispersant for the purpose of altering the engineering properties of the soil. Properties that may be altered include strength, plasticity, and permeability. Construction activities include applying the amendment at the specified rate, uniformly incorporating the amendment into the soil, compacting the amended soil to the specified density at the specified moisture content, and curing and protecting the product.

Materials such as cement, pozzolan, lime, bentonite, and dispersants may pose a health hazard. They are generally applied in the form of a dry powder, which can easily become airborne and may be hazardous to the eyes, skin, or respiratory system. A materials safety data sheet (MSDS) can be obtained from the supplier or from their Web site. The inspector should verify that MSDS-recommended protection measures are in place prior to handling or working around the materials. Provisions for administering first aid should be in place to address exposure to these materials.

Specific safety issues related to amendments should be addressed in the contractor's safety plan, in safety meetings, and at any time necessary to ensure protection from hazards associated with the materials being used.

The inspector's responsibilities related to soil material hazards include but are not limited to, verifying that:

- Material hazard datasheets are reviewed by onsite NRCS and contractor personnel prior to handling or working around amendments.
- Material hazards are addressed in the safety plan, safety meetings, and whenever appropriate.
- First aid provisions and a plan of action are in place to address illness resulting from exposure.
- Materials are handled and used in a safe manner to protect workers and the public.
- Protective equipment is worn as applicable.
- Safety concerns are documented and addressed as soon as they are recognized.

645.0901 Installation

(a) Soil-cement

(1) Materials (soil-cement)

Soil-cement is a mixture of pulverized soil and measured amounts of Portland cement and water that is compacted to a specified density. When mixed with soil, the cement decreases its water-holding capacity and volume-change tendencies, and increases its shear strength. It is either mixed in place or mixed in a remote location and quickly moved to its final position, spread, compacted, and cured.

Soil used for soil-cement is typically obtained from designated areas on or near the site. The quality of the soil cement is dependent on the gradation, plasticity, and fines content of the soil used. Deleterious material, such as frozen soil, sod, brush, roots, or other perishable material must be separated from soil material during the soil selection, blending, and routing operations. Rock particles larger than the maximum size specified must be removed before adding the cement.

The soils selected for making soil-cement in the field should be the same or very similar to what was used in the lab to design the mix. Similar soils will yield soil-cement of a similar quality to that attained in the lab but those with markedly different gradation and plasticity will produce soil-cement of a different quality than the lab mix. A new mix design must be developed if the soil used to make soil-cement in the field is markedly different than the soils used in the lab to design the mix.

Borrow areas should be excavated in a manner to aid in the identification of soils. Exposing vertical faces will allow the various layers of soil to be identified. Soils will vary throughout the soil profile and are likely to change across the borrow area. Overburden soils that are not to be used for making soil-cement must be stockpiled or otherwise utilized while soils to be used for soil-cement are being obtained. Every effort should be made to ensure that the proper soil is consistently being used for making soil-cement. If more than one type of soil is used, the locations of where the various soils are placed within the soil-cement structure should be documented.

Portland cement must meet the requirements specified. There are several types of Portland cement. The type and brand of cement used should be consistent with that used in the laboratory mix design program. Cement must be kept dry and uncontaminated until used.

Water used in mixing or curing soil-cement must be clean and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances. Water that is drinkable and has no pronounced taste or odor can be used for making soil-cement. Water not fit for drinking may also be suitable for use in soil-cement. Soil-cement of acceptable quality can even be made from water containing some fines. When water of questionable quality is to be used in the field, it should be tested to evaluate its impact on the mix. This is done by making lab mixtures with this water and testing the mixtures for compressive strength and time of set as described in American Society for Testing and Materials (ASTM) International's C94 standard.

Pozzolanic material, such as fly ash or natural pozzolan may be added to the soil-cement. When combined with cement, pozzolan becomes a cementitious material.

The quality of pozzolan has historically varied from source to source and may even vary when obtained from a single source. Since it is a by-product of coal-fired electrical generating plants, pozzolan may contain combustible impurities that could have adverse effects on strength and durability of the soil-cement. Pozzolan can be tested to determine if it contains significant amounts of impurities. The test determines the loss on ignition (LOI) by burning off the impurities at a high temperature and measuring the weight change of the sample. Adverse effects on strength and durability of the soil-cement have generally not been observed from pozzolan having an LOI of three percent or less. Pozzolans that meet the requirements of ASTM C618 are generally accepted for use in soil-cement. Pozzolan should be kept dry and uncontaminated until used.

Curing compounds may be used to cure soil-cement. ASTM C309, Type 2 curing compound is normally specified. Type 2 is a white pigmented compound as opposed to the clear Type 1 compound. Type 1 and Type 2 work equally well, but the Type 2 compound can be seen making it easier to tell where it has been applied. Occasionally, the designer will specify a Type 1-D compound, which is a Type 1 containing a fugitive dye. A fugitive dye is one that gives the compound color (a shade of red) for a period of about 4 hours then begins to fade and after 7 hours it can no longer be seen. Where the Type 1 compound has been applied generally results in a sheen or glossy appearance. Curing compounds generally require agitation to keep the solids suspended and those containing a fugitive dye must be agitated to keep the dye in suspension.

The inspector should notify the engineer whenever there is a change in any material source or when there are other material-related issues.

The inspector's responsibilities related to soil cement materials include but are not limited to, verifying that:

- Deleterious materials and rock particles larger than the maximum specified are removed before mixing.
- Soil is of the type specified.
- Gradation and plasticity (Atterberg limits) test data are obtained when specified.
- For soil with gradation and plasticity markedly different from that specified, test data is provided to show that soil-cement made with these soils is of a quality equal to or exceeding the required quality.
- Cement meets specified requirements.
- Cement is stored in a dry and uncontaminated condition.
- Water meets specified requirements.
- Pozzolan, when used, meets specified requirements.
- Pozzolan, when used, is stored in a dry and uncontaminated condition.
- Curing compound meets specified requirements.
- Changes in the source of soil, cement, water, pozzolan or curing compound are made known to the engineer.

(2) Equipment (soil-cement)

Soil-cement is mixed in a stationary mixing plant, a truck mixer, or mixed by traveling mixing equipment that mixes the cementitious materials and soil on the ground. These are described in more detail in the next section.

A water truck and disk plow or tillers are needed to incorporate water into the soil-cement mixture. The disk plow or tiller must be capable of mixing to the full depth of the lift. A 24-inch-diameter disk plow can mix a loose lift that is 6 inches thick if the disks are not too worn and the plow is properly adjusted. Disk plows that are 30 inches or greater in diameter may be required to fully mix a 9-inch lift.

Cement and pozzolan are generally transported in bulk and pneumatically transferred from the tanker truck to a silo on the job. They are then conveyed to a mixing plant or deposited, spread, and mixed with the soil on the ground. All equipment used to convey or transport cement or pozzolan should be covered or enclosed to avoid dust problems and protect the material from rain. Drop-type agricultural spreaders, such as those used to apply agricultural lime or fertilizer, may be used to apply the cementitious materials. Rotary or "whirly-bird" spreaders should be avoided due to inaccurate application rates and significant dust problems associated with these types of spreaders.

Soils commonly used to make soil-cement are most often coarse-grained (less than 50% passing the No. 200 sieve) and are best compacted with a smooth drum roller or a pneumatic roller. Vibratory pad-foot drum rollers may be used if the depth of pad penetration is shallow (1 to 2 in.). Deeply penetrating compaction equipment, such as a sheepsfoot roller, should not be used.

Equipment that is allowed to operate on the lift surface must not leak fluids. Hydraulic fluid, motor oil, grease, and antifreeze are all detrimental to attaining bond. Equipment that mars and loosens compacted soil-cement should also be prevented from operating on the lift surface.

The inspector's responsibilities related to equipment for soil-cement construction includes but not limited to, verifying that:

- Mixing equipment is in place and properly functioning as described in the section in this chapter entitled "Proportioning and Mixing (Soil-Cement)."
- Equipment used to transport and apply cementitious materials is covered or enclosed.
- Application equipment is capable of uniformly applying cementitious materials at the specified rate with little or no dust problems.
- Equipment that is to operate on soil-cement does not leak fluids or mar or loosen surface of compacted soil-cement.
- Compaction equipment is suited for compacting the soil-cement to the planned lift depth.

(3) Mix design (soil-cement)

Prior to soil-cement construction, soils are sampled from the borrow source, generally at or near the site, and mixed with cementitious materials (cement and pozzolan or cement only) and water in a laboratory. Several mixtures of various proportions of ingredients are made. Each mixture is tested to determine the properties of that mixture. Optimum moisture and maximum density are determined for the mixtures selected for evaluation. Based on various other tests including wet-dry loss, freeze-thaw loss, and compressive strength tests, a final mix is selected. In some cases, extra cement is specified as a safety factor over what lab testing show is minimally required.

The mix selected for making soil-cement in the field is called the job mix. The job mix will state the amount of cement to be added to the soil as a percentage of the dry weight of soil. For example, a soil cement mix containing 6 percent cement would contain 6 pounds of cement per 100 pounds of dry soil. The moisture content will be the specified compaction moisture expressed as a percentage of the dry weight of the soil-cement mixture. For example, soil-cement containing 12 percent moisture would contain 12 pounds of water per 100 pounds of dry soil-cement.

The principal requirement of the job mix is that, when properly placed, compacted, and cured, it withstands exposure to the elements. Two tests are used to indicate the durability of a soil-cement mixture. One test indicates durability of the mixture when subjected to wetting and drying, and the other test looks at durability of the mixture when subjected to freezing and thawing. Soil-cement mixtures that pass these tests are considered to have adequate durability to withstand exposure to the elements. Historical data has shown that compressive strength of soil-cement can also be used to predict soil-cement durability.

NRCS Construction Specification 29, Soil Cement, hereafter referred to as Spec 29, provides two methods of mix design. Method 1 requires that the contractor develop the mix design. Method 2 specifies the materials and proportions to be used. Changes to the job mix such as the use of soils other than those used in the lab to design the mix, changes in the type of cementitious materials in the mix, or changes in the proportioning of the mix ingredients will require the submittal and approval of a new job mix. Minor adjustments in water content are generally made in the field without requiring a new mix design.

With regards to the soil-cement mix, the inspector is responsible for verifying that:

- Materials and mix proportions are in accordance with the job mix.
- Other than minor changes in water content, the job mix does not change without the engineer's concurrence.

(4) Site preparation (soil-cement)

Site preparation will depend on whether the soil-cement is mixed in a remote area and transported to the site or mixed in-place.

Remotely mixed—Where the soil-cement is remotely mixed and transported to the site, the subgrade must be shaped to a line and grade that will result in attaining the specified finished grade upon completion. The subgrade should firmly support the construction equipment used to transport and place the soil-cement. Compaction of the subgrade may be necessary to meet this criterion. Immediately before placement of the soil-cement, the compacted subgrade surface should be moistened to approximately the same moisture content as specified for the soil-cement, and kept moist until the soil-cement is placed. This is done to prevent moisture from being wicked out of the soil-cement by a dry subgrade.

Mixed in-place—Where the soil-cement is to be mixed in-place, unsuitable soils must be removed and replaced with acceptable material. It may be necessary to import soils in lieu of using in situ soils. The soil must be loosened or broken up by plow or tiller to the treatment depth. The effective depth of the plowing or tilling must be checked and adjustments made until the specified treatment depth is attained. If the depth of plowing or tilling is shallow, the planned lift thickness may not be attained. Plowing or tilling too deep will result in the mix being improperly proportioned.

After the soil is loosened, it may require pulverizing to produce a loose, friable soil. Each soil type has its own pulverizing characteristics, and soil moisture content can significantly affect the breakdown rate. Sandy soils pulverize quite readily, even when wet, but clayey soils can be difficult to break down. Rotary mixers, harrows, offset disks, rollers, or moldboard plows are used for pulverizing.

Just before depositing the cementitious materials, the pulverized soil must be checked for the correct cross section and grade to ensure the finished surface of the compacted soil-cement will end up at the designed grade.

The inspector's responsibilities related to preparing the site for soil-cement include verifying that:

- The area to receive the remotely mixed soil-cement is shaped to the proper line and grade.
- The subgrade surface is moistened prior to placing remotely mixed soil-cement.
- Where in situ soil is used, it is loosened to the specified depth and pulverized.
- The pulverized in situ soil is graded to the proper line and grade before adding cementitious materials.
- Soil to be mixed with cement is free of deleterious material.
- Rock particles larger than the maximum size specified are removed from the soil before mixing in the cementitious material.

(5) Proportioning and mixing (soil-cement)

The objective in mixing soil-cement is to consistently produce a thoroughly blended mix of ingredients that are proportioned according to the job mix. Stationary and truck mixing plants do a better job of this than traveling mixers.

