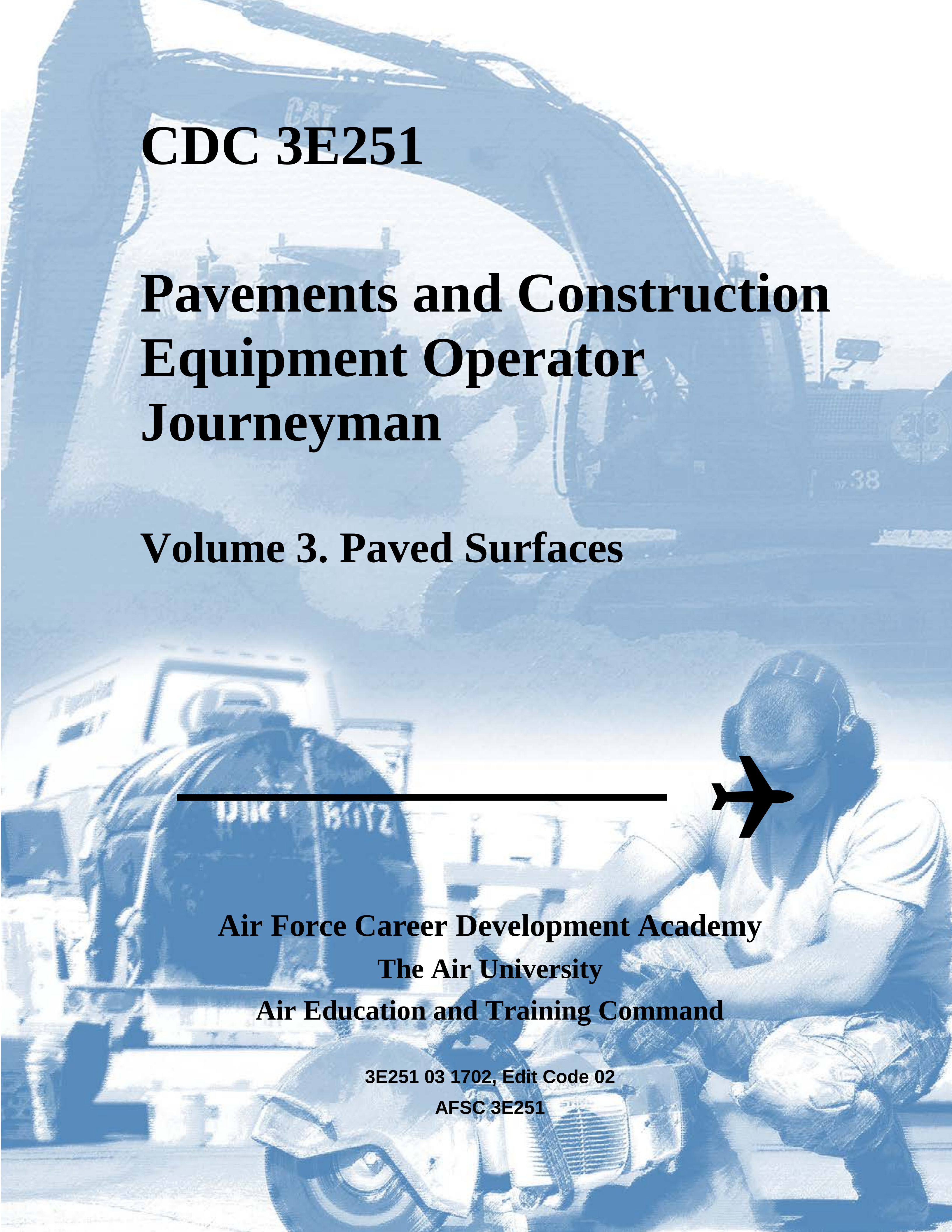

CDC 3E251

Pavements and Construction Equipment Operator Journeyman

Volume 3. Paved Surfaces

Air Force Career Development Academy
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THIS VOLUME of career development course (CDC) 3E251, *Pavements and Construction Equipment Operator Journeyman*, provides information about concrete and asphalt pavement construction.

In this volume, unit 1 considers contructing paved surfaces as it discusses effective site preparation and area layout; preparing a base course, which includes excavating an area for construction, properly computing material and its placement; and finally, it discusses the construction of surface and subsurface drainage structures, as well as inspecting and repairing them.

Unit 2 focuses on Portland cement concrete pavement as it presents the types of concrete material and their uses, design mixes, and concrete additives; it also discusses the preparation for concrete, including calculations, formwork, load transfers, and material reinforcements; and finally, it considers the concrete quality, preparing and testing, the worksite itself, and placing as well as finishing the concrete.

Unit 3 considers the effective maintenance of Portland cement concrete pavement through the process of inspecting for and determining the types of defects within the pavement, repairing and replacing them, and the proper maintenance of joints and cracks.

Unit 4 discusses asphalt cement concrete pavement with an overview of bituminous materials; preparing a base for an asphalt surface; asphalt surface construction; as well as computing, inspecting, placing, and compacting asphalt.

Finally, unit 5 considers asphalt cement concrete pavement maintenance as it indentifies the types and causes of pavement defects and discusses their inspection; it also looks at effective pavement repair through sealing of cracks and removal and replacement of pavement; and finally, it discusses the treatment of road surfaces and the purpose and maintenance of road shoulders.

A glossary is included for your use.

Code numbers on figures are for preparing agency identification only.

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This volume is valued at 18 hours and 6 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Unit 1. Constructing Paved Surfaces

AS PAVEMENTS AND CONSTRUCTION equipment operator or supervisor, you will build, repair, and maintain roads, runways, and other paved areas. Some of these surfaces will be concrete; others will be asphalt; and still others will use gravel, dirt, or reclaimed material from another project. The Department of Defense (DOD) initiated the Unified Facilities Criteria (UFC) program to unify all technical criteria and standards pertaining to planning, design construction and operation, and maintenance of real property facilities. This gives us guidelines to follow when preparing, placing and finishing pavements projects. The following are specific UFCs that provide our technical publications and guide specifications for pavements:

- 3–250–01FA, *Pavement Designs for Roads, Streets, Walks, and Open Storage Areas*.
- 3–250–03, *Standard Practice Manual for Flexible Pavements*.
- 3–250–04, *Standard Practice for Concrete Pavements*, *with Change 2*.
- 3–250–06, *Repair of Rigid Pavements Using Epoxy Resin Grouts, Mortars and Concretes*.
- 3–260–02, *Pavement Design for Airfields*.
- 3–260–16FA, *Airfield Pavement Condition Survey Procedures for Pavements*.
- 3–270–03, *Concrete Crack and Partial-Depth Spall Repair*.
- 3–270–04, *Concrete Repair*.
- 3–270–06, *Paver Asphalt Surfaced Airfields Pavement Condition Index (PCI)*
- 3–270–08, *Pavement Maintenance Management*.

1–1. Site Preparation and Area Layout

Site preparation is a very important part of building a road or runway. The amount of preparation depends on terrain, location, and expected use. Normally, site preparation work is associated with new construction; it may also involve work to bring existing facilities into conformance with applicable pavement design standards. Typically, you need to understand the tasks related with the clearing and grading. Additionally, you will be able to use the knowledge gained previously about classification of soils and the symbols, abbreviations, and overall layout of construction drawings. We will discuss drainage later in this unit.

401. The layout of an area

This lesson pertains to laying out an area, which is the same for both concrete and asphalt pavement construction; however, procedures differ depending on the size of the project. Ensure a completed AF Form 103, Base Civil Engineering Work Clearance Request, is on hand before starting any work.

Small areas

The first step in laying out a small area is to clear it of brush and other obstructions. You can do the clearing by hand unless you have large trees. Then you may need to use a front-end loader or dozer. However, in regards to efficiency and utilizing resources effectively, you would want to try and use powered equipment whenever practical. For instance, a skid-steer loader can be used on the majority of projects we will be involved with.

Next, use a flexible tape measure to measure the area's dimensions. Normally, you would use a 50–100 foot tape measure. If the area is to be concrete, allow for the width of the forms—as a rule, 6 inches on each side.

After you measure the area, outline it with string stretched very tight so that there is no play in it. You can use one- by two-inch wood stakes or form stakes to support the string. Generally, if you cut your stakes 3 feet (ft.) long, they provide adequate strength.

Once you have a side's string set on one side, you can use the 3, 4, 5 method to ensure perfectly square corners.

- Pull a second stringline tight, perpendicular to the first, and hold it tight. The two string lines will cross approximately 1 foot from the stakes (this establishes the corner point).
- Measure down the set stringline from the corner point 3 feet and make a mark.
- Measure down the second stringline and make a mark at 4 feet.
- Then measure the distance between both marks, and move the stringline until the tape measures exactly 5 feet. (At this point, the two string lines are at a 90 degree [°] angle.)
- Drive a stake and secure the stringline. Recheck to be sure the stringline didn't move.
- Repeat the procedure for the third side.

NOTE: The last side can be set by measuring the width of the project and simply setting both ends at that measurement.

Large areas

Laying out a large area is the same as laying out the small area; the only difference is the amount of work involved. The first step is to clear the area of brush, debris, and any other obstructions. In a large area, it is impractical to do this by hand. Instead, use front-end loaders and dozers.

Next, have the area surveyed by an engineer specialist. When the specialist conducts the survey, the area will be marked with construction stakes to guide pavement and construction equipment specialists with construction. The layout of a concrete pad would be identical to a small area.

402. Construction stakes

Construction stakes, sometimes referred to as grade stakes, are the guides and reference markers for earthwork operations to show cuts, fills, drainage, alignment, and boundaries of the construction area.

The number of stakes and the information contained on them will vary with the project as to whether they are temporary or permanent. A three- to five-person survey party using a level, a level rod, a tape, and range poles usually places stakes. You will mostly work with the following types of construction stakes:

- Alignment stakes.
- Slope stakes.

- Shoulder stakes.
- Finish-grade stakes.

The distance markings on these stakes are feet and fractions of feet, not feet and inches. The fractions may be tenths or hundredths of a foot.

Alignment stakes

Alignment stakes are used to lay out construction projects and identify boundaries. The alignment stakes you will work with include centerline, point of curvature (PC), point of tangency (PT), and point of intersection (PI).

Centerline

Centerline stakes usually are placed at 100-foot intervals, known as stations. The first stake is placed at the beginning of the project and is marked 0 + 00 (fig. 1–1, A). It is on the project centerline (the center or middle of the project). The centerline symbol is placed above the station number at the top of the stake (fig. 1–1, B). Although stations normally are placed at 100-foot intervals, they can be placed closer if there is a sharp break in the ground profile or a directional change of the project. Stakes positioned closer than 100 feet are called plus stations. All 100-foot readings precede the plus sign, and readings of less than 100 feet follow the plus sign. You can see that figure 1–1, C, is a plus station because the number following the plus sign is less than 100 feet.

The stake (fig. 1–1, C) has 12 + 25 on it, which means 12 × 100 + 25 or the stake marks the centerline 1,225 feet from the start of the project.

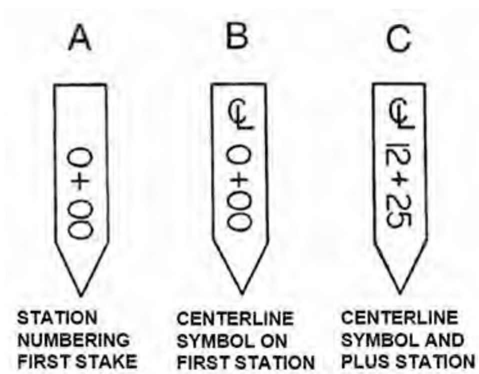


Figure 1–1. Centerline stakes.

Point of curvature

A change in road direction by a gradual bend is known in engineering terms as a horizontal curve. A stake is placed on the inside edge at the start of a horizontal curve, where the curve breaks away from the straightaway. On this stake, the symbol PC is used (fig. 1–2, part 1). The exact measurement of that station or plus station is written on the stake (fig. 1–2, part 2).

Point of tangency

At the end of a horizontal curve, where the curve returns to the straightaway, the symbol PT replaces the centerline symbol (fig. 1–2, part 3). The exact measurement of this station or plus station is placed on the stake (fig. 1–2, part 4).

Point of intersection

If the two straightaways (known as tangents) were to continue, they eventually would cross. This crossing is known as the PI. When placing a stake at this intersection, the symbol PI replaces the centerline symbol (fig. 1–2, part 5). The exact measurement of that station or plus station is written on the stake (fig. 1–2, part 6).

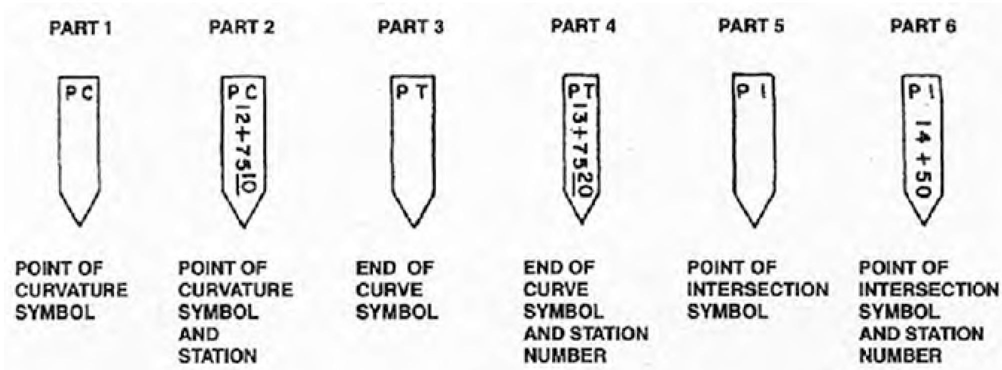


Figure 1–2. Alignment stakes used on curves.

All these markings are placed on the front of the stakes (flat side facing the start of the construction project). While centerline stakes also show the amount of earthwork to be accomplished at that point, this information is marked on the back of the stakes. If the elevation of the ground is above the elevation of the project (proposed finish-grade elevation), it is known as a cut section. The symbol for a cut section is a C or a minus sign (–) (fig. 1–3, A). If the elevation of the ground is below the project (proposed finish-grade elevation), it is known as a fill section. The symbol for a fill section is an F or a plus sign (+) (fig. 1–3, B). The information given in figure 1–3, A means that 4.50 feet of earth must be removed; conversely, the information given in figure 1–3, B means 2.30 feet of earth must be added.

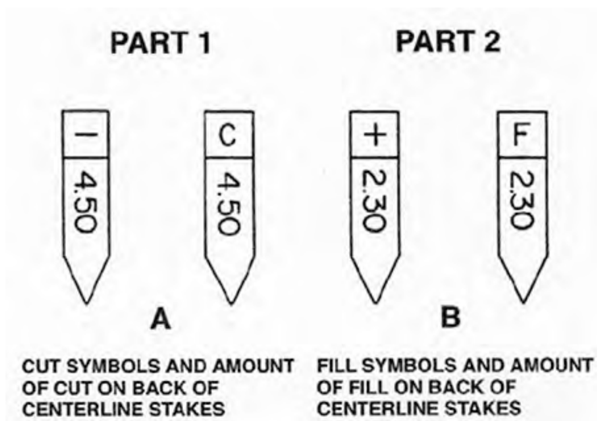


Figure 1–3. Markings on the back of centerline stakes.

If you are to remove 4.50 feet of earth, remove the earth to its full depth all around the stake before disturbing the stake. This precaution ensures that you have a reference point for removing the right amount of earth. It works the same way when you are filling or adding earth; fill the area near the stake last.

Slope stakes

Slope stakes (fig. 1–4) mark the outside limits of the construction zone and are placed where the proposed slope leaves the ground line. Slope stakes are placed at right angles to the centerline and are placed 100 feet apart on curves. Also notice in figure 1–4, the centerline and shoulder stakes. All of these stakes are marked for the cut and fill needed to transform the original ground shape into the form of a road.

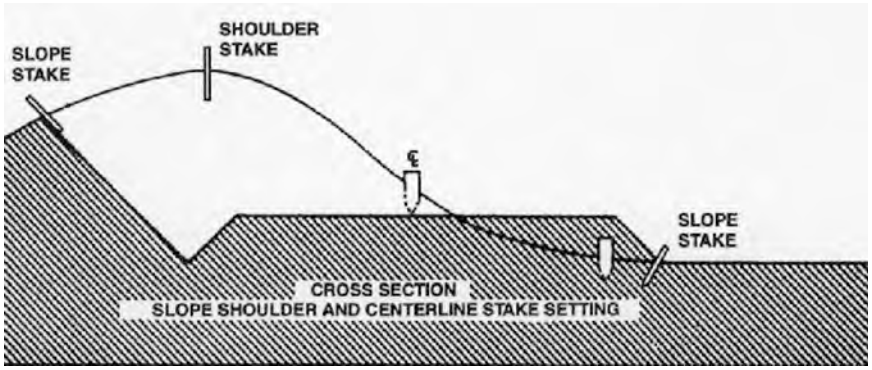


Figure 1–4. Location of slope stakes.

Notice in figure 1–4 that the slope stakes lean outward. This is to allow equipment to work within a close proximity to the stakes without destroying them; in addition, it allows the equipment operators to read the markings without dismounting.

The flat side of the slope stake, facing away from the centerline, has station markings identical to those on the corresponding centerline stake (fig. 1–5, A). These markings identify the location of each cross section. The proposed slope ratio is marked on the side of the stake (fig. 1–5, B). Slope ratio is an engineering term that expresses the horizontal distance to vertical rise. Thus, a slope of three-to one (3:1) is one that rises 1 foot over each 3 feet of horizontal distance.

On the side of the slope facing the centerline, the cut or fill symbol is at the top of the stake. Below this symbol is the amount of cut or fill required to obtain the slope ratio at the station where the stake is placed. The horizontal distances from the centerline to the slope stake is marked on the stake below the amount of cut or fill (fig. 1–5, C). Remember that this stake marks the outside limits of the construction zone. The cut or fill starts at the stake. Cutting starts at the stake and proceeds toward the centerline with 5.50 feet being the deepest cut.

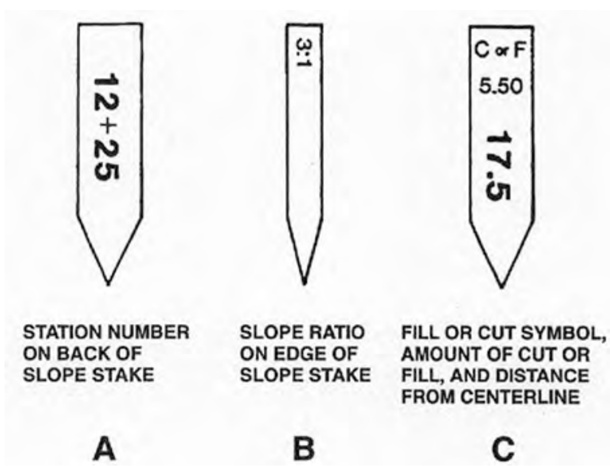


Figure 1–5. Slope-stake markings.

Shoulder stakes

In road construction, shoulder stakes are placed with a flat side facing the centerline. The flat side facing away from the centerline has the same station markings as the corresponding centerline stake (fig. 1–6, A). On the side of the stake facing the centerline (fig. 1–6, B), the cut or fill symbol is placed. Below this symbol, the amount of cut or fill at that location is shown. The horizontal distances to the centerline is below the amount of cut or fill (fig. 1–6, B).

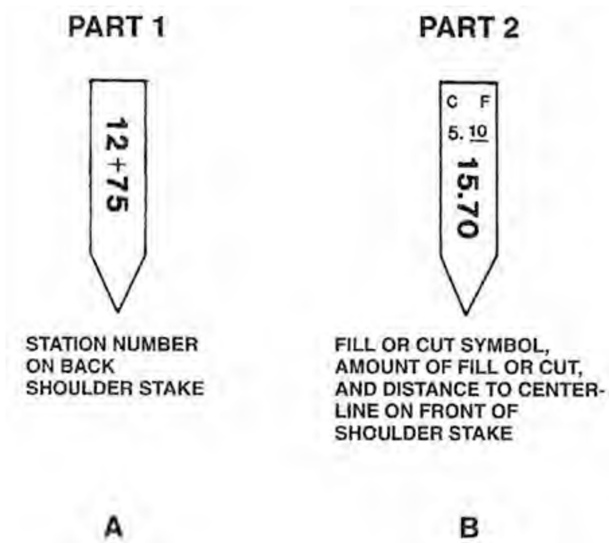


Figure 1–6. Shoulder-stake markings.

Grade stakes

The two kinds of grade stakes are rough-grade and finish-grade. Rough-grade stakes are placed before construction begins; finish-grade stakes are placed when construction is nearly completed. One side of each rough-grade stake has the horizontal distance to the centerline marked on it (fig. 1–7, A), and the other has a cut or fill symbol at the top with the amount of cut or fill shown below (fig. 1–7, B).

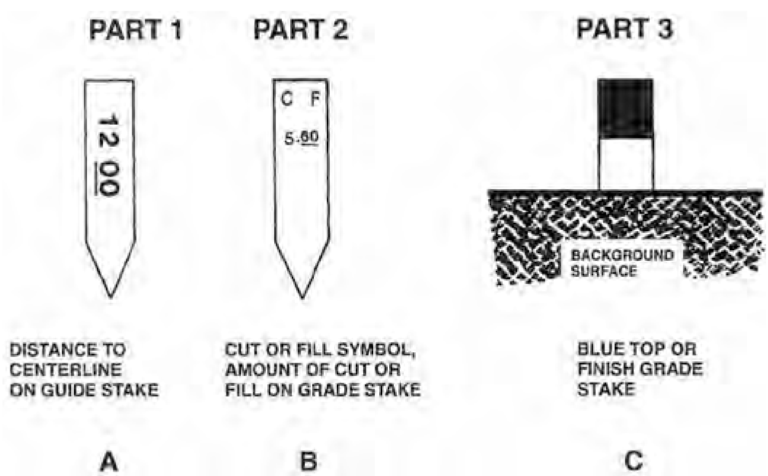


Figure 1–7. Rough-grade and finish-grade stakes.

Finish-grade stakes are driven into the ground until their tops are at finish-grade elevation. They are then colored with a blue lumber crayon, which identifies them as finish-grade stakes. They also have a blue “feather” attached to the top of the stake to make it more visible. Stakes colored in this manner are known as blue tops (fig. 1–7, C).

Construction stakes are placed for your convenience, as well as for the convenience of the supervisor and the rest of the construction crew. Without construction stakes to guide you, there is little way to know how much cut or fill to make or whether you are working in the right place. You must be able to differentiate between the types of construction stakes and be able to read the stakes easily. When working around stakes, make sure you do not damage or destroy them.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

401. The layout of an area

1. What is the first step in laying out a small construction area?

2. What is the difference between laying out a small area and a large area?

402. Construction stakes

1. What are the four types of construction stakes?

2. When should centerline stakes be placed at less than 100-foot intervals?

3. What symbols are placed on stakes to indicate a cut section?

4. Why are slope stakes placed so that they lean outward?

5. What are the two types of grade stakes?

1–2. Base Course

A paved surface is only as strong as its foundation. As discussed earlier, subgrade and base course make up the foundation for paved surfaces; when you build a paved surface, the subgrade must be at the proper level and contain the desirable material. To reach the proper subgrade, you may have to excavate excess dirt, fill the area with the compatible subgrade material, stabilize and compact the soil, and lay a blanket or insulating course. Within this section, we will discuss excavating an area, constructing a base course, and computing materials and their placement.

403. Excavating an area for pavement construction

The term "excavate" simply means to dig or scoop out earth. We do this task after we have our area properly laid out, and if necessary, after construction stakes are placed. The way we excavate our area is determined by the size of the area. Large areas can be done with large construction equipment, such as dozers and scrapers. Small areas can be excavated with front-end loaders or backhoes. In areas inaccessible to our bigger machines, hand tools are used.

Large areas

Generally, excavation for large areas involves making cuts. Through cuts are made to lower the grade for the road or runway. Side hill cuts are made along the sides of hills or canyons.

The method used to make a cut depends on the equipment available and the type and amount of material to be moved. If the material can be used to make a fill, spread it in the fill areas at the time of excavation. If the material is unsuitable for fill dirt, then dump it where it is not objectionable. You can also haul it completely from the site to an area where fill material is acceptable. If the excavated material is good but not needed for fill, save it for a future project.

Pay particular attention to drainage when you are making a cut. A hard rain may fill low spots or wash away needed materials. This causes extra work and slows the construction. When making cuts, observe the following rules:

- Keep the center of through cuts high.
- Keep the inside edge of side hill cuts low.
- Start the excavation at the slope stake and work down the natural angle. Another way, called the bench method, is to cut into the hill at grade level. It is effective for cuts up to 8 feet.
- Slope the bank while making the cut.
- Make the cut wide. There must be enough room for both road-bed and drainage ditches.

Normally, large area excavation is done with a scraper or a dozer. Scrapers are very good for earthwork involving both cuts and fills. The dirt can be removed from the cut and spread in layers in the fill site. Scrapers are well adapted for long hauls due to its high-traveling speed. However, loading of excavation material may require a pusher dozer.

In hard ground, you may need a dozer equipped with ripper teeth to loosen the ground before loading.

Use a dozer where the earth is to be drifted or moved a short distance only. A dozer is also used where turnaround space is limited, for stripping or end and side casting fills, and for initial stages of through cuts.

When you are excavating large amounts of earth below ground level, use an excavator. A clamshell or dragline can be used in underwater excavation.

Small areas

Excavation for small areas is a little less complicated. As you learned earlier in this lesson, small areas can be excavated with smaller types of equipment. Don't use hand tools unless you must—using them slows down the construction process, and time means money.

Procedures

No matter what method you use, excavation requires the complete removal of all "A" horizon soils. After you remove the "A" horizon soils, your job may be complete, or you may have to continue until you reach the desired elevation or depth. The desired elevation is the depth at which the support structures and pavement can be placed at the specified level. If you are to build a four-inch concrete slab with a six-inch base course as a supporting structure, you must excavate to a minimum depth of 10 inches, depending on the soil conditions encountered. You must also consider the length and width of the area. If the slab previously mentioned measures 10 feet by 10 feet, you should excavate 10 feet, 6 inches by 10 feet, 6 inches by 10 inches to allow for forming materials.

404. How to construct a base course

The base course is essential. In fact, it is required in all pavements that will have stresses of wheel loads. It completes the foundation—it is a section of high-quality material placed between the subgrade and the paved surface.

Purpose of base course

A base course distributes wheel-load stresses from the pavement's surface to the subgrade. If the subgrade is strong enough, the base course can be relatively thin. Since stresses in the base course are more concentrated than in the subgrade, the base course must be the stronger of the two.

Base-course requirements

If the base course consists of two or more materials, the best quality material is always put on top. Select base-course materials carefully. Pit-run gravel, shells, limestone, and caliche (a surface deposit consisting of sand or clay impregnated with crystalline salts, such as sodium nitrate or sodium chloride) make good base courses. If they are not dense enough, or if they cannot be well compacted, crush and grade them. In any case, the base-course material must meet certain gradation requirements so that it can be well compacted.

Material reclamation

As the price of construction increases and budget cuts loom, there are some things we can do to get the most for our construction dollars. Material recycling and reclamation are two ways to save money. Discarded materials, such as asphalt and concrete, can be reused for other purposes.

Concrete

Recycling concrete generally involves breaking the pavement, removing the reinforcement steel, and hauling the broken pavement to a crusher. Although removing the reinforcing steel can be labor intensive, some of the labor cost can be recovered by selling the reinforcing steel as scrap. After the broken pavement has been processed, it can be stockpiled and treated just as any other aggregate material. The processed material can then be reused as a good source of base material. Make sure the engineering assistants take a sample and have it analyzed (gradation) to see if anything needs to be added to ensure it will compact properly.

Asphalt

A wide range of pavement surface removal equipment has been designed and several removal techniques developed; however, milling is perhaps the most popular method for reclamation of asphalt. Milling removes surface deterioration by means of a rotating drum lined with cutting teeth that grind the pavement and uses a conveyor to carry material into a waiting dump truck. It can and should be specified by the engineer that the milling material be recycled into new material or that the base keep the material. The old material can be used as a base course (or blended with traditional base material), improving an area, such as a gravel perimeter road, or used in shoulder and drainage repair or improvement.

Gradation requirements

Considerable thought must be given to the gradation of the base-course materials. The gradation of particle sizes is determined by sieve analysis. Crushed rock or gravelly material makes a satisfactory base, depending upon the following:

- 50 percent of the material is made up of well-graded gravel.
- 40 percent of the material is made up of well-graded sand.
- 10 percent of the material is made up of fine-grained soil (slightly plastic silt and clay).

405. Computing materials and placement

To find out how much fill material you need for a job, you must be able to compute both area and volume in US standards and, when needed, convert to metric standards. Why convert to metric standards? Basically, with deployments all over the world, we have to order needed materials to the standards of the deployed area. We can convert total tonnage (1 ton = 2000 pounds [lbs.]) by multiplying 0.907 to get the metric ton weight.