The NRCS inspector should understand the entire batching and mixing process prior to beginning production, including:

- How the ingredients are batched.
- How the batching is monitored.

- Adjustments that can be made to achieve better mix uniformity.
- How records and summaries of daily materials use are generated.
- How moisture adjustments are made.
- Any other knowledge needed to verify and document that the job mix is being produced or necessary remedies are being performed when problems occur with mix production.

Plant operator—Mixing soil-cement is a process enlisting many system components. A key component of the system is the plant operator or person in charge of batching and mixing. The plant operator must have a thorough knowledge of the equipment used to batch and mix the soil-cement and be able to make adjustments as needed to continuously produce a uniform job mix. The NRCS inspector should observe the batching and mixing operations, particularly the plant operator's ability to conduct the batching and mixing operation. Concerns related to the competence of the plant operator should be made known to the engineer.

Materials feed—For plant (pug mill or truck) mixed soil-cement, soils are stockpiled and supplied to the plant by various methods. The simplest method, generally employed for low-production projects, is to use a front-end loader to carry soils from stockpiles to the mixer. For higher-production, continuous feed systems provide a continuous, uninterrupted flow of soil and soil-cement to the mixer. A continuous feed system usually includes an initial bin from which soil is discharged through an adjustable gate opening onto a conveyor belt that carries the soil to mixing plant bins.

Cement and pozzolan are pneumatically conveyed into silos at the plant. There will be a silo for the cement and, if pozzolan is used, one for the pozzolan, or there will be one silo with two compartments to allow the cement and pozzolan to be stored and metered separately. Occasionally, additional storage silos or containers will be used as needed to keep up with demand on high-production jobs. Silos must be watertight to prevent the cementitious materials from getting wet. Cement and pozzolan tend to cake or set up due to a condition called "false set." Silos must be equipped with vibrators or other devices that prevent false set and ensure that the material continues to flow freely.

The cement and pozzolan are discharged through a metering device onto a conveyor belt. The belt may first pass under the soil bin and then under the cement and pozzolan discharge so that the cement and pozzolan are deposited onto the soil that is already on the belt. The belt then dumps all of the granular materials into the mixing chamber.

Mixing systems—Several systems are available for mixing soil cement. Soil cement can be batched and mixed either in a plant or on the ground.

The continuous-flow twin-screw pug mill has a mixing chamber containing two horizontal counter-rotating shafts fitted with paddles. The mix components are batched by volume in that they are metered through a certain size opening or volumetric metering device. The materials are carried to the mixing chamber on a conveyor belt that runs under the bins and silos. Water is added in the mixing chamber.

Changes in material moisture content and bulking of materials make volumetric batching less accurate than batching by weight. Some sophisticated continuous-flow systems are equipped with computers and sensors that monitor the weight of materials and continuously adjust the feed rates. With any continuous-flow system, regardless of the sophistication of the system, there is a potential for an ingredient to be improperly metered or left out of the mix. The plant operator must constantly monitor the mix for signs of a change that would indicate a batching problem.

The ingredients are pushed through the mixing chamber by paddles fixed at an angle on two counter-rotating shafts. At the proper rotational speed, the ingredients are thoroughly mixed as they are being pushed through the mixing chamber. It only takes a few seconds from the time the ingredients enter the mixing chamber until they exit the chamber. This time interval is referred to as the mix retention time. Only minor adjustments can be made to shorten or extend the mix retention time, but the few seconds that the mix remains in the mixing chamber are generally adequate for thoroughly mixing soil-cement. There is an optimum rotational speed of the rotating shafts. The plant operator must adjust the feed belt speed and the rotational speed of the shafts to that best suited for the mix being produced.

Compulsory mixers consist of one or two horizontal shafts with fixed paddles similar to those in a continuous-flow twin-screw pug mill. Unlike the continuous flow twin screw pug mill, compulsory mixers mix in discrete batches. The mixing mechanism is contained in an enclosed mixing chamber. The mix can be retained for as long as needed to produce a thoroughly mixed product. The bottom of the mixing chamber opens to drop the mix onto a delivery belt that delivers the soil-cement to the conveyance system. The horizontal shaft mixers provide complete mixing in much shorter time periods than drum mixers. Mix retention times of less than 20 seconds are generally adequate for thorough mixing with a compulsory mixer.

Tilting drum mixers are used to mix discrete batches. The ingredients are proportioned and fed into a drum that employs the same mixing action as that of a concrete ready-mix truck. The difference between this type of mixer and a concrete ready-mix truck is the manner in which it discharges. A tilting drum mixer discharges by tilting the drum whereas a concrete ready-mix truck discharges by reversing the direction of drum rotation which forces the mix out along the fins inside the drum. When a drum mixer is used, care must be taken not to overcharge the drum, as inadequate mixing and buildup of material on drum surfaces are common problems when the drum is overcharged. The mix must be retained in the drum mixer for a time similar to that for conventional concrete mixing. Too little mixing will result in poor mix uniformity. Too much mixing can cause heat buildup and drying of the mix. Drum mixers must be cleaned periodically to remove any buildup of soil-cement that might impair the function of the mixer.

Truck mixers are allowed by Spec 29; however, it is often difficult to discharge stiff soil-cement mixtures from a ready-mix truck. If a truck mixer is used, the end of the truck opposite the discharge end may have to be elevated to discharge the stiff mix.

Traveling mixing equipment can be used to mix soil-cement on the ground.

When using a traveling mixer, it is important to ensure that the volume of mixture per unit of travel is consistent. This requires the machine to be set to mix at a uniform depth and the cementitious materials to be applied in a consistent and uniform manner. The uniformity and depth of the soil-cement mixture must be checked frequently. A simple test for determining mixing depth is explained in the "Sampling and Testing" section of this chapter. It is common practice to blade the soil into a windrow with a uniform cross section and flatten the top of the windrow prior to adding the cementitious materials. The cementitious materials are then added to the top of the windrow and mixed by the traveling mixer. Light wind can cause cement and pozzolan particles to become airborne.

Whenever the soil-cement is mixed in place, cementitious materials must be distributed evenly over the area. If bulk cementitious materials are used, they may be deposited in windrows. When bags of cement are used, the bags are emptied in a uniform grid pattern, spaced to attain the proper application rate. In either case, the cementitious materials must be evenly spread with a motor grader, dozer, or other equipment prior to mixing with the traveling mixer.

The moisture content for the soil-cement mixture is critical for incorporating cementitious materials into the soil and for compaction of the mixture. If the soil is too wet whenever cementitious materials are added, cement balls will form resulting in an uneven distribution of cement throughout the soil lift. If the mixture is too dry, a considerable amount of time may be required to incorporate moisture into the mixture. Soil moisture should be 1 to 2 percentage points below optimum at the time cement is deposited, spread, and incorporated into the soil. Water should then be incorporated as quickly as possible to bring the moisture content of the mixture up to the specified compaction moisture. Moisture tests should be made just prior to compaction to ensure that the moisture is within the specified range.

It is best to add water before the mix is transported to the placement site because incorporating water requires mixing to full-lift depth which could damage previously placed soil-cement. Traveling mixers are usually equipped with a spray bar to add water as the mixer travels and mixes.

All batching and mixing equipment should be operated according to the manufacturer's recommendations, maintained in satisfactory operating condition, and cleaned as needed and after each production run. During production, all supply bins and silos should be kept sufficiently full to ensure a uniform and constant flow of all materials.

Uniformity of the mixing operation is critical to obtaining consistent quality soil-cement. Soil-cement uniformity should be monitored by continuous visual inspection by the plant operator and by periodic visual inspection by contractor quality control personnel and the NRCS inspector. Changes in the color of soil-cement can indicate a lack of uniformity. If a uniformity problem is suspected, the contractor must take appropriate corrective measures including adjustments in the soil borrow, batching, and mixing operation. Confer with the engineer whenever uniformity problems occur to determine if proposed corrective measures are appropriate.

Uniformity problems can be caused by malfunctions of the batching and mixing operation, such as clogging of bins and silos, inaccurate metering devices, inconsistent feed belt delivery, worn pug mill mixing paddles or vanes in a mixing drum, etc. Uniformity problems can also be the result of changes in the type of soil being mixed or inconsistent soil moisture.

The inspector's responsibilities related to proportioning and mixing of soil-cement includes verifying that:

- The plant operator exhibits the capability to oversee the proportioning and mixing operation.
- Equipment is in good condition, has adequate capacity, and hoppers discharge completely.
- Drums are inspected and cleaned periodically and are not overcharged.
- Adequate quantities of all ingredients (soils, cement, pozzolan, and water) are available on site to allow uninterrupted production.
- Only specified soils are used.
- Soil moisture is 1-2 percent below optimum when cementitious materials are added.
- Soil-cement is mixed immediately after the cement is added.
- Mix moisture tests are conducted and water is added to bring moisture of the mixture to within the specified range for compaction.
- The plant operator visually inspects the mix for uniformity on a continuous basis.
- Quality control personnel visually inspect the mix for uniformity on a periodic basis.
- The mixture has uniform color, moisture, and cement content or uniformity problems are isolated and corrected.
- Mix uniformity is documented periodically and before and after uniformity problems are corrected.

(6) Transporting and placing (soil-cement)

Whenever soil-cement is not mixed in place, it must be transported from the mixing plant to the placement site. The inspector must inspect this process to ensure that the mixture is not contaminated or segregated during pickup and transport. If the soil-cement is mixed on the ground, care must be taken to ensure that only the soil-cement is picked up to prevent untreated soil from being mixed into the soil-cement. Soil-cement is not as prone to segregation as concrete, but if it is placed in a leaky dump truck or other container, cement paste could leak from the mixture resulting in a leaner mixture than called for. Also, a leaky transport vehicle will waste cement and could be a pollution concern.

The haul time should be limited to less than 30 minutes to allow adequate time for the mixture to be placed, compacted, and finished before the cement sets up. This is more critical in dry, hot, windy conditions; in these conditions, the mixture should be protected from sun and wind. The mixture should be protected from rainfall. Too much rain could wash cement from a portion of the mixture or increase the moisture content of the mixture above the allowable moisture content.

The foundation must be inspected and approved prior to depositing the mix. Earthen foundations should be firm and moist because a dry foundation will wick water from the material, resulting in weak soil-cement due to lack of water needed to fully hydrate the cement.

Avoid placement when the air temperature is less than 40 degrees Fahrenheit. There are three primary concerns associated with cold weather. First, if the soil is frozen, chunks of frozen soil will remain unblended in the mixture. Second, if the soil-cement freezes before developing adequate strength, it may be damaged from stresses imposed by the expansion of freezing water within the soil-cement. Thirdly, the curing period must be extended until such time that there has been

adequate moisture and temperature to allow for the development of the desired strength.

Whenever the air temperature is expected to be below 45 degrees Fahrenheit, the contractor may be required to make provisions to protect the soil-cement from the damaging effects of cold weather. These provisions should be outlined in a protection plan developed and submitted by the contractor and approved by the engineer. Equipment and materials needed for protection must be on site and ready to be employed as per the approved protection plan before soil-cement is placed.

Joints occur at the edge of placement lanes and between the soil-cement layers (lifts). Lift joint preparation should be specified for soil-cement that is more than 2 hours old because it is likely that the surface of the lift has hardened to the point that it would not bond well with soil-cement place above it. The bond can be enhanced by scarifying the surface to expose some of the soil-cement just below the surface. In some instances, cement and water is added to the lift surface to enhance bond. Any loosened materials or contaminants must be removed prior to covering the lift surface with the next layer of soil-cement. All lift joints should be clean and moist when covered with the next lift of soil-cement.

At the end of each workday, or when the adjacent placing operation is terminated for more than 2 hours, a vertical construction joint should be made along all unfinished edges of the thoroughly compacted soil-cement. Just before placing operations are resumed, the construction joint must be shaved to remove all dry soil-cement and all curing compound from the joint face. Applying a joint enhancement (e.g., neat cement grout or mortar) prior to placing soil-cement against the edge may be specified.

Small dozers with cleated tracks can be used to spread and level soil-cement but should never operate directly on compacted soil-cement surfaces. They should spread the uncompacted material in front of them as they extend the lift. When it is necessary to traverse compacted soil-cement surfaces, protective sheets, such as waste conveyor belts or plywood, should be placed on the surface to protect it from the dozer cleats. Earth ramps for accessing and crossing previously compacted soil-cement must be of sufficient thickness to distribute equipment load so as not to damage the surface.

The soil-cement mixture should be spread to a uniform thickness. Ruts, bellies, and humps in the uncompacted soil-cement surface should be removed. The loose lift thickness must be slightly thicker than the planned compacted lift thickness. For example, the loose lift thickness may need to be 6.5 inches to achieve a 6-inch compacted lift thickness.

The lift thickness is dependent on the equipment's mixing and compacting capabilities and must be determined by trial and error in the field. If a 12-inch layer of soil cement is desired, placement in two 6-inch lifts will likely be required to achieve thorough mixing and compaction throughout the full depth of the lift.

Some compaction will occur as the result of the dozer spreading operations. It is best to limit this compaction unless it can be uniformly distributed over the entire lift. Otherwise, when the loose lift is leveled and made ready for the compactor, some areas will be denser than others resulting in an uneven surface. Thus, it is important to develop a process of depositing and spreading the soil-cement mixture so that any premature compaction of the loose lift is either minimal or is uniform over the entire surface of the loose lift.

Spreading of the soil-cement should be completed quickly after being deposited. It is more important to spread the soil-cement to a uniform surface in as short a time as possible, than to spend extra time to perfect the final grade. Some techniques for controlling grade can perfect the grade of the surface of the loose lift in a very short time. One such technique is to use laser-guided automatics for equipment. Receivers are mounted on the dozer blade for exacting control of the loose lift grade.

The placement of soil-cement should be performed in as nearly a continuous nonstop operation as is practical. To the extent practicable, the structure should be brought up in lifts of uniform thickness across the entire area. It is best to orient the direction of soil-cement placement parallel to the main axis of the placement so that the number of lanes and specifically the number of edge joints are minimized.

If moisture adjustments are made after placement, care should be taken not to damage the underlying soil-cement or mix untreated foundation materials into the soil-cement. If the mix contains adequate moisture whenever it is deposited, moisture adjustments may

only be needed in the top few inches. Check moisture at various depths to determine the depth at which moisture can be adjusted to ensure adequate moisture throughout the entire lift while avoiding damage to the underlying materials or the mixing of foundation materials into the soil-cement.

The inspector's responsibilities related to transporting and placing soil-cement includes verifying that:

- Foundation or lift joint preparation is complete as specified.
- Mixture is not contaminated.
- Transport containers do not leak.
- Haul time does not exceed 30 minutes.
- Mixture is protected from rainfall or excessive drying from wind and sun.
- Equipment does not damage previously placed and compacted soil-cement.
- Soil-cement is spread in lifts of uniform thickness resulting in compacted layers of the specified grade and thickness.
- Mix is placed in a configuration that limits edge joints.
- Thickness of lift does not exceed the depth that can be efficiently mixed and compacted with available equipment.
- The surface of soil-cement that is more than 2-hours old is treated as specified before being covered by a new layer of soil-cement.
- Placement does not occur if the air temperature is less than 40 degrees Fahrenheit.
- Placement does not occur if the foundation or the soil used to make the soil-cement is frozen.
- Placement does not occur if the soil-cement cannot be completely compacted and protected before the onset of damaging weather.
- Whenever the air temperature is expected to be below 45 degrees Fahrenheit, the planned method of protection is approved by the engineer before soil-cement is placed.
- Whenever the air temperature is expected to be below 45 degrees Fahrenheit, protection equipment and materials are onsite and ready to be employed as per the approved protection plan.
- Mix contains specified moisture in preparation for compaction.
- Moisture adjustments are made without damage to underlying materials or the mixing of foundation materials into the soil-cement.

(7) Compaction (soil-cement)

Compaction is essential to producing durable soil-cement. Soil-cement that is well compacted will be less likely to absorb water and or injurious substances that, over time, cause deterioration from within.

Compaction should begin within 60 minutes after introduction of water into the soil-cement and be complete no longer than 90 minutes after water introduction.

Soil-cement compaction is commonly accomplished with smooth-drum vibratory compactors or rubber tired rollers. Tamping foot rollers that do not penetrate through the entire lift may be used; however, they leave indentions in the surface. These indentions will increase the potential for absorption of injurious substances or the formation of ice that could damage the soil-cement. Sheepsfoot and other deeply penetrating rollers should be avoided as they may damage previously placed soil-cement or mix in foundation soils that would contaminate the soil-cement.

Maximum dry density and optimum moisture of soil-cement are determined in the lab using ASTM Standard Test Method D558. The field density is typically specified as a percentage of maximum dry density and compaction moisture is typically specified to be at or above optimum moisture obtained by the D558 test. For soil-cement made with sandy soils, optimum moisture typically falls within 10 to 14 percent.

Soil-cement exhibits compaction characteristics that are similar to that for soil. The compaction equipment should be routed in a pattern that provides uniform coverage. Moisture and density of the material must be checked and adjusted as compaction proceeds. The lift thickness must be controlled so that the compaction equipment can compact the entire lift thickness to the specified density. If the lift is too thick, the compaction energy may not be sufficient to attain the specified

density in the lower portion of the lift. Very thin lifts are not desirable because more lift joints are required.

It is possible to roll or compact the soil-cement so much that most of the moisture is squeezed out of the top portion of the lift. This will be evident whenever patterned surface cracking occurs. If surface cracking occurs before the specified density is attained throughout the lift, the lift thickness must be reduced or a larger compactor must be employed. A compactor that can attain density throughout the lift with six or less passes (rolling over a point one time constitutes one pass) is generally adequate to attain density without drying the lift too much.

If the surface of a compacted layer of soil-cement has been severely over compacted, rutted or damaged, the contractor should scarify and recompact the surface within 2 hours from the time the cement is first added to the soil. If more than 2 hours has transpired, the damaged soil-cement should be removed in a manner and to the extent approved by the engineer.

Blading in connection with compaction operations may be required to attain a uniform surface. If blading is required, raw unmixed soil should not be bladed onto the soil-cement where it might wick moisture from the soil and contaminate the bonding surface.

For more on compaction, refer to the section on earthfill compaction in chapter 8 of this handbook.

The inspector's responsibilities related to compaction of soil-cement includes verifying that:

- Sheepsfoot or other deep penetrating compactors are not used.
- The soil-cement is compacted to the specified density.
- Compaction is attained throughout the entire depth of the lift.
- Lift thickness is controlled or compaction effort is increased to prevent surface damage caused by over compacting.
- Raw unmixed soil is not bladed onto the soil-cement.
- Compaction is accomplished as soon as possible after the soil-cement is placed.

(8) Curing (soil-cement)

Soil-cement, like conventional concrete, must be cured to allow for hydration of the cementitious materials in the mix. Unlike conventional concrete, there is no bleed water to keep the surface moist, so surface drying begins during compaction. Thus, curing must begin immediately after compaction. It is critical that the surface is not allowed to dry out during the curing period or before being covered with bonding materials or soil-cement.

Soil cement is normally cured for 7 days. The temperature of the soil-cement should be maintained at or above 40 degrees Fahrenheit for 7 days during the curing period. If the temperature of the soil-cement falls below 40 degrees Fahrenheit during the curing period, the curing period should be extended to allow this requirement to be met.

Wet curing—Wet cured soil-cement must be maintained in a continuously damp condition for the entire curing period. This can be accomplished by a continuous application of water or water supplemented by a saturated cover material such as sand. Water should initially be applied in a fine mist that does not erode, mar, or otherwise damage the soil-cement. If sand is used, it should be wetted prior to being placed on the soil-cement; otherwise, dry sand will wick moisture out of the soil-cement.

Wet curing often entails the application of water and a covering of plastic. Soaker hoses are typically placed under the plastic covering to replenish any moisture that is lost. Plastic covering must be secured to keep it in place and held tightly against the soil-cement to limit air movement between the plastic and the soil-cement. Plastic covering should meet the requirements of ASTM C171. During hot weather, white or reflective coverings should be used.

Curing compound—Areas to be cured with curing compound must be kept continuously moist until applied. All standing water must be removed before applying the curing compound. Curing compound acts as a bond breaker, so it should not be applied to bonding surfaces, such as lift joints or areas to be repaired or patched. Only curing compound that meets specification requirements should be used and it must be reapplied every 7 days during the curing period whenever the period is extended beyond 7 days. In areas where

the curing compound is damaged, it should be reapplied immediately.

For large areas, curing compound can not be applied in a timely manner using manual hand pump sprayers. It is best to use continuously agitating sprayers that produce a steady uniform flow rate to quickly and efficiently cover the surface.

Apply curing compound in two applications. For large areas, the second application can be applied in lanes oriented at an approximate right angle to those of the first application. This will provide for a more complete coverage and lessen the potential for failing to cover some areas. If the soil-cement surface is long and narrow, the first and second application may be placed in lanes oriented in the same direction but with lane edges staggered to ensure a better chance of full coverage.

The inspector must verify that the curing compound application rate is equal to or greater than the manufacturer's recommended rate and the specified rate. The recommended rate should be listed on the product container and on manufacturer's product specification sheets. ASTM C309, Type 2 curing compound is typically applied at a rate of 200 square feet per gallon. Spec 29 specifies curing compound be applied at a rate of 150 square feet per gallon.

The inspector's responsibilities related to curing includes verifying that:

- Prior to beginning soil-cement placement, curing equipment and materials are on site and ready to be deployed.
- Curing begins immediately after compaction.
- Curing continues until the soil-cement has been maintained at or above 40 degrees Fahrenheit for 7 days.
- Application of curing water does not erode the surface.
- Coverings are secured to prevent the movement of air between the soil-cement and the covering.
- White or reflective coverings are used during hot weather.
- Curing compound conforms to specification requirements.
- The entire surface to be cured with curing compound is uniformly covered at or in excess of the manufacturer's recommended rate and the specified rate.
- Curing compound is not applied to bonding surfaces or areas to be repaired.
- The surface is kept continuously moist until curing compound is applied.
- All standing water is removed prior to applying the curing compound.
- Curing compound is applied in a timely manner.
- Curing compound is reapplied every 7 days during the curing period when the curing period is extended beyond 7 days.

(9) Protection (soil-cement)

Soil-cement must be protected from rainfall, cold weather, and damage from construction operations.

Cement hydration slows considerably when the soil-cement temperature is less than 40 degrees Fahrenheit. If there is potential for the air temperature to drop below that temperature during placement or in the days following placement, a plan should be in place to protect the soil-cement from freezing. Insulating the soil-cement with blankets, straw, or sand may be adequate to prevent freezing of the soil-cement. It is not a common practice to add supplemental heat to soil-cement; however, if supplemental heat is added, it is best to use steam or other means of adding moisture to prevent drying.

Damage from construction operations typically occurs whenever equipment operates on soil-cement before it develops sufficient strength to support the equipment or otherwise resist damage. The contractor is responsible for protecting the work so that the structure conforms to specification requirements including the quality of the finished surface and specified tolerances in line and grade.

If the work is not being adequately protected, the inspector should contact the engineer to request action be taken to correct the problem.

The inspector's responsibilities related to protection of the soil-cement includes verifying that:

- Soil-cement is protected against erosive rainfall or flowing water.
- Cold weather plan is implemented.
- Vehicular traffic is prohibited if it causes damage to the soil-cement.

(b) Lime-treated earthfill

(1) Materials (lime-treated earthfill)

Lime is typically added to fine-grained soils to reduce soil plasticity (thereby reducing its shrink-swell potential), to make the soil less dispersive, or to increase the soil's strength.

Soil to be treated with lime is typically obtained from designated areas at or near the site. Deleterious material, such as frozen soil, sod, brush, roots, or other perishable material must be separated from the soil. Rock particles larger than the maximum size specified for each type of lime-treated earthfill should be removed before adding the lime.

Water—Most water that is relatively clean is acceptable for use with lime-treated soils. Sediment laden water should have little to no adverse effect on the limes ability to treat the soil. NRCS Construction Specification 28, Lime Treated Earthfill, hereafter referred to as Spec 28, requires the water to be clean and free from injurious amounts of oil, acid, organic matter, or other deleterious substances. There are no specific tests or submittals required by Spec 28 related to the quality of water.

Lime is available in three forms: agricultural lime, quicklime and hydrated lime. Agricultural lime is inexpensive and readily available but it is not suitable for lime-treated earthfill.

Quicklime is made by heating naturally occurring limestone to a high temperature in a rotary kiln. It is then ground or screened to a uniform pebble size. Although less common, it may be further ground or pulverized to form a powder. Because quicklime reacts strongly when it contacts water, it can cause severe health issues if inhaled or comes into contact with moist skin, eyes, or nasal passages.

Whenever water is added to quicklime, a chemical reaction called slaking occurs. During slaking, the pebbles break down into a powder. When enough water is added to satisfy quicklime's affinity for water, a powdery substance called hydrated lime is formed. Both quicklime and hydrated lime are available in 50 pound bags or in bulk. Lime trucks that transport bulk lime generally transport 15 to 24 tons per truck.

The inspector's responsibilities related to soil, water, and lime materials include verifying that:

- Soil is obtained from designated areas.
- Deleterious materials and rock particles larger than the specified maximum allowable size are removed from the soil before mixing.
- Water conforms to specification requirements.
- Lime complies with the specification and the source and form of lime has been approved by the engineer.