For example, let's take 150 US tons and convert it into metric tons. To do this, simply multiply 150 by 0.907:

150 US tons × 0.907 = 136.05 metric tons.

A simple Internet search will yield conversion factors for all the problems we will face while overseas.

Area

Area (A) is defined as any plane surface within boundaries. To compute the area of a square or rectangle, you *multiply length (L) by width (W):* A = L × W.

Let's say you want to build a parking lot measuring 130-feet long and 120-feet wide. To find the area of the rectangular parking lot, multiply length by width:

A = L×W.

A = 130 feet (ft.) × 120 ft.

A = 15,600 square feet (sq. ft.).

Now let's say the measurements of the parking lot are 120 feet, 6 inches wide and 130 feet, 4 inches long. Because it is easier to work with one unit of measurement, convert the inches to feet. Divide 6 (inches) by 12 (number of inches in 1 foot) to get 0.5 feet. Thus, the width is 120.5 feet.

Now do the same with the length. Divide 4 (inches) by 12 (number of inches in 1 foot) to get 0.33 feet. The length of the parking lot is 130.33 feet. To find the total area of the parking lot, multiply the width (120.5 feet) by the length (130.33 feet):

A = L × W.

A = 130.33 ft. × 120.5 ft.

A = 15,704.77 sq. ft.

Since our work is not always square or rectangular, how do we find the total square feet of a circle?

With an area shaped like a circle, you must use a different formula: Pi (π) times the radius (r) squared (r^2), or:

$A = \pi r^2$

π is the symbol for the ratio of the circumference of a circle to its diameter; as such, it is an unending, nonrepeating decimal number. However, for our purposes, it is represented by the rounded number 3.14. The radius of a circle is half its diameter. So if a circle is 100 feet in diameter, the radius is 50 feet. To find the value of r^2, multiply the radius (50 ft.) by itself. Here is the formula for the area of a circle with the values substituted.

$A = \pi r^2$.

$A = 3.14 \times 50^2$.

$A = 3.14 \times 2500$.

A = 7850 sq. ft.

Another example: To find the area of a circle having a diameter of 50 feet, first find the radius:

$50 \div 2 = 25$.

Then, substitute in the formula:

$A = \pi r^2$.

$A = 3.14 \times 25^2$.

A = 3.14 × 625 sq. ft.

A = 1962.5 sq. ft.

Don't forget to convert any inches in your measurements to feet. If needed to convert the *area* of a project to a metric equivalent, multiply the square footage by 0.093 to get square meters (sm):

A × 0.093 = sm.

Volume

Volume (V) can be defined as the amount of anything in three dimensions. The third dimension is depth (D). To compute the volume of a square or rectangular space, multiply L by W by D. This gives you cubic feet (cu. ft. or ft^3). Simply divide cubic feet by 27 to get cubic yards (cu. yd. or yd^3) (there are 27 cubic feet in one cubic yard).

For example, we'll see how much base-course material to order for a parking lot measuring 130-feet long, 120-feet wide, and 4 inches deep. First convert the depth measurement into feet (divide 4 inches by 12 inches to get 0.33 foot). Then multiply accordingly:

$V = L \times W \times D.$

$V = 130 \times 120 \times 0.33.$

V = 5148 cu. ft.

This volume is stated in cubic feet, but most of the time base-course materials are ordered by the ton. We simply divide the volume by 20 to get the number of tons required. Twenty (20) represents cubic feet per ton. Using a factor of 20 simplifies the math and is good for a general idea of how much material is needed. It is an average volume per ton of a general base-course mix. However, for exact amounts, you need to call the company and ask them how much a compacted cubic yard of their material weighs (or the exact weight of their material). The differences come in because of different gradations and components that make up the base course. No base-course mix is exactly the same and varies greatly from region to region and even company to company.

For example, in Missouri, a cubic yard of compacted material may weigh 2500 lbs. per cubic yard. This equates to 21.6 ft^3 per ton. In contrast, a cubic yard of base course in Arizona may weigh 3300 lbs. per cubic yard. This equates to 16 ft^3 per ton. As you can see, the material in Missouri weighs less per unit of volume; as such, you will get more of it for the same amount ordered, which means you may have overage (238.33 tons using 21.6 as a factor). Conversely, if you use 20 when ordering material in Arizona, you will probably come up far short due to its higher weight per unit of volume (321.75 using 16 as a factor). For small jobs, the difference is minimal. However, the larger the job, the bigger the difference becomes when you use 20 as a factor.

For this lesson, we will use 20 to simplify things. Just remember to call the company when you are ready to order.

To find the number of tons needed for the base course in this example, divide 5148 (volume in ft^3) by 20 to get 257.4 tons. Remember, we usually round up to the nearest ton needed.

$5148 \div 20 = 257.4$ tons.

But, don't order that amount. Why? Because there are often low spots in the subgrade and you need to order a little more to compensate (normally 5 percent). Calculate the excess by multiplying 257.4 by 1.05 (5 percent) to get 270.27 tons. This amount allows enough material to complete the job.

$257.4 \times 1.05 = 270.27.$

Placement

You may begin placing and spreading base-course material on a prepared subgrade at the point nearest the source or at the point farthest from the source. You then place the material progressively away from or toward the source, respectively.

The advantage of working from the point nearest the source is the haul vehicles can be routed over the spread material, which helps compact the base course and avoids cutting up the subgrade.

Advantages of working from the point farthest from the source are that the hauling equipment further compacts the subgrade, reveals any soft spots, and interferes less with the movement of spreading and compaction equipment.

Compaction

Base-course compaction must produce a uniformly dense layer conforming in every way to specified requirements. The thickness of the layers of material should not exceed that which can be compacted to the required density by the equipment available. The thickness of each layer is determined by the *size of compaction equipment*. When rollers are used, the layer thickness can be as thick as 6 inches. In areas inaccessible to rollers, use small tampers and compactors. In this case, the layer thickness must be 3 inches or less. Optimum moisture content must be maintained during compaction.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

403. Excavating an area for pavement construction

1. What is the purpose of making through cuts?

2. What equipment is normally used for large area excavation?

3. Where should you use a dozer for excavating?

4. What jobs require the use of a clamshell?

404. How to construct a base course

1. What can you do to old concrete and asphalt which saves money and makes it useful again?

2. What percent of the base-course material should be made up of well-graded gravel?

405. Computing materials and placement

1. To compute the area of a rectangle, what dimensions must you multiply?

2. What is the area of a rectangular region that measures 10 feet by 10 feet?

3. What is the area of a circular region having a diameter of 8 feet?

4. To compute the volume of a rectangle, which dimensions must you multiply?

5. Compute the volume of a rectangular area that measures 6 feet by 14 feet by 3 inches.

6. How do you compensate for low spots in the subgrade?

7. How many cubic yards of base-course materials are required for the area in question no. 5? (Hint, do not forget to compensate for low spots).

8. What is the advantage of beginning base-course placement at the point nearest the source?

9. What are the advantages of working from the point farthest from the source?

1–3. Drainage Structures

Drainage structures collect and dispose of water that might damage or interfere with the use of roads, railroads, runways, and buildings. A good drainage system can help in providing lower maintenance costs and protect pavements and structures from unnecessary deterioration. Water on roadways and runways can contribute to accidents from hydroplaning, reduced visibility, and icy situations. Water is responsible for most pavement deterioration and failure. Always investigate for poor drainage when pavement structure fails. Improving drainage usually is the best way to keep pavement from failing.

All drainage structures fall into two general classifications—surface and subsurface. The classification depends on whether the water is above or below the ground when it is first intercepted or collected. If a structure first intercepts or collects water on the surface of the ground, it is a *surface* drainage structure; however, if it first intercepts or collects water within the ground itself, it is a *subsurface* drainage structure.

Where both surface and subsurface drainage structures are needed, it is generally best for each structure to be installed and to function independently. In this section, you will learn which types of structures are in each classification, why each installation step is needed under given conditions, and the principles of how to install the structures. The first lesson starts with the basics: the types of water disposed of by surface and subsurface drainage structures and the conditions that require one or both of the two classes of disposal structures to be built.

406. Surface and subsurface drainage structures

Adequate drainage of surface and subsurface water is one of the most important considerations in the design, construction, and maintenance of roads, railroads, airfields, parking, and cantonment areas.

Disposal of surface runoff and removal of excess ground water are vital to the stability and serviceability of foundations and pavements. A major factor in serviceability of a pavement depends on the adequacy of the drainage system in that a washout of a single culvert may close a facility to traffic at a vital time. Water is directly or partly responsible for most pavement failures and deterioration. Proper drainage is fundamental to preventive maintenance. Properly formed drainage structures, such as shoulders, ditches, channels, collector pipes, conduits, filters, blind drains, and French drains, help prevent pavement failure.

Surface drainage structures

Surface drainage provides for the interception, collection, and removal of surface runoff. These drainage structures control and dispose of water from rains, melting snow, and springs. A surface drainage structure must handle water that originates on or near the pavement surface. It must also control the water flowing from outlying areas. Water standing near paved surfaces remains until it evaporates or soaks through the pavement into the soil. The soaking can cause the pavement to crack and fail and weaken the subgrade. Both natural and artificial means are used to dispose of surface water.

Natural drainage structures

Use natural drainage, if possible, because it requires very little attention. Rivers, creeks, ponds, streams, floodplains, natural depressions, tributary areas, gorges, lakes, or other conveyance that serves to direct and produce natural surface drainage are all considered natural drainage structures.

Artificial drainage structures

Constructed surface drainage includes shoulders, gutters, storm drains, ditches, channels, check dams, flumes, dikes, culverts, chutes, detention ponds, infiltration or leaching basins, and pumping stations.

Properly designed and maintained surface drainage systems may reduce the need for special facilities for control and disposal of ground water. Proper drainage is essential to the service life of transportation routes, dwellings, and facilities.

Handling water by surface methods is more efficient and economical than by underground structures.

Do not use storm drains except where space is restricted or where the natural slope of the ground is not suited for drainage by open ditches, gutters, or other drainage conveyances.

Subsurface drainage structures

Some subsurface drainage structures include open, jointed, perforated, or porous collector pipes; conduits; filters; blind drains; French drains; and outlet structures. These structures dispose of water after it has entered the soil. Soil below the surface varies in moisture content from a small percentage to complete saturation. Subsurface water is also known as *groundwater*. The upper level of groundwater is known as the *water table*. An increase in surface water raises the water table, where a long, dry period lowers the water table. The level of the water table can be found by drilling test wells. Wells also reveal the thickness of the porous strata, that area where water flows freely from one area to another. The need for subsurface drainage is determined by a detailed survey. Subsurface drainage is required when it is necessary to:

- Lower the water table.
- Divert water away from structures.
- Intercept free flowing areas.

407. Constructing surface drainage structures

The first step of any drainage installation is to select the proper drainage system (structure) for the specified site. It would not make sense to put an open earth channel in downtown Dallas, nor would it be wise to have curbs and gutters along a country road in rural West Virginia.

The next step is to select the best place to remove the greatest amount of unwanted water. After you select the type of drainage system and decide on the location, you must then prepare the area for excavation. Depending on the distance to be covered, you can prepare for excavation in two ways. The first way considers short distances; you can use unmarked construction stakes, string, and line levels. The second way covers long distances and considers the drainage of hundreds of feet of land. This way requires precise survey measurements, and the area is laid out with marked construction stakes.

All drainage structures need a slope so that water flows away from the place where it has collected. You can create a slope where one does not naturally exist. For a short distance, raise or lower one end of your string. For a long distance, you must calculate slope by surveying and marking with construction stakes. The engineering assistants will help with the proper slope for the amount of water expected and the type of material used in the structure.

There are many types of surface drainage structures and many ways to build them. To build most surface structures, you first must dig a trench or ditch. Be careful to ensure that the trench bottom and sides are the correct slope and grade to accept the maximum amount of water expected at that location. If you are building a lined channel, the trench must be deep enough to maintain correct slope and grade after the lining is installed. If you are installing culverts or storm drains, make sure the bottom of the trench is shaped to fit the pipe.

While excavating a trench or ditch, replace soft or otherwise unsuitable soil with soil that does not wash away easily. After you have prepared the trench or ditch, place the structure, then backfill and compact in layers of 6 inches or less. It is a good practice to shape inlets and outlets to ensure smooth water flow. Remove and haul away all excess soil and construction material.

Open ditches

Open ditches provide the most convenient and economical type of surface drainage. They are particularly effective when tied into a natural drainage structure like a stream or lake.

Size and shape

The location and size of a drainage ditch depends on the space available and the amount of water it must carry. Side slopes on ditches are governed by the stability of the soil and by traffic safety.

The slope ratio is a representation of a unit of horizontal distance with its corresponding unit of vertical distance. For example: a slope of 4 to 1 (or 4:1) means 4 horizontal units for each vertical unit. Slope can also be represented by a percent. Percent slope is easy to calculate if you know your vertical rise and the distance covered. Using our 4:1 slope example, simply divide the rise (1) by the distance (4) and multiply by 100, as shown in the following equation:

$$1 \div 4 = 0.25$$

$$0.25 \times 100 = 25\%.$$

Therefore, 4:1 is equal to a 25% slope. This ratio can be expressed both ways and be correct.

As slopes get closer to 1 to 1 (vertical), the steeper they are. As they get further from 1:1, the gentler the slope is. Slopes *less* than a 2 to 1 ratio (50 percent slope) are desirable to reduce degradation of the sides (sloughing). Provide slopes of 4 to 1 (25 percent slope) on ditches adjacent to road shoulders. This ratio affords reasonable traffic safety and discourages drivers from driving across the ditch. Slopes of 10 to 1 (10 percent slope) or flatter are desirable within airfield safety zones.

The minimum grade for a ditch should be approximately 0.3 to 0.5 percent (333:1 to 200:1). For positive runoff, a minimum grade of 1 percent (100:1 ratio) is preferable. However, the steeper the slope, there is a greater chance of erosion. If erosion is a concern and the slope cannot be less, steps will have to be taken to combat it.

Road ditches should be 18–24 inches deep if roadway width is sufficient to prevent the ditch from being hazardous. In the northern part of the country, ditches should be large enough for plowed snow storage. Flat ditches with rounded slopes are pleasing in appearance and relatively easy to maintain.

Construction equipment

Open ditches can be built with graders, dozers, scrapers, and excavators. In fact, any type of earth-moving equipment can be used. The type of equipment to use depends on the size of the ditch, equipment available, and the area to be worked. Graders, dozers, and scrapers are often used for shallow, wide ditches. Excavators are used on deep, narrow ditches. Short, shallow ditches may be dug by hand, but digging ditches by hand is not very practical. Use powered equipment, if at all possible.

Ditch lining

Ditches carved in sandy soil must have shallow channels that slope gently on both sides. After completion, a channel must be lined to prevent erosion, especially where water flows rapidly. Several types of linings may be used, depending on the degree of protection needed. Figure 1–8 shows a ditch with a partial concrete base and side. The figure also shows foliage planted on the split-channel slopes to stabilize the surrounding soil.

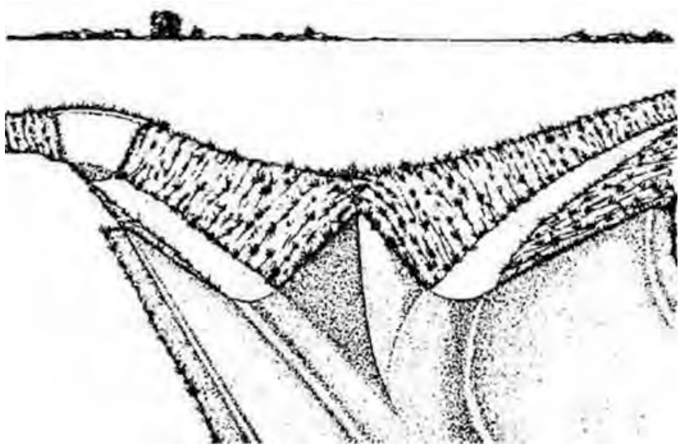


Figure 1–8. Lined channel.

Grass or sod linings are the most commonly used linings because they are inexpensive and easy to maintain. Any type of grass (adaptable to the area) is suitable. In many cases, all that is needed to establish a grass lining is to sow grass seed on the banks. In other cases, some type of protection must be provided until the grass can establish itself. Straw mulches are commonly used for protecting seeds and slopes from erosion while the seeds are sprouting. The straw also maintains moisture to aid in germination. Another means of protection is a hydro-seeding technique where a thick mixture of seed and a mulching medium are sprayed over the area. This mixture provides erosion control and maintains moisture until the grass is established. Where good turf cannot be established, you may need to line the channel with riprap (stone), asphalt, or concrete.

Light, reinforced concrete is very good for lining drainage channels. In some cases, drainage ditches can be lined with segmented concrete. But, segmented concrete fails unless it is constructed properly. Figure 1–9 shows a properly configured (segmented) drainage channel.

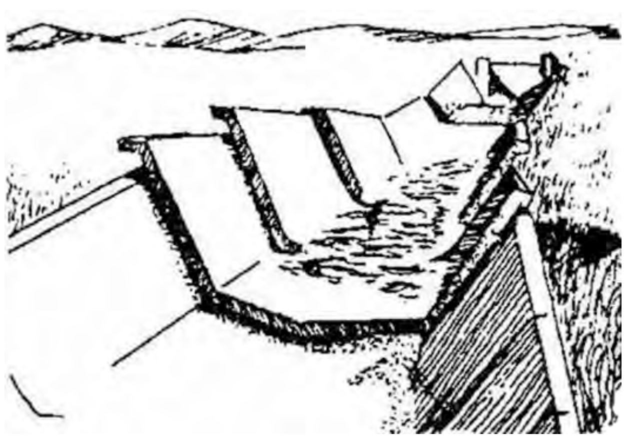


Figure 1–9. Breaks in lined channel.

Shallow, lateral channels can be lined with reinforced concrete pipe rounds (fig. 1–10). The pipe rounds are precast in the form of culvert pipe. The concrete pipe rounds have break inserts that allow the pipe to be broken into segments equaling one-third or one-half the pipe's circumference. The separated pipe rounds are then laid to form a ditch lining. Though the initial cost of this type of lining is relatively expensive, maintenance and replacement of washed-out or settled sections are inexpensive.

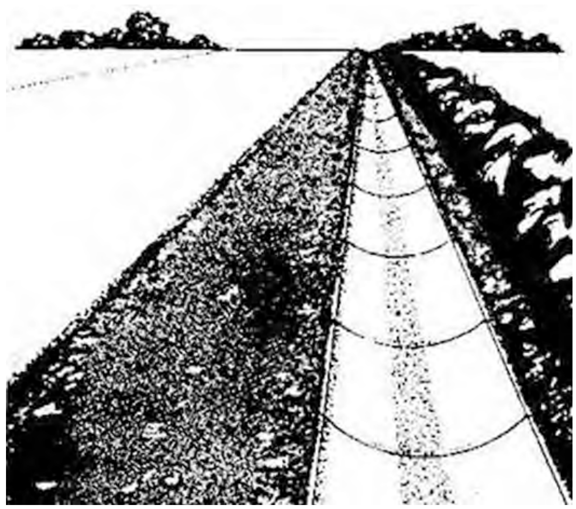


Figure 1–10. Ditch lined with reinforced concrete pipe rounds.

In some situations, asphaltic concrete (hot or cold), 2–3 inches thick, is an economical material to use when lining channels. This material is often used for roadside channels where standard gutters or curbs have been installed. When an asphaltic concrete lining is used, the soil should contain sufficient material to provide a stable supporting base. Asphaltic concrete lining is hard to keep backfilled, and weeds can grow through it. To prevent weed growth, treat the channel surfaces with a soil sterilant (herbicide) before placing the asphalt.

Check dams

Check dams are often used to retard the flow of water in drainage ditches. Depending on the situation, these dams can be built with several types of materials. They must be high enough and long enough to keep water from flowing around the ends. Notches are left in the center of the dams to allow for the normal flow of water (albeit slower due to the check dams themselves). Figure 1–11 shows check dams being used to control erosion in a drainage ditch.

Figure 1–11. Check dams.

Several small check dams are more desirable than one large dam. Build the dams far enough into the bed and sidewalls of the ditch to prevent washouts. Inspect them periodically, especially after heavy rainstorms, to see whether they are functioning properly and whether repairs are needed.

Culverts

Culverts are normally made of pipes or cement enclosures. They are used to divert water under all types of paved surfaces. Culverts carry off surface water that cannot be diverted any other way. The most common type of culvert is a single, straight conduit. Both the inlet and outlet are at ground level.

Multiple conduits are sometimes used where high water flow is expected. Culverts are most often made of pipe. Pipe culverts are usually made of corrugated metal or plastic, concrete, or cast iron. A culvert should be long enough to extend completely through the fill. This length often eliminates the need for protection around the culvert ends. If protection is needed, cover the area around each end with native grass. If the length of the culvert is *less than* 30 feet, the diameter of the pipe must be 15 inches or more. If the length of the culvert is *over* 30 feet, the diameter of the pipe must be at least 18 inches. Small pipes clog easily and are difficult to maintain. Positioning, installing, and maintaining culverts are covered in the following paragraphs.

Positioning

Culverts should coincide, as closely as possible, with the flow of water. Position the inlet of the culvert so the water does not have to travel outside of its natural course to enter the opening.

Whenever drainage allows flooding across a paved surface, a relief culvert is used to provide cross drainage. Cross drainage allows water to be drained away from the road or pavement area. The number of relief culverts to be installed is determined by the grade of the road. Relief culverts should be separated no more than 300 feet (fig. 1–12). When two or more pipes are placed side by side, a space equal to one-half the diameter of the pipe must be left between them. This permits proper compaction of the backfill. Inlet and outlet elevations of relief culverts should follow the natural ground slope.

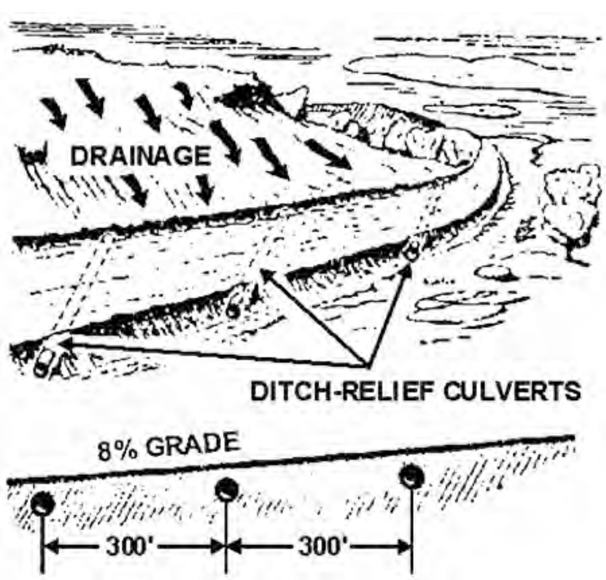


Figure 1–12. Spacing of ditch-relief culverts.

When the culvert grade must be flatter than the inlet ditch grade, use a sump at the inlet. A sump helps to eliminate silting inside the culvert. If the inlet end of the culvert is below ditch level, use a drop inlet (fig. 1–13).

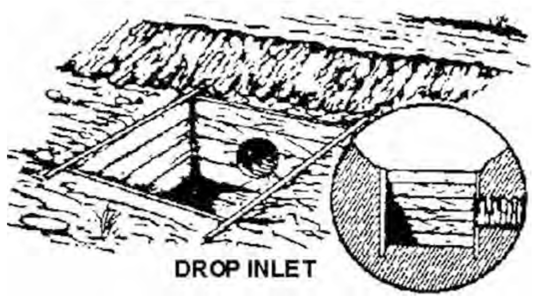


Figure 1–13. Drop inlet for culverts.

The culvert should extend considerably beyond the fill if the ground drops sharply at the outlet. A spillway must be built under the outlet to prevent erosion and backwash.

Installation

Except in extremely flat lands, install culverts with a minimum grade of 2 percent to help drainage. This grade also helps eliminate silting in the culvert. To ensure that culverts are installed true to grade, use a reference string (fig. 1–14) or engineer level. After you find the centerline of the culvert, drive stakes about 1 foot in length, past the end position. Mark these stakes at a predetermined distance above the ends of the culvert. Stretch a string between these reference marks. Maintain the proper grade by measuring from the string. You can also take elevation readings as you install sections of pipe using an engineer level or laser level.

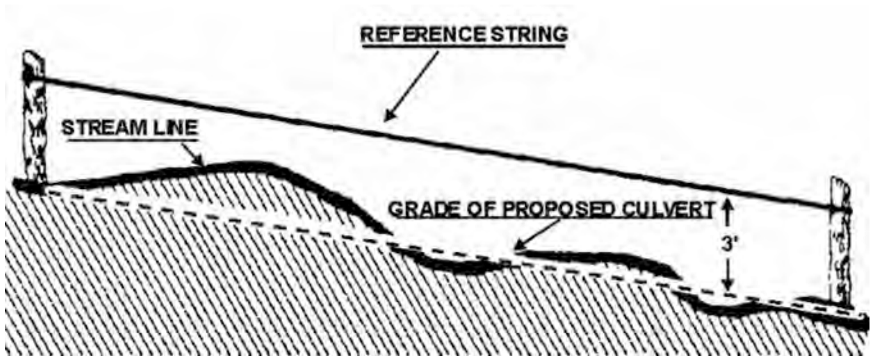


Figure 1–14. Establishing culvert grade with reference string.

When you install a culvert under a roadway carrying traffic, open the trench half the width of the road. Install the culvert in that half and cover it. Then, open the trench in the other half of the road. This method of installation eliminates the need for closing the road completely. If pipe is to be installed under roads or railroads where fills are deep or traffic cannot be disturbed, use the jacking method of installation. The jacking method uses a hydraulic jack of 30- to 250-ton capacity.

Before the pipe is positioned for jacking, trench the fill at the grade from each side. Trench as far as is practical to reduce the amount of jacking required. Do not trench closer to the roadway than the shoulder line. The pipe may be cast iron, sheet metal, or concrete. The work should progress from outlet to inlet. Place a heavy timber frame behind the pipe to serve as a push block (fig. 1–15). Before you start to push, scoop all earth from the end of the pipe and from the side of the bank for 2 or 3 feet ahead of it. Lay jacks flat, backed against the push block. Apply pressure slowly. You may use jacks individually or in tandem. After every 2 or 3 feet of jacking, stop the operation, remove the jacks, and clean the material from the inlet end of the pipe.

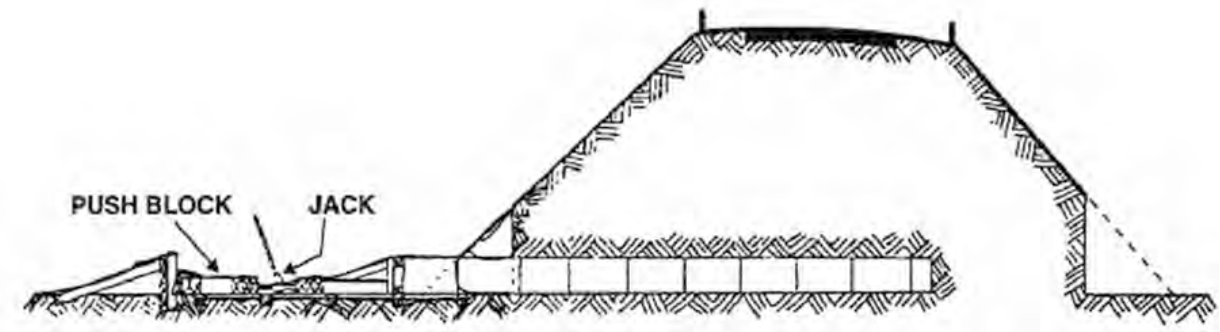


Figure 1–15. Culvert installation using jacking method.

Culvert inlets need protection if water velocity is high or if the direction of flow is changed. Flaring the endwalls funnels water into the opening. End, head, or cutoff walls at the end of culverts prevent undermining and erosion. Use concrete, laid stone, or riprap to protect the inlet of culverts.

Storm drains

Storm drains are large underground pipes. They collect and dispose of unwanted surface water.

Underground storm drains are very expensive. Do not use those if open ditches or natural drainage can be used. Storm drains are used only in improved areas and on airfields where open ditches are undesirable because of congestion, safety, and health.

Storm drain construction

Storm drains are usually made of precast concrete pipe. The drains are best installed in small, independent units. To help you with installation, each unit has a bell and spigot, tongue and groove, or a butt-type joint and incorporates some form of gasket. These joints are also designed to permit expansion and contraction of the pipe without damage to the joints. Each storm drain should drain a small area and should carry the runoff to the nearest natural watercourse. The storm drain catch basins and manholes are usually made of concrete, brick, or tile with cast-iron covers.