(2) Equipment (lime-treated earthfill)

Treatment of clayey soils, such as those normally treated by lime, requires a heavy disk plow and a heavy high-speed rotary mixer. Most rototillers that are attached to a farm tractor will not mix to the depth specified and do not have the same mixing ability as a high-speed rotary mixer. Thus, the type of equipment used for plowing and mixing will generally be specified. The inspector should verify that the equipment planned for mixing meets specification requirements and is capable of mixing to the required depth. A simple test for determining mixing depth is explained in this chapter.

All equipment used to convey or transport lime should be covered or enclosed to avoid lime dust problems. This is especially important when finely ground quicklime or hydrated lime is used, due to their very small particle size. Trucks that deliver bulk lime generally have a pneumatic distribution system that blows lime through holes in a distribution bar located at the rear of the truck. A boot or shield may be placed over the bar and extended to the ground in windy conditions to guard against lime dust problems.

Lime may be mixed with water and applied in slurry form. Trucks that transport slurry to the site must be capable of agitating the slurry to keep the lime particles in suspension. Agitation of the slurry is accomplished through internal paddles, recirculation pumps,

or a combination of these devices. The slurry is discharged through a spray bar.

Paddle wheel or elevating scrapers are an excellent way of transferring the lime treated material from the mixing area to the structure. They can be operated to remove the treated material at the appropriate depth and distribute it in a thin lift. The action of elevating and placing the materials has the added benefit of providing additional mixing of the materials.

The soil particles in most lime-treated earthfill are predominantly fine grained and are best compacted with a compactor that is suited for compacting clay. A sheepsfoot roller is best for compacting clay soils. Pad-foot drum rollers may be used but will not compact the lower portion of the lift as well as a sheepsfoot roller. Rubber tire and smooth drum rollers are not effective at compacting clay soils.

The inspector's responsibilities related to equipment for lime treatment include verifying that:

- Mixing equipment is of the type and size specified.
- Mixing equipment is capable of mixing at various depths up to and including the planned lift depth.
- Transport equipment is covered or enclosed to avoid dust problems.
- Slurry transport vehicles sufficiently agitate the slurry to keep the lime in suspension.
- Compaction equipment is capable of compacting the lime-treated earthfill to the full planned lift depth.

(3) Site preparation (lime-treated earthfill

If lime is to be mixed in-place, the area to receive the lime must be shaped to the appropriate lines and grades. Topsoil and unsuitable soil must be removed and replaced with acceptable material. The subgrade should firmly support the lime transport and construction equipment.

If lime is to be mixed with soil in a processing area and hauled to the placement area, the processing area must first be stripped of topsoil and graded to a relatively smooth and uniform surface. Specifications may require that topsoil be stockpiled and placed back on the area after the processing area is no longer needed.

Figure 9–1 shows the measuring of a mixing area so that the lime can be mixed at the correct proportion. It is helpful if your mixing area is at least large enough to accommodate a fully loaded truck at one time.

The chemical reaction that occurs whenever dry lime is added consumes moisture and dries out the soil. Soil moisture may be adjusted prior to or after adding dry lime. It may be beneficial to partially raise the soil moisture prior to adding lime and finish adjusting the moisture after lime is added. The best times to incorporate water will be dependent on the soil and the mixing equipment and should be determined by field trial at the beginning of the work.

The inspector's responsibilities related to site preparation for lime treatment for in-place mixing and curing include verifying that:

- The area to receive the lime is shaped to the specified line and grade.
- Topsoil and unsuitable materials are replaced with acceptable material.
- Subgrade is firm enough to support equipment.
- Soil moisture adjustments are made as necessary.

Figure 9–1 Measuring the mixing area



The inspector's responsibilities related to site preparation for lime treatment for mixing and curing in a processing area include verifying that:

- Mixing and curing are conducted at the designated site.
- The site is stripped of topsoil.
- If specified, topsoil is stockpiled to be placed back on the processing area.
- The area is graded to a relatively smooth and uniform surface.

(4) Lime and soil proportioning (lime-treated earthfill)

The lime application rate is expressed as a percentage of the dry weight of soil being treated. Even though an application rate of approximately one percent lime is generally all that is required to treat soils for dispersion, it is difficult to evenly distribute less than two percent, unless it is applied in slurry form. Thus, a two percent application rate is generally specified to treat soil for dispersion. A higher application rate is required to significantly change soil plasticity or increase soil strength. The rate needed to change plasticity or increase strength is determined by testing the soil treated at various application rates.

The application rate is dependent on the form of lime being applied. In general, 1 pound of quicklime will provide approximately the same treatment as 1.3 pounds of hydrated lime. For treating dispersion, a two percent application rate of either quicklime or hydrated lime will likely be sufficient. For changing the plasticity or strength of the soil, separate application rates should be specified for quicklime and hydrated lime.

As the work progresses, test results for plasticity or strength of the treated soil may dictate that adjustments in the application rate are necessary. The amount of lime necessary to affect strength and plasticity of soil is directly related to the pH of the soil-lime mixture. The pH of the mixture can be utilized per ASTM D6276 to determine if adjustments to the lime application rate are needed.

The inspector's responsibilities related to proportioning of lime and soil includes verifying that:

- The planned application rate conforms to the specified rate for the form of lime used.
- Tests such as those to test for Atterberg limits and pH are conducted as applicable.
- Application rate adjustments are made based on results of tests for strength, plasticity, or pH, as applicable.
- Rate adjustments are approved by the engineer.

(5) Lime application (lime-treated earthfill

The treatment of soil with lime involves a chemical reaction that produces heat, but in cold weather the heat produced may not be sufficient to allow for the chemical reaction to continue at the level necessary to effect the desired change in the soil. Therefore, Spec. 28 requires that lime not be applied when the temperature is below or is expected to drop below 40 degrees Fahrenheit within 24 hours.

Dry lime (quicklime or hydrated) should not be applied during high-wind conditions. It may be possible to apply pebble-size granulated quicklime in light winds; however, dry hydrated lime will become airborne in windy conditions.

Lime in powdered form is uniformly applied in dry form on the soil surface at the specified rate (fig. 9–2) then lightly sprinkled with water to minimize blowing.

Figure 9–2 Applying lime in the mixing area



Caution should be taken as the reaction between lime, especially quicklime, and water can irritate eyes, skin, and the respiratory system. This reaction (called lime slaking) produces steam which can irritate the eyes and respiratory system. Individuals should remain upwind of the process as the lime is being applied and avoid contact with the lime or steam.

Lime may also be applied in slurry form. Lime is mixed with water to form a slurry and maintained as a uniform mixture in an agitating tank. The slurry is applied through spray bars located on the back of the transport/agitation equipment.

The inspector must ensure that the lime is being applied at the specified rate. One way of doing this, for lime applied in powder or granular form, is described in this chapter.

The inspector's responsibilities related to application of lime include verifying that:

- Lime is not applied when the temperature is below or is expected to drop below 40 degrees Fahrenheit within 24 hours.
- Dry lime is not applied in windy conditions that cause dusting problems.
- Tests are conducted to document that lime is uniformly and evenly applied and spread.
- After spreading, dry lime is sprinkled with water to minimize blowing.
- Caution is taken to avoid exposure to lime dust and steam produced by lime slaking.
- Where applicable, slurry is evenly distributed and lime is kept in suspension throughout the distribution process.

(6) Mixing (lime-treated earthfill)

After lime is applied, it is mixed into the soil to the proper depth (figs. 9–3 and 9–4). This process evenly distributes the lime and pulverizes the soil. The soil, lime, and water are mixed by disking and high-speed rotary mixers until a uniform mixture is obtained. Disking is generally required first to break apart large chunks of soil that are too large and damaging to rotary mixers. After disking, rotary mixers further break down the chunks to pulverize and thoroughly mix the lime and water into the soil. Sometimes multiple operations are necessary to completely mix the soil and lime. Color or texture change is a good, visual indication of whether the lime has been adequately mixed into the soil. White spots or wet spots are an indication that the lime has not been thoroughly mixed. It will be necessary to raise moisture 2 to 5 percent above optimum to satisfy the lime's affinity for water and maintain soil moisture for curing and compaction. The cycle of watering and mixing must continue until the soil, lime, and water are thoroughly processed to a uniform mixture without lumps of soil or lime.

Figure 9–3 Mixing lime with a high-speed rotary mixer



Figure 9–4 Mixing the lime into the soil



The inspector should verify that the depth of the lift for treatment is no greater than can be effectively mixed by the equipment. The inspector should also verify that tests for moisture are conducted and moisture adjustments are made throughout the process to maintain the moisture content within the specified range. The next step in the treatment process depends on the objective for treating the soil

Treatment for dispersion—If the soil is being treated to make it less dispersive, the change occurs very rapidly upon introducing the lime to the soil. It may be placed and compacted without curing.

Treatment to lower plasticity—If the soil is being treated to lower its plasticity, it must be cured for a specified amount of time. Curing involves sealing the lime treated layer to minimize evaporation loss, lime carbonation, and excessive wetting from rainfall or other sources. Carbonation occurs when lime reacts with carbon dioxide in the air and, over time, reverts to calcium carbonate. Carbonation is undesirable because it reduces the amount of lime available to treat the soil.

Sealing can be accomplished by lightly compacting the surface of the treated layer. Even though the soil-lime mixture is sealed, moisture will be consumed as the lime reacts with the soil, and tests will be required to ensure that the moisture remains above that specified. It may be necessary to incorporate additional water into the mixture during the curing process in order to maintain the moisture content at or above the specified level. If this is necessary, the seal must be broken to incorporate the water and then the mixture must be resealed. The process of testing and adjusting the moisture and resealing the mixture must continue until the curing period has expired.

Some specifications require that the plasticity of the soil be monitored to determine the necessary length of curing time. On many jobs the soil-lime mixture is processed and cured in a remote area. This allows for the placement and compaction of soil-lime mixtures to continue while other soil-lime mixtures are being cured, but it requires the soils to be excavated and hauled to the treatment area and then hauled to the placement area after treatment. A more efficient process might be to treat and cure the soil in place. The decision to treat and cure in place will likely hinge on the amount of curing time needed to effectively change the plasticity of the soil. Monitoring the change in plasticity is necessary for making this determination. Atterberg limits can be determined in the field per ASTM D4318 to access the plasticity of the treated soil.

After curing, the treated material must be thoroughly remixed so that all soil lumps and lime particles larger than the No. 4 sieve size are broken apart.

Treatment for improving strength—If improving soil strength is the primary objective, the lime-soil mixture should be compacted and cured in place. Sufficient moisture must be added to the mixture so that the mixture can be cured without having to incorporate more water. The compacted mixture is then allowed to cure in a moistened state without further disturbance as it gains strength.

All treatments—The application and mixing of lime should be completed as quickly as possible to reduce the potential for lime carbonation. Lime should not be applied when there is a high probability that the entire application and mixing process cannot be completed on the same day. This may preclude applying lime late in the workday or whenever it appears that the process cannot be completed in a timely manner.

The inspector's responsibilities related to mixing of lime, soil, and water includes verifying that:

- The depth of lift or layer into which the lime is mixed allows for the proper proportioning of lime and soil.
- The depth of the mixture is no greater than can be effectively mixed by the mixing equipment.
- Soil, lime, and water are processed to provide for a uniform mixture without lumps of soil or lime.
- The water content of the mixture is maintained as specified throughout the mixing process.
- The mixture is sealed, as applicable, to prevent evaporation, lime carbonation and excessive wetting from rainfall.
- The process of mixing the lime, soil, and water is completed within the same workday as it is started.
- The mixture is cured as specified.

- When specified, material is remixed after curing to break up clods and reduce any non-slaked lime particles to less than the No. 4 sieve size.

(7) Compaction (lime-treated earthfill)

Compaction processes and principals for lime-treated earthfill are the same as those for untreated earthfill. The density is normally specified as a percentage of standard Proctor maximum density as determined by ASTM D698. The addition of lime to the soil will change the compaction characteristics of the soil. The Proctor curve must be developed using treated material to determine the correct maximum density and optimum moisture. Note that the hydration of lime affects the moisture content determination on a nuclear gauge. If a nuclear gauge is being used to determine density it is recommended that another method be used to determine the moisture content. For more on compaction, refer to the section on earthfill compaction in chapter 8 of this handbook.

The inspector's responsibilities related to compaction of lime-treated soil includes verifying that:

- The mixture contains the specified amount of water evenly distributed throughout the lift being compacted.
- The mixture is compacted to the minimum density specified throughout the depth of the lift.

(c) Bentonite-treated soil

(1) Materials (bentonite-treated soil)

Bentonite is highly plastic clay that can be added to sands and some silts to reduce their permeability. Compacted soil-bentonite is commonly used to reduce seepage from ponds or waste impoundments. NRCS Conservation Practice Standard (CPS), Code 521C, Pond Sealing or Lining, Bentonite Treatment, has useful information on the use of bentonite treatment.

Soil to be treated will be nonplastic or slightly plastic sand or silt with a plasticity index (PI) less than 7. The soil should contain no frozen material, sod, brush, roots, or other perishable materials. Soils should be avoided that have concentrations of leachable nonsodium cations, particularly calcium, magnesium, and iron, and high concentrations of soluble chloride or sulfate. Soils that have been contaminated with organic solutions should also be avoided. Rock particles larger than the lift thickness divided by 10 should be removed. To avoid stacking and bridging of large particles, no more than 25 percent of the soil should be larger than the No. 10 sieve size.

The inspector must verify that the soils used are of the type specified. When borrow soils are used, the inspector must verify that the specified soils are obtained from designated borrow areas. When in-place soils are used, the inspector must verify that the type of soil is as specified or is removed and replaced with the type specified.

Water that is relatively clean and free of organic contaminants and concentrations of dissolved salts is acceptable for use with bentonite-treated soils. Generally, water with a total nonsodium hardness of less than 250 parts per million (ppm) will be acceptable. The presence of sediments in the water should have no adverse effect on the bentonite-treated soil.

Bentonite is a good sealant because of its ability to swell, fill voids, and thereby reduce soil permeability. There are many grades and types of bentonite available from a variety of sources. The two most common types are sodium bentonite and calcium bentonite. NRCS ordinarily specifies the use of sodium bentonite because of its high swell potential. Bentonite with a free swell of at least 22 milliliters per 2 grams, as measured by ASTM D5890, is the highest quality type of bentonite and is normally recommended. Lower quality bentonite may be specified for a particular job when the costs are significantly less and laboratory tests verify that the tested rate of application results in an acceptably low permeability. Often, lower quality bentonite requires 2 to 3 times the quantity to produce a low permeability soil mixture than high quality sodium bentonite.

Bentonite is available in a fine powder with 80 percent passing the No. 200 sieve. It also comes in coarse granular form with less than 15 percent passing the No. 200 sieve and less than 15 percent retained above the No. 20 sieve. When evenly distributed, it takes less of the fine bentonite than it does the coarse bentonite to arrive at the same reduction in permeability. However, the coarse bentonite is easier to handle and distribute than the fine powder and is easier to incorporate into wet soils. Soils that are to be treated may be mixed with bentonite in various proportions in the lab and tested for permeability. The type and form of bentonite

specified and used in the field should be the same as that used in the laboratory.

Bentonite is delivered in 50 or 100 pound bags or in "super sacks" weighing up to 2 tons. It should be kept dry until it is applied.

Inhalation of fine powder bentonite can irritate the respiratory system. When working around fine powder bentonite, try to stay upwind and wear a respirator to prevent inhalation.

The inspector's responsibilities related to soil, water, and bentonite materials include verifying that:

- Borrow soils are obtained from designated areas.
- In-place soils are of the type specified or are replaced with the type specified.
- Deleterious materials and rock particles larger than the lift thickness divided by 10 are removed from the soil before mixing.
- No more than 25 percent of the soil is larger than the No. 10 sieve.
- Water is relatively clean and meets specification requirements.
- When specified, sodium bentonite with a free swell of at least 22 milliliters per 2 grams is used.
- Bentonite is of the specified form (fine powder or coarse granular) or adjustments are made, as necessary, in the proportioning of bentonite and soil.
- Bentonite is kept dry until spread.
- Bentonite is protected and handled in a manner to prevent blowing.
- Workers are protected from breathing fine powder bentonite.

(2) Equipment (bentonite-treated soil)

Bentonite and soil may be plant mixed; however, it is more common on NRCS jobs to mix them in place. Tractor-drawn agricultural harrows, disks, or plows may not be capable of thoroughly mixing bentonite into the soil. A small-sized rototiller attached to a farm tractor is suitable for small jobs as long as it has a depth adjustment and is capable of mixing to the full lift depth. Heavy, high-speed rotary mixers are better at mixing than the small farm-tractor-mounted tillers. The inspector must ensure that the mixer is capable of mixing the soil and bentonite to the full lift depth. A simple test for determining mixing depth is explained in this chapter.

A water truck and a disk plow are needed to incorporate water into the soil-bentonite mixture. Farm-tractor-mounted tillers may be adequate for incorporating water, but the sticky mixture generally balls up on the tines and limits their mixing ability. The disk plow must be capable of mixing the full depth of the lift. A 24-inch-diameter disk plow can mix a loose lift that is 6 to 8 inches thick if the disks are not too worn and the plow is properly weighted and adjusted. When mixing in water, the surface of the soil-bentonite mixture will be slick and may require that the plow be pulled with track-type equipment such as a dozer, especially when plowing on slopes.

All equipment used to convey or transport bentonite in fine-powder form should be covered or enclosed to avoid dust problems. Drop-type agricultural spreaders, such as those used to apply agricultural lime or fertilizer, may be used to apply the bentonite. Rotary or whirly-bird spreaders should be avoided due to inaccurate application rates and significant bentonite dust problems associated with these types of spreaders.

Bentonite may be applied from bags deposited in a uniform pattern and uniformly spread over the treatment area. Distribution of bentonite delivered in super sacks can be transferred into a drop-type agricultural spreader. Ensure that bentonite is covered to prevent blowing, and protect it from rain.

Most bentonite-treated soils are predominantly coarse-grained and are best compacted with a smooth drum roller or a pneumatic roller. Pad-foot drum rollers may be used if the depth of pad penetration is shallow (1 to 2 in.); however, it is best to avoid penetrating compaction equipment to lessen the potential for puncturing the soil-bentonite liner. Any deeply penetrating compaction equipment, such as a sheepsfoot roller, should not be used.

The inspector's responsibilities related to equipment for treating soils with bentonite include verifying that:

- Mixing equipment is of the type and size specified.

- Mixing equipment can be adjusted for various mixing depths.
- Mixing equipment is capable of thorough mixing at the planned lift depth.
- Equipment used to transport and distribute bentonite is covered or enclosed.
- Equipment used for spreading is capable of uniformly applying the bentonite at the rate specified with little or no bentonite dust problems.

(3) Site and soil preparation (bentonite-treated soil)

The first step in constructing a soil-bentonite liner is to ensure that it has a dense stable subgrade on which to rest. The liner is being constructed to reduce permeability; however, it will not be completely impermeable. Thus, the subgrade soil may require processing or additional materials may have to be imported to provide a subgrade that is filter-compatible with the soil-bentonite liner.

Soil and bentonite will either be mixed in place or in a designated area from where it is transported to the area to be treated. The area to be treated must be shaped to the appropriate lines and grades. Topsoil and unsuitable soil must be removed and replaced with acceptable material. The soil should support the bentonite transport and construction equipment.

For in-place treatment where more than one lift of bentonite-treated soil is to be processed and in situ soils are to be used, soil must be removed and stockpiled prior to treatment of the subgrade or the bottom lift. For example, if the soil-bentonite membrane liner is to have an overall finished thickness of 12 inches, it is likely that two 6-inch thick compacted lifts will be required. If the liner subgrade requires processing, a full 12 inches of soil would have to be removed and stockpiled until completion of subgrade processing. Otherwise, the top 6 inches would be removed and stockpiled until the bottom lift has been treated and compacted, then the stockpiled material would be returned to the area to be treated and compacted.

Frozen material, sod, brush, roots, or other perishable materials must be removed from the foundation and from soils that are to be treated. Rock particles larger than the lift thickness divided by 10 must be removed. If more than 25 percent of the soil is larger than the No. 10 sieve size, soil must be screened to reduce the oversize (plus No. 10) fraction to less than 25 percent.

Soil to be mixed with bentonite should have a moisture content of 1 to 2 percent below optimum, as defined in ASTM D698, at the time the bentonite is applied. If the soil is too wet, the bentonite will become sticky and clump during mixing. Conversely, it is difficult to incorporate water into soil-bentonite mixtures that are very dry, so it is important that the soil not be dryer than approximately 2 percent below optimum. To judge moisture content of nonplastic or slightly plastic soils, mold the soil by hand and drop it a distance of 1 to 2 feet. The molded soil is near optimum if it breaks into only a couple of pieces when dropped. It is too wet if it leaves small traces of moisture on the hand and stays in one piece when dropped. If the soil is moist but breaks into several pieces when dropped, it is at the moisture content (1 to 2% below optimum) desired for adding bentonite.

If bentonite is to be mixed with soil in a processing area and hauled to the placement area, the processing area must first be stripped of topsoil and graded to a relatively smooth and uniform surface. The topsoil may be stockpiled and placed back on the processing area when the area is no longer needed for mixing.

The inspector's responsibilities related to site and soil preparation for bentonite treatment for in-place mixing and curing include verifying that:

- The area to receive the bentonite is shaped to the specified line and grade.
- Topsoil and unsuitable soils are removed and replaced with acceptable material.
- When specified, the subgrade is made filter-compatible with the soil-bentonite mixture.
- Soil above the subgrade or bottom lift is removed and stockpiled.
- Oversize particles are removed from soils to be treated.
- Soil is firm enough to support equipment.
- Soil to be modified has a moisture content that is 1 to 2 percent below optimum.

The inspector's responsibilities related to site and soil preparation for bentonite treatment for mixing and curing at a processing area include verifying that:

- Mixing and curing are conducted at the designated processing area.
- Topsoil is stripped and removed to expose the soil that is to be treated.
- When specified, topsoil is stockpiled to be placed back on the processing area.
- The area is graded to a relatively smooth and uniform surface.

(4) Bentonite application (bentonite-treated soil)

The lift thickness must be limited to a thickness that will allow for uniform incorporation of the bentonite and water throughout the full depth of the lift. The lift thickness must also be limited to allow for uniform compaction to the minimum specified density throughout the full depth of the lift. The thickness of the lift must be known prior to applying the bentonite. It is a good idea to experiment with the mixing and compacting equipment prior to placing the bentonite to ensure that the lift can be fully mixed and compacted with the equipment to the planned lift depth.

The bentonite application rate is expressed in pounds per square foot-inch depth of soil being treated. If a specification requires 0.5 pounds per square foot-inch, 3 pounds per square foot of bentonite would be applied for a 6-inch compacted lift thickness. Proportioning may be different for fine powder bentonite than for coarse granular bentonite. The application rate should be specified for the form of bentonite to be used. If both fine and coarse forms of bentonite are allowed, the application rate should be given for each. The inspector should consult with the engineer if it is not clear for which form of bentonite the application rate is given.

Fine powder bentonite should not be applied during windy conditions. Coarse granular bentonite may be applied in light winds; however, it is best to wait until the wind has subsided whenever possible.

The inspector must ensure that the bentonite is applied evenly over the area at the specified rate. Two applications of bentonite should be made with half of the bentonite applied at a right angle to the other. A test to determine the actual application rate is described in the Sampling and Testing section of this chapter.

Whenever mixing is done in a designated mixing area and the mixture is picked up and transported to the placement site, the mixture must be deposited and bladed to a loose lift thickness that will result in the specified compacted lift thickness. If two or more lifts are to be placed, the seams or edge joints between placement lanes should be staggered so that they are not oriented directly above or below the seams on adjacent lifts.

The inspector's responsibilities related to application of bentonite include verifying that:

- Caution is taken to avoid breathing fine bentonite powder.
- Bentonite is not applied in windy conditions that cause dusting problems.
- Bentonite is uniformly and evenly applied at the rate specified for the form of bentonite used.
- Where the mixture is transported to the placement site, lift seams are staggered.

(5) Mixing (bentonite-treated soil)

After bentonite is uniformly applied, it is mixed into the soil to the proper depth (fig. 9–5). Mixing to incorporate the bentonite should be accomplished in a minimum of two passes of the tiller.

There is a tendency for granular bentonite to segregate to the bottom of the lift with each pass of the tiller. Thus, if granular bentonite is used, limit mixing to two passes. During the first pass the mixing depth should be set to approximately one half the full depth of the lift. The mixing depth should then be adjusted for full depth mixing during the second pass. If possible, one pass should be performed at a right angle to the other.

The inspector should verify that the bentonite is evenly mixed throughout the full depth of the lift. If bentonite is only mixed into the top portion of the lift, it may be necessary to reduce the lift thickness or use a mixer that can incorporate the bentonite to full depth. If most of the bentonite ends up in the bottom portion of the lift, employing the technique, mentioned above, of mixing in two passes with the first pass set

at half the full depth and the second set at full depth will likely improve the bentonite distribution. If the bentonite becomes sticky and begins to clump before being uniformly incorporated, soil moisture is too high. When this occurs, the soil must be dried out prior to continuing bentonite application.

A greater reduction in the permeability will occur if the soil-bentonite mixture is compacted before the bentonite begins to hydrate. Thus, the application and mixing of bentonite should be completed as quickly as possible to reduce the potential for bentonite hydration before the soil-bentonite mixture is compacted. If the bentonite is allowed to remain on the surface, it will be prone to blowing and the portion that remains on the surface will begin to hydrate. Hydrated bentonite will become sticky and clump when mixed. This will prevent even distribution throughout the lift.