A well-planned structure avoids deep cuts and keeps the depth of pipelines to a minimum. Manholes are normally placed about 400 feet apart and at all changes in grade, direction, or size of pipe. Catch basins built over drain lines are sometimes used to replace manholes. In such installations, the catch basins must be the same size as manholes so that people can work inside them. Manholes are located so that pipe can be cleaned on a straight line from manhole to manhole. It should be possible to flash a mirror or flashlight from one manhole to another to see obstructions or settlement in the line.

The primary purpose of storm drains is to carry rainwater away from developed areas to prevent flooding. Contaminants such as used motor oil, unused paint, pesticides, and other household chemicals that have been dumped on the ground or in the street are carried by storm water to our creeks, lagoons, and the oceans.

As part of the Clean Water Act Amendments of 1987, Congress acted to directly address the environmental impact of storm water by adding section 402(p), which required the establishment of a comprehensive two-phased approach to control storm water discharges. In response, the Environmental Protection Agency (EPA) issued permit application regulations for Phase I storm water discharges on 16 November 1990. The regulation established a two-part permit application procedure for large and medium municipal separate storm water systems. This required, among other things, that storm drains should not be connected to the sanitary sewer system. Always coordinate with your local environmental flight prior to doing any storm water drainage work.

Storm drain size

The heaviest rainfall expected determines storm drain size. The drain may allow temporary ponding of some water during intense storms. For connecting lines or connections from catch basins, pipe diameter should not be less than 10 inches. Manholes and catch basins should have a 4- to 5-foot inside diameter to permit the use of cleaning equipment. Try to position the drain with enough grade to make it self-cleaning. Joints should include gaskets, or they must be caulked to prevent leakage. Water from leaks tends to follow the pipe, causing the pipe to settle and deform. Always seal the joints with approved material.

Open-top drains

Open-top drains are used to collect water from the following:

- Low spots on roads.
- Around hangars and large buildings.
- Along the edges of runways and aprons.

The open-top drain is a box type. A continuous grating over the top provides a wide inlet for water. Open-top drains are used where open ditches present a hazard. The grating is removable for cleaning. The structure must be strong enough to withstand maximum wheel loads. Part of your job is to ensure these drains are free of silt and refuse.

Since open-top drains are exposed to the atmosphere, water may freeze in them. If freezing occurs, thaw the ice enough for the drain to function properly.

Flumes

Flumes are installed on the surface of steep slopes to carry accumulations of surface water to open ditches or natural drainage channels (fig. 1–16). They are normally shallow-sided, trough-like structures.

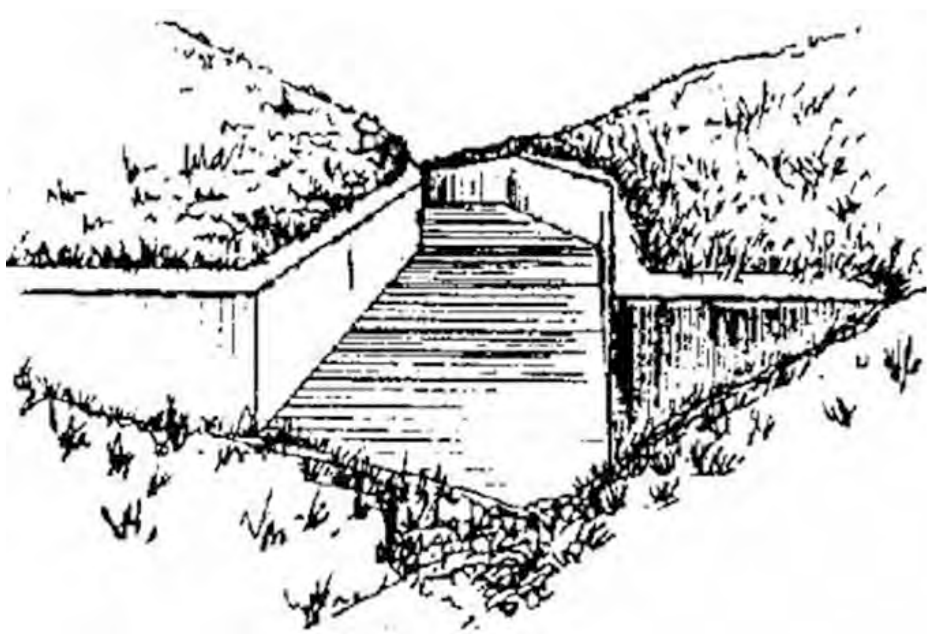


Figure 1–16. Flume.

Curbs and gutters

Gutters, or combination curbs and gutters, collect and control surface runoff water where open ditches would be hazardous or impractical. They are most commonly used along streets in densely populated areas and along roads through heavy cuts, where the width of the roadway is limited.

Paved surfaces and shoulders

Most people do not consider paved surfaces and shoulders as types of drainage structures. But, if built properly, they provide drainage to the road. To ensure proper drainage, paved surfaces should be crowned or sloped. The slope should be $^{1}/_{8}$ inch per foot. Paved surfaces work best when used with curbs, gutters, and storm drains.

408. Constructing subsurface drainage structures

Drainage of water from pavements has been an important consideration in road construction since the Romans first developed a road system over 2,000 years ago. However, modern processing, handling, and placement of materials frequently result in base courses that do not transmit water or drain as fast as we like. This often leads to pavement distress caused by moisture in the structures. The primary source of water in pavements is atmospheric precipitation. This water can enter the pavement through several ways (e.g., cracks, infiltration, through shoulders and ditches, and high groundwater) and is moved by an energy gradient, such as gravity, capillary forces, osmotic forces, and temperature or pressure differences. Water can also reduce stability and load-bearing capacity of pavements and add to the danger of frost action in areas subject to severe cold weather.

Subsurface drainage is required in areas where groundwater is encountered near the base of foundations and pavements. So to help with this drainage, systems like intercepting drains, French drains, vertical dry wells, and combination drains can be used.

Intercepting drains

Intercepting subsurface drainage is required where groundwater flows or seepage raises the groundwater table within 1 foot of the base course or within 5 feet of the finished grade of the road or runway surface. Intercepting drainage also collects water from springs in subgrade excavation and intercepts groundwater flowing on impervious strata. These drains may have subsurface drain pipe or open channels. Figure 1–17 shows a typical pipe drainage systems installed just off the shoulder of a road or runway. Note that the drains are placed along the line of the side channels and are at least 5 feet below the surface.

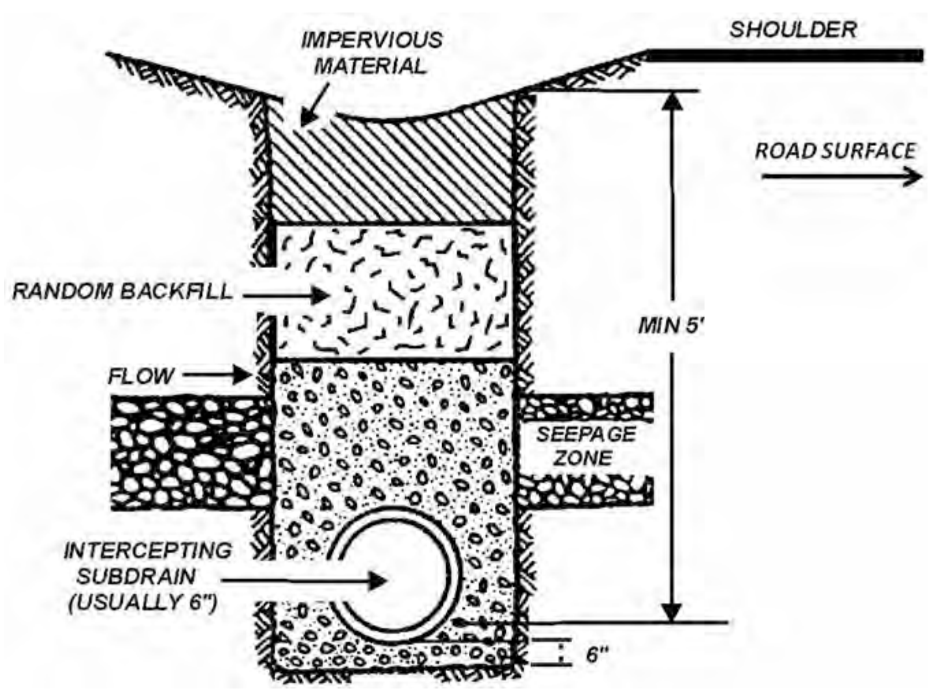


Figure 1–17. Intercepting drain (airfield).

French drains

A French drain starts with digging a trench. Grading is a critical consideration—you must ensure that enough slope exists for the water to actually flow and flow in the right direction. Filling the ditch or trench with broken or crushed rocks will help with drainage. The top surface of rock may be left exposed so that the trench acts as a combination drain, or the rock may be covered by a relatively impervious soil that no surface water can penetrate. The latter is the most common practice. In general, French drains are not recommended for permanent construction because they have a tendency to silt up with prolonged use. In theater-of-operations construction, though, such drains often substitute for perforated or open joint pipe because of limitations on piping or on filter materials suitable for use with such piping.

Vertical dry wells

Vertical dry wells sometimes are built to permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer of soil. If drainage is obstructed, you can either drill additional wells, or the pocket can be drained with a lateral subdrain. Vertical dry wells are used most often in northern tier states where deep freezing is common. The wells permit runoff from melting snow to get through the frozen soil and reach a pervious soil. The bottom of these wells is treated with calcium chloride or a layer of hay to prevent freezing.

Combination drains

Subsurface drains sometimes serve as both storm drains and subdrains. This type of structure is known as a combination drain. Combination drains are usually subdrains modified to let surface water enter them. The disadvantage of combination drains is that surface water brings silt, trash, and debris, causing blockage. Avoid combination drains, if possible.

Common subsurface drainage installation procedures

Installation procedures for the different types of subsurface drainage structures are basically alike, except for those for the vertical dry well, which is installed by digging a deep vertical shaft and placing a pipe down through it.

First steps

The first few steps in the installation of subsurface drains are the same as for surface drains:

1. Select the drainage system, location, and layout.
2. Dig a trench with the bottom dug to the proper grade.
3. Remove large chunks or rocks so they do not damage the pipe when it is placed in the trench.
4. Discard the soil removed from the trench (do not use it as backfill; use only clean gravel or crushed stone).

Feed holes

The feed holes in the perforated pipe are positioned up or down, depending on the location and placement of the drainage structure (fig. 1–18). If the drainage structure is to be placed along the side of the pavement, place the feed holes in the pipe *upward*. If the structure is to be placed under a pavement, place the holes *down*.

Lining the trench

When you place pipe with the holes facing up, first line the bottom of the trench with an impervious material. When you install pipe with the holes facing down, first line the bottom of the trench with at least 6 inches of selected filter material. After placing either the impervious soil layer or filter material, make sure the bottom of the trench is shaped to fit the pipe.

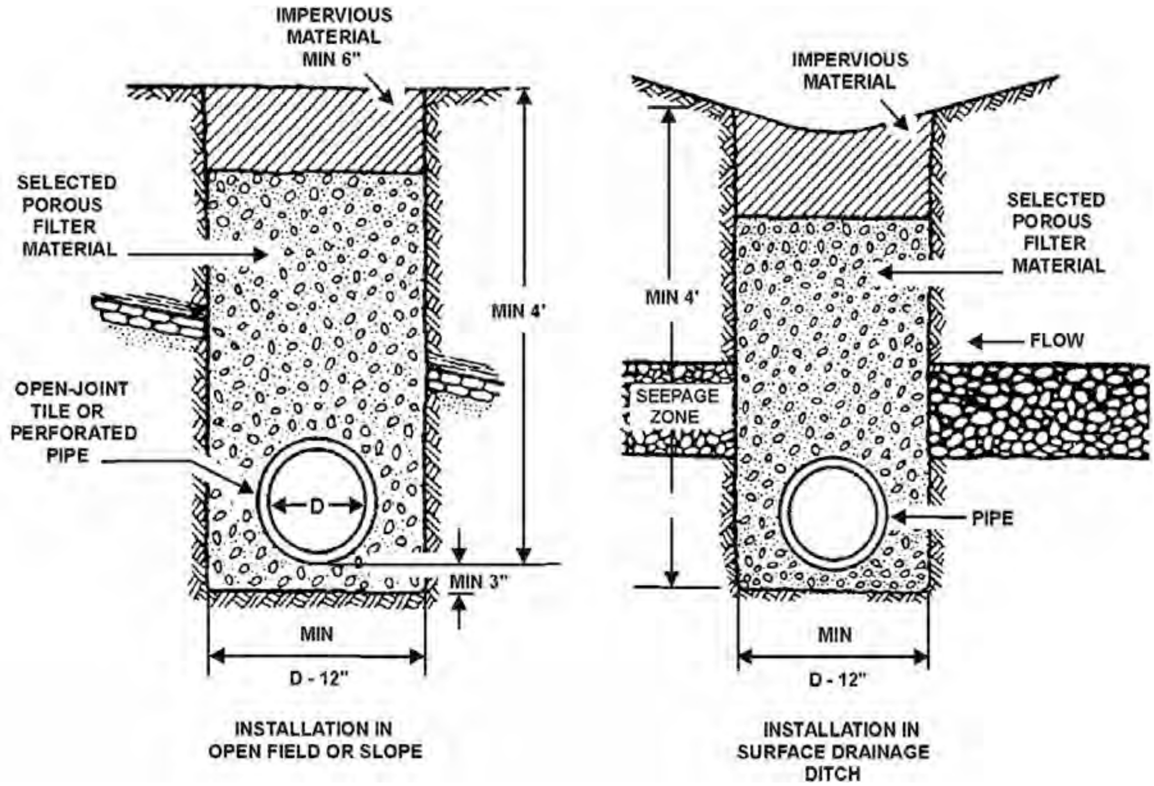


Figure 1–18. Perforated pipe placement depends on drainage structure location.

Placing the pipe
Next, place the pipe and backfill with a selected filter material. The minimum size of your material should be at least twice the size of the perforations of the pipe. Place and compact this material in six-inch layers. When compacting, be careful not to damage the pipe. Continue to backfill up to at least 6 inches or until you reach the depth of the base course. The last 6 inches (for pipe along the roadway) should have an impervious layer placed on top. This prevents large amounts of surface water from entering the system and causing the structure to clog up. This layer is normally the road shoulder made of asphalt. Pipe placed under the roadway will be covered with base-course material.

409. Inspecting drainage structures
You can prevent a drainage structure from deteriorating before its time by inspecting and repairing damage when required. Inspections ensure that drainage structures on your base are operating properly and can help to identify items that need to be repaired. The repair of drainage structures may be as simple as replacing soil or as complicated as replacing an entire drainage system. No matter how extensive the repair, your first step is to identify and eliminate the cause of the failure. It is a total waste of time and money to repair any drainage structure without first correcting the cause of trouble.

When you inspect drainage systems, you are basically inspecting the various components of your drainage structure. Inspections can include inlets, catch basins, manholes, and the pipes that connect them all. Drainage structures are inspected to ensure that they function properly.

Purpose of inspection
An inspection is a comprehensive, visual examination of the accessible areas, components, and systems of the drainage structure. Its purpose is to report on the condition, function, and safety of the items inspected. A full, comprehensive inspection addresses grade and drainage issues and determines whether requirements are met:

1. Water is draining from the areas that the drainage structure was designed to relieve.

2. Drainage structures are in good condition. By frequent inspection, problem areas can be found and repaired before any further damage can take place.

Types of inspections

Inspections are part of a preventative maintenance program, which involves the regular inspection, testing, and replacement or repair of equipment and operational systems. The main types of drainage inspections you will perform include both operational and maintenance.

Operational inspection

An operational inspection is accomplished during and immediately after a rainstorm to see whether the structure is functioning properly. The water must enter and exit the structure without being slowed down by debris or stopped by blockage.

Maintenance inspection

A maintenance inspection is performed after all the water has cleared from the structure; its purpose is to identify what maintenance the structure needs.

Types of defects

During an inspection, drainage defects are categorized in one or more of following areas:

- Breaks (cracks).
- Erosion.
- Vegetation.
- Obstructions.

Breaks

Breaks in a drainage structure allow water to seep into, behind, and under the structure causing it to leak and eventually cause erosion. Breaks can be minor or very noticeable. A close inspection will determine the amount of damage.

Erosion

Erosion is the act of wearing away. This can be caused by wind or water. The soil is washed away because the force of the water exceeds the binding strength of the soil. Evidence of erosion is the appearance of gullies, washouts, and loose topsoil.

Vegetation

Vegetation can be good or bad for drainage structures, depending on its location. Some structures, such as culverts, gutters, and flumes, are not designed for vegetation. In sod-lined channels, vegetation is good because it prevents erosion, but you must not allow vegetation to grow out of control and cause an obstruction.

Obstructions

An obstruction is anything that blocks the rate of flow of water in the system. It slows down or stops the drainage structure from working at its maximum capacity. The most common types of obstruction are limbs, leaves, and trash. Soil washed away from another defect can accumulate and cause blockage as well.

410. Repairing drainage structures

For a road or paved surface to be kept in acceptable condition, it must be well constructed, well maintained, and have an adequate drainage system. The amount of maintenance necessary after construction can be reduced by a high standard of construction. Even if the paved surface or drainage system was constructed to a high standard, it will soon fall into disrepair if neglected after construction. In order for a restoration project to be successful, it must be planned, organized, and executed to the best of your ability.

Surface drains

Of course, any structure can have something go wrong with it. The following information should give you some ideas on common repair requirements for surface drains.

Ditches

Ditch repair consists mainly of preserving turf or other ground cover on banks and flow lines to reduce erosion. You should strive to develop a dense sod to stabilize open ditches and keep ditches free of brush, logs, silt, and other debris that might divert or restrict water flow during heavy runoffs. Maintain ditches to line and grade, and correct sags and minor washes as they occur. When you clean and reshape, make sure no unnecessary cutting is done. Unnecessary cutting destroys ground cover. Make slopes flat and corners rounded. V-shaped ditches are undesirable, especially where large capacity is required.

Storm drains

Various methods are used to clean storm drains. One method is to flush them with water. Block all pipe openings in a manhole. Fill the manhole with water. Using a rope connected to the block, quickly remove the block from the outlet. The force of the released water usually cleans the pipe. To increase the effectiveness of this method, insert a ball (slightly smaller than the diameter of the pipe) in the pipe. The scouring action of the water working around the ball has a greater loosening effect.

Other methods of cleaning use mechanical devices. You can remove silt, sand, or tree roots from drain lines with cutters, brushes, scoops, scrapers, and screws that you force through by hand or by power-operated equipment. You can use sectional sewer rods with working and flushing heads alone or with cutting devices. Tools, some of which are adjustable, are available to fit all sizes of pipe.

Additionally, utilities personnel may have a sewer truck equipped with a water-jet cleaning tool specifically for this purpose. They may be willing to clean out drains that we are ill-equipped to handle.

Where a drain line is blocked because of pipe collapse, find the blockage by probing with cleaning rods. Calculate the distance to the block, and measure it off on the surface of the ground. Dig up the collapsed pipe and replace it with new sections.

Erosion and vegetation normally are not a problem in storm drains. Your main concern should be to look for breaks and obstructions. If you have small breaks or cracks in a storm drain and you can get to them, try to seal them with concrete mortar. If you cannot get to the area, then you may have to dig up the structure. Of course, you’ll have to consider the size and extent of the break.

People tend to think a storm drain is the same as a garbage can. That is, if they have trash and a storm drain inlet is near, they throw the trash down the drain. This is on top of all the other debris washed down during rains. When you have a 10-inch pipe that everything is supposed to wash down, you have the potential for a really big problem. As with other drainage structures, remove and haul away debris in and around the storm drain. You can flush silt sediment in the storm drain with high-pressure water. Remember that it is easier to remove a little bit of debris before the system is plugged than after it is blocked.

Open top drains

Your major maintenance concern is removing debris from open-top drains. Relieve stoppages during a storm by removing enough debris to allow the drain to function. Then, after the storm is over, haul away the debris, silt, and trash. Otherwise, it can get back into the drain.

You can use various methods to remove ice from open drains. One way is to break up the ice and shovel it out of the way. Often, you can scoop up slush ice with a front-end loader. Dump the removed ice so that it melts without getting back into the drain. You can also use such chemicals as calcium or sodium chloride to melt ice. They are expensive and should not be used unless absolutely necessary. If steam is available, use it to open frozen drains. You get the best results by concentrating on a small area at a time, letting water drain off before it freezes again.

Check dams

The main enemy of check dams is erosion; if it occurs around the sides of your check dam, you may have to build the dam farther into the channel sidewalls. If you have erosion in the front of the dam, you may need to build a spillway or to expand the existing one.

Breaks and vegetation are not normally problems with check dams; however, if they are, repair the breaks and remove the vegetation.

Obstructions in check dams are the result of debris in the channel. Debris tends to block or slow down water flow over the low point of a dam. The blockage can cause water to flow around the sides, leading to erosion.

Flumes

Remember that flumes most often are made of concrete. The only problems you should run into here are erosion around the flume and obstructions.

Check to see why erosion has occurred. If it was the result of the flume not being large enough to handle the water flow, you may need to expand the sides. If it was the result of an unusual amount of rain, you can repair the area by replacing and compacting the soil.

Culverts

You can reduce erosion around culverts by following simple construction practices. If there is a lot of erosion at the inlet end of a culvert, you can install a headwall to control it (fig. 1–19). If erosion takes place at the outlet end, your culvert may have been installed at too steep an angle. To control erosion here, build a spillway with concrete or riprap. Breaks in culverts usually require replacement of the structure. If you neglect to repair or replace a broken culvert, the result can be a saturated base and subgrade and a failed roadway.

Vegetation is normally not a problem for culverts unless the grass is so high that it becomes an obstruction, which can be a big problem in a culvert. Due to the force of water funneling into a culvert, a little debris can reduce the culvert's capacity and cause the roadway to flood. To stop this problem, remove trash and other items in and around the area, and install a drop inlet at the end of the culvert to help control silt buildup.

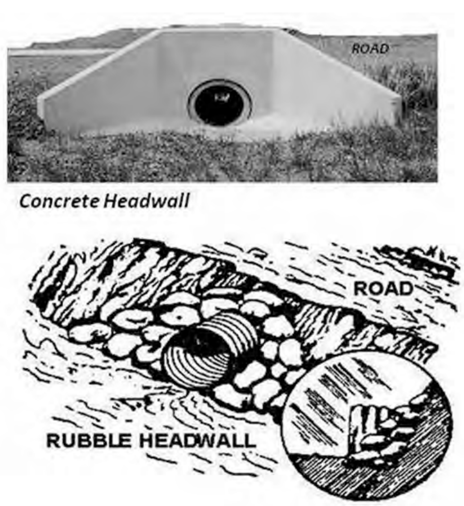


Figure 1–19. Culvert headwalls control erosion at the inlet end.

Curbs and gutters

The biggest problem with curbs and gutters is erosion. Normally, erosion occurs at the back of the curb and gutter because of water flowing over the gutter during very heavy rains. It also can be caused by debris blocking a storm drain. In any case, you can make repairs by replacing the soil and removing any obstructions.

Paved surfaces and shoulders

Pavement breaks are the most frequent repair item on paved surfaces and shoulders. When they are left unattended, water seeps into the support structure of the paved surface and shoulder; when this happens, your paved area cracks and breaks off. Seal breaks and cracks with an approved sealer.

Subsurface drains

Subsurface drains are a little harder to maintain than surface drains because of their limited accessibility. About the only repair procedure that can be accomplished is on the intercepting drain. If the drainpipes become clogged, clean them by flushing with high-pressure water. If necessary, sewer rods or wires can be used. Like culverts, the outlets require protection against washing.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

406. Surface and subsurface drainage structures

1. What is one of the most important considerations in the design and maintenance of roads, railroads, airfields, parking, and cantonment areas?

2. What is the function of surface drainage?

3. What are some types of constructed surface drainage structures?

4. What is another term for subsurface water?

5. What is the water table?

6. What are the three main functions of subsurface drainage?

407. Constructing surface drainage structures

1. What is the first step you must take before installing a drainage system?

2. When building many types of surface drainage structures, what is usually your first step?

3. How thick should the layers of backfill material be before compacting it around the drainage structure?

4. What should you do with excess soil and construction material?

5. What determines the location and size of a drainage ditch?

6. What is the recommended side slope on ditches adjacent to road shoulders?

7. What should the *minimum* grade for a ditch be?

8. What types of equipment can be used to build open ditches?

9. When asphalt concrete is used for lining channels, how thick should it be?

10. What is the most common type of culvert?

11. If the length of a culvert is *less than* 30 feet, what is the *minimum* diameter of the pipe?

12. What is the *minimum* diameter of the pipe if the length of a culvert is *over* 30 feet?

13. How far apart should relief culverts be?

14. Except in extremely flat land, what should be the *minimum* grade of culverts?

15. How far apart are manholes normally placed?

16. What determines the size of storm drains?

17. What should be the inside diameter of manholes and catch basins?

18. What should be the slope of paved surfaces and shoulders?

408. Constructing subsurface drainage structures

1. What type of damage can water do to a pavement?

2. What are the first three steps to building a French drain?

3. What is the purpose of vertical dry wells?

4. How can freezing be prevented in vertical dry wells?

5. Combination drains are usually subdrains that have been modified for what purpose?

6. What is a disadvantage of combination drains?

7. When you dig a trench for a subsurface drainage structure, what should you do with soil removed from the trench?

8. When you place perforated pipe with the feed holes facing up, what should you use to first line the bottom of the trench?

9. When you place perforated pipe with the feed holes facing down, what should you use to first line the bottom of the trench?

10. What should be the *minimum* size of the filter material for a subsurface drainage structure?

409. Inspecting drainage structures

1. Identify and define the two types of drainage inspections.

2. Into what four categories are drainage defects normally broken down?

410. Repairing drainage structures

1. How should you find the blockage when a drain line is blocked by a pipe collapse?

2. What is your major maintenance concern with open-top drains?

3. What is the procedure for correcting erosion around the sides of a check dam?

4. What can you do to control erosion at the inlet end of a culvert?

5. To control erosion at the outlet end of a culvert, what can you do?

6. What must be done if breaks occur in culverts?

7. What can you do to stop debris from reducing a culvert's capacity?

8. What happens when breaks in paved surfaces are left unattended?

Answers to Self-Test Questions

401

1. Clear it of brush and other obstructions.
2. The amount of work involved.

402

1. Alignment, slope, shoulder, and finished grade.
2. When there is a sharp break in the ground profile or a directional change of the project.
3. A C or a minus sign (–).
4. It allows equipment to work within a close proximity to the stake without destroying the stake. It also allows the equipment operators to read the markings without dismounting.
5. Rough-grade and finish-grade.

403

1. To lower the grade for the road or runway.
2. Scraper or dozer.
3. Where the earth is to be drifted or moved a short distance only, where turnaround space is limited, for stripping, or end and side casting fills, and for the initial stages of through cuts.
4. Underwater excavation.

404

1. Recycling or reclamation.
2. Fifty.

405

1. L by W.
2. One hundred square feet.
3. 50.24 sq. ft.
4. L by W by D.
5. 21 cu. ft.
6. By ordering 5 percent extra.
7. One cubic yard (21 ÷ 27 = 0.77; 0.77 × 1.05 = 0.81, and round up to 1 $yd^{3)}$.
8. The hauling vehicles can be routed over the spread material, which assists in compacting the base course and avoids cutting up the subgrade.
9. The hauling equipment further compacts the subgrade, reveals any soft spots in the subgrade, and interferes less with the movement of spreading and compaction equipment.

406

1. Adequate drainage of surface and subsurface water.
2. It provides for the interception, collection, and removal of surface runoff.
3. Shoulders, gutters, storm drains, ditches, channels, check dams, flumes, dikes, culverts, chutes, detention ponds, infiltration or leaching basins, and pumping stations.
4. Groundwater.
5. The upper level of groundwater.
6. To lower the water table, to intercept free-flowing areas, and divert water away from structures.

407

1. Select the proper drainage system (structure) for the specified site.
2. Dig a trench or ditch.
3. Six inches or less.
4. Remove and haul it away from the site.

5. The space available and the amount of water it must carry.
6. Four to one.
7. 0.3 to 0.5 percent.
8. Graders, dozers, scrapers, and excavators.
9. Two to three inches.
10. Single straight conduit.
11. Fifteen inches.
12. Eighteen inches.
13. No more than 300 feet.
14. Two percent.
15. Four hundred feet.
16. The heaviest rainfall expected.
17. Four to five feet.
18. ⅛ inch per foot.

408

1. It reduces stability and load-bearing capacity and adds to the danger of frost action.
2. Digging, grading, and filling a trench or ditch with broken or crushed rock.
3. To permit trapped subsurface water to pass through an impervious soil or rock layer to a lower, freely draining layer of soil.
4. By treating the bottom with calcium chloride or a layer of hay.
5. To let surface water enter them.
6. Surface water brings silt, trash, and debris, causing blockage.
7. Discard it. Use only clean gravel or crushed stone.
8. An impervious material.
9. At least 6 inches of selected filter material.
10. Twice the size of the perforations of the pipe.