After the bentonite is uniformly distributed to the full depth of the lift, water must be incorporated to increase the moisture content to that specified for compaction. It may not be possible to apply all of the needed water at one time, because this amount of water may cause the surface to become slick. A disk plow may be needed to incorporate the water if the soil-bentonite mixture sticks to and becomes balled up on the tiller tines. High-speed tillers may work better than the slower-speed farm tractor tiller implements in preventing the sticky mixture from getting balled up on the tines. The inspector should verify that tests for moisture are conducted and moisture adjustments are made to ensure that the soil moisture is as specified for compaction throughout the full depth of the lift.

Bentonite should not be applied when there is a high probability of wind or rain. It should not be applied if the application, mixing, and compaction processes cannot be completed on the same day. This may preclude applying bentonite late in the workday or whenever it appears that construction will be delayed for any reason.

The inspector's responsibilities related to mixing of bentonite, soil, and water includes verifying that:

- The depth of the mixture allows for the proper proportioning of bentonite and soil.
- The depth of the mixture is no greater than can be effectively mixed by the mixing equipment.
- The soil and bentonite are uniformly mixed prior to adding water.
- Water is evenly distributed throughout the mixture to arrive at the specified moisture content for compaction.
- The process is not begun unless the entire process from bentonite application through compaction can be completed within the same day.

Figure 9–5 Mixing benonite to the proper depth with a tiller



(6) Compaction (bentonite-treated soil)

The soil-bentonite mixture should be compacted before the bentonite has had a chance to completely swell to produce the lowest possible permeability of a given mixture. The soil-bentonite mixture should be compacted as soon as possible after incorporating the water.

Compaction processes and principals for bentonite-treated earthfill are similar to those employed when compacting untreated earthfill (fig. 9–6). The lift thickness must be limited to a depth that will allow the specified density to be attained throughout the full lift depth. The density is normally specified as a percentage of standard Proctor maximum density as determined by ASTM D698. A Proctor curve is developed using the treated material in order to determine the

maximum density and optimum moisture of the soil. For more on compaction, refer to the section on earthfill compaction in chapter 8 of this handbook.

On slopes that are steeper than 4H:1V, the compactor should be supported by being cabled to a dozer or other equipment that is positioned to travel parallel to the compactor on relatively level ground above the top of the slope. Otherwise, the compactor may slip or slide down the slope and damage the soil-bentonite liner.

The inspector's responsibilities related to compaction of bentonite-treated soil includes verifying that:

- Compaction is accomplished as soon as practicable after incorporating the bentonite and water.
- Deep penetrating compaction equipment is not used.
- The lift thickness is conducive to attaining the specified density throughout the full lift depth.
- The mixture is compacted to the minimum density specified throughout the depth of the lift.
- On slopes that are steeper than 4H:1V, the compactor is cabled to a dozer or other equipment to prevent slippage.

(7) Protective cover (bentonite-treatedsoil)

Bentonite-treated soil must be protected against drying to prevent shrinkage and cracking. A 6 inch or thicker layer of compacted soil is typically placed on top of the soil-bentonite liner. This protective cover should be installed as quickly as possible to prevent drying. The soil should be of a quality similar to the treated soils and be compacted to the specified density.

The inspector's responsibilities related to installation of the protective cover include verifying that:

- The cover is installed as soon as practicable after completion of the soil-bentonite liner.
- The cover is compacted to the specified density.

Figure 9–6 Series of 3 photos showing subgrade preparation, placement, and compaction of treated soil







(d) Dispersants

(1) Materials (dispersants)

Some permeable fine-grained soils may be made less permeable with the addition of dispersants. When fully incorporated into the soil, a dispersant breaks down electrochemical bonds between the soil particles, making it easier for the particles to be rearranged and compacted into a dense, less-permeable state. NRCS CPS Code 521B, Pond Sealing or Lining, Soil Dispersant, has useful information on the use of dispersants as a soil amendment.

Soil to be treated will be aggregated clays and silts that are known to have higher than normal permeability caused by their aggregated structure. The permeability of these soil types can be significantly reduced by adding soil dispersants at a rate estimated from prior experience or determined from laboratory tests. The soil should contain no frozen material, sod, brush, roots, or other perishable materials. Rock particles larger than the maximum specified particle size must be removed from the soil prior to treatment.

The inspector must verify that the soils used are of the type specified. When borrow soils are used, the inspector must verify that the specified soils are obtained from designated borrow areas. When in-place soils are used, the inspector must verify that the type of soil is as specified or is removed and replaced with the specified type.

Water that is relatively clean and free of organic contaminants is acceptable for use with dispersant-treated soils. The presence of sediments in the water should have no adverse effect on the dispersant-treated soil.

Dispersants of various types may be used and are available from a variety of sources. The three most commonly used in NRCS work are tetra sodium pyrophosphate (TSPP), sodium tripolyphosphate (STPP), and soda ash (Na_2Co_3). These dispersants are sold in various grades with particle size being the difference between grades. Generally, the coarser grades are better for soil modification because they flow better than the very fine grades and are not as prone to blowing.

The type of dispersant used should be determined from the results of laboratory tests of the soil mixed with various dispersants, compacted, and tested for permeability. The type of dispersant specified and used in the field should be the same as that used in the laboratory. The grade of dispersant used in the field is not critical.

Dispersants are delivered in 50-pound bags, 1- to 2-ton sacks, or in bulk up to 22.5 tons. They dissolve in water and should be kept dry until applied. Bulk dispersants in the form of a fine powder should be transported in containers that are covered to protect against blowing.

Inhalation of dispersant can irritate the respiratory system. When working around a dispersant, try to stay upwind and wear a respirator to prevent inhalation.

The inspector's responsibilities related to soil, water, and dispersant materials include verifying that:

- Borrow soils are obtained from designated areas.
- In-place soils are of the type specified or are replaced with the type specified.
- Deleterious materials and rock particles larger than the specified allowable maximum particle size are removed from the soil before mixing.
- Water is relatively clean and meets specification requirements.
- The specified type of dispersant is used.
- Dispersant is kept dry until spread.
- Dispersant is protected and handled in a manner to prevent blowing.
- Workers and others are protected from breathing the dispersant.

(2) Equipment (dispersants)

The dispersant and soil may be plant mixed; however, it is more common on NRCS jobs to mix them in place. Tractor-drawn agricultural harrows, disks, or plows do a poor job of incorporating the dispersant into the soil. A small-sized rototiller attached to a farm tractor is suitable for small jobs as long as it has a depth adjustment and is capable of digging through the full lift depth. Heavy, high-speed rotary mixers are better at mixing than the small farm tractor-mounted tillers. The inspector must ensure that the mixer is capable of mixing the soil and dispersant to the full depth of

the lift. A simple test for determining mixing depth is explained in this chapter.

A water truck and a disk plow are generally needed to incorporate water into the soil-dispersant mixture. Farm tractor-mounted tillers may be adequate for incorporating water. The disk plow or tiller must be capable of mixing the full depth of the lift. A 24-inch-diameter disk plow can mix a loose lift that is 6 to 8 inches thick if the disks are not too worn and the plow is properly adjusted. When mixing in water, the surface of the soil-dispersant mixture will be slick and may require that the plow be pulled with track-type equipment such as a dozer, especially when plowing on slopes.

All equipment used to convey or transport dispersant in bulk form should be covered or enclosed to avoid dust problems. Drop-type agricultural spreaders, such as those used to apply agricultural lime or fertilizer, may be used to apply the dispersant. Rotary or whirly-bird spreaders should be avoided due to inaccurate application rates and significant dispersant dust problems associated with these types of spreaders. Dispersants may be mixed with water and applied in slurry form if the soil moisture is below the specified compaction moisture content. An accurate rate of application can be attained with a spray bar as long as the flow and rate of travel are consistent. It is difficult to attain an accurate rate of application with a hand directed hose. These should only be used in tight areas where equipment travel is limited.

Dispersant-treated soils are usually fine-grained and are best compacted with a sheepsfoot roller. Deeply penetrating compaction equipment such as a sheepsfoot roller will puncture the soil-dispersant liner during the compaction process; however, as compaction continues the compactor should walk out of the liner. When this occurs, the compactor feet will walk on the surface with only slight penetration of the liner. If density tests show the specified density is being attained and the compactor is still penetrating the liner to a significant depth, it may be necessary to finish compaction with a smooth drum or pneumatic roller. A smooth drum or pneumatic roller would not effectively compact a thick lift, but would be able to compact the top few inches after the penetrating compaction equipment has compacted the lower portion of the lift.

The inspector's responsibilities related to equipment for dispersant treatment include verifying that:

- Mixing equipment is of the type and size specified.
- Mixing equipment can be adjusted for various mixing depths.
- Mixing equipment is capable of thoroughly mixing at the planned lift depth.
- Equipment used to transport and apply fine powder dispersant is covered or enclosed.
- Equipment used for spreading is capable of uniformly applying the dispersant at the rate specified with little or no dispersant dust problems.

(3) Site and soil preparation dispersants)

The first step in constructing a soil-dispersant liner is to ensure that it has a dense, stable, nonporous subgrade on which to rest. The liner is being constructed to reduce permeability; however, it will not be completely impermeable. Thus, the subgrade soil may require processing or additional materials may have to be imported to provide a subgrade that is filter-compatible with the soil-dispersant liner.

Soil and dispersant will either be mixed in place or in a designated area where it is picked up and transported to the area to be treated. The area to be treated must be shaped to the appropriate lines and grades. Topsoil and unsuitable soil must be removed and replaced with acceptable material. The soil should support the dispersant transport and construction equipment so as to avoid rutting.

For in-place treatment where more than one lift of dispersant treated soil is to be processed and in situ soils are to be used, soil must be removed and stockpiled prior to treatment of the subgrade or the bottom lift. For example, if the soil-dispersant membrane liner is to have an overall finished thickness of 12 inches, it is likely that two 6-inch thick compacted lifts will be required. If the liner subgrade requires processing, a full 12 inches of soil would have to be removed and stockpiled until completion of subgrade processing. Otherwise, the top 6 inches would be removed and stockpiled until the bottom lift has been treated and compacted, then the stockpiled material would be returned to the area to be processed in place and compacted.

Frozen material, sod, brush, roots, or other perishable materials must be removed from the foundation and from soils that are to be treated. Rock particles larger than the specified allowable particle size must be removed.

It is difficult to incorporate water into soil-dispersant mixtures because adding water to the surface of the mixture makes for a slick surface. Traction will be significantly reduced for the tractor or dozer pulling the disk plow. The problem is compounded if the equipment has to plow the slick mixture on a slope. Thus, at the time the dispersant is applied, the soil should have a moisture content within the range specified for compaction.

If the dispersant is to be mixed with soil in a processing area and hauled to the placement area, the processing area must first be stripped of topsoil and graded to a relatively smooth and uniform surface. The topsoil will be stockpiled and placed back on the processing area when the area is no longer needed for mixing.

The inspector's responsibilities related to site and soil preparation for dispersant treatment for in-place mixing and curing include verifying that:

- The area to receive the dispersant is shaped to the specified line and grade.
- Topsoil and unsuitable soils are removed and replaced with acceptable material.
- When specified, the subgrade is made filter-compatible with the soil-dispersant mixture.
- Soil above the subgrade or bottom lift is removed and stockpiled.
- Oversize particles are removed from soils to be treated.
- Soil is firm enough to support equipment.
- Soil has a moisture content within the range specified for compaction.

The inspector's responsibilities related to site and soil preparation for dispersant treatment for mixing and curing at a processing area include verifying that:

- Mixing and curing are conducted at the designated processing area.
- Topsoil is stripped and removed to expose the soil that is to be treated.
- When specified, topsoil is stockpiled to be placed back on the processing area.
- The area is graded to a relatively smooth and uniform surface.

(4) Dispersant application (dispersants)

The lift thickness must be limited to a thickness that will allow for uniform incorporation of the dispersant and water throughout the full depth of the lift. The lift thickness must also be limited to allow for uniform compaction to the minimum specified density throughout the full depth of the lift. The thickness of the lift must be known prior to applying the dispersant. It is a good idea to experiment with the mixing and compacting equipment prior to placing the dispersant to ensure that the lift can be fully mixed and compacted with the equipment to the planned lift depth.

The dispersant application rate is normally expressed in pounds per square foot -inch depth of soil being treated. Proportioning should be the same for all grades of a specific type of dispersant. Proportioning varies between dispersant types. For example, STPP and TSPP may be applied at a rate of 7.5 pounds per square foot-inch, however, soda ash may require twice as much material to achieve the same reduction in permeability. A rate of 7.5 pounds per square foot-inch may be difficult to achieve as it results in only a light dusting of material on the surface. Attaining a uniform distribution is generally easier with soda ash than the other dispersants.

Dispersant should not be applied in high winds. The inspector must verify that all workers and others present wear approved masks to protect against inhalation as necessary to avoid inhalation of dispersant.

The dispersant must be applied evenly over the area at the specified rate. For a more even distribution, two applications of dispersant should be made with half of the dispersant applied at a right angle to the other. A test to determine the actual application rate is described in this chapter.

Whenever mixing is done in a designated mixing area and the mixture is picked up and transported to the placement site, the mixture must be deposited and bladed to a loose lift thickness that will result in the

specified compacted lift thickness. If two or more lifts are to be placed, the seams or edge joints between placement lanes should be staggered so that they are not oriented directly above the seams on the adjacent lift.

The inspector's responsibilities related to application of dispersant include verifying that:

- Caution is taken to avoid breathing dispersant.
- Dispersant is not applied in windy conditions that cause dusting problems.
- Dispersant is uniformly and evenly applied at the rate specified for the type of dispersant used.
- Where the mixture is transported to the placement site, lift seams are staggered.

(5) Mixing (dispersant)

After the dispersant is uniformly applied, it is mixed into the soil to the proper depth. It is recommended that mixing to incorporate the dispersant be accomplished in two or more passes of the tiller. If possible, one pass should be performed at a right angle to the other.

The inspector should verify that the dispersant is evenly mixed throughout the full depth of the lift. If dispersant is only mixed into the top portion of the lift, it may be necessary to reduce the lift thickness or change to a mixer that can incorporate the dispersant to full depth.

The application and mixing of dispersant should be completed as quickly as possible to reduce the potential for the dispersant to become airborne. Dispersant should not be applied when there is a high probability of wind or rain, or if the application, mixing, and compaction processes cannot be completed on the same day. This may preclude applying dispersant late in the workday or whenever it appears that construction will be delayed for any reason.

After the dispersant is uniformly distributed to the full depth of the lift, additional water may be needed to increase the moisture content to that specified for compaction. It may not be possible to apply all of the needed water at one time, because this amount of water may cause the surface to become slick. A disk plow may be needed to incorporate the water if the soil-dispersant mixture sticks to and becomes balled up on the tiller tines. High-speed tillers may work better than the slower-speed farm tractor tiller implements in preventing the mixture from getting balled up on the tines. The inspector should verify that tests for moisture are conducted and moisture adjustments are made to insure that the soil moisture is as specified for compaction throughout the full depth of the lift.

The inspector's responsibilities related to mixing of dispersant, soil, and water includes verifying that:

- The depth of the mixture allows for the proper proportioning of dispersant and soil.
- The depth of the mixture is no greater than can be effectively mixed by the mixing equipment.
- The soil and dispersant are uniformly mixed prior to making final moisture adjustment.
- Water is evenly distributed throughout the mixture to arrive at the specified moisture content for compaction.
- The process of mixing and compacting the dispersant, soil, and water is completed within the same workday as it is started.

(6) Compaction (dispersants)

Compaction processes and principals for dispersant-treated earthfill are the same as those for untreated earthfill. The lift thickness must be limited to a depth that will allow the specified density to be attained throughout the full lift depth. The density is normally specified as a percentage of standard Proctor maximum density as determined by ASTM D698. The Proctor curve is developed using the treated material in order to determine the maximum density and optimum moisture of the mixture.

Whenever deep penetrating compactors are used, compaction is attained in the lower portions of the lift first. As the lower portion of the lift becomes dense enough to support the penetrating tines of the compactor, the compactor will rise. This process will continue until the ends of the tines are walking on the top of the lift. If the specified density is achieved and the compactor continues to penetrate the lift, a less penetrating compactor may be needed to finish compaction so as to attain the full lift thickness of the liner without having holes punctured in the surface of the lift.

On slopes that are steeper than 4H:1V, the compactor should be supported by being cabled to a dozer or other equipment that is positioned to travel parallel to the compactor on relatively level ground above the top of the slope. Otherwise, the compactor may slip or slide down the slope and damage the liner.

For more on compaction, refer to the section on earthfill compaction in chapter 8 of this handbook.

The inspector's responsibilities related to compaction of dispersant treated soil includes verifying that:

- The lift thickness is conducive to attaining the specified density throughout the full lift depth.
- The mixture is compacted to the minimum density specified throughout the depth of the lift.
- Deep-penetrating compaction equipment walks out of the liner or compaction is finished with less-penetrating compaction equipment.
- On slopes that are steeper than 4H:1V, the compactor is cabled to a dozer or other equipment to prevent slippage.

(7) Protective cover (dispersants)

Dispersant-treated soil must be protected against drying to prevent shrinkage and cracking. Normally, a minimum of 6 inches of compacted soil is placed on top of the soil-dispersant liner. This liner should be installed as quickly as possible to prevent drying. The soil should be of a quality similar to the treated soils and be compacted to the specified density.

The inspector's responsibilities related to installation of the protective cover includes verifying that:

- The cover is installed as soon as practicable after completion of the soil-dispersant liner.
- The cover is compacted to the specified density.

645.0902 Sampling and testing

During the course of the work, the inspector should perform quality assurance tests, as required, to identify materials and determine application rate, reference compaction test values, moisture content, and density of the modified soil in place. The tests performed by the inspector will be used to verify that the modified soil conforms to specification requirements. Tests made by the NRCS inspector do not replace the testing to be conducted under the contractor's quality control program. For work performed under formal contract, the contractor conducts all required quality control tests in accordance with the approved contractor quality control plan to ensure that work performed meets all contract requirements.

Sampling and testing is the act, process, or technique of selecting a representative part of a soil or soil-amendment mixture for the purpose of determining characteristics of the whole volume of soil to be represented by the sample. The process involves the following:

- Assessing what the sample and test will represent
- Employing proper sampling techniques
- Preserving the sample so that when tested it is representative of the field condition
- Performing the test in accordance with the specified test standard
- Reporting the results as required by the test standard
- Documenting the results and exactly what the results are intended to represent

For an example of proper sampling and testing, assume that a soil is to be compacted within a specified moisture range. Tests should be made of samples obtained from the driest and the wettest soils within the area to be represented by the tests because, if the moisture contents of the driest and wettest soils fall within the specified range, the moisture content of the remainder of the soil will fall within the specified range. The sampling and testing process would be as follows:

- Samples are obtained from near the center of the loose lift.
- Three or four samples are combined to form a composite sample.
- Samples are immediately placed in an airtight container and transported to the field lab in accordance with ASTM D4220, Standard Practices for Preserving and Transporting Soil Samples.
- Tests are performed and the results reported in accordance with ASTM D2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.
- Test results are documented in a manner that well defines the limits of the area represented by the tests.
- Corrective action to adjust the moisture content to within the specified range is taken if necessary.

In the example, assume that the soil is being placed in a dam. The entire process, including incorporation of water, controlling the lift thickness and compaction, is performed well over most of the area with the exception of the area where the dam ties into the abutment. Since density tests that are made in the open area of the fill would not represent the density of the earth fill near the abutment, density tests should be made near the abutment. If the density near the abutment interface is below the specified density, a series of tests should be made from the abutment to the open area to delineate the area where the density is below that specified.

For project work, the inspector must rely on the quality assurance plan and quality control (QC) plan as guidance for determining the frequency of testing. Most of the testing should be conducted by the contractor's quality control personnel with quality assurance (QA) testing being done to verify the adequacy of the QC program. For nonproject work, the line between QA and QC may be less defined; the inspector may be the only one doing testing on the job. Regardless of the type of work, project or nonproject, the inspector must ensure that adequate testing is being performed to assure and document the work is installed as per design.

QA is not just performing companion testing of the earth fill to ensure that similar results are obtained as were obtained by the QC team. QA testing should verify that the equipment used by the QC team is calibrated and that procedures are correctly followed. As an example, QA procedures should ensure that the QC persons are using the correct procedures for correcting nuclear meter water contents. Other things to check would be how they are selecting reference Proctor tests using family of curves, or other procedure, and whether this is done properly.

Appendix A contains checklists designed to assist QA inspectors in performing their duties. These checklists incorporate all of the bulleted items in this chapter under the headings "The inspector's responsibilities… includes verifying that." The following inspection checklists are available in appendix A:

- NEH 645 CL 9.1—Soil-Cement Checklist
- NEH 645 CL 9.2—Lime-Treated Earthfill Checklist
- NEH 645 CL 9.3—Bentonite-Treated Soil Checklist
- NEH 645 CL 9.4—Dispersant Checklist

(a) Soil identification

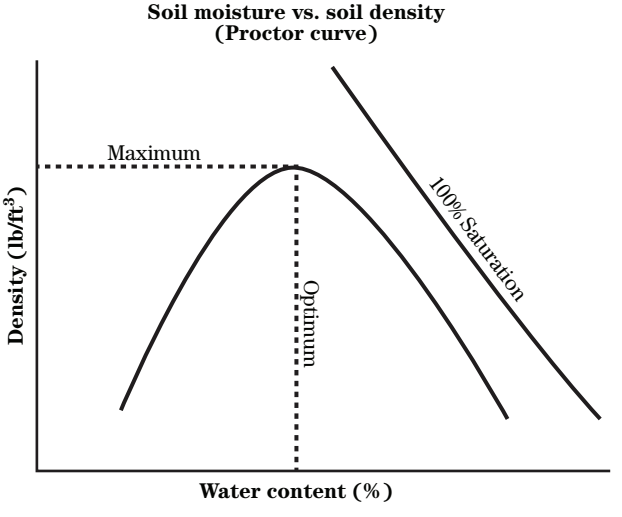
Laboratory procedures for classifying soils are provided in ASTM D2487, Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System). The procedures described are commonly performed in a laboratory setting to classify the soils that are to be modified. Amendment application rates are then specified for each class of soil to be modified in the field. The soils to be modified must be properly identified in the field to ensure the amendment application rate conforms to that determined by the laboratory for each class of soil being modified. Procedures for making visual-manual descriptions of soils are given in ASTM D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). The inspector must use this procedure to classify soils in the field in order to ensure amendments are being applied at the specified rate. Chapter 7 of this handbook contains more information on soil identification and worksheet 7.1 in appendix B has been developed for this purpose.

(b) Moisture density tests

Compaction moisture and in-place density are specified as a percentage of the optimum moisture and maximum density attained by compacting the soil or soil-amendment mixture into a mold using a specific compaction effort. The soil or mixture is compacted at various moisture contents resulting in a wet density value corresponding to the moisture content at which it is compacted. The wet density value is converted to dry density and plotted against the percent moisture to form a curve similar to the one shown in figure 9–7. This curve is known as a Proctor Curve named after R.R. Proctor, who developed the procedure.

For soil-cement, the moisture-density curve is determined in accordance with ASTM D558, Moisture Density (Unit Weight) Relations of Soil-Cement Mixtures. For other soil-amendment mixtures, the moisture-density curve is determined according to ASTM D698, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. The same amount of compactive effort (standard effort) and mold size are used for both D558 and D698. ASTM D1557, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort, is sometimes specified to be used with soil-cement, but it is not commonly specified by NRCS when modifying soils with cement, pozzolan, lime, bentonite, or dispersants.

Figure 9–7 Moisture-density curve (Proctor curve)



Proctor curves should be prepared for each soil-amendment mixture. These curves are prepared in the laboratory at the time the mix is proportioned. Due to the variability of soils as they occur in the field, the small sample used to develop the lab curves may not represent the soil being modified in the field. It is common to develop Proctor curves in the field to obtain a more accurate moisture-density relationship for each soil-amendment mixture.

Materials excavated from different borrow sources can vary significantly from load to load. Several Proctor curves may be needed to represent all of the soil being modified. Poor selection of the Proctor curve is likely the most common error in verifying that conformance with compaction specifications. This error may be avoided by employing a family of curves and the one point method.