409

1. Operational and maintenance. An operational inspection is accomplished during or immediately after a rainstorm to see whether the structure is functioning properly. A maintenance inspection is accomplished after all water has cleared the structure and is used to identify what maintenance the structure needs.
2. Breaks, erosion, vegetation, and obstructions.

410

1. By probing with cleaning rods.
2. Removing debris.
3. Construct the dam farther into the channel sidewalls.
4. Install a headwall.
5. Build a spillway with concrete or riprap.
6. Replace the structure.
7. Remove trash and other items in and around the area, and install a drop inlet at the end of the culvert.
8. Water seeps into the support structure of the paved surface and shoulder; when this happens, your paved area cracks and breaks off.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (401) What method can you use to ensure perfectly square corners when laying out an area for concrete?
   a. 3, 4, 5 method.
   b. 2, 4, 6 method.
   c. 1/3, 1/4, 1/5 method.
   d. 1/2, 1/4, 1/6 method.

2. (401) What is the *only* real difference between laying out a large area and a small area?
   a. Terrain.
   b. Amount of work.
   c. Weather conditions.
   d. Equipment available.

3. (402) You should place the first centerline stake for a large concrete project at the
   a. first curve.
   b. end of the project.
   c. end of the first curve.
   d. beginning of the project.

4. (403) Which piece of equipment is *not* recommended for excavating large areas?
   a. Dozer.
   b. Scraper.
   c. Backhoe.
   d. Excavator.

5. (404) The base course distributes wheel load stresses to the
   a. insulating course.
   b. subgrade.
   c. shoulder.
   d. surface.

6. (404) What two construction materials can you recycle to use for other purposes?
   a. Asphalt and concrete.
   b. Base course and subgrade.
   c. Hot and cold applied sealants.
   d. Plywood bendable forms and fasteners.

7. (405) The *area* of a rectangle 8 feet by 12 feet is 96
   a. square yards.
   b. cubic yards.
   c. square feet.
   d. cubic feet.

8. (405) What is the rounded numerical value of π?
   a. Half the diameter.
   b. Half the radius.
   c. 0.666.
   d. 3.14.

9. (405) What is the *approximate* area of a circle that measures 18 feet in diameter?
   a. 28 square feet.
   b. 38 square feet.
   c. 254 square feet.
   d. 324 square feet.

10. (406) What is directly or indirectly responsible for *most* pavement failures and deterioration?
    a. Water.
    b. Weather.
    c. Wheel loads.
    d. Unsealed surfaces.

11. (406) Which of these conditions is *not* a function of subsurface drainage?
    a. Divert water away from structures.
    b. Intercept free flowing areas.
    c. Lower the water table.
    d. Raise the water table.

12. (407) If you are installing culverts or storm drains, the bottom of the trench should be
    a. shaped to fit the pipe.
    b. shaped the same as the sides.
    c. filled with select filter material.
    d. filled with a layer of impervious soil.

13. (407) Notches are created in the center of check dams to
    a. prevent washouts.
    b. retard the water flow.
    c. prevent silt settlement.
    d. allow for the normal flow of water.

14. (407) What can you do if you want to funnel water into the inlet of a culvert?
    a. Build a spillway.
    b. Install a drop inlet.
    c. Flare the end walls.
    d. Install a riprap headwall.

15. (408) French drains are *not* recommended for permanent construction because they have
    a. an ability to carry only a low amount of water.
    b. a tendency to overflow.
    c. a tendency to silt up.
    d. inadequate slope.

16. (408) You should treat the bottom of vertical dry wells with calcium chloride or hay to
    a. lower the water table.
    b. raise the water table.
    c. assist in drainage.
    d. prevent freezing.

17. (408) Holes in perforated pipe should be placed *up* when the
    a. structure is to be placed along the side of the pavement.
    b. structure is to be placed under the pavement.
    c. slope is not a factor.
    d. grade is steep.

18. (408) After you place either your impervious soil layer or filter material for a subsurface structure, make sure the *bottom* of the trench is
    a. shaped to fit the pipe.
    b. at the correct slope.
    c. in a v-shape.
    d. rounded.

19. (409) The purpose of a drainage inspection is to report on the
    a. condition of the items inspected.
    b. safety of the items inspected only.
    c. function of the items inspected only.
    d. condition, function, and safety of the items inspected.

20. (409) What type of drainage inspection should you perform during or immediately after a rainstorm?
    a. Riding.
    b. Walking.
    c. Operational.
    d. Maintenance.

21. (409) What are the types of drainage defects?
    a. Silt, trash and debris.
    b. Operational and maintenance.
    c. Breaks, erosion, vegetation and cracks.
    d. Breaks, erosion, vegetation and obstructions.

22. (410) To control erosion at the *outlet* end of a culvert, you should
    a. install a check dam.
    b. expand the flume sides.
    c. install a plank headwall.
    d. build a concrete spillway.

23. (410) You should install a drop inlet at the end of a culvert to
    a. act as a funnel.
    b. prevent erosion.
    c. control silt buildup.
    d. increase water flow.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Portland Cement Concrete Pavements

THE PAVEMENTS you will learn about in this unit are used to construct sidewalks, roads, and runways. Since most construction areas use concrete as a building material, this unit focuses on concrete and its uses, as well as in preparing and placing the concrete. As a mixture of cement, sand, gravel, and water, whether it is wet or dry (cured), these ingredients all work to form concrete once they are combined. Every step of construction, from the preparation of the subgrade and sub-base, through curing and opening to traffic, has a definite effect on the durability and structural integrity of the finished pavement.

2–1. Concrete Materials and Uses

Concrete must be 4 inches thick to resist breakage, which is why you will normally find most sidewalks, driveways, and floor slabs meet this requirement. In general, a considerable portion of the concrete pavements you will construct will be non-reinforced. However, concrete can be reinforced with items like rebar, welded wire fabric, and reinforcing fibers. In some instances, such as odd-shaped slabs and mismatched joints, reinforcement is required.

The minimum thickness of a street or other traffic-bearing concrete surface is 6 inches, while much greater thickness is required in some cases. The thickness depends upon the subgrade, the calculated flexural strength of the finished concrete, and the anticipated wheel loads. For example, an alert apron (parking area) for a B–1B bomber aircraft is sometimes as thick as 6 feet due to the aircraft's weight and bearing pressure exerted on the pavement. Concrete pavements will have a long life when properly constructed, maintained, and used for purposes and loads for which they were designed.

Because of its rigidity, concrete pavement will bridge small, soft, or settled areas of subgrade when it is moderately loaded. Bituminous pavement (asphalt) will deform and settle with the subgrade. When an excessively heavy load is applied to a concrete pavement on a poor foundation, the pavement will crack or break to the point of failure. In this section, we will focus on concrete materials and their uses. You will learn how to calculate the amount of concrete materials, prepare an area for concrete, mix and place concrete, as well as finish and cure concrete.

While the materials used in making concrete are essentially the same as mentioned earlier (cement, sand, gravel, and water) they can sometimes include admixtures. The term "admixture" encompasses a host of materials that you will learn about later. The following lessons detail information concerning the composition of concrete and how to determine which concrete materials are best for a given project. Let's begin by giving you an explanation of cement.

411. The types and uses of Portland cement

As we use it, the term "cement" means Portland cement. This is not a specific trade name; it is a type of cement that can be bought under many trade names. Portland cement is hydraulic cement (cement that not only hardens by reacting with water but also forms a water-resistant product) manufactured under carefully selected and closely controlled processes. Cement is made of such materials as limestone, marl, shale, or clay. Blast furnace slag is sometimes used as one of the ingredients. The raw materials for cement are crushed and pulverized, mixed in proper proportions for the correct chemical composition, and fed into kilns. These materials are converted by heating them to a temperature of approximately 27,000°F (Fahrenheit) to form a clinker, which is then cooled and pulverized. A small amount of gypsum is added to regulate the setting time. The pulverizing process grinds the clinkers so fine that nearly all the powder will pass through a sieve having 200 meshes per linear inch, or 40,000 openings per square inch (No. 200 sieve).

When cement and water are mixed, they form a paste that first sets, or becomes firm, and then cures for an indefinite length of time. The process of curing is known as hydration. Hydration is the chemical reaction between the components of the cement and the water. The strength of concrete begins with hydration and continues as long as hydration continues. If hydration stops, curing stops. At the end of 28 days, the concrete will have reached its maximum strength.

Concrete strength is dependent upon the materials in the mixture. Other types of cement can increase or decrease your concrete strength. However, since we mainly use Portland cement, we will take a look at the five types in the following paragraphs.

Type I (normal Portland cement)

Type I is the most widely used cement for pavements, sidewalks, buildings, bridges, and masonry units. In other words, this is general-purpose cement used for roads and ordinary construction projects.

Type II (modified Portland cement)

Type II generates less heat during hydration than type I and is used for structures of considerable size. It is also slightly resistant to alkaline soil or water (sulfate resistant).

Type III (high-early-strength Portland cement)

Type III is used when high strength is required in a very short time, such as in cold-weather construction. Type III cement requires less protection time from freezing and will attain normal three-day strength in one day. The volume of heat during hydration is also accelerated, which can cause cracking. Normally, this cement is not used in large-scale operations, since it is more expensive than ordinary cement.

Type IV (low-heat Portland cement)

Type IV generates a relatively small amount of heat while hydrating. It is used in large masses of concrete, such as large dams.

Type V (sulfate-resistant Portland cement)

Type V is intended for use where the concrete will be in contact with soil or water of high-alkali content.

When the letter "A" follows any of the above types of cement, it is cement with air entrainment materials added used to trap bubbles. We will discuss air entrainment when we cover additives.

There is one other type of cement referred to as *alumina*. It is manufactured with bauxite ore (aluminum ore) and has high-alumina content. Alumina cement has a high-early strength, and it offers an advantage for cold-weather concreting because of its rapid rate of curing. Concrete made with high-alumina cement becomes as hard in 24 hours as type I concrete does in 28 days.

412. The mix design

As mentioned earlier, concrete is a predetermined mixture of Portland cement, water, aggregates, and in some cases, admixtures combined into what is called the "mix design." You already know that cement and water form a paste that cures (hydrates) and bonds the aggregates together. You should now start to realize that concrete quality is directly related to the amount and properties of the materials used, and the way that it is placed, finished, and cured.

Aggregates

The aggregates used in concrete must be strong, durable, and chemically inert. Aggregates make up the majority (60–75 percent of the volume) of any concrete. The most commonly used aggregates are sand (coarse or fine) and crushed stone. The aggregate should be washed to remove any dust, organic matter, or any other impurities which would interfere with the bonding reaction with the cement paste.

Sand and stone combined with cement produce a strong, durable mass that is practically without voids if placed properly. A well-graded (all sizes represented) sample of aggregate works best to increase hydration efficiency and reduces the amount of cement required. All of the aggregate in concrete must be covered with the water-cement paste. The fine particles fill the voids between the larger ones, forming a solid mass.

Coarse aggregate

Coarse aggregate passes through a 3-inch sieve and is retained on a No. 4 sieve. Coarse aggregate is primarily used as a filler to reduce the amount of cement needed and to increase its overall strength. For runways and road pavements, the aggregate should not exceed 2 inches, and the largest size particles should not be more than one-fourth the pavement thickness. However, it is not unusual for 1½-inch aggregate to be used in light load-bearing pavements, such as sidewalks and driveways, which are only 4 inches thick.

Fine aggregate

Fine aggregate, or sand, in concrete is used to fill the voids between the large aggregates. Take care to prevent dirt and other debris from getting mixed into the sand. The foreign material will affect the chemical reaction taking place during hydration and will ultimately affect the bonding quality of the sand type.

Gradation

Gradation of aggregate is a major factor in the workability, water requirements, and strength of the concrete. Fine and coarse aggregates are handled separately and mixed in exact proportions. The proportions of each are adjusted to produce a dense and workable mixture. A good crushed angular aggregate will produce a strong mix.

Water

Water that is safe for drinking (potable) is safe for making concrete. Water that is not potable is questionable in concrete mixtures and should be avoided if possible. Make sure a plentiful supply of water is at the mixer before and during concrete mixing. If you have to pump water from a stream, let it settle or try and strain the solids out before using it. It is common practice to store water in large tanks near the mixer. Of course, if you have a fixed water supply handy, connect a water hose and use as needed. Even under this ideal condition, fill a large container, or two, with water just in case. You can also use the water to wash your concrete tools when you are through.

Changes in water after the mix is designed will fundamentally change the mix and its load-bearing capacity. If you add water at the jobsite, you are changing the water-cement ratio; as such, you are changing the end strength of that concrete. If the concrete was ordered at a specified consistency (slump) and it arrives much stiffer and perhaps unworkable for the job, water can be added to conform to that preferred consistency. However, never exceed 1–2 gallons/yd^3 as any more will have a detrimental effect on the finished product. This addition of water will increase the slump by approximately 1 inch.

413. Concrete additives

There are several additives or admixtures you can use to change the composition of concrete or to accelerate or retard its curing. The four commonly used additives are air-entrainment agents, retarders, accelerators, and fibers. Additives are not recommended if the end result can be reached more economically by altering the mix's proportions.

Air-entrainment agents

One of the greatest advances in concrete technology was the development of air-entrained concrete in the late 1930s. Today, air entrainment is recommended for nearly all concretes, principally to improve resistance to freezing and defects associated with exposure to deicing chemicals. However, there are other important benefits of entrained air in both freshly mixed and cured concrete. Air-entrained concrete contains billions of microscopic air bubbles. These relieve internal pressure on the concrete by providing tiny chambers for the expansion of water when it freezes. Air-entrained concrete is produced through the use of air-entraining Portland cement or by introducing air-entraining admixtures under careful engineering supervision as the concrete is mixed on the job. The amount of entrained air is usually between 5 and 8 percent of the total volume of the concrete; however, the percentage may vary as required by special conditions. The use of air-entraining agents results in concrete that is highly resistant to severe frost action and cycles of wetting and drying or freezing and thawing and has a high degree of workability and durability.

Many different air-entrainment agents may be used to produce air-entrained concrete. Air-entrainment agents are liquids derived from natural wood resins, animal fats, vegetable fats, or various wetting agents, such as alkali salts and water-soluble soaps. Air-entrainment agents increase resistance to the action of chemicals. Agents may be blended with the cement during manufacturing or added at the mixing site. If done at the site, the agent is added to the mixing water. Manufactured air-entrainment cements have a letter "A" as a suffix in the type number (type IA, type IIA, type IIIA, etc.). Some reduction of strength results from the entrainment of air; however, this can be offset somewhat by reducing the water-cement ratio. For example, use one-half gallon less water per sack of cement. The mix retains the same workability. Air entrainment is especially useful for pavement construction in severe climates where there is high exposure to freezing and thawing cycles.

Retarders

Retarders are used to slow down the hydration rate of concrete. When the rate of hydration is slowed, more time is available for finishing. Also, high temperatures of fresh concrete 90°F and higher are often the cause of an increased rate of setting that makes placing and finishing difficult. One of the most practical ways to counteract this effect is to reduce the temperature of the concrete by cooling the mixing water or, if possible, work at night when ambient temperatures are lower.

Retarders are sometimes used to accomplish the following:

- Offset the accelerating effort of hot weather on the setting of concrete.

- Delay the initial set of concrete when difficult or unusual conditions of placement occur, such as placing concrete in large piers and foundations.
- Delay the set for special finishing processes, such as an exposed aggregate surface.

Some of the materials used to retard the set of a concrete mixture are lignin, borax, sugars, tartaric acids, and salts. Add these materials to the mixing water.

NOTE: A word of caution about using retarders—if you add more than 20 percent by volume of retarding agent to the mix, the effect is reversed, and it acts as an accelerator. It's best to order concrete from a commercial source for special project needs instead of trying to establish a specific mix design on your own.

Accelerators

Accelerators are used to accelerate the strength development of concrete in the early setting stages. Calcium chloride is the material most commonly used in accelerating mixes. However, in addition to accelerating strength gain, calcium chloride causes an increase in drying shrinkage, potential reinforcement corrosion, discoloration, and scaling potential.

Add calcium chloride to the concrete mix in solution form as part of the mixing water. If added to the concrete in dry form, all of the dry particles may not be completely dissolved during mixing. Undissolved lumps in the mix can cause pop-outs of dark spots in cured concrete.

The amount of calcium chloride added should be no more than is necessary to produce the desired results; in no case should the amount added exceed 2 percent by weight of cement.

Manufactured fiber additives

Reinforcing concrete to keep it from cracking is nothing new; even the earliest civilizations used natural fibers (silk, cotton, wool, etc.) to inhibit cracking in structures. Manufactured fibers help to control plastic and drying shrinkage and prevent thermal cracking, while reducing permeability to chloride and increasing the impact resistance of hardened concrete. Usually, these fibers are made from plastic, glass, steel, or other material. The fibers will not affect the concrete's basic characteristic, such as viscosity (resistance to flow-slump), set time, or finishing characteristics; however, they will improve tensile strength. Steel fiber has been shown to be the best type of fiber for resistance to cracking.

Fibers are added at a ratio of 1–2 percent per volume of concrete mix. Adding fiber to a mix is a great way to reduce the use of welded wire mesh for many projects. Ask your engineering section whether fiber is a good alternative to other forms of reinforcing.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

411. The types and uses of Portland cement

1. What are the five types of Portland cement?

2. Match the term in column B with its description in column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) Used for structures of considerable size and is slightly resistant to alkaline soil or water.	a. Type I.
____ (2) Sulfate resistant and is intended for use where the concrete will be in contact with soil or water of high-alkali content.	b. Type II.
____ (3) Widely used for pavements, buildings, sidewalks, and ordinary construction projects.	c. Type III.
____ (4) Generates a relatively small amount of heat while hydrating and is used in large masses of concrete, such as large dams.	d. Type IV.
____ (5) Used when high strength is required in a short time; it is also used in cold-weather construction.	e. Type V.

412. The mix design

1. What characteristics must aggregates have if used in a concrete mix?

2. For runways and road pavements, the aggregate size should not exceed what size?

3. What is the *maximum* size of the largest aggregate used in a concrete mixture?

4. What is the purpose of fine aggregate, or sand, used in a concrete mixture?

413. Concrete additives

1. Name the four types of additives or admixtures commonly used.

2. What effects do air-entrainment agents have on concrete mixtures?

3. How can you tell whether a bag of cement is air entrained?

4. What happens if you add more than 20 percent retarding agent to a concrete mixture?

5. The amount of calcium chloride added to a concrete mixture should never exceed what amount?

6. What are manufactured reinforcing fibers usually made of?

2–2. Preparing for Concrete

The concrete projects you will be on will vary in size and shape, from sidewalks or curbs to aircraft parking areas and runways. Before any concrete gets poured, there is a lot of work that goes into preparing. Information provided in this section includes calculating concrete, preparing concrete formwork, the use of load-transfer devices, and reinforcing materials.

Working with concrete can be a challenging task. You can design and place forms to mold concrete into any shape. Make sure your forms are placed exactly where you want them. Once the concrete is placed and takes its initial set, it is virtually impossible to move without destroying it.

414. Calculating concrete

This lesson considers calculating the amount of concrete a job calls for. To find out how much concrete you need for a job, you must be able to compute volume. In a previous unit, you learned how to compute the base course needed for a project; now you will learn how to compute for concrete needs. The same principles and formulas apply to computing volumes of concrete. To help solidify your knowledge, you will work some sample scenarios to practice the computations. To begin, you will need to take some measurements of your project. The amount of concrete needed depends solely on the size of the "pour." The way to figure out the amount needed is to measure the area you are going to be filling, and then convert the area into volume (yd^3).

Area

As a review, area is defined as any plane surface within boundaries. To compute the area of a square or rectangle, you must multiply the length times the width. Let's say you want to build a patio to measure 20 feet long and 30 feet wide. To find the area of the patio, multiply 20 feet by 30 feet. The result is 600 sq. ft.

Now let's say the measurements of the patio are 20 feet, 6 inches long and 30 feet, 4 inches wide. It is always easier to work with one unit of measurement (feet in this case). Therefore, you must first convert the inches into feet. To do this, divide 6 (inches) by 12 (inches per foot) and you'll get 0.5 feet. Thus, the length is 20.5 feet.

Now do the same with the width. For example, divide 12 (inches) into 4 (inches per foot) and the result is 0.33 feet. The width of the patio is 30.33 feet.

To find the total area of the patio, multiply as follows:

$20.5 \text{ feet} \times 30.33 \text{ feet} = 621.77 \text{ ft}^2$.

As discussed in the previous unit, the formula for computing the area of a circle is πr^2, with π representing the rounded number 3.14, and r^2 being the square of the circle's radius (which is half of the circle's diameter).

For example, a circle with a diameter of 10 feet has a radius of 5 feet. Now, multiply the radius by itself to get r^2.

To find the area of this circle, use the following formula:

$A = \pi r^2$.

$A = 3.14 \times 5^2$.

$A = 3.14 \times 25$.

$A = 78.5\ ft^2$.

Don't forget, if you have inches involved in the measurements, you must convert the inches into feet before you multiply. The following table displays the conversions from inches to feet.

Inches	1	2	3	4	5	6	7	8	9	10	11
Feet	0.083	0.167	0.25	0.333	0.417	0.5	0.583	0.667	0.75	0.833	0.917

Volume

Calculating volume brings in a third dimension–depth. In area calculations, we determined the surface area. In volume calculations, we still use the surface area, but then multiply that value by the height or depth as the third multiple.

Computing the volume of rectangular spaces

To compute the volume of a square or rectangular area, you know to multiply the length by width by depth:

$L \times W \times D = V$.

Computing the volume of circular spaces

To find the volume of a circular object, first compute the area using the following formula:

$V = \pi r^2 \times D$.

If the circular area discussed earlier is to be 6 inches deep, first convert 6 inches to 0.5 feet, and then multiply:

$\pi \times 25$ (r^2 in feet) $\times 0.5$ (depth in feet) $= 39.25\ ft^3$.

Concrete is ordered in cubic yards, so you need to convert your cubic feet measurement into cubic yards.

It is simply a matter of dividing your total by 27 (there are 27 ft^3 in 1 yd^3).

$39.25 \div 27 = 1.45\ yd^3$.

Compensating for low spots

Because of low spots in the base course, order a little more concrete to compensate, normally 5 percent. To calculate the total amount of concrete needed, multiply the volume (yd^3) by 1.05 (volume plus 5 percent) to find the amount of concrete to order:

$1.45 \times 1.05 = 1.52\ yd^3$.

You would order 2 cubic yards for this circular project because usually you can't get ½ of a cubic yard.

Let's look at another example of calculating the concrete for a project using everything we have learned. Suppose you want to pour a patio measuring 30 feet by 20 feet by 3 inches thick. First, convert the inches into feet by dividing 3 by 12, giving you 0.25 feet. Next, use the entire formula in the following manner for computing concrete in a rectangle:

$V = L \times W \times D \div 27 \times 1.05$.

$V = 30 \times 20 \times 0.25 \div 27 \times 1.05$.

$V = 600 \times 0.25 \div 27 \times 1.05$.

$V = 150 \div 27 \times 1.05$.

$V = 5.56 \times 1.05.$

$V = 5.84 = 6 \text{ yd}^3.$

You would round up and order 6 cubc yard[s] of concrete for this particular example.

Use the same exact procedures for computing the amount of concrete needed for any shape. If possible, make the shape of the concrete as simple as possible (i.e. square, rectangle, circle, triangle, etc.). If you can't, break the shape into manageable shapes and figure volumes for each of the shapes, then add them all together.

If you are ever in the situation where you would need to convert from US to metric, the following is a convenient table with common conversions.

Conversion Table		
Multiply	**By**	**To Obtain**
Millimeters	0.0394	Inches
Inches	25.4	Millimeters
Meters	3.281	Feet
Square Inches	6.45	Square Centimeters
Square Centimeters	155	Square Inches
Square Meters	10.76	Square Feet
Liters	0.264	US Gallons
Yards	0.914	Meters
Square Yards	0.836	Square Meters
Gallons of Water	8.35	Pounds of Water
Pounds of Water	27.65	Cubic Inches
Gallons	231	Cubic Inches
Grams	0.0353	Ounces
Cubic Yards	0.7645	Cubic Meters
Pounds	0.45359	Kilograms
Kilograms	2.2046	Pounds
Grams	15.43	Grains
Meters	1.0936	Yards
Or divide the right column by the middle column to get the value in the left column.		

415. Concrete formwork

Concrete forms establish the edges of concrete structures. Setting them up in advance, and correctly, saves time and money when pouring cast-in-place concrete structures. Forms must be strong enough to resist the high pressure exerted by the concrete.

Small areas

Forms for small areas, such as concrete sidewalks and driveways, are usually made from wood 2-by-4s turned up on edges. Since the actual dimensions of a 2-by-4 is only 1 ½ by 3 ½ inches, the extra ½ inch can be made up by making sure the bottom inside edge of the form does not touch the ground, thus giving you the full 4 inches. You could also set the elevation inside of the forms; 6 inches is usually sufficient.

To set forms for sidewalks and driveways, drive stakes at each corner of the layout. Stretch a string to use as a guide from one stake to the other when setting forms. Nylon string is best because it stretches tight without breaking. Cotton or other string usually breaks before you can stretch it tight enough to keep it from sagging in the middle. If necessary, excavate the area so that the forms go under the string. Dig out enough soil on the outside of the string to give you plenty of room for the forms.

Set the forms with the inside of the 2-by-4's top edges just below the string. Drive a 2-by-4 stake at one end of the first 2-by-4 and another where the next 2-by-4 joins the first. Drive the second stake so that you can nail the ends of both 2-by-4s to it. In other words, split the 2-by-4 joint with the 2-by-4 stake. Drive a stake every 2 feet along the form. Adjust the form to the string by packing the dirt at the side of the stake. If you want the form to move outward, hit the dirt on the inside of the stake.

Remove any material inside the forms that needs to come out. You can make a simple screed to even up the bottom of the dug area. Cut a 2-by-4 about 2 inches shorter than the width of your project. Stand the 2-by-4 on one two-inch flat, and nail a short piece of 2-by-4 onto the other two-inch flat. The short pieces should extend about 4 inches past the ends of the long 2-by-4 and over the sides of the form (the ends will ride on the form, creating a uniform depth of material). Screed the area between the forms as you dig out the high spots and fill and compact the low spots.

If space allows, use a skid-steer loader or front-end loader to level and move material throughout the project. Use a stringline or straightedge to check elevations as you progress.

Large areas

Forms for larger and heavier pavements, such as those used for parking lots, streets, and runways, are made of steel. Steel forms sometimes are used for sidewalks and other four- to six-inch thick pavements; they are always used in any major job where you use large riding equipment. Steel forms serve two purposes: to contain the concrete and to provide a track for form-riding equipment.

Steel forms are long and vary from 4–12 inches in height; as such, they can be extremely heavy as the size increases. All standard forms have three stake pockets with wedges to hold the forms firmly in place. Figure 2–1 shows a steel form and its working parts. Note the locking plate and the wedges. The locking plate is shown in the locked position. To join the next form to this one, knock the locking plate back, butt the second form against it, and lock the forms together by driving the locking plate back to the position shown.

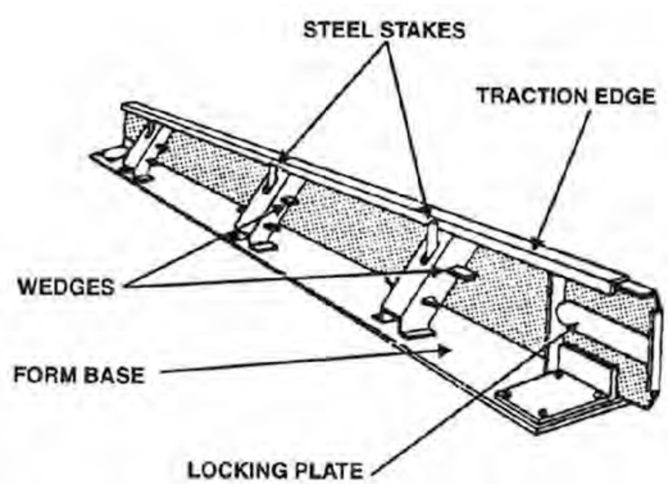


Figure 2–1. Steel concrete form.

Lock the form to the steel stakes by driving the wedges against the stakes. You can make some minor adjustments with the locking wedges. For example, if you want to move the form forward (toward where you want to place the concrete), drive the inside wedge farther in than the outside edge, but make sure you loosen that outside wedge first or it won't move.

In the following paragraphs, you will learn how to position steel forms on curves. You will also learn how to adjust the form height and alignment by trimming the base or by using wood blocks.

Use of forms on curves

You can use standard forms on curves with a radius as short as 150 feet. A shorter radius requires some type of flexible form, such as sheet metal or plywood. Flexible forms do not have to be of the same heavy construction as standard forms because most form-riding equipment cannot turn on a radius of less than 150 feet. You will have to hand-finish the concrete in short-radius curves. You must also secure the flexible forms with stakes at close intervals to hold them into position.

Height of the form

The height of the form should be equal to the thickness of the concrete to be placed. The width of the steel form base should be at least 80 percent of the form height. For example, a 10-inch form should have an 8-inch base.

If your forms do not meet the height requirement needed for the pavement, increase the height of the form by bolting a plate onto the bottom of the form. The plate should not exceed 25 percent of the original form height.

Alignment of steel forms

Steel forms (8 inches or higher) are very heavy. Use a front-end loader, skid steer, or any mechanical lifting device available to place the forms as near to final alignment as possible. Move them into final alignment by hand, using your stringline as a guide. Use a sledgehammer to join the sections (drive the locking plate into place). Make sure that the forms butt together closely. Drive steel stakes to hold the forms in place, and drive the wedges against the stakes so the forms don't move.

Driving the stakes

Stake length varies with form height. For 8-inch forms, the stakes must be at least 18-inches long; for 12-inch forms, the stakes must be at least 30-inches long. Drive the stakes with a sledgehammer or a pneumatic pin driver. You can also use a pin driver attachment for a small jackhammer to drive the stakes. You can drive the pins with the 35-lb. pneumatic hammer much easier and faster than you can with a sledgehammer. The pin driver also cuts down on mushrooming at the top of the pin.

Making corrections

After you have the steel forms set, they should be rigid. They should deflect no more than ¼ inch. Find variations by sighting along the top of the forms. You can correct low spots by loosening the locking wedges, raising the form with a steel bar at the low spot and tamping base material into it. Correct high spots by removing one or more sections of the form and trimming off the material.

416. Load-transfer devices

Earlier, you learned the need for adequate distribution of wheel loads from the pavement through the base course to the subgrade. Your concrete slab probably will fail if you do not maintain the load distribution properly. The same principle applies to the transfer of loads from slab to slab and even within individual slabs. If the load is not transferred, the isolated stresses at the ends results in spalling and cracking. You can transfer the load several ways. The most common methods are dowels and keyways.

Dowels

Dowels are the most effective way of transferring loads from slab to slab. The weight of the traffic is distributed through the concrete to the dowels. A portion of the load is then distributed through the dowel and into the adjacent slab. The load transfer must be uniformly maintained throughout the slab. The dowels must be put evenly across the slab to keep the joint from shifting out of alignment.

If the dowel is to be put across an expansion or construction joint, it must be smooth to allow for movement of the concrete. Concrete expands and contracts with fluctuations in temperature and as it ages. The proper placement of these dowels is vital if they are to function as designed. To ensure adequate and uniform load transfer, the dowels should be put at mid-depth. The placement of the dowel hole in the vertical face of the pavement is determined by the thickness of the pavement. The dowel length and diameter also depends on the slab thickness. Dowels put across expansion joints must be able to move longitudinally from expansion and contraction of the concrete. To facilitate this movement, coat the capped end of the dowel with grease or install plastic sleeves which also allow for movement.

Keyways

Keyways are constructed when you bolt, screw, or nail metal or wooden strips to the midsection of forms. You can make them using a sheet metal form, premolded mastic $^1/_8$-inch thick, composite hardboard, or two-inch lumber with a metal strip or wooden strip attached to form the groove (fig. 2–2).

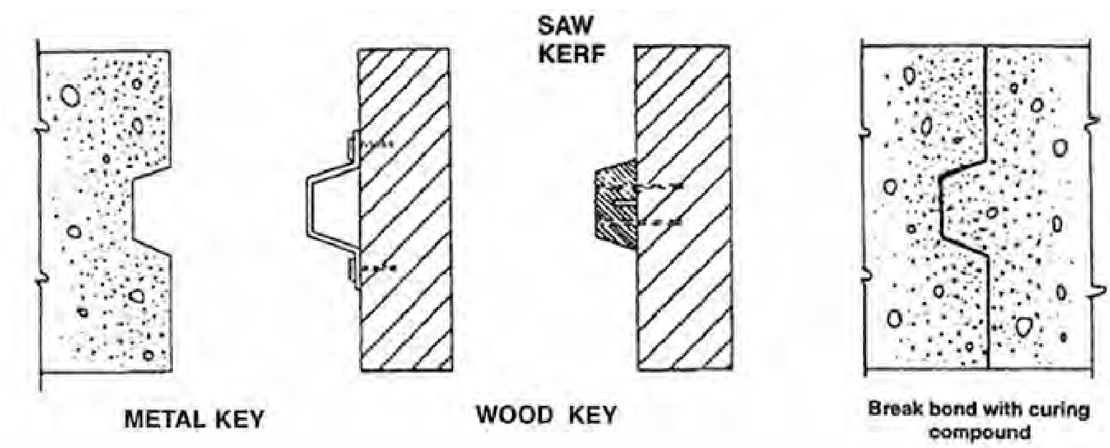


Figure 2–2. Keyways.

If you use wooden strips to form the keyway, they may absorb moisture from the concrete, swell, and cause the concrete lip to crack above the keyway. To prevent cracking, oil the wooden strips and groove them with a saw kerf to minimize swelling. A one- by two-inch keyway with beveled edges is sufficient for slabs from five- to eight-inches thick. Avoid larger keyways. If metal is used to form the keyways, it should be thick enough to withstand handling. One advantage of the metal keyway is the ease of cleaning for reuse.

417. Reinforcing materials

Previously, you read about manufactured fibers being added to concrete to increase its strength and inhibit cracking. Now it’s time to learn about the most commonly applied reinforcing material used to strengthen concrete—metal.

Reinforced concrete units consist of metal (usually steel) and concrete bonded together. Patterns of steel rods (bars) in a reinforced concrete building can withstand stresses and strains imposed by other parts of the building. They also permit the concrete to withstand most of the compressive stresses it will endure. The combination of steel and concrete makes an excellent structure of economic design.

Bonding of concrete and steel

Because of its tensile strength, steel is the best metal for reinforcing concrete. To guarantee the strength of the concrete, there must be a good bond between the steel and the concrete. Bonds are created by natural means and improved by mechanical means. Natural bonding of concrete to steel is brought about by adhesion and shrinkage of concrete during hydration. This action causes the concrete to grip the metal tightly. Mechanical bonding of concrete to steel is brought about by twisting or otherwise deforming the metal. Various types and sizes of reinforcing material are used to reinforce concrete. Any type of steel used in concrete construction should be clean and free of flaking rust.

Use of steel rods

Reinforcement steel, most commonly called "rebar," is available in various sizes. They may be plain, twisted, or deformed by rolling or stamping. Individual rods are woven, welded, or tied together to form reinforcing units. Units of special design are placed together according to a predetermined system or pattern. When used for concrete floors, columns, and slabs, reinforcing steel is assembled at the beginning of the job so that it is ready for installation when the formwork is completed.

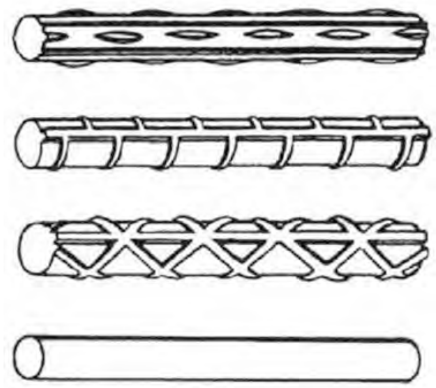


Figure 2–3. Types of steel reinforcement rods.

A plain rod is a straight piece of steel that *is not* twisted or deformed. A deformed rod is one that has been stamped or rolled to form rough edges on the outer surface. Plain and deformed reinforcing rods are shown in figure 2–3.

Tie bars

Tie bars are deformed steel bars used to hold slabs together. They are used in the longitudinal joint of the edge and end slabs of runways. They can also be used in full-depth repairs and in curbs. These bars are usually $^5/_8$-inch in diameter, 30 inches in length, and installed at mid-depth.

Use of welded wire mesh

Welded wire mesh is steel-reinforcing fabric. There are a great number of mesh patterns you can buy, which come in several sizes and different sized wire. The longitudinal wires are spaced and tied in position by smaller transverse locking wires.

Welded wire fabric commonly is used as reinforcement in horizontal slabs. Welding produces a more rigid, less distorted fabric than woven wire. Wire mesh most commonly comes in sheets of various sizes or in rolls as shown in figure 2–4.

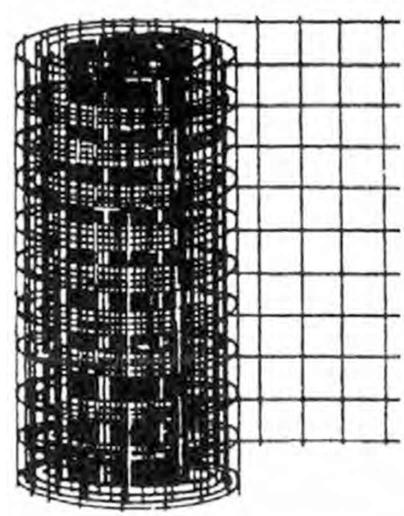


Figure 2–4. Welded wire fabric.

Placing reinforcements in forms

When reinforcing units, such as rebar and wire mesh, are placed in a form, it must then be braced to retain its shape and position while the concrete is placed. Concrete is extremely heavy and will disrupt the placement of your reinforcement if precautions are not taken. After placing reinforcing units, always inspect them for defects (e.g., loose tie wires, corrosion, etc.). Place the reinforcement so that it will be surrounded by concrete when the concrete is placed.

Welded wire fabric

You can cut and work welded wire fabric easily by hand. Normally, all you need is a pair of bolt cutters. Never try to cut wire fabric from a roll by yourself. The recoil of the tensioned wire can be very dangerous. Always have another person hold down one end while you unroll the other. If you need overlap between two pieces, the overlap should be at least 6 inches, or one complete square. Use a seven-gauge tie wire to secure the pieces to each other. Just before you put the cut wire into the area, oil your forms. Oil prevents concrete from binding to the forms. Because it also keeps concrete from bonding to reinforcement wire, be careful not to get the oil on the wire. After the forms are oiled, put the wire into the formed area.

When you begin pouring concrete, keep the reinforcement material off the ground but below the surface. You can do this by placing chairs under the wire at various points. An alternative is to remove the wire from the forms, place half the concrete, replace the wire, and then place the rest of the concrete. This way, you are not constantly stepping on the wire mesh.

Rebar

This material is a lot harder to work with than welded wire, and it requires more people to install it. Normally, it must be cut to length by a saw (K–12 with a metal blade on it), shear, or similar cutting tools. You can bend rebar in different ways, depending on its size. If the material is large, heat the rebar with a torch and bend it to the desired angle. You can bend medium-size pieces to shape on a bar-bending table. You can bend small pieces of rebar by hand.

Supporting and spacing reinforcements

Different devices are used to support and space reinforcement steel. The steel rods must be correctly spaced in relation to each other and to the sides of the formwork. Supports and spacers (also called chairs and saddles) are placed in the forms to support and space the reinforcing material. Slab bolsters, stone of the proper size, and precast concrete block with metal ties are used to support the steel. Stirrups are used to support reinforcing material in concrete girders and beams. Several types of supports and spacers are shown in figure 2–5.

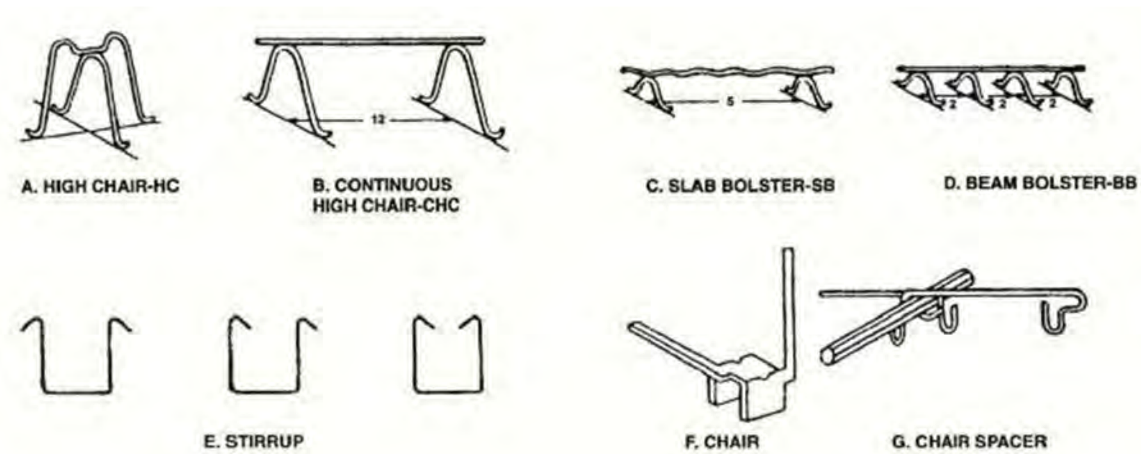


Figure 2–5. Types of supports and spacers.

The specified concrete protective cover determines the height of the supports used to hold the reinforcing material in a concrete slab. Footings and other principal structural members, which are against the ground or exposed to the weather, should have at least 3 inches of concrete between the steel reinforcement and the ground. There should also be a two-inch protective covering of concrete above the steel reinforcement.

NOTE: From the preceding discussion, it would stand to reason that you would want at least a five-inch pad before using reinforcing material. A good rule of thumb is that you don't need reinforcement in slabs (flatwork) less than 6 inches, but always use reinforcement in vertical concrete (walls, footers, pillars, etc.). However, when in doubt contact the engineer to see whether it should be used or not depending on the design and the anticipated use.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

414. Calculating concrete

1. What is the area of a square that measures 14 feet, 4 inches by 14 feet, 4 inches?

2. What is the volume of a circle having a diameter of 22 feet and a depth of 6 inches?

3. How many cubic yards of concrete are required to complete the circle in question no. 2 (including the 5 percent)?

415. Concrete formwork

1. How many feet apart should you drive stakes for wooden forms?

2. What are the two purposes for using steel forms?

3. How do you lock steel forms to the steel stakes?

4. What is the recommended height of forms?

5. What is the recommended width of steel forms?

6. What is the *minimum* length for stakes used on steel forms that are 8-inches high?

7. What is the *maximum* allowable deflection for forms?

416. Load-transfer devices

1. Where should you put dowels to ensure adequate and uniform load transfer?

2. How are keyways constructed?

417. Reinforcing materials

1. If an overlap between two pieces of wire fabric is needed, how much should the overlap be?

2. What is used to support reinforcing material in concrete girders and beams?

2–3. Placing Concrete

Concrete materials must be mixed, placed, finished, and cured in the proper manner to prevent them from deteriorating prematurely. Once delivered to the site, you must also test the concrete for quality criteria, if needed. The following information outlines the proper steps in the construction of long-lasting, concrete pavement.

418. Concrete quality

To minimize the maintenance cost of concrete failure, always insist on quality concrete material. Even when quality material is used, always test your concrete mixture and design procedures for conformance.

There are several basic requirements for good quality concrete, including the following:

- Good materials–cement, aggregate (sand and gravel or crushed stone), admixtures, and water.
- Proper proportioning of concrete materials.
- Thorough mixing of materials.
- Skillful placing and finishing of concrete.
- Proper curing of concrete.

All of these requirements are important, and failure to satisfy any one of them will always result in a reduction in concrete quality and the possibility of failure.

Testing concrete

Concrete's strength can be tested only after it has cured, and then it's usually too late. Normally, a test known as a slump test is used to evaluate the concrete mixture during placement. Slump is a measure of the concrete's uniformity from batch to batch (consistency). It is not a measure of concrete quality in regards to the design, only in its physical qualities, such as plasticity and the placeability. For given proportions of cement and aggregates, the higher the slump, the wetter the mixture. A slump test may also indicate either an inadequate or an overabundant proportion of an ingredient. For instance, the color may indicate a rich (too much cement) condition; the size of the aggregate may be too small or too large; and too much water will have obvious signs.

Flexural and compressive strength tests on a cured sample taken at the time the concrete was placed are the only tests that show how the concrete will perform in-place. Reputable companies have tried and true mix designs and historical data to back up their performance claims.

Concrete mixtures should always be of a consistency and workability suitable for the conditions of the job. Thinner placement and heavily reinforced areas require more fluid mixtures than thicker placements with little reinforcing. When utilizing a pumper truck, the mix needs to flow easily so it can travel through the pump and out the hose.

Slump test

The slump test measures consistency; it shouldn't be used to compare mixes of wholly different proportions or those of different designs. Under uniform operating conditions, the consistency changes indicated by the slump are useful keys to the character of the mix. To avoid using mixes that are too stiff or too fluid, slumps falling within these limits provided in the following table are best.

Type of Construction	Slump (inches)
Unreinforced footings and substructure walls.	1” to 4”
Reinforced foundation walls and footings.	3” to 6”
Reinforced slabs, beams, and walls.	3” to 6”
Sidewalks, driveways, and slabs on ground.	3” to 6”
Pavements.	1” to 3”
Heavy-mass construction.	1” to 3”

The slump, or consistency, is governed by all the factors we discussed to include the amount of aggregate added to the mix, the gradation of the sand and the relative percentages of sand to gravel, and, of course, the amount of water introduced into the mix. Even the admixtures we include in our design will have an effect on slump.

Slump-test procedure

The slump cone (fig. 2–6, A) is dampened and placed on a flat, smooth, nonabsorbent surface, then filled in three roughly equal volumes, using a representative sample of the concrete, usually at different stages of the pour.

In placing each scoop-full of concrete in the slump cone, move the scoop around to ensure equal distribution of concrete in the cone. Rod each of the three layers of concrete with 25 strokes using a tamping rod. Then distribute the concrete uniformly over the cross section of the slump cone. Each stroke should penetrate into (not through) the underlying layer, with the bottom layer being rodded throughout its entire depth. After you have rodded the top layer of concrete, strike the surface of the concrete with a trowel so that the slump cone is completely filled. Raise the cone very carefully from the concrete in a vertical direction. You then measure the slump immediately by determining the difference between the height of the slump cone and the height of the pile of concrete at its vertical axis (fig. 2–6, B). The result is recorded in inches to the nearest ¼ inch.

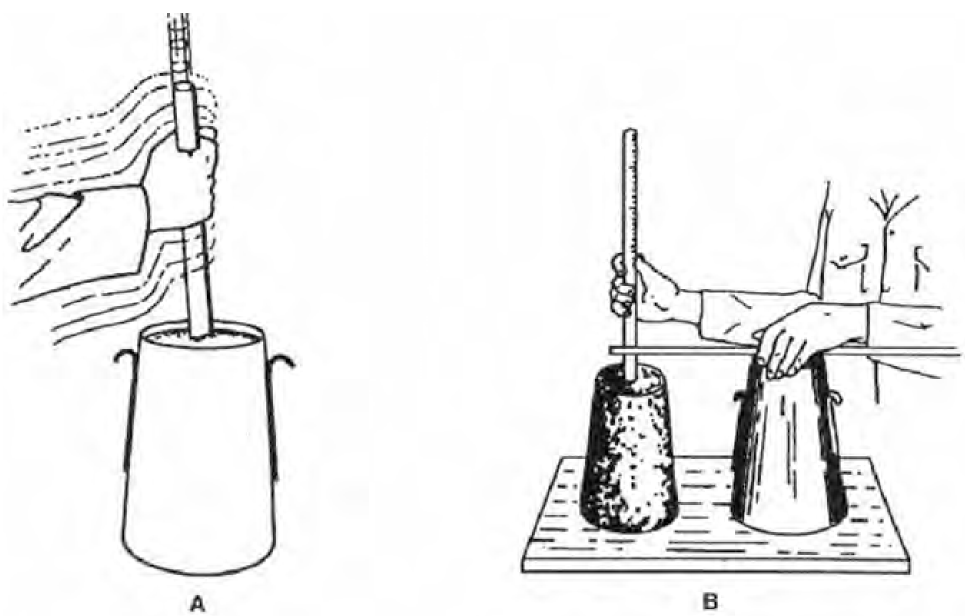


Figure 2–6. Measuring slump.

The desired slump is established by prerequisite specifications set by an engineer. A slump of 2½ inches is generally satisfactory for concrete pavement. After the slump measurement is complete, the side of the pile of concrete on which the slump was determined should be tapped gently with the tamping rod. The behavior of the concrete under this treatment is a valuable indication of its *cohesiveness, workability, and placeability*. A well-proportioned, workable mix will gradually slump to lower elevations and keep its original identity, while a poor mix will crumble, segregate, and fall apart. Slump tests should be started and finished within two and one half minutes of discharge.

419. Preparing cylinders for testing

The concrete's compressive strength is important in structural design. The main factors affecting strength are the water-cement ratio and the extent to which hydration has occurred. The compressive strength test, like the test for flexural strength done in a laboratory, is a follow-up test to determine the effectiveness of the job's field control methods. Although specimens may be taken from the cured concrete, the usual practice is to make test specimens in standard-size molds from the fresh concrete as it is being placed on the job.

The test uses a testing machine designed specifically for applying compression to concrete molds. The standard test specimen for compressive strength is a 6-inch diameter, 12-inch-long cylinder. In all cases, the diameter of the cylinder should be at least three times the maximum size of the aggregate. While metal molds are preferred, you can use paraffin cardboard or plastic molds. No matter what mold you use, always make sure the bottom of the mold is attached and hold the mold on a smooth, level surface. Fill the mold carefully so as not to distort the shape. Fill it in three equal layers, rodding each layer 25 times.

Curing

Typically 3E5X1 Engineering Assistant personnel or civilian contractors will prepare the cylinders and cure the specimens in a lab or in the field. Lab curing gives a more accurate indication of the concrete's *potential strength* due to its controlled environment. Field-cured specimens may give a more accurate interpretation of the *actual strength* in the structure. Compressive strength testing should be done on the 7^{th}, 14^{th}, and 28^{th} day of curing to ensure the concrete meets the particular project's needs. On some jobs both methods are used, especially when the weather is unfavorable.

Capping end surfaces

The condition of the cylinder ends has an important influence on the test results, so you must finish end surfaces carefully. You will need to ensure the cylinder ends are properly finished (perfectly flat); otherwise, the results may be skewed. For example, tests of cylinders with a convexity of 0.01 inch give results 20–35 percent lower than tests of cylinders with properly finished ends. Troweling the top of the cylinders or pressing down the concrete with a steel plate is not enough, for the settlement will be uneven. The Engineering Assistants should be on-site to ensure the samples are properly prepared.

420. Concrete at the worksite

Most of the concrete you will use is prepared at a central plant and delivered by transit truck to your job site. This is normal for jobs requiring large amounts of concrete. For jobs that take reasonably small amounts of concrete, you can use a portable concrete mixer if the handling of individual materials (gravel, sand, cement, and water) is acceptable. Very small jobs can be hand mixed in a wheelbarrow. The type of mixer depends on the job size.

Small jobs

For small jobs, you can best mix concrete by hand in a wheelbarrow (less than 1 yd^3). The most common rate of mix is known as one-two-three (one part cement + two parts sand + three parts gravel).

Spread the sand uniformly over the center, then spread the correct amount of cement over the sand. Thoroughly mix them with a mortar hoe. When you have the sand and cement well mixed, the combination should be a uniform gray color, free from streaks. Measure the correct amount of coarse aggregate and add it to the mix. Turn all of the dry ingredients at least three or four times to distribute the aggregate properly.

After you completely mix the dry ingredients, make a depression in the center of the pile to hold the water. Pour water slowly into the depression. Don’t add the full measure of water all at once. Stir the ingredients into the water. Keep adding water and mixing the ingredients until the concrete has the proper consistency. The water-cement ratio is simply the weight of water divided by the weight of the cement. During the concrete-mix design process, selection of the appropriate water-cement ratio for the durability and strength needed of the hardened concrete is determined by the quality of the cement paste. Generally speaking, if the water-cement ratio is low, then the compressive strength of the concrete is high. Typically, a mix is about 10–15 percent cement, 60–75 percent aggregate, and 15–20 percent water.

Medium jobs

A portable concrete mixer is best used on medium jobs (1–3 yd^3). Start by putting 10 percent of the water into the mixer. Place your cement, sand, and gravel into the skip of the mixer. Lower the skip before you load it. Raise the skip after you load it and dump your materials into the mixer drum. Add 80 percent of the water as the material goes into the drum. After all the other materials are in the drum, add the remaining 10 percent of the water.

The length of time the ingredients should be mixed varies with the type of mixer. In most cases, concrete is to be mixed at least one minute for the first cubic yard with an increase of 15 seconds for each additional cubic yard or fraction thereof. Follow the manufacturer’s instructions or the technical order (TO) for the mixer you are using.

Large jobs

For larger jobs, use a transit mixer. The American Society for Testing and Materials (ASTM) requires that concrete be delivered and completely discharged within 1½ hours (90 minutes) or before the drum has revolved 300 times after the introduction of water to the cement and aggregates. Fresh concrete that is left to agitate in the truck mixer tends to stiffen before the initial set develops. This concrete may be used if, upon remixing, it becomes sufficiently plastic to be consolidated in the forms. Under careful supervision, the truck driver or contractor may add a small amount of water to the concrete to attempt a remix. This is not recommended if the following conditions apply: (1) the maximum water-to-cement ratio will be exceeded, (2) the maximum slump will be exceeded, and (3) the maximum revolutions or mixing time will be exceeded.

A transit mixer can bring a dry mix (no water) and then add water when they arrive on-site. This helps to prevent the mixture from setting due to long-haul distances. Be sure to watch as the water is added to ensure the proper amount is adhered to.

421. Placing concrete

Immediately before placing the concrete, you should moisten the base; this prevents the base from absorbing water from the concrete. If you place concrete on a dry base, water leaves the concrete so fast that it can be extremely difficult to put a good finish on it. Also, a plastic vapor barrier can be placed on the base to essentially do the same thing as wetting does.

Transporting

You can use almost any device that can hold concrete to move it to the job. The main thing you must watch for when moving concrete is segregation of the mix. When you haul concrete for a considerable distance, the coarse aggregate settles to the bottom. To minimize or prevent segregation, keep the haul distance as short as possible. Also, prepare a stiff mix that contains an air-entrainment agent to keep it workable.

Placing

Always place concrete as near to its final resting place as possible. If you dump concrete in piles and then spread it, you not only cause yourself extra work, but you also cause segregation of the mix.

To place concrete from a ready-mix truck, you must have enough people and the proper equipment. Extensions can be added to the truck's chute to reach the area where you are working. When the mixer drum is reversed, the concrete moves out of the mixer and down the chute. The truck driver makes the necessary adjustments to regulate flow. The truck driver also handles the mechanism for starting and stopping the rotation of the mixer drum. You must guide the end of the chute as the concrete spills out. You can swing the chute to either side until it bumps against the truck. It can also be raised and lowered hydraulically. Adjust the height of the chute until it is about 1 foot from the ground. As the concrete comes out, swing the chute to get as much coverage as possible. Keep the thickness near the required level; too high and the guys on the rakes are in for some extra work; too low and the same guys will have to rake and shovel the concrete into the low areas. Working the chute is a very important job and takes a lot of practice.

As you place the concrete from a ready-mix truck, station two people very close behind the chute to screed the concrete. The closer they stay to the chute, the less need for going back to fill low spots or to remove excess concrete. We cover screeding further when we discuss finishing.

Consolidation

Consolidation is the process of compacting concrete and eliminating all the voids. Large voids, sometimes called "honeycomb," reduce a concrete's strength and can be the cause of failures. The only way to avoid honeycombed concrete is through consolidation. Consolidation is usually accomplished by vibration of newly placed concrete to a minimum practical volume, molding it within forms and around embedded parts and reinforcement and eliminating voids other than entrained air. The vibration force needed for consolidation is done by hand or by mechanical methods. The method you choose depends on the consistency of the mixture and the placement conditions, such as the complexity of the formwork and amount and spacing of reinforcement members.

Hand method

Workable, flowing mixtures can be consolidated by hand rodding; that is, thrusting a tamping rod or other suitable tool repeatedly into the concrete. The rod should be long enough to reach the bottom of the form and thin enough to pass between the reinforcing steel and the forms.

Spading can be used to improve the appearance of formed surfaces. A flat, spade-like tool should be repeatedly inserted and withdrawn adjacent to the form. This forces the larger coarse aggregates away from the forms and assists entrapped air voids in their upward movement toward the top surface where they can escape. A mixture that can be consolidated readily by hand tools should not be consolidated by mechanical methods because the concrete is likely to segregate under intense mechanical action.

Mechanical method

Vibration, either internal or external, is the most widely used mechanical method for consolidating concrete. When concrete is vibrated, the internal friction between the aggregate particles is temporarily destroyed and the concrete behaves like a liquid; it settles in the forms under the action of gravity and the large, entrapped air voids rise more easily to the surface. Internal friction is reestablished as soon as vibration stops.

Internal vibration

Proper use of internal vibrators is important for best results. Do not use vibrators to move concrete horizontally since this causes segregation. Whenever possible, lower the vibrator vertically into the concrete at regularly spaced intervals and allow it to descend by gravity. It should penetrate quickly to the bottom of the layer being placed and at least 6 inches into any previous placed layer.

In thin slabs, insert the vibrator at an angle or horizontally to keep the vibrator head completely immersed. For slabs on a grade, the vibrator should not make contact with the subgrade or base course. Be careful to not vibrate too much as the concrete could slough down the grade.

Hold the vibrator stationary until adequate consolidation is attained and then slowly withdraw it. An insertion time of 5–15 seconds usually will provide adequate consolidation. The concrete should move to fill the hole left by the vibrator. If the hole does not refill, reinsertion of the vibrator at a nearby point should solve the problem.

External vibration

The most common type of external vibrator that you will use most is the vibratory screed. It is used to consolidate concrete in floors and other flat work. Vibratory screeds give positive control of the strike-off operation and save a great deal of labor. However, do not use this equipment on concrete with slumps in excess of 3 inches. Surface vibration of such concrete results in an excessive accumulation of mortar and fine materials on the surface and thus reduces wear resistance. For the same reason, do not operate surface vibrators after the concrete has been consolidated adequately.

Because surface vibration of concrete slabs is least effective along the edges, use a spud or poker-type vibrator along the edges of the forms immediately before the vibratory screed is applied. Vibratory screeds are used for consolidating slabs up to 10-inches thick if the slabs are reinforced or only lightly reinforced (welded wire fabric). Internal vibration or a combination of internal and surface vibration is recommended for reinforced slabs.

422. Finishing concrete

Concrete is rarely at the right elevation after it has been placed. To get it to the correct elevation, level it off by screeding and then floating. Install joints and either broom finish the surface or trowel the surface to get the desired results.

Screeding

Screeding or strike off is the process of cutting off excess concrete to bring the surface of a slab to the proper grade. The template used in the manual method is called a straightedge, although the lower edge may be straight or slightly curved, depending on the surface specified. Move it across the concrete with a sawing motion and advanced forward a short distance with each movement. There should be a surplus of concrete against the front face of the straightedge to fill in low areas as the straightedge passes over the slab.

Floating

The step after screeding is the floating operation. Use the floats after screeding to remove high spots, fill low spots, and bring paste to the surface. Use a long-handled bull float for large areas. Use a small hand float for small areas and along the edges of the forms. Floats are made of many different materials to include wood, aluminum, and magnesium (fig. 2–7). Floating must be completed before bleed water accumulates on the surface. Be careful not to overwork the concrete as this could result in a less durable surface, which could include cracking, discoloration, or even spalling.

Figure 2–7. Bull float and "mag" float.

Edging

Edging is required along all edge forms and joints. Edging makes the concrete up against the forms denser and consolidates the concrete in these areas. It compacts the concrete next to the form where the floating process was less effective, making it more durable and less vulnerable to spalling and chipping. Edging is usually accomplished after the moisture film disappears from the floated surface and it can hold its shape.

In the edging operation, cut the concrete away from the forms. Then, hold the edger (fig. 2–8) almost flat on the surface and run it with the front slightly raised to prevent the edger from leaving too deep an impression. Additional edging may be required after subsequent finishing operations to maintain a clean edge. Edging can become difficult after the concrete has had a chance to set up, so be sure you have enough people to dedicate someone (or more if necessary) to perform this task.

Figure 2–8. Edger.

Jointing

All plastic concrete contains more water than is required for the hydration of the cement. When this extra water starts to evaporate, the process of dry-shrinkage creates tensile stresses in the concrete slab. Tensile stresses are those that act on the concrete horizontally. Joints are used to relieve these tensile stresses. If the stresses are not relieved, unsightly cracks develop.

Concrete slabs expand and contract by different amounts depending on their shape and size. The larger the slab (in depth and spatially), the greater the horizontal movement becomes. Provisions must be made for this movement to prevent unnecessary cracking. Provisions, such as jointing, help prevent cracking.

The types of joints that you will be constructing are expansion, contraction (sometimes called dummy), and construction.

Expansion joints

Expansion joints relieve compressive stresses caused by expansion of the pavement. They usually consist of some form of nonextruding filler, such as wood, asphalt, fiber, spun glass, or other preformed elastic or compressible material. It must permit horizontal expansion of the concrete.

Expansion joints must be provided between concrete pavements and all buildings (or other structures). Expansion joints may sometimes be required at intersections of runways, taxiways, or aprons. These joints are also part of concrete repairs which will be discussed later.

Contraction joints

Contraction joints (sometimes called dummy joints) relieve tensile stresses caused by pavement contraction. They consist of grooves formed in the surface of the concrete with a jointer (fig. 2–9) or concrete saw. These grooves reduce the pavement cross section at prescribed locations so that cracks, conforming to a given pattern, will occur below the joint. These grooves are pressed or sawed to a depth of one-eighth to one-fourth of the slab thickness and are one-half to five-eighths inch wide, maximum.

Construction joints

Anyplace where fresh concrete comes in direct contact with old concrete is a construction joint. Construction joints are normally placed where one day's placement ends and the next day's placement begins. The joint should be a doweled or keyed joint or a combination of both.

Troweling

If you want a dense, smooth surface, follow the initial floating by steel troweling. A typical steel trowel is shown in figure 2–10.

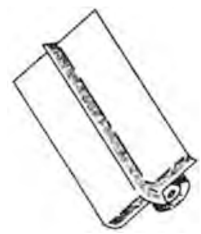


Figure 2–9. Jointer.

Figure 2–10. Steel trowel.

Start troweling after the bleed water disappears from the floated surface. The concrete should have set up enough to prevent fine material and water from working to the surface. However, concrete that sets up too quickly before troweling does not finish properly. The usual tendency is to start to trowel too soon. When you finish troweling, the surface should be smooth, even, and free of marks and ripples. Do not spread dry cement on a wet surface to take up excess water. This practice reduces wear resistance and surface durability. If you notice wet spots in the concrete surface, postpone troweling until the surplus water evaporates. Conversely, do not add water to the surface of the concrete to make it more workable. This only changes the surface water cement ratio and can lead to defects.

Where a hard, steel-troweled finish is required, follow the first troweling with a second troweling. Start after the concrete becomes set up enough that mortar will not stick to the trowel. The trowel should produce a ringing sound as you pass it over the surface. During this final troweling, use a slight tilt and put heavy pressure on the trowel to compact the surface thoroughly.

Brooming

Most concrete projects you will work on require a nonskid finish. The most common way to leave a coarse-textured finish is to float the concrete smooth and, while the concrete is still plastic, sweep the surface with a wet broom. Sweep it so that the broom bristle scoring is at right angles to the direction of traffic. The finer the broom bristles, the finer the texture. Also, the wetter the surface, the deeper the texture becomes.

423. Curing concrete

All concrete must be given time to cure. Correct curing of concrete, which is often overlooked, is an important part of any concrete project. If concrete is going to reach its potential strength and the strength gain is to be at a reasonable rate, then concrete must be given time to cure properly. Curing protects your project from the harmful effects of wind, sun, and other weather conditions, which may be harmful to the hydration process. How you cure your concrete will usually be determined by economics and the specifications set by the engineer.

Purpose of curing

The objective of curing concrete is to prevent or replenish moisture loss during the early, relatively rapid stages of hydration. Cure concrete by keeping the exposed surface of the concrete continuously moist. The earlier you start curing and the longer you can employ it, the stronger the concrete will be. Cure concrete for at least three days (preferably for seven days).

Major methods of curing concrete

The four major methods of curing concrete are water curing, water-retaining methods, waterproof mechanical barriers, and chemical membranes.

Water curing

Curing by flooding, ponding, or mist spraying is widely used. Of all known curing methods, water curing is the most effective for the prevention of mix water evaporation. A small dam of earth or other water-retaining material is placed around the perimeter of the surface, and the enclosed area is continuously flooded with water. Continuous sprinkling with water is also an excellent method of curing. If the sprinkling is done at intervals, the concrete must not be allowed to dry between applications of water. A constant supply of water prevents the possibility of crazing or cracking due to alternate wetting and drying.

Water-retaining methods

These methods involve the use of coverings that are kept continuously wet, such as sand, burlap, canvas, or straw. When concrete is cured by one of these methods, the entire concrete surface, including exposed edges or sides, must be covered. The materials used to retain the water must be kept damp during the entire curing period. If drying is permitted, the cover itself may absorb excessive moisture.

Waterproof mechanical barriers

Barriers of waterproof paper or plastic film seal in the water and prevent evaporation. One important advantage of mechanical barriers is that periodic additions of water are not required. These materials are applied as soon as the concrete is set up enough to resist surface damage. Use the widest practical width of material. The edges of adjacent sheets are overlapped by several inches. The seams are then tightly sealed by placing sand, wood planks, pressure-sensitive tape, mastic, or glue on the overlapping surfaces.

An added feature of mechanical barriers is that they provide some protection against damage from subsequent construction activity as well as protection from the sun.

In some cases, plastic films may cause discoloration of hardened concrete. When discoloration is objectionable, use some other curing method.

Chemical membranes

Chemicals can be sprayed or rolled on the surface to cure concrete. Liquid membrane-forming curing compounds retard or prevent the evaporation of moisture from the concrete. These compounds are effective curing materials when used correctly. Apply chemicals as soon as the concrete is finished. If there is any delay, you must keep the concrete moist until the membrane is applied. The membrane curing compound must not be applied when there is free water on the surface. The concrete absorbs free water and the membrane will be broken. Do not apply the compound after the concrete is dry since it will be absorbed into the surface of the concrete and a continuous membrane will not be formed. The correct time to apply the membrane is when the water sheen disappears from the surface of the finished concrete. The adequate and uniform application of curing compound is essential. In most cases, two applications are required. Chemical membranes are suitable not only for curing fresh concrete but also for further curing the concrete after the removal of forms or after initial moist curing.

424. After the pour

Remove forms as soon as the concrete has set enough so that the concrete will not be damaged when you remove them. You can usually remove the forms one to three days after the concrete is placed. In cold weather, leave forms in place for seven days.

Removing 2-by-4 forms

To remove 2-by-4 forms, hook one point of an ordinary pick under the edge of the form, press your foot down on the other pick point, and pull the handle toward you. This will lift the form straight up, without damaging the concrete. As you pull each form, move it away from the new concrete. If you lay the forms on or against the new concrete, you will damage it. Clean and stack the forms as soon as you get them pulled if they are to be reused.

Removing steel forms

The first step in removing steel forms is to loosen the pin wedges. Then you unlock the locking plates, pull the pins, and lift the form sections from the concrete. You may loosen the pin wedges and locking plates by driving them back with a sledgehammer. Be careful to not damage the new concrete while swinging the hammer.

The easiest and fastest way to pull pins is to use some type of mechanical pin puller. It also cuts down on manpower. You can use almost any type of equipment that has a boom or even a front-end loader. The boom should rotate or be side mounted, allowing you to drive alongside the forms and pull the pins. To pull pins, you can use almost any device that will hold onto them. One such device is a chain with a pair of heavy washer-shaped pieces of metal welded to the chain. The hole in the washers should be just large enough to go over the pin easily. When you raise the chain with the boom, the washers will catch the pin at an angle and pull it. To release the pin, straighten the washers so that they will come off. Another such device is a large bar similar to a railroad spike puller.

Before you remove the form, break up all spilled concrete and free the form. If your form has a keyway bolted to it, or if it has dowels through it, you must move it directly away from the concrete before you lift it. If you have a boom-equipped piece of equipment, use it to lift the form out of place and load it onto a truck or trailer. If you don't have such equipment, you must free, remove, and load the forms by hand. Clean and oil the forms as soon as possible.

Landscaping

One of the last details to complete during construction of most projects is landscaping. Some might find this task as being minor in detail; however, landscaping can have a great impact on the overall appearance of your work and provide required drainage for the new construction. The importance of landscaping at the end of a project falls into the two categories of appearance and drainage.

Appearance

First let's address appearance, and its importance to the final part of any construction job. No matter how well a project is constructed, if the area around the project is not appealing to the eyes, this will be what draws concerns to those driving by the area. The effort is required to ensure the area is up to base standards. The landscaping requirements might be as small as raking and reseeding the area or could require planting of trees and flowers. No matter the requirements, always ask yourself if you would pay someone else to leave the work site as you're leaving it.

Drainage

This bring us to drainage, which is the second and most important part of landscaping. Why is drainage so important? Simply put, if water fails to drain away from the structure, water could undermine the foundation and cause major damage. Always slope the area so water will flow into drainage in the area.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

418. Concrete quality

1. Which property of plastic concrete is measured by the slump test?

2. What should be the slump (in inches) of a typical driveway or sidewalk mix?

3. Which slump is considered satisfactory for most concrete pavements?

4. How will a poor slump react when it is tapped gently with a tamping rod?

419. Preparing cylinders for testing

1. What size cylinder is used as a standard for a compressive strength test?

2. How does the condition of the cylinder ends influence the slump test results?

3. Cylinders with a convexity of 0.01 inch can yield results how much lower than those with properly finished ends?

420. Concrete at the worksite

1. How many times should you turn dry ingredients to distribute aggregate properly?

2. Typically, what is the percentage of cement, aggregate, and water in a concrete mixture?

3. What type of equipment should you use to mix concrete for medium jobs?

4. At a *minimum*, how long should you mix ingredients in a portable concrete mixer?

421. Placing concrete

1. What is the main thing to watch for when transporting concrete?

2. How far should the chute of a ready-mix truck be from the ground when pouring concrete?

3. What is meant by consolidation?

4. What is the most widely used mechanical method of consolidating concrete?

422. Finishing concrete

1. What is meant by screeding?

2. What is the next step after screeding?

3. Briefly describe the edging operation.

4. What type of joint consists of grooves formed in the surface of the concrete with a jointer or sawed with a concrete saw?

5. When should troweling begin?

423. Curing concrete

1. List the four main ways to cure concrete.

2. Why must you *not* apply membrane-curing compound when there is free water on the surface of concrete?

424. After the pour

1. Briefly describe procedures for removing 2-by-4 forms.

2. Briefly describe procedures for removing steel forms.

Answers to Self-Test Questions

411

1. Type I, normal; Type II, modified; Type III, high-early-strength; Type IV, low-heat; Type V, sulfate-resistant.
2. (1) b.
   (2) e.
   (3) a.
   (4) d.
   (5) c.

412

1. They must be strong, durable, and chemically inert.
2. Two inches.
3. One-fourth the pavement thickness.
4. To fill the voids between the large aggregates.

413

1. Air-entrainment agents, retarders, accelerators, and fibers.
2. They result in concrete that is highly resistant to severe frost action and cycles of wetting and drying or freezing and thawing and has a high degree of workability and durability.
3. By whether it has the letter "A" as a suffix in the type number.
4. The effect is reversed, and it acts as an accelerator.
5. Two percent by weight.
6. Plastic, glass, steel, or other material.

414

1. 205.35 sq. ft.
2. 189.97 yd^3.
3. 7.39 yd^3.

415

1. Two feet.
2. To contain the concrete and to provide a track for the form-riding equipment.
3. By driving the wedges against the stakes.
4. It should equal the thickness of the concrete to be placed.
5. At least 80 percent of the form height.
6. Eighteen inches.
7. 1/4 inch.

416

1. Mid-depth.
2. By bolting, screwing, or nailing metal or wooden strips to the midsection of the forms.

417

1. At least 6 inches, or one complete square.
2. Stirrups.

418

1. Consistency.
2. Three to six inches slump.

3. A slump of 2½ inches.
4. It will crumble, segregate, and fall apart.

419

1. A cylinder 6 inches in diameter and 12 inches long.
2. If the ends aren't properly finished (perfectly flat), the results may be skewed.
3. Tests can yield results 20–35 percent lower than those with properly finished ends.

420

1. Three or four.
2. Ten to 15 percent cement, 60–75 percent aggregate and 15–20 percent water.
3. A portable concrete mixer.
4. At least one minute for the first cubic yard with an increase of 15 seconds for each additional cubic yard, or fraction thereof.

421

1. Segregation of the mix.
2. About 1 foot.
3. The process of compacting concrete and eliminating all the voids.
4. Vibration, either internal or external.

422

1. The process of cutting off excess concrete to bring the surface of a slab to proper grade.
2. Floating.
3. Cut the concrete away from the forms. Then, hold the edger almost flat on the surface and run it with the front slightly raised to prevent the edger from leaving too deep an impression.
4. Contraction joint.
5. After the bleed water disappears from the floated surface.

423

1. Water curing, water-retaining methods, waterproof mechanical barriers, and chemical membranes.
2. Free water will be absorbed by the concrete and the membrane will be broken.

424

1. Hook one point of an ordinary pick under the edge of the form, press your foot down on the other pick point, and pull the handle toward you.
2. Loosen the pin wedges, unlock the locking plates, pull the pins, and lift the form sections from the concrete.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

24. (411) Which type of Portland cement is used when high strength is required in a very short time?
    a. II.
    b. III.
    c. IV.
    d. V.

25. (411) What type of Portland cement is used in large masses of concrete, such as large dams?
    a. I.
    b. II.
    c. IV.
    d. V.

26. (412) What percent of the volume of a concrete mix is made up of aggregates?
    a. 50–60.
    b. 60–75.
    c. 70–80.
    d. 80–95.

27. (412) How much water in gallons per cubic yard can be added at the jobsite without detrimental effects?
    a. 4–5.
    b. 3–4.
    c. 2–3.
    d. 1–2.

28. (413) One purpose of air-entraining agents is to
    a. decrease curing time.
    b. decrease the water-cement ratio.
    c. increase the specified consistency (slump).
    d. increase resistance to the action of chemicals.

29. (413) Which material is most *commonly* used in accelerating concrete mixes?
    a. Calcium chloride.
    b. Sodium formate.
    c. Calcium acetate.
    d. Sodium dioxin.

30. (414) When ordering concrete, how much *excess* should you normally order?
    a. 1 percent.
    b. 5 percent.
    c. 9 percent.
    d. 10 percent.

31. (415) What type of string is best to use should you use as a guide for setting forms?
    a. Thread.
    b. Cotton.
    c. Nylon.
    d. Yarn.

32. (415) What type of form needs to be used with a radius under 150 feet?
    a. Wood.
    b. Flexible.
    c. Curb and gutter.
    d. Traditional steel.

33. (416) If a dowel is to be placed *across* an expansion joint, it must be
    a. Deformed.
    b. Stamped.
    c. Grooved.
    d. Smooth.

34. (416) Other than greasing a dowel, what can be done to allow for movement?
    a. Install plastic sleeves.
    b. Bur the length of the exposed dowel.
    c. Nothing other than grease is available.
    d. Apply epoxy to the exposed length of dowel.

35. (416) You can prevent wooden keyways from cracking by
    a. Pressure treating.
    b. Installing dowels.
    c. Using larger forms.
    d. Oiling and grooving with a saw kerf.

36. (417) What is the purpose of using tie bars in concrete?
    a. Hold slabs together.
    b. Hold dowels together.
    c. Used as load transfer devices.
    d. Tie bars are not used in concrete.

37. (417) When installing multiple sections of welded wire fabric, how much should be overlapped?
    a. 2 inches.
    b. 4 inches.
    c. 6 inches.
    d. 8 inches.

38. (418) What are the *only* tests that show how the concrete will perform in-place?
    a. Flexural and compressive strength on cured samples.
    b. Flexural and compressive strength on green samples.
    c. Compressive strength on green samples only.
    d. Flexural strength on cured samples only.

39. (418) What does the slump test of a concrete mix measure?
    a. Hardness.
    b. Durability.
    c. Consistency.
    d. Consolidation.

40. (418) What can you do to the pile of concrete after a slump test is completed to indicate its cohesiveness, workability, and placeability?
    a. These characteristic can only be measured when placed.
    b. Slowly float the top of the pile to work up paste.
    c. Insert a mechanical vibrator into the pile.
    d. Tap gently with the tamping rod.

41. (419) The *main* factor(s) affecting concrete's strength is (are) the
    a. amount of sand in the mix.
    b. size of the course aggregate.
    c. length and the diameter of the cylinder used in tests.
    d. water-cement ratio and hydration that has occurred.

42. (419) Which type of specimens may give a more accurate interpretation of the actual strength in the structure?
    a. Lab-cured.
    b. Field-cured.
    c. Chemical induced curing.
    d. Mechanical induced curing.

43. (419) The ends of cylinders used for testing are must be finished carefully; if they are not
    a. perfectly flat, the cylinders will not fit in the machine properly.
    b. perfectly flat, the results could be skewed.
    c. slightly concave, the results could be skewed.
    d. slightly convex, the results could be skewed.

44. (420) What is the *most* common mix for concrete when mixing it by hand?
    a. 1 part gravel + 2 parts cement + 3 parts sand.
    b. 1 part sand + 2 parts gravel + 3 parts cement.
    c. 1 part cement + 2 parts sand + 3 parts gravel.
    d. 1 part cement + 2 parts gravel + 3 parts sand.

45. (420) How long should the first cubic yard of concrete be mixed in a portable concrete mixer for a medium job?
    a. 1 minute.
    b. 3 minutes.
    c. 5 minutes.
    d. 7 minutes.

46. (420) When a transit truck is used, the concrete should be delivered and discharged within
    a. 2½ hours.
    b. 1½ hours.
    c. 2 hours.
    d. 1 hour.

47. (421) What is it called when large voids are visible in concrete that *hasn't* been consolidated properly?
    a. Honeycomb.
    b. Chasms.
    c. Fissures.
    d. Cavity.

48. (421) What is the *most* widely used mechanical method for consolidating concrete?
    a. Stabilization.
    b. Compaction.
    c. Gradation.
    d. Vibration.

49. (422) What type of joint is installed to relieve compressive stresses of a slab?
    a. Dummy.
    b. Expansion.
    c. Contraction.
    d. Construction.

50. (422) If you want a dense, smooth surface, follow the initial floating by
    a. edging.
    b. brooming.
    c. bull floating.
    d. steel troweling.

51. (423) Which curing method should you *not* use when discoloration is objectionable?
    a. Chemical membranes.
    b. Continuous flooding.
    c. Water curing.
    d. Plastic films.

52. (423) When should you apply chemical membranes?
    a. As soon as the concrete is finished.
    b. As soon as the joints are installed.
    c. After floating.
    d. After edging.

53. (424) What is the *most important* part of landscaping?
    a. Cost.
    b. Labor.
    c. Drainage.
    d. Appearance.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Portland Cement Concrete Pavement Maintenance

PORTLAND CEMENT CONCRETE (PCC) roads, airfields and buildings all need be maintained in as nearly perfect condition as climate, funds, materials, equipment, and labor permit. Our goals are to maintain a smooth surface, keep the subgrade as dry as possible, and most importantly, extend the useful life of the pavement. A smooth surface protects pavement from destructive effects of traffic impact and reduces vehicle wear and tear. To extend the useful life of our pavements, maintenance must be done at the proper time and according to the best practices for maximum benefits. In this unit you learn about pavement inspection, failures and their causes, maintenance and repair, and which equipment and materials to use.

3–1. Identifying Pavement Defects

As you probably know, you may be assigned anywhere in the world, including areas of extreme cold or intense heat. Because of this, you should be aware of how the environment affects concrete. You will learn that defects are not caused by environmental factors alone. This section will give you an understanding of how to inspect pavement using the pavement condition index (PCI) rating system, identify the type of defect, while also identifying the root cause of the pavement failure.

425. Inspecting concrete pavements

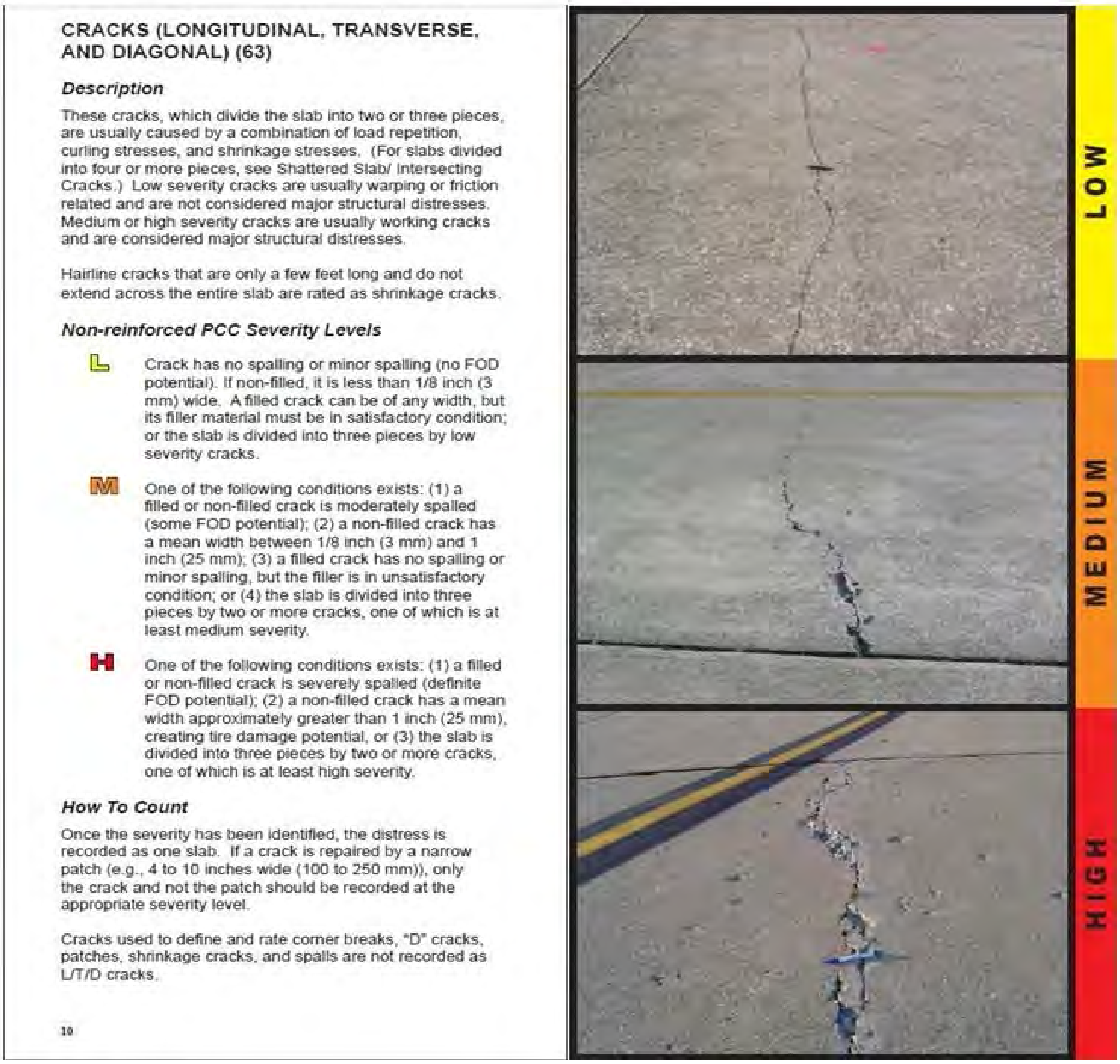
Foreign object debris (FOD) is present on all airfields and is any object that can be sucked up into an aircraft engine causing severe damage. One common cause of FOD is pavement breakdown, leading to failures. It is our responsibility to identify, catalog, and prioritize these failures. Within this lesson, you will be provided the information that will enable you to effectively inspect different types of concrete pavements; knowing the causes for failure will provide the right course of action to repair any defects. Before you try to repair a defect, you must identify its cause. Only then can you begin proper, corrective action. Failure to identify the cause and repair it correctly will just cost more by requiring additional materials and labor down the road when having to repair the same area again.

Pavement preventive maintenance plans

Each base should have some type of preventive maintenance plan for roads, streets (paved and unpaved), and for the airfield. Early detection and maintenance of these areas is a major factor in increasing its useful life and reducing maintenance and repair problems and costs. A good preventive maintenance plan results in more efficient and economical operations. Divide all roads, streets, and airfield areas according to makeup, location, and frequency of use. These areas are normally coded on a map in such a way that they are readily identifiable. The system should, as a minimum, relate to a description of the area, date of inspection, recommended maintenance, and work accomplished. The maps may be color coded, identifying the frequency of inspections. By having a precise history of the area, planning maintenance and obligating funds may be done more economically.

Pavement condition index

The PCI is an objective rating system in which we follow ASTM standards and procedures to measure the condition of a pavement on a scale of 100, which is brand-new pavement with minimal defects to 0, which would be identified as completely failed. The UFC that governs rigid and flexible pavement surveys is UFC 3–260–16FA, *Airfield Pavement Condition Survey Procedures Pavements*. To ensure we are providing accurate accounts of our base pavements, a PCI survey is performed. By following the ASTM (UFC) standards, we ensure that PCI results are similar, even when conducted by individuals of a different rank or experience. Figure 3–1, from the Paver Distress Identification Manual for Concrete Surfaced Airfields, briefly describes one of the many distress types and how to identify its severity level.



CRACKS (LONGITUDINAL, TRANSVERSE, AND DIAGONAL) (63)

Description

These cracks, which divide the slab into two or three pieces, are usually caused by a combination of load repetition, curling stresses, and shrinkage stresses. (For slabs divided into four or more pieces, see Shattered Slab/ Intersecting Cracks.) Low severity cracks are usually warping or friction related and are not considered major structural distresses. Medium or high severity cracks are usually working cracks and are considered major structural distresses.

Hairline cracks that are only a few feet long and do not extend across the entire slab are rated as shrinkage cracks.

Non-reinforced PCC Severity Levels

L Crack has no spalling or minor spalling (no FOD potential). If non-filled, it is less than 1/8 inch (3 mm) wide. A filled crack can be of any width, but its filler material must be in satisfactory condition; or the slab is divided into three pieces by low severity cracks.

M One of the following conditions exists: (1) a filled or non-filled crack is moderately spalled (some FOD potential); (2) a non-filled crack has a mean width between 1/8 inch (3 mm) and 1 inch (25 mm); (3) a filled crack has no spalling or minor spalling, but the filler is in unsatisfactory condition; or (4) the slab is divided into three pieces by two or more cracks, one of which is at least medium severity.

H One of the following conditions exists: (1) a filled or non-filled crack is severely spalled (definite FOD potential); (2) a non-filled crack has a mean width approximately greater than 1 inch (25 mm), creating tire damage potential, or (3) the slab is divided into three pieces by two or more cracks, one of which is at least high severity.

How To Count

Once the severity has been identified, the distress is recorded as one slab. If a crack is repaired by a narrow patch (e.g., 4 to 10 inches wide (100 to 250 mm)), only the crack and not the patch should be recorded at the appropriate severity level.

Cracks used to define and rate corner breaks, "D" cracks, patches, shrinkage cracks, and spalls are not recorded as L/T/D cracks.

10

Figure 3–1. Longitudinal-, transverse-, diagonal-crack severity levels.

The airfield Pavement Condition Survey is a visual inspection of both rigid and flexible pavement for signs of pavement distress. Its primary objective is to update the pavement inventory, document work history, and determine the present condition of the pavement in terms of structural integrity and operational surface condition. This survey and its resulting PCI rating are the primary means of obtaining and recording important pavement performance data.

When computing the PCI, we inspect random sample units rather than inspecting 100 percent of the pavements. Providing representative samples of the pavements saves time while still providing results accurate enough to make sound engineering decisions (i.e., repair versus replace). There are three factors that determine the PCI: distress type, distress quantity, and distress severity. The individual steps to perform PCI surveys are described in the following paragraphs.

Step 1: Identify pavement facilities, branches, and sections

Each pavement facility in the real property record should be documented in mapping and in the PAVER database. Branches are subsections of facilities and are further divided into sections, which are areas of pavement that are similar in material, thickness, date of construction, and so forth. Each main operating base and auxiliary airfield has a survey conducted within the last five years. The report for each survey fully documents the facilities, branches, and sections. PCI surveys are conducted by Air Force Civil Engineer Center (AFCEC) on a four-year cycle. Changes to any mapping should be coordinated with the local GeoBase office or the AFCEC Airfield Pavement Evaluation (APE) team through the AFCEC reachback center. All roads and parking pavements at main operating bases and auxiliary airfields have also had at least one PCI. Similar to the airfield PCI reports, the road and parking PCI reports document the pavement facilities, branches, and sections. Any changes to the inventory should be coordinated with the local pavement engineer and GeoBase office.

Step 2: Divide features into sample units

The pavement section is divided into sample units. A sample unit for jointed, rigid pavement is approximately 20 slabs. A sample for flexible airfield pavement is roughly 5,000 sq. ft., and 2,500 sq. ft. for roads and parking areas.

Step 3: Inspect sample units

The sample units are inspected and the distress types, severity, and quantity are listed on the appropriate Pavement Condition Survey data sheets. The density of the defects are determined by dividing the number of slabs the defect was located in by the number of slabs in the sample unit.

Step 4: Determine deduct values

For each distress type, density, and severity level within a sample unit, a deduct value is determined from the appropriate curve. These curves can be found in the respective UFCs that governs all TOs, Air Force Instructions (AFI), and so forth for rigid or flexible pavements.

Step 5: Determine total deduct value

The total deduct value (TDV) for each sample unit is determined by adding the deduct values for all distresses observed.

Step 6: Determine corrected deduct value

The corrected deduct value (CDV) is determined by counting the number of individual deduct values that are greater than five, then consulting the appropriate curve in the Pavement Condition Survey Section for rigid pavement. If the CDV is less than the highest individual distress deduct value, use the highest value.

Step 7: Calculate the PCI

The PCI is calculated by subtracting the CDV from 100 (PCI = 100 - CDV). Calculate the PCI for each sample unit inspected.

Step 8: Compute the PCI of entire feature

The PCI of the entire feature is the areas weighted average of PCIs from all the sample units inspected.

After the inspections have been accomplished, the Pavement Condition Survey sheets are turned into the pavement engineer. The survey sheets are included in the Condition Survey Report.

Your role in the PCI process may not directly affect full-scale airfield repair projects; however, knowing how to accurately identify the type, quantity, and severity of defects is an important step in becoming an effective 3E2. In addition, by performing these surveys, it will help determine if your next steps will be preventative or corrective maintenance.

Pavement maintenance management system

Guidance concerning pavement maintenance management can be found in UFC 3–270–05, *Paver Concrete Surfaced Airfields Pavement Condition Index (PCI)*, and UFC 3–270–08, *Pavement Maintenance Management*. The guidance in these publications gives procedures to use for inspecting your pavements. PCI is simply a process; its results are input in a computer program called PAVER, which is a tool we use to implement the process, analyze the data, and document the results. The PAVER system is based on pavement condition, with a rating of "100" being excellent and a rating of "0" meaning failure. The information obtained from the program should help civil engineering (CE) prioritize pavement work, give maintenance, and repair alternatives to better utilize resources, and to prioritize time and money in the areas it will do the most good for all pavement systems.

Types of inspections

Riding and walking are the two types of concrete pavement inspections. The way you inspect is dictated by the condition of the pavement being inspected.

Riding inspection

Use a riding inspection to find obvious failures and to determine the general condition of the pavement. You can see and *hear* many of the defects we will discuss later while conducting a riding inspection, so it is an essential part of our maintenance program. A riding inspection enables you to cover a large area of pavement in a short period of time. A *disadvantage* of riding is that in order for you to find defects, you must be able to see the defects from your vehicle or to detect them by the roughness of the ride. On the airfield, your sweeper operator can act as your eyes for a daily riding inspection program. Sweeper operators can mark areas on the airfield map inside their sweeper and report to their supervisor any areas that need to be looked at closer by conducting a walking inspection.

Walking inspection

You can use a walking inspection to discover most potential or existing pavement failures. These failures include cracking, undermining, pumping of the slabs, spalling, scaling, settling, and weathering on the surface of the pavement. You can make a much more thorough inspection by walking leisurely than you can with a riding inspection.

Because a walking inspection is time consuming, you may not be able to do this type of inspection when time is critical. For example, you couldn't do a walking inspection of a runway where flying operations cannot be halted long enough to permit one.

426. Types and causes of concrete pavement failure

By now you realize that proper construction practices throughout a paving project are vital to the life of the pavement. If any step in the process is not done right, the pavement will deteriorate (fig. 3–2). If this happens, you must be able to identify the defect so that corrective action can be taken.

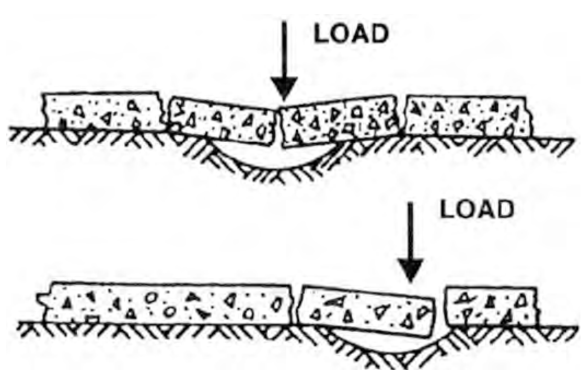


Figure 3–2. Unsupported load.

Failure of concrete pavement usually can be traced to one or more of following causes:

- Poor or improper design (P/ID).
- Poor drainage.
- Poor workmanship.

Poor or improper design

P/ID leads to many defects that we will discuss. Pavements must be designed to carry the expected wheel loads; not just an average but the highest load expected. If there is a chance of something extremely heavy utilizing that pavement system, design it to that weight.

P/ID would be part of the cause of cracking and pavement failure.

- Lack of the supporting base/subgrade.
- Improper drainage.
- Lack of proper load-transfer design.
- Insufficient number of joints or poor placement of expansion and contraction joints.

Poor drainage

Poor drainage is the biggest problem. Water can cause a pavement to crack, break, spall, settle, or blow up.

Poor workmanship

Poor workmanship before, during, and after placement of concrete construction could result in failure and costing money that could be used elsewhere. The following list are just a few examples of poor workmanship:

- Subgrade and base courses that are not built properly.
- Poor consolidation of the mix.
- Failure to seal joints.
- Overworking concrete surfaces.

Now we can look at the types of failures and what may cause them.

Cracking

This is the breaking or fracturing of a concrete section into two or more parts. The most common cause is from overloading by traffic where there is a lack of proper support. Let's look at the seven most common cracks and what areas the failures may result from. Cause: *P/ID, poor drainage, or poor workmanship*.

Longitudinal cracking

These cracks run parallel to the centerline. The principle causes of these cracks include traffic, lateral contraction or shrinkage of the concrete, lateral warping or curling of the slab when subjected to heavy loads, loss of support under the slab because of nonuniform support, pumping, and the presence of expansive, subgrade soils under the center of the pavement. Longitudinal cracking usually occurs in thin slabs 16 feet or more in width without the benefit of a proper longitudinal joint. Cause: *P/ID, poor drainage, or poor workmanship* (fig. 3–3).

Transverse cracking

Cracks running at right angles to longitudinal joints and between transverse joints are transverse cracks. The main causes are traffic, excessive expansion joint spacing, and contraction of the slab where insufficient or improperly cut contraction joints are present. Overloading and upward-curled slabs are combined with pumping. Causes: *P/ID, poor drainage, or poor workmanship* (fig. 3–4).

Figure 3–3. Longitudinal cracking.

Figure 3–4. Transverse cracking.

Corner cracking

These are cracks located less than half the slab length measuring from the corner forming a rough triangle. The cracks are caused by overloading or loss of uniform subgrade support. The lack of support may be created by curling or warping of the slab, lack of proper load transfer at the joints, and pumping, which removes a portion of the material below the unsupported ends. Causes: *P/ID and poor workmanship* (fig. 3–5).

Diagonal cracking

These are similar to corner cracks, but one side will be larger than one-half the slab length beginning and ending at the joint. The cause of these cracks is from overloading a substandard slab on poorly supported slab ends. As in corner cracking, the lack of proper support may be caused by curling or warping of the slab, lack of proper load transfer at the joints, and pumping, which removes a portion of the material below the unsupported ends. Causes: *P/ID and poor workmanship* (fig. 3–6).

Figure 3–5. Corner crack.

Figure 3–6. Diagonal crack.

Durability cracking

Durability, or “D,” cracking is progressive formation of fine cracks at rather close intervals, paralleling edges and joints and curving around corners where joints or cracks intersect edges. These are caused by repetitive freezing and thawing cycles in the presence of variable, expansive aggregates, over-finishing, and those having an undesirable pore structure. Cause: *P/ID* (fig. 3–7).

Crazing

These are shallow, fine, or hairline cracks which apparently extend only in the upper surface of the concrete. Crazing usually results from a too rapid of a loss of moisture from the surface through evaporation during the early curing period. This causes excessive shrinkage of the surface mortar. You can also aggravate this condition by excessive finishing, which brings too much paste to the surface. Cause: *Poor workmanship* (fig. 3–8).

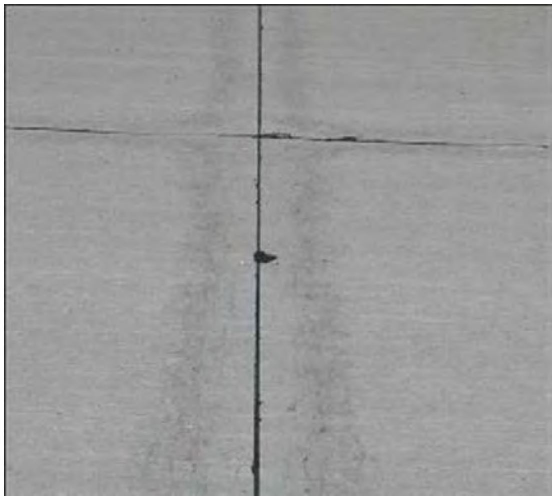


Figure 3–7. Durability crack.

Figure 3–8. Crazing.

Additional defects

The following defects continue on the same theme from the section on cracking. With thorough understanding of the causes of these defects, you will be better prepared to reduce or eliminate their occurrence.

Scaling

This is progressive disintegration and loss of the concrete-wearing surface. The major causes of scaling include the physical and chemical reactions of deicing materials in the presence of repetitive freeze-thaw or wet-dry cycles, a weakened surface created by improper mixing, over-finishing or improper curing, and the use of unsuitable aggregates in the mix. Causes: *P/ID and poor workmanship* (fig. 3–9).

Spalling

Spalling is the chipping or breaking away of the concrete at the joints, cracks, or edges. The primary cause of spalling is inferior concrete or excessive stress concentration at the joint or crack. The stress concentration may result from several different factors. These include hard pieces of gravel or other debris lodged in a joint or crack (incompressible materials), improper forming or sawing of joints, and improperly installed load-transfer devices. Inferior concrete at a joint may cause spalling under normal loading, as will insufficient pavement thickness for the normal design loads. If the thickness is not adequate, excessive deflections under traffic will occur at joints and cracks. Causes: *P/ID and poor workmanship* (fig. 3–10).

Figure 3–9. Scaling.

Figure 3–10. Spalling.

Settlement

This is gradual sinking of a slab resulting in surface misalignment. This condition may result from loss of fines through improperly designed subdrains or other drainage systems, from differential frost heave, and from swelling soils. Causes: *P/ID, poor drainage, or poor workmanship* (fig. 3–11).

Pop-outs

Pop-outs are small, isolated voids or holes in the surface caused by absorption of water and subsequent freezing, and by the chemical reaction to alkali, or a combination of both. To better understand this phenomenon, you need to know what alkali is, which is any of various soluble mineral salts found in natural water (untreated) and soils found in arid regions. The alkalis can absorb water which can increase the size causing them to expand and subsequently cause pop-outs. Cause: *P/ID or poor workmanship* (fig. 3–12).

Figure 3–11. Settlement.

Figure 3–12. Pop-outs.

Pumping

This is forceful ejection of water by deflection of a pavement slab. This condition is caused by an unfavorable combination of free water in the subgrade compounded by an unsupported slab and continuous use by traffic. The slab is forced downward under the wheel loads, compressing any water between the slab and subgrade, which forces the water and soil out through cracks and joints. Causes: *P/ID, poor drainage, or poor workmanship* (fig. 3–13).

Blowup

Blowups are localized, upward movement of a rigid pavement. This condition is caused primarily by infiltration of incompressible material in joints and possible expansion of the concrete. During hot weather, the pressure due to slab expansion builds up at transverse cracks or joints until buckling occurs. Causes: *P/ID and poor workmanship* (fig. 3–14).

Figure 3–13. Pumping.

Figure 3–14. Concrete blowup.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

425. Inspecting concrete pavements

1. Which UFC governs rigid/flexible pavement surveys?

2. How do you provide accurate accounts of the condition of base pavements?

3. What is the primary objective of the Pavement Condition Survey?

4. What type of defects will a riding inspection detect?

5. What type of defects will a walking inspection detect?

426. Types and causes of concrete pavement failure

1. Match the term in column B with its description in column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) Cracks that run parallel to the centerline.	a. Diagonal cracking.
____ (2) Cracks that run at right angles to longitudinal joints between transverse joints.	b. Spalling.
____ (3) Similar to corner cracks, but one side will be larger then half the slab length beginning and ending at the joint.	c. Longitudinal cracking.
____ (4) The chipping or breaking away of the concrete at joints, cracks, or edges.	d. Transverse cracking.

2. Match the defect in column B with its cause in column A. Each defect in column B may only be used once.

Column A	*Column B*
____ (1) Repetitive freezing and thawing cycles in the presence of variable, expansive aggregates and those having an undesirable pore structure.	a. Pop-outs.
____ (2) Loss of fine soils through improperly designed subdrains or other drainage systems, from differential frost heave, and from swelling soils.	b. Blowup.
____ (3) Absorption of water and freezing, chemical reaction to alkali, or a combination of both.	c. "D" cracks.
____ (4) Infiltration of incompressible material in the joints and possible expansion of the concrete.	d. Settlement.

3–2. Repairing/Replacing Defective Pavements

After you have conducted your inspection and have determined the cause of any defects found, your next step is to repair the area. In this section, you will learn about the types of repairs for concrete you will use most often employ, which are partial-depth patch and full-depth patch.

427. Partial-depth patch procedures

In this lesson, you will learn the procedures to apply partial-depth patches, which are used to repair spalling, scaling, pop-outs, replacing defective partial-depth patches, and in rebuilding joints. The first step in repairing a defective area of rigid pavement is to prepare the area to be removed.

Determine outer limits of defect

Before you begin to remove concrete, you must determine how much area is to be removed to correct the situation. The most common way to detect unsound pavement, beyond the visual inspection, is to use a *sounding rod*. A sounding rod is a solid metal rod that produces a ringing sound when it is dropped on sound, solid concrete. If the concrete is cracked beneath the surface or if voids are present in or under the slab, you hear a dull thud. If a sounding rod is not available, any hard object will do, such as a digging bar or sledge lightly tapped on the surface. The sound of hollow concrete is very distinctive and hard to misinterpret.

Mark area

The purpose of marking an area is to give the person who will saw the area a reference line to follow. Make the mark *at least* 2 inches away from the defect into sound pavement and make it so that the patch is square or rectangular. Make the marks with a waterproof material, such as spray paint. Don't use a chalk line to mark the area because water from the concrete saw will wash the chalk off.

Saw pavement

Remember from previous lessons, always do a thorough inspection of your saw and choose a blade which matches the job. Make sure the fluids are at the proper level and check all nuts and bolts for tightness. A loose saw blade can come off very easily and do a lot of damage to anyone standing in front of it. After you have checked out the machine, connect the water source to the saw if you are utilizing a wet cut blade.

Start the concrete saw and position it over the marks. If the saw you are using has a saw guide, place the guide on the marks you made earlier. If not, make a couple of dry runs over the area to see where you will make the cuts, aligning the blade with the mark. When you have the saw positioned properly, slowly lower the blade into the pavement and adjust the blade to cut a minimum depth of 2 inches. Concrete slabs that have reinforcing steel in them require deeper cuts. Additionally, remember to overlap your cuts by half the diameter of your blade to ensure the corners are cut sufficiently and are square.

A good way to keep from damaging the edges of the joint when jackhammering the defective area for the patch is to make a saw cut about 2 inches off the joint; this is called a "relief cut." Remove the concrete in the relief area from inside the cut after you remove the defective area. This way, there is less support for the remaining concrete near the cut line. If your repair is located on a joint, make a cut just skimming along the joint face. This gives you a good vertical joint face and removes the old sealant. If time permits, make additional saw cuts in the patch to weaken the concrete, but do not cross the outer saw cuts or joint.

Remove pavement

The most common way to remove defective concrete is by use of a pneumatic hammer, commonly called a "jackhammer." Check all couplings and wire the hose couplings together for safety once you do a thorough inspection of the equipment.

Pneumatic hammers are available in many sizes. For breaking concrete slabs, the pneumatic hammers most commonly used are in the 30–90 lb. class. The thicker the concrete, the heavier the hammer. When working on partial-depth repairs, or working near joints or spalls, never use anything heavier than the 30-lb.–type hammer; this will help prevent you from damaging sound pavement below the defective area.

When you use a pneumatic hammer, it is absolutely necessary to wear steel-toe boots or toe guards as your feet will be in close proximity to the bit. When ready to begin breaking the pavement, start at the defect, as the pavement is weaker there and easier to break. Hold the hammer in a vertical position and slowly depress the lever until the bit just bites into the concrete, leaving an indentation. With your mark established, depress the lever fully and pay attention to the bit. If you don't make an indentation first, the hammer has a tendency of jumping around. As the bit works its way through the concrete, watch for cracking and movement. If you don't see any, pull the bit out and move over several inches and start again. Eventually, you will establish a section that can be removed. The process continues until the area is fully removed.

For shallow partial-depth repairs, use a smaller hammer (30 lbs.) and remove only the defective concrete. You still need to square the patch and saw the edges, but only remove enough material to reach sound concrete. Use the hammer at an angle to the surface so you can peel away layers and control the amount of material removed.

Cleaning concrete surfaces

After you have removed the defective material, thoroughly clean the patch area. It should be free from all dust or moisture before you place the repair material. By cleaning the concrete surface, you will increase the bond of the new concrete to the old surface. The use of high-pressure air and high-pressure water are the two methods used to clean concrete surfaces. The method you use depends on the location of the patch and the surrounding area.

High-pressure air

High-pressure air is the most common method to clean a repair project prior to placing your repair materials. The high-velocity air is much more efficient at loosening and removing dust and debris from the prepared site than say the suction hose on a sweeper. When using high-pressure air to clean concrete, ensure that you have and use the appropriate safety equipment. Such items as gloves, goggles, respirators, and ear and eye protectors are a must due to extreme noise levels and the potential for flying debris to enter the your eyes, lungs, and ears. Because the debris is ejected from the repair area, make sure you sweep the entire area around it to ensure debris does not end up back in the repair.

High-pressure water

You also can use high-pressure water with the correct tip to clean a repair project. This method involves washing the project and vacuuming the water with a suction hose on a sweeper. The most important factor to remember is to remove standing water and thoroughly dry the area before patching.

Joint replacement

Any time your patch includes an expansion joint, you want to reestablish that joint to ensure the patch lasts. The most common material to use is fiberboard. When in place, it should be flat against the joint face and level with the surface. After the patch has cured, use a pavement router to remove enough fiberboard to establish a sufficient depth for sealant application.

After you place the patch material, be sure to give it enough time to set before you saw cut contraction joints. Then you can come back and saw the joint without damaging the patch. Theses sawed joints usually follow existing joint patterns or are established because of the shape of the patch. In a later section, you will learn how to seal and reseal joints.

Apply bonding agent

A bonding agent aids in creating a tight bond between the existing concrete and the fresh patch material.

There are many commercially available bonding agents, which include simple brush-on liquid acrylic polymer latex to multicomponent epoxy with long set times. The two types regularly used are Portland cement and epoxy; the type to use depends on availability. Find the product that will increase efficiency while extending the life of your repairs.

Mixing

Procedures differ for mixing bonding agents. Epoxy bonding agents require that you mix epoxy resin with hardener. Portland cements are mixed with sand and water. The proportions for Portland cement bonding agents are one part cement, one part sand, and no more than 5 gallons of water per sack of cement. This mixture should be thick and creamy in appearance.

Application

Apply bonding agents immediately before the repair materials are to be placed. The time you have to apply your bonding agent depends on the type you are using. Epoxy sets up rapidly—you won’t have much time to apply it.

Whatever type you use, never apply a bonding agent more than $^{1}/_{16}$ inch in thickness or depth. Use a stiff brush to apply bonding agents. You are now ready to place the patch material.

Patching materials

There is a myriad of patching materials available, the most common being good old-fashioned “Sack Crete.” It is an easy method that produces predictable and dependable results. However, the long set time is undesirable for areas where traffic will be resuming shortly after the repair is completed. In these areas, we can use quick-setting concrete materials. These products usually set up within minutes and can be an efficient way of opening the area quickly, such as on an aircraft taxiway or runway. However, quick-setting products pose some potential drawbacks. These products usually have superior compressive strengths, even surpassing traditional concrete; however, the tensile strengths are quite low and the patches tend to not last as long, necessitating a repair in the future.

Choose the product that will work best for your mission after you try out several. Don't be afraid to try something new if your old patch material isn't performing. Always refer to the manufacturer's application recommendations and precautions.

428. Full-depth repair procedures

The next type of repair you will be studying is a full-depth concrete repair, which involves much more than the partial-depth patch. Full-depth patches are used for repairing blowups, shattered slabs, "D" cracking, faulting/settlement, and punch outs. A full-depth repair does as its name implies by removing the defective area all the way down to a suitable base.

Sawing and removing defective concrete

The procedures for sawing a defective area for a full-depth repair are much the same as a partial-depth repair. One exception is you should try and cut the concrete all the way through to the base course and everything comes out of the hole. You must get down to suitable base material and the only way to do that is to remove everything.

Mark and saw the area as you would for a partial-depth repair, keeping the cut at least 2 inches into sound pavement. Overlap cuts to ensure square corners.

For breaking up concrete, use a large jackhammer, or if the repair is large enough, use an impactor mounted to an excavator, backhoe, or skid-steer. Once all the defective concrete is broken up into manageable pieces, load it into a haul unit and haul it away to an approved landfill.

Utilize heavy equipment, such as backhoes, loaders, or skid-steers, to remove the concrete. The equipment you use is dictated by the size of the repair. Make sure to create a ramp into the repair area so you don't damage the sides with the equipment. You may be able to reach the entire area from outside the repair with a backhoe or excavator, but be careful not to disturb the base if it is still suitable for use.

Remove, replace, and compact base

Once the defective concrete is removed, replace any defective base material. The question always arises about how much base material to remove. Because you must remove all material until you reach hard, firm soil or base, the answer is that you must remove as much base material as is needed. When removing this material, you can use a backhoe, or, if done by hand, use a spade bit on the pneumatic hammer to loosen the base material. If you must excavate the base material, keep the sides vertical and the bottom as level as possible. Try not to disturb adjacent base material. All of the defective material should be removed and hauled away.

NOTE: Do not reuse the materials; if the material had been worth using, you would not have taken it out.

Stabilize the subgrade

Before you start to replace the base-course materials, look closely at the subgrade. It may need stabilization. If it does, you must pick the best way to stabilize it, depending on the type of soil. After you have checked the subgrade and made the necessary correction, you should get enough base course materials to replace what you removed. Replace the base course materials in two- to three-inch layers when you are using small equipment. You can place up to six-inch layers if you are using larger rollers.

Avoid segregation

You must avoid segregation of the material during placement. Segregation occurs when the aggregate in the material separates and like sizes have a chance to accumulate. For instance, all the large rock in the base course is at the top. All sizes should be blended together. You can avoid segregation by dropping the material in the hole as opposed to "pouring" it in. If segregation occurs, simply rake it out until all the aggregate is blended again.

Compacting subgrade or base materials

Continue placing and compacting the base-course materials until it is to the proper elevation. There are various ways to compact base-course materials, including the use of a hand tamper, or the pneumatic tamper, and the vibratory tamper discussed in the previous volume.

1. Use the hand tamper for very small areas, corners, and along the edges.
2. The vibratory plate tamper provides an efficient way to compact subgrade or base materials when the size or location of the construction site prohibits the use of larger, heavier compaction equipment. It is designed for the compaction of granular-type soil (sand or gravel) and has a maximum compaction depth of about 3 inches depending on its size.

When you compact base-course materials, do it at optimum moisture content in the soil to get maximum density. Compact the material until you get the desired density and you have a tight water-shedding surface.

Installing load transfer and tie bars

Aggregate interlock and dowels are the two good ways to accomplish load transfer in a full-depth repair Aggregate interlock is accomplished by making a cut on the outer limit of the patch and an inner full-depth cut several inches from the first. The other method uses a full-depth cut on both ends of the repair and utilizes dowels for load transfer.

Aggregate interlock

Let’s look at the aggregate interlock method first. The first step is to make your outer saw cut about one-fourth the slab thickness, a minimum of 2 feet away from any joint. Then make your inner full-depth cut 2–3 inches away from the defect. The concrete is now ready to be removed by jackhammering, preferably with an attachment on a backhoe or excavator (depending on the size of the repair). Once the material has been removed, you are left with a ledge that carries the load from the new repair.

Dowels

Install the dowels for load transfer in the transverse joints, and put tie bars in the edges where the saw cuts were made. Make sure the longitudinal joint is doweled or keyed. Dowels and tie bars are put in the middle of the slab thickness. The spacing and size of dowels and tie bars in the concrete varies according to the depth of the concrete; these can be found in UFC 3–270–04, *Concrete Repair*.

To install the dowels, drill holes into the concrete slightly larger than the dowel or tie bar, and then fill the hole with a nonexpanding grout. Fully insert each dowel with a twisting motion. Be sure they are each straight—both vertically and horizontally. If the grout does not stay in the hole, you may have to use a grout retention disk over the bar against the edge of the concrete.

Utility cuts

After the utility has been installed, start to backfill the cut in thin lifts, compacting each lift as you go. When you have filled and compacted the area to the level of the concrete depth, cut the pavement back 9–12 inches from the original utility cut. Try not to disturb the base when you remove the concrete from this area. This edge provides a good support for the repair. The edges of the cut are also tied with tie bars. Make sure you install an expansion joint for the repair.

Concrete repair materials

When placing the concrete, use a delivered concrete mix. Place the concrete, using the same basic principles that applied to the partial-depth patch; however, also use a vibrator to consolidate the mix. After you place the patch, cure the repair and seal the joints. It is best to use a mixture that gives a higher early strength than is attained in regular construction work. Early strength permits the patch to be opened to traffic sooner. Otherwise, close patches to traffic until the concrete has a resistance to breakage of at least 550 lbs. per square inch. For emergency purposes, you may open the pavement sooner if possible damage to the patch is justified.

Mix concrete for patches as dry as possible, place it properly, compact it, and finish it. The water cement ratio should be no less than 4 gallons of water per sack of cement. This mixture eliminates difficulties in placing, finishing, and curing the concrete. You can get high-early strength with standard Portland cement if you increase cement by 20–25 percent from the normal concrete mix. But, adding cement increases shrinkage—do it only in emergencies.

You can add calcium chloride to a concrete mixture to increase the concrete's early strength. When you use calcium chloride (dry or in solution), do not add more than 2 percent of the weight of the cement. When you use dry calcium chloride, put it in the mixer with the aggregate—but not in contact with the cement. If the calcium chloride is in solution, put it in with the mixing water. The wet solution replaces an equal volume of water. Because concrete containing calcium chloride hardens quickly, you must place and finish it promptly after mixing.

When you have placed the concrete, treat it as any other concrete project. Finish the surface to match the surface texture of the adjacent slab. If the repair includes joints, edge the joint to restore its original condition and appearance. After finishing, apply a curing compound to the patched area.

Bituminous patches

Concrete can be repaired with bituminous materials, but consider it a *temporary* patch and replace it with concrete as soon as possible. Good, dense-graded, hot-plant-mixed asphalt is the best. You may, however, use a cold mix, either plant-mixed or commercial. A bituminous patch must be strong enough to carry the same wheel load as the surrounding pavement. The basic patching procedures are the same, except you should use a tack coat, much like a bonding agent for concrete repairs discussed earlier.

Allow time for the tack to cure and become tacky before you apply the patch material. Place the material, overfilling enough to allow for compaction, then rake and level. Remember, your patch should be flush to ⅛ inch higher than the existing pavement.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

427. Partial-depth patch procedures

1. What is the most common method of detecting unsound pavement?

2. What type of material is used to mark an area?

3. Why should saw cuts overlap at least one-half the blade diameter?

4. Why do you start breaking pavement somewhere close to the defect itself?

5. What are the proportions for Portland cement bonding agents?

6. When should you apply bonding agents?

428. Full-depth repair procedures

1. How much base material must you remove from a defective area?

2. How long should you compact base materials?

3. What determines the spacing and size of dowels and tie bars in the concrete?

4. How should utility cuts be backfilled?

5. What is the purpose of adding calcium chloride to a concrete mixture?

3–3. Joint and Crack Maintenance

This section discusses the inspection on joints and cracks, determining when to remove defective sealing material, as well as how to seal joints and cracks.

There are two basic reasons for sealing joints and cracks. One is to prevent damage to the pavement from water that would seep into the base course through openings. The other is to prevent dirt, rocks, and other debris from lodging in the joint. If debris happens to be harder than the concrete slab, it keeps the joint from closing as the concrete expands. This can cause the slab to buckle or the joint faces to spall. Placing sealing materials properly and maintaining them is vital to the life of the joints.

Cracks are much the same in that they must be sealed or resealed to maintain that watertight seal. If left unattended, cracks will get larger and water will enter the base.

429. How to remove defective sealing material

In this lesson, we will discuss performing inspection on joints and cracks and determining when to remove defective sealing materials. The inspection of joints and cracks must be thorough and accomplished according to established guidelines. Perform an inspection when the temperature is around 50°F. When inspecting crack and joint sealant, you can identify defects by using those listed in the pavement distresses identification section. When considering what actions must be taken while performing inspections on cracks, consider the following guidelines:

- Cracks less than $^{3}/_{16}$-inch–wide with no spalling—Take no action.
- Cracks $^{3}/_{16}$ inch and larger and less two-inches–wide—Must be sealed.
- Cracks larger than 2 inches wide—Full-depth repair.

Before you can start any sealing operation, all joints and cracks must be free of old, dry sealing materials, dirt, oil, or other matter that could impair the bond between the new sealer and the faces of the joint or crack.

Clean cracks and joints to the width and depth marked on the plans or the sealant manufacturer's guidelines. The removal depth of the joints should be twice the final width of the joint. All joints and cracks must be clean, dry, and as dust free as possible before joint-sealing materials are applied. If excessive dust or moisture is present in the crack or joint, the sealer may not make a firm bond to the concrete and your efforts will have been wasted. Once joints and cracks are clean and dry, they are ready to receive the sealing material. The tools and equipment used for cleaning include, but are not limited to, the items in the following paragraphs.

Hand tools

Tools, such as straight or hooked metal bars, are used when equipment is not available or the area being sealed will not accommodate them.

Vertical routers

Vertical routers can be used for initial crack and joint maintenance or as tools to remove old sealant. These are normally small gasoline-powered machines with vertical rotating bits that are of different sizes to fit different-size joints and cracks.

Joint plows

Joint plows are vehicle-mounted cutting tools used to remove old sealant. The plow is pulled through the joint, removing the sealant from joint walls. The shape of the tool must be rectangular and the widths close to but narrower than the joint. Never use a V-shaped tool; it may spall the concrete. The tool must also have both vertical and lateral movement to prevent damage. It is usually equipped with a hydraulic-release mechanism or other pressure-sensitive safety device that releases pressure before damage to the concrete can occur. Unfortunately, joint plows are not readily available and may have to be manufactured for use.

Concrete saw

A standard concrete saw can be used for removing old sealant from joints by using a gang-blade setup (blades stacked together effectively making the blade thicker) or by sawing along each face, removing just enough concrete to remove the sealing material.

Random-crack saws

Random-crack saws are similar to a regular concrete saw, except the machine is smaller and the blade is about 5 inches in diameter as compared to 12–14-inch blades commonly used on a concrete saw. Some models have blades in the front or in the rear, but both follow random cracks very well and create a better reservoir for the sealant.

Brooms

Use power or hand brooms after routing to remove loose materials from the joint or crack and from the surrounding area.

High-pressure air

This serves the same purpose as brooming but is much more efficient. When you clean a project with high-pressure air, ensure you have and use the appropriate safety equipment. Items such as gloves, eye protection, respiratory protection, and ear protectors are a must.

Water blasting

Water blasting can be used but is usually done by a contractor. If done in-house, use extreme caution because of the high water pressure.

High-pressure water

High-pressure water, such as that from a pressure washer, can be used to remove residual dust and debris from the joints and cracks. Be careful not to soak the area as the water will find its way into the base course. Remember, you must ensure the repair area is dry before applying sealants.

430. Sealing joints and cracks

Immediately after you remove defective sealer from a joint or crack, and the joint or crack has been cleaned and dried, it may be necessary to install backer rod or other separating medium. It serves the following purposes:

- Prevents contact between incompatible materials.

- Keeps you from using too much sealant (fills the void).
- Provides the proper shape for the sealant to conform to.

The material should not be twisted, stretched, or otherwise damaged when being installed, and it must be installed to the proper depth. The backer rod or separating medium is made of a nonshrinking, flexible material that does not absorb and that has a melting point at least 5°F higher than the pouring temperature of the sealant (if applied hot).

Backer rod must be 25-percent wider than the joint and be compressed firmly into the joint when used. This will ensure that it does not migrate up or down when you are applying the sealant. At one time, asphalts and tars were used most often to seal joints and cracks in concrete. Rubber-asphalt and rubber-tar compounds have gained favor because they have less of a tendency to become brittle during cold weather or to become soft in hot weather. They are much more flexible and durable than pure asphalt or tar.

The sealing materials that you will be working with are either hot-applied or cold-applied. Hot-applied sealers have rubber compounds in them that can break down if overheated. They must be melted in a double-boiler–type of kettle. Hot-applied sealers are one-component materials. Cold-applied sealers, on the other hand, are one- or two-part compounds. The two-part sealants require mixing before application.

Hot-applied sealers

There are different types of hot-applied sealers for different uses. Make sure you check the specifications for the sealer you are using. The criteria for what type of sealer you use will use depends on where the sealer is located. For instance, you would need a fuel-resistant sealer in an area prone to fuel spillage. Check the manufacturer's specifications for this information.

Cold-applied sealers

As with the hot-applied sealers, there are different types of materials for different uses. Again, refer to the manufacturer's specifications for specifics on where to use the sealer. Some manufacturers require primers to be used before cold-applied sealers are applied. If priming is required, use the manufacturer's recommended material. Paint this mixture on the inner surfaces of the joint or crack with a brush. Curing time for this primer is normally 30 minutes to one hour. If you dry the joint or crack with a torch burner, priming is not necessary. The warm surfaces of the joint or crack create a satisfactory bond with the sealing material.

Sealing operation

When the joints or cracks have been fully prepared, you can proceed with the sealing operation. One thing to remember is that the prepared joints or cracks should never be left unsealed for more than one day.

Prepare only as many as you can seal in one day. If they must be left unsealed for any period, and incompressible materials or dust gets into them, they must be blown out with compressed air before sealing resumes. Always apply the sealant from the bottom to the top to prevent trapping air. Fill the joint or crack one-eighth– to one-fourth–inch below the pavement surface to prevent extrusion of the sealant. Also, in northern areas where snow removal is prevalent, the blades of the equipment won't catch the exposed sealant and pull it out of the joint.

Equipment

The equipment used to seal joints and cracks include, but are not limited to, pressure applicators and hot joint-sealing machines.

Pressure applicators

As the name applies, this item applies sealing material under pressure. Applicators for cold two-component sealants have a pump that delivers the two components through separate hoses to a portable mixer, then through the delivery hose. The components are contained in separate reservoirs.

The single-component, cold-applied sealant equipment has an extrusion pump, air compressor, plunger, following plate, and a hose and nozzle. Some units are large enough to handle 55-gallon drums of sealant. The plunger goes into the drum and pressurizes it. A hole in the plunger allows the sealant to escape into the wand when the valve is opened. The biggest drawback to large-pressure applicators is keeping them clean and keeping the sealant from setting up in the wand and on the plunger. When you are through, clean the machine and blow out the lines to make sure it will be ready for use on another project at a later time.

There are also small, handheld units that are manually operated (like a large caulking gun) or electrically actuated. They can be used satisfactorily for short distances and small amounts of sealer.

Hot joint-sealing machine

Hot-sealing material is normally applied with a hot joint-sealing machine (fig. 3–15). The components of the machine are the engine, kettle, heating system, circulating system, agitator, and the delivery hose (wand).

The hydraulics, agitator, and circulating pump are operated by the engine. A double-jacketed kettle with heat transfer oil is used to heat and hold the sealer. The double-jacketed kettle prevents heat from being applied directly to the sealer. A burner heats the transfer oil, which, in turn, heats the sealer. The kettle can be heated by either propane or diesel fuel. Thermostats are used to monitor the temperature of the sealer and the heating oil. The agitator in the heating kettle continually turns the sealer while a circulating pump keeps the material moving.

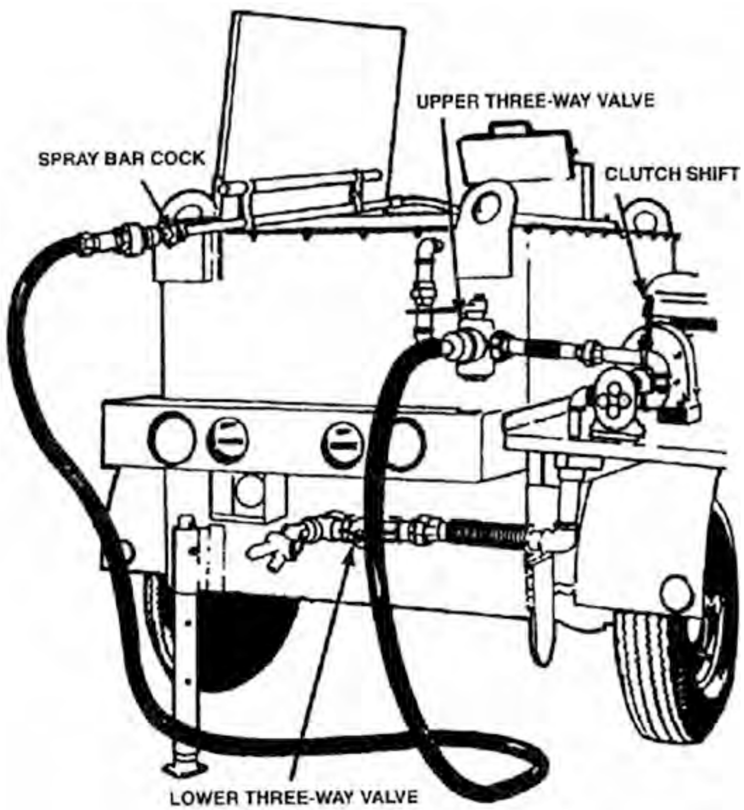


Figure 3–15. Hot joint-sealing machine.

As with operating any piece of equipment, there are hazards you need to be aware of. The following is a list of precautions to take when using the hot joint-sealing machine:

1. Use protective clothing, gloves, and eye protection.
2. Avoid contact with the hot sealant.

3. Read the operator's manual before operating.
4. Stop the mixer whenever sealant is added.
5. Keep an approved fire extinguisher nearby.
6. Do NOT exceed the recommended heat transfer oil temperature. Heat transfer oil will burn and become unusable if heated beyond the recommended temperature.

The first step in operating the hot joint-sealing machine is to heat the sealer. First, add the sealer to the kettle; then, light the burner. Start the engine when the heat transfer oil reaches approximately 450°F.

NOTE: Every machine is slightly different, so check the operator's manual for specific temperatures before beginning.

Allow the material to melt completely before starting the circulation pump. This could take a considerable amount of time, depending on the machine. Once you are confident the material has melted thoroughly, turn the agitator on slowly to get the material moving around the kettle. This will ensure the material is heated evenly.

Once the material is completely melted and agitating continually, open the circulation valve to circulate the material until it reaches its application temperature. Check the material temperature periodically. Also check the oil temperature and make adjustments as needed to ensure you don't get it too hot.

Open the applicator valve over the heat chamber to check for flow. If it does flow well, you may need to warm the wand. Once it is flowing freely, you are ready to apply the sealer. If the sealer stops for some reason, place the spray nozzle over the opening of the kettle and spray material back into the tank for about two minutes.

Once you are ready to apply the sealant, place the nozzle in the crack or slightly above it and slowly open the valve. Fill the joint or crack to just below the surface and slowly walk backward until you reach the end of the repair area.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

429. How to remove defective sealing material

1. When should you consider sealing pavement cracks?

2. How deep must expansion joints be cleaned?

3. What is one difference between a random-crack saw and a regular concrete saw?

4. What serves the same purpose as brooming but is much more efficient?

430. Sealing joints and cracks

1. Why are rubber-tar and rubber-asphalt compounds recommended?

2. What is the curing time for cold joint primer?

3. During sealing operations, how can you prevent air from becoming trapped in the sealant?

4. Name the equipment used in sealing joints and cracks.

Answers to Self-Test Questions

425

1. UFC 3–260–16FA.
2. Perform a PCI survey.
3. Update the pavement inventory, document work history, and determine the present condition of the pavement in terms of structural integrity and operational surface condition.
4. The obvious failures.
5. Most potential or existing pavement failures.

426

1. (1) c.
   (2) d.
   (3) a.
   (4) b.
2. (1) c.
   (2) d.
   (3) a.
   (4) b.

427

1. Use a sounding rod.
2. Waterproof, such as spray paint.
3. To ensure the corners are cut sufficiently and are square.
4. The pavement is weaker there and is easier to break.
5. One part cement, one part sand, and no more than 5 gallons of water per sack of cement.
6. Immediately before the repair materials are to be placed.

428

1. Remove all material needed before reaching hard, firm soil or base.
2. Until you have obtained the desired density and you have a tighter water-shedding surface.
3. The depth of the concrete.
4. In thin lifts, compacting each lift as you go.
5. To increase the concrete’s early strength.

429

1. When they are $^{3}/_{16}$ inches and larger and less than two-inches wide.
2. To the width and depth marked on the plans or the sealant manufacturer's guidelines. The removal depth of the joints should be twice the final width of the joint.
3. The random-crack saw uses a smaller blade, about 5 inches in diameter.
4. High-pressure air.

430

1. They have less of a tendency to become brittle during cold weather or to become soft in hot weather.
2. Normally, 30 minutes to one hour.
3. Applying the sealant from the bottom to the top.
4. Pressure applicators and hot joint-sealing machines.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

54. (425) The "pavement preventive maintenance plan" should, *as a minimum*, relate to all of the following *except*
    a. cost of materials.
    b. date of inspection.
    c. work accomplished.
    d. recommended maintenance.

55. (425) The primary objective of a pavement condition survey is to
    a. Monitor pavements tolerance to hot and cold weather.
    b. Determine the structural integrity of the pavement.
    c. Determine density of the pavement base.
    d. Track overloading traffic patterns.

56. (426) What is the *most common* cause of cracking in concrete pavements?
    a. Overloading by traffic.
    b. Environmental extremes.
    c. Poor aggregate used in the mix.
    d. Non-potable water was used in the mix.

57. (426) The defect characterized by chipping or breaking away of concrete at joints, cracks, or edges is called
    a. pumping.
    b. pop-outs.
    c. spalling.
    d. blowup.

58. (426) What substance is present in the concrete mix to make pop-outs occur?
    a. Sulfur.
    b. Alkali.
    c. Borax.
    d. Acids.

59. (427) When should you apply bonding agents?
    a. Immediately before the repair material is placed.
    b. Immediately before the concrete is mixed.
    c. After cleaning the concrete.
    d. After sealing the concrete.

60. (428) When performing a full-depth repair, how much material must be removed?
    a. The base course has no bearing on a full-depth repair.
    b. Enough to permit reaching hard, firm soil or base.
    c. Until six inches of material has been removed.
    d. Enough to expose subgrade.

61. (428) You should add calcium chloride to a concrete mixture to
    a. allow easier mixing.
    b. decrease water content.
    c. get a better water-cement ratio.
    d. increase the concrete's early strength.

62. (429) What action *must* be taken for a crack measuring 3/16 of an inch or less?
   a. Rout the crack.
   b. Full-depth repair.
   c. Overlay with asphalt.
   d. No action is necessary.

63. (430) How much wider than the joint must the backer rod be when it is compressed into the joint?
   a. 10 percent.
   b. 15 percent.
   c. 20 percent.
   d. 25 percent.

Please read the unit menu for unit 4 and continue ➔

Unit 4. Asphalt Cement Concrete Pavement

BITUMINOUS MATERIALS have been used in building and paving for thousands of years. Archaeologists have found that asphalt (one of the two basic types of bituminous materials) is one of the oldest adhesives. Its earliest known use has been determined to be around 3200 Before Christ (B.C.), or Before Common Era (B.C.E.), when it was used as mortar for building stones. The asphalt that mortared the building blocks of civilization was called natural asphalt. It was found in scattered seeps or pools where it had collected as a petroleum residue formed from natural geologic processes. Besides the natural deposits of asphalt, asphalt impregnated rocks, called rock asphalt, were (and still are) found around the world.

The use of bituminous materials for street paving in the United States began in 1870 with the laying of a stretch of pavement in front of city hall in Newark, New Jersey. It was made of rock asphalt from the Rhône Valley in France. Until then, American bituminous paving experiments had centered on coal tar, which found limited use due to its hazardous nature, both in its manufacturing and application. During this same time, the discovery and subsequent refining of petroleum was ending the feverish hunt for natural asphalt. With the advent of the motor age, American refineries began pouring out a wide variety of petroleum products, a key constituent in the production of asphalt.

As time moved on, so did the technology of flexible pavement. In 1987, the Strategic Highway Research Program (SHRP) began development of a new system for specifying asphalt material called Superpave. This system is the basis on which most flexible pavement construction is done today.

As you learned in the study of rigid pavements, the preparation of the subgrade and base course for concrete pavement is the same for asphalt cement concrete (ACC) or bituminous pavement. In this unit, we will discuss only the points of difference between asphalt and concrete pavement construction.

Laying ACC pavements is a major part of your job in the Air Force. Because of the variations in methods and materials used throughout the world, you must know why it is best done in a certain way. Once you understand the basic principles in constructing bituminous pavements, you can cope with the variations in the field.

4–1. Bituminous Materials

Within this section, you will be provided with an overview of bituminous materials, as well as with a discussion in preparing a base for an asphalt surface.

The term “bituminous material” refers to adhesive substances commonly called “asphalts” or “tars.” Asphalts and tars are classified by some as being the same material; however, such is not the case. Although the two materials are similar in appearance, they are dissimilar in chemical structure and origin. Asphalts are most commonly derived from petroleum refining. Tars are derived from the distillation of soft coal. The chemical structure of these two bituminous materials is so dissimilar that they cannot be mixed together. They can, however, be used in successive layers on a road.

When applying these layers on a road, you must do your part to cut down on wasting money, especially in these times of tight budget constraints. You need to know how to adequately use the appropriate amount of material to complete a job, with a small amount of extra to allow for low spots in the base course. If you order too much hot-mix asphalt (HMA), for instance, it will go to waste because it cannot be stored for future use. It is very important that you become familiar with the procedures presented within this section in order for you to be able to do your part in saving the Air Force money.

431. Bituminous materials overview

Bituminous materials include a wide variety of materials; however, for this lesson, we will only discuss asphalt because this is the primary product you will work with.

Asphalts

Within the asphalt family are several specific types with special characteristics of their own. Figure 4–1 gives an overview of the refining process, of which we derive asphalt for use in road construction.

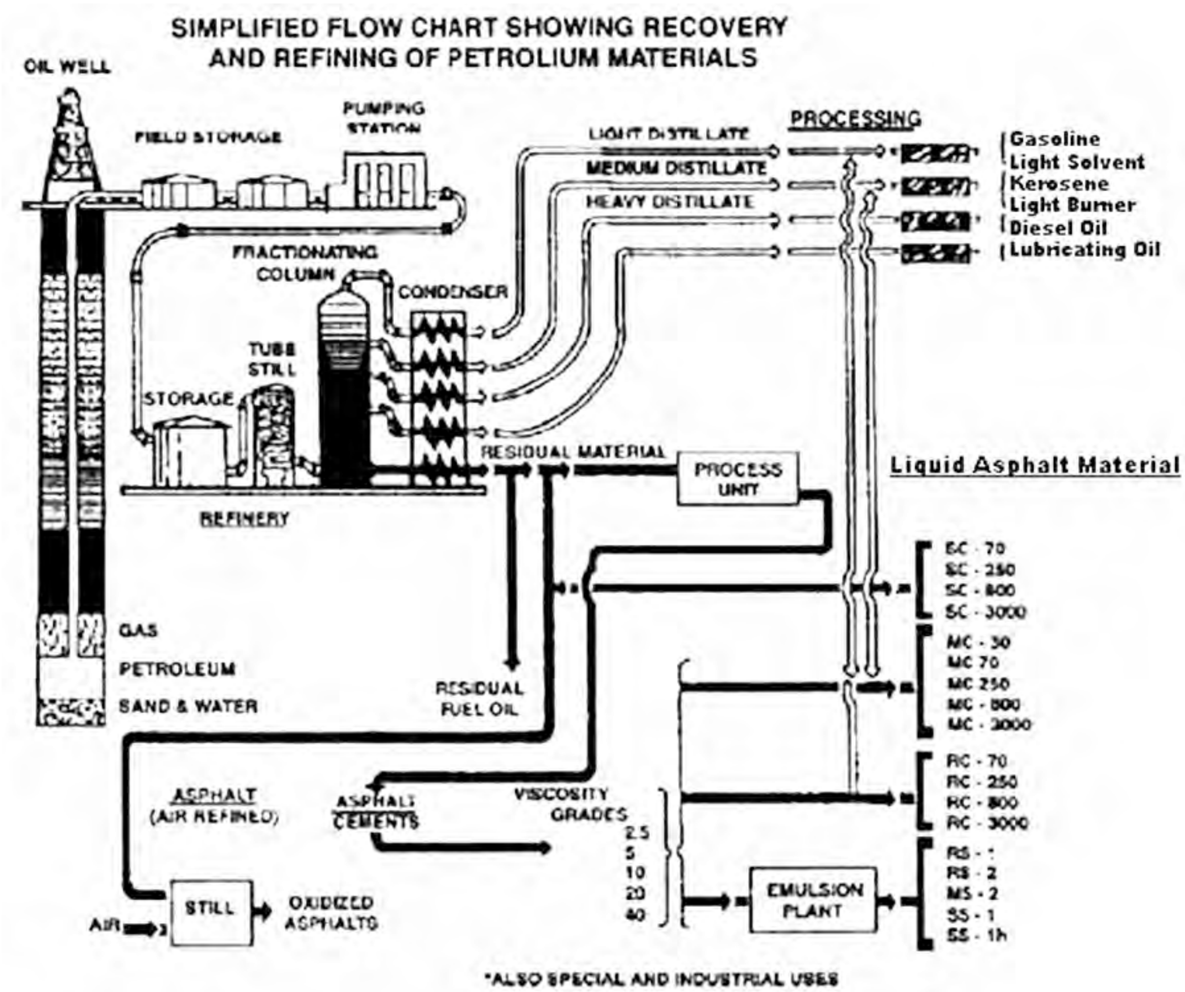


Figure 4–1. Asphalt flow chart.

Types and grades of bitumen are important in pavement work. You can do a better job of construction and maintenance if you understand clearly the types and grades of bituminous materials. Under a specific set of conditions, one particular type and grade of bitumen is usually better than the others and will produce a superior surface. You should be able to select the best bitumen for each different set of conditions that has been developed by SHRP.

Asphalt cement

Asphalt cement (AC) is the basic material used to produce all other asphalt materials. It is pure asphalt in the sense that it has no additives. At normal atmospheric temperatures, it is solid or semi-solid. To be used in construction, it must be fluid enough to coat the aggregates. AC is used alone—that is, without aggregates—where a high-quality material or product is desired. AC also is used where extra time for curing or setting is not desired or feasible. ACs are produced by refining crude petroleum. They are black, practically pure bitumen, and at normal temperatures, vary from very soft to very hard semi-solids.

A grading system is used as a method or way to tell the user exactly how the asphalt cement will act. The current three ways asphalt cements can be graded include penetration, viscosity, and performance.

Penetration

The first, and the oldest method, is the penetration grade. This test involves the penetration of a pen vertically under a specified load for a specified period of time. The distance of penetration is measured in hundredths of a centimeter; however, this test is no longer used because of newer technology.

Viscosity

The second method of grading ACs is according to viscosity (a material's resistance to flow). The viscosity test measures the time a given amount of asphalt cement takes to flow through a tube. The viscosity test is done by placing a viscometer in a bath that contains clear oil. The viscometer is mounted in the bath, and asphalt heated to 140° F is poured into the large opening until it reaches the filling line. Slight pressure is applied to the small opening to start the asphalt flowing over the siphon section just above the filling line. A timer is started when the asphalt reaches the first timing mark and stopped when it reaches the second. The time interval, multiplied by a calibration factor for the viscometer, gives the viscosity. The following table lists the five types of asphalt cement and their grades:

Asphalt Type	Grade
AC–2.5	Soft
AC–5	Semi-Soft
AC–10	Medium
AC–20	Semi-Hard
AC–40	Hard

Performance

The third, and most current, method to grade ACs is called performance grading, established from the Superpave program. As part of the Superpave research effort, new binder tests and specifications were developed to more accurately and fully characterize asphalt binders for use in HMA pavements. These tests and specifications are specifically designed to address HMA pavement performance parameters, such as rutting, fatigue cracking, and thermal cracking. The selecting of a grade of asphalt cement is based on several items. Among the most important are:

- Climate.
- Traffic condition.
- Economic of asphalt availability.
- Previous regional experiences.

Superpave performance grading (PG) is based on the idea that an HMA asphalt binder's properties should be related to the conditions under which it is used. For asphalt binders, this involves expected climatic conditions as well as aging considerations. Therefore, the PG system uses a common battery of tests (as the older penetration- and viscosity-grading systems do) but