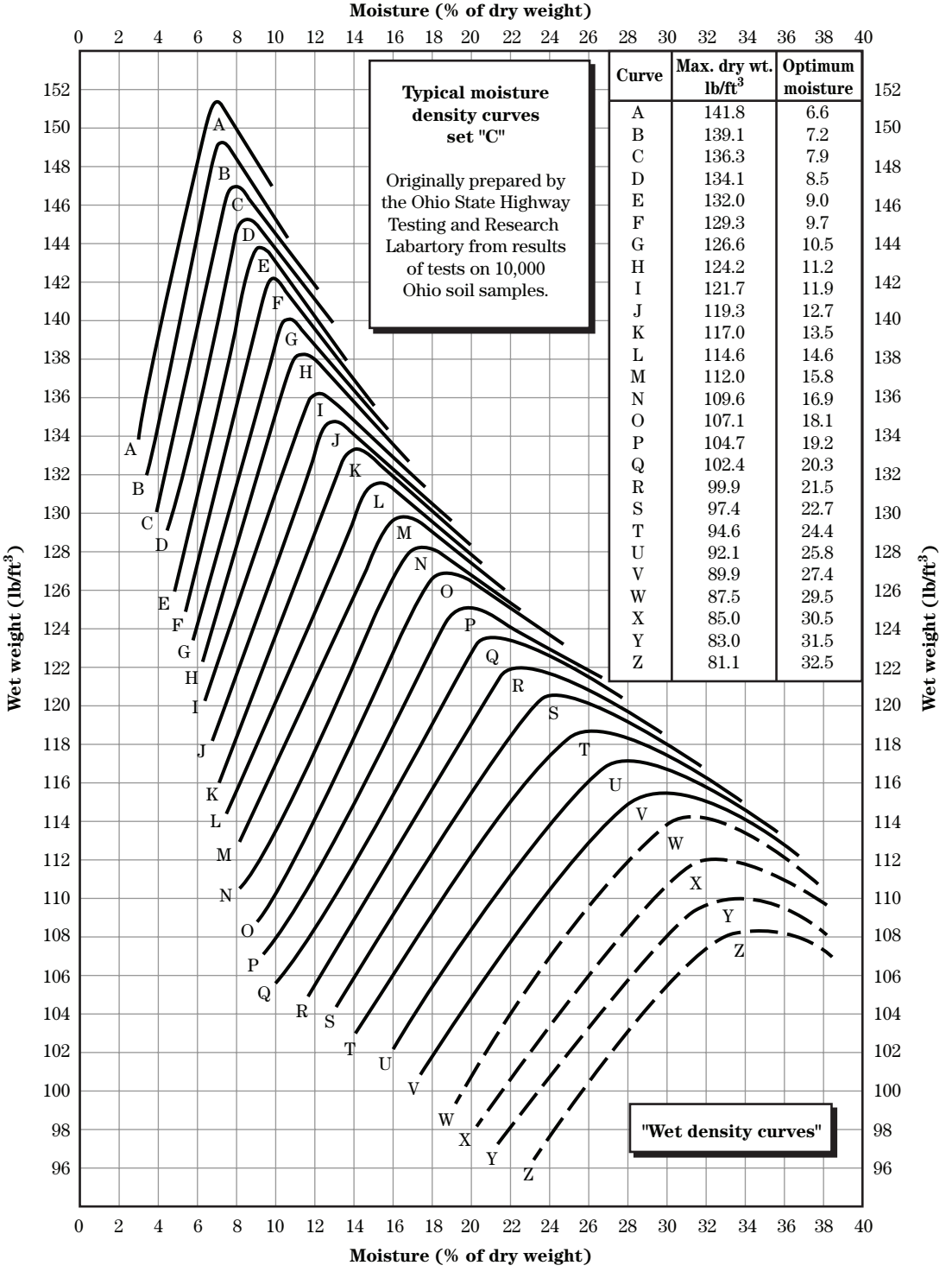
To develop a family of curves, several curves are plotted on one sheet. As few as three soil-amendment mixtures may be all that is needed to develop a family of curves that adequately represents all of the soil-amendment mixtures on any one site. The density of a soil-amendment mixture at a moisture content that is approximately two percent dry of optimum can then be plotted on the family of curves to determine which curve best represents the moisture-density relationship for that soil-amendment mixture. This shortcut method is termed the one point method.

The family of curves shown in figure 9–8 was established by the Ohio Department of Transportation. Other entities have developed similar families of curves. These curves may be referenced when working with amended soils as the moisture-density relationships have proven to be compatible from region to region and from amended soil to nonamended soil. Proctor curves that are developed from soil-amendment mixtures on site can be plotted on one or more of these established sets of curves to verify their compatibility.

For more on the family of curves and the one-point method, refer to chapter 8 of this handbook.

After the moisture-density curve for the soil-amendment mixture is determined, the dry density and moisture content that must be attained in the field can be computed. This can best be explained by example. Assume the maximum dry density is 120 pounds per cubic foot and the optimum moisture is 14 percent. If

Figure 9–8 Typical family of curves



Curve	Max. dry wt. lb/ft^3	Optimum moisture
A	141.8	6.6
B	139.1	7.2
C	136.3	7.9
D	134.1	8.5
E	132.0	9.0
F	129.3	9.7
G	126.6	10.5
H	124.2	11.2
I	121.7	11.9
J	119.3	12.7
K	117.0	13.5
L	114.6	14.6
M	112.0	15.8
N	109.6	16.9
O	107.1	18.1
P	104.7	19.2
Q	102.4	20.3
R	99.9	21.5
S	97.4	22.7
T	94.6	24.4
U	92.1	25.8
V	89.9	27.4
W	87.5	29.5
X	85.0	30.5
Y	83.0	31.5
Z	81.1	32.5

the specification requires the mixture be placed at a moisture content of 2 to 4 percent above optimum, the moisture content at the time of placement would have to be 16.0 to 18.0 percent. If the specification requires the mixture be compacted to at least 95 percent of maximum density, the density of the in-place mixture would have to be equal to or greater than 114 pounds per cubic foot. The moisture and density of modified soils in-place can be determined by one of the following methods:

- Moisture
  - — ASTM D2216, Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
  - — ASTM D6938, Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth). The hydration of lime affects the moisture reading of a nuclear gauge. If the soil amendment is lime, it is recommended that the moisture content be obtained by a method other than the nuclear gauge.
  - — ASTM D4643, Standard Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method
  - — ASTM D4944, Standard Test Method for Field Determination of Water (Moisture) Content of Soil by Calcium Carbide Gas Pressure Tester
  - — ASTM D4959, Standard Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating
- Density
  - — ASTM D1556, Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method
  - — ASTM D2167, Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method
  - — ASTM D2937, Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method
  - — ASTM D6938 Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
  - — ASTM D4564, Standard Test Method for Density of Soil in Place by the Sleeve Method

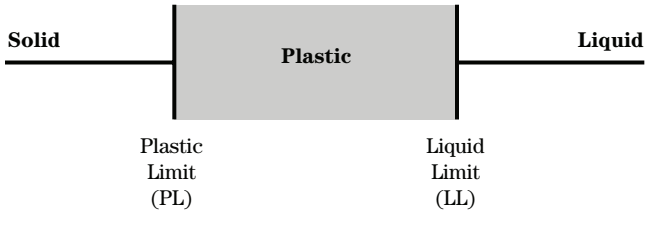
For a more detailed description of moisture and compaction tests, refer to chapter 8 of this handbook.

(c) Plasticity tests (Atterberg limits)

Cohesive soil is brittle whenever it is dry and becomes plastic at a specific moisture content termed the plastic limit. Above the plastic limit the soil will remain plastic until it contains so much water that it liquefies. The moisture content at which the soil becomes liquid is called the liquid limit. The plastic and liquid limits are called Atterberg limits, after the soil scientist who developed the test method by which they are determined. The difference between the liquid and plastic limits, termed the plasticity index (PI), represents the range in water contents through which the soil is in the plastic state. This is illustrated in figure 9–9.

The LL and PI are used to classify soils in the laboratory according to the Unified Soil Classification System (USCS). When treating a high PI soil with lime to reduce its plasticity, specifications may require the liquid limit and PI of the treated soil to be determined to verify that they are being reduced to the specified values. The standard test methods for determining the Atterberg limits and plasticity index of a soil is described in ASTM D4318, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

Figure 9–9 Atterberg limits



The plasticity index (PI)=LL–PL

(d) Dispersion tests

When adding lime to a soil to make it less dispersive, dispersion tests are made to identify dispersive soils and to monitor the effectiveness of the treatment. Three standard tests are available to determine the dispersion characteristics of the soil or soil-amendment mixture:

- ASTM D6572, Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test
- ASTM D4221, Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer
- ASTM D4647, Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test

The crumb test is the simplest dispersion test and the one most commonly used by field personnel. The double hydrometer test is commonly used in the lab. The pinhole test is a test that is specified to be used in the lab or field whenever it has been determined that the soils are dispersive but the degree of dispersion is not evident from the crumb test. This is not a common occurrence; the pinhole testing apparatus is not commonly stocked by NRCS inspection personnel.

(e) Soil-cement tests

The following tests are applicable to soil-cement and do not apply to the other types of soil modification described in this chapter:

- ASTM D558, Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures
- ASTM D559, Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures
- ASTM D560, Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures
- ASTM D806, Standard Test Method for Cement Content of Hardened Soil-Cement Mixtures
- ASTM D1632, Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory
- ASTM D1633, Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders
- ASTM D2901, Standard Test Method for Cement Content of Freshly Mixed Soil-Cement

ASTM D558, D559, and D560 are tests that are typically conducted in the laboratory at the time the mix is proportioned. D558 is also conducted in the field to develop field Proctor curves. D806 and D2901 may be conducted if the amount of cement being added to the mixture is in question; otherwise, they are not commonly used for NRCS soil-cement work. D1632 and D1633 may be employed to verify that the compressive strength of the soil-cement mixture attains the strength anticipated by the design engineer.

(f) Lime tests

The following tests apply to soil-lime mixtures only:

- ASTM D3155, Standard Test Method for Lime Content of Uncured Soil-Lime Mixtures
- ASTM D3551, Standard Practice for Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer
- ASTM D5102, Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures

ASTM D3155 is not commonly conducted for NRCS work if the process of applying and incorporating the lime is well controlled and Atterberg limits tests of field-modified soil verify the effectiveness of the lime treatment at reducing the liquid limit and PI of the soil. ASTM D3551 is commonly conducted in the laboratory when proportioning soil-lime mixtures. ASTM D5102 is conducted on jobs where the strength of the lime-treated soil is specified such as when lime is used to stabilize and improve the strength of a road base. NRCS normally uses lime to lower the liquid limit and PI and is not as concerned with the strength gain of a soil-cement mixture.

(g) Application rate

When applying granular materials, the inspector must ensure that the material is applied at the specified rate. One way of doing this is to place a tarpaulin on the soil surface in the path of the distribution equipment. The weight of the granular material that falls on the tarpaulin can be determined by subtracting the weight of the tarpaulin from the weight of the tarpaulin and material. The application rate can then be determined by dividing the weight of the granular material by the area of the tarpaulin to yield an application rate in terms of weight per unit area. Worksheet WS 9.1, Granular Material Application Rate, can be used to calculate the application rate.

(h) Mixing depth

The depth of plowing and mixing must be determined whenever amendments or water are being mixed into the soil. One way to verify that the tiller or plow is mixing to the full depth of the lift is to place a piece of surveyor's ribbon on the ground and cover it with the soil that is to be treated. After deposing the soil to be treated, it should be bladed to the planned loose lift thickness and mixed with the plow or mixer. If the plow or mixer is mixing to full loose-lift depth, some of the survey ribbon will be brought to the surface. If the survey ribbon is not visible, dig into the mixed soil just above where the ribbon was placed until the ribbon is found. If the ribbon has not been disturbed, the mixer did not mix to the planned depth. If some of the ribbon is found mixed into the soil mixture but none was brought to the surface, the plow or mixer reached to the bottom of the lift, but it likely did a poor job of mixing since it did not bring some of the ribbon to the surface.

645.0903 Records and reports

The following records and reports are related to soil modification:

- Daily diary—used to record the day to day activities of construction
- WS 8.1—Test Fill Report
- WS 8.2—Weekly Summary of Density Determinations
- WS 8.3—Determination of Volume of Compaction Mold
- WS 8.4—Worksheet for Reference Density Compaction Data
- WS 8.5—Moisture Content Determination Summary Sheet for ASTM Methods
- WS 8.6—Earthfill Construction Report
- WS 8.7—Bulk Sand Density Determination and Calibration of Cone and Base Plate for ASTM D1556

- WS 8.8—In-Place Moisture-Density Determination: Sand Cone Method ASTM D1556
- WS 8.9—In-place Moisture-Density Determination: Rubber Balloon Method ASTM D2167
- WS 8.10—In-place Moisture-Density Determination: Calibrated Cylinder Method ASTM D2937
- WS 8.11—Nuclear Compaction Test Data ASTM D6938
- WS 8.12—In-place Moisture-Density Determination: Template and Plastic Liner Method ASTM D5030
- WS 8.13—Correction of Unit Weight and Water Content for Soils Containing Oversized Particles ASTM D4718
- WS 9.1—Computing the Application Rate of Granular Materials

Blank worksheets and filled examples of all of the worksheets are in appendix B of this handbook. Not all of the worksheets listed will be used for a specific job. The inspector must select worksheets that are applicable when inspecting the modification of soils at a specific site.

Inspectors should record in the daily diary a description of the soil modification work inspected on a daily basis and the conditions under which the work took place. This includes the weather conditions, the type of materials and features, finishing and curing processes, and other descriptions of the work performed. An example of a daily entry is provided in appendix C of this handbook.

645.0904 References

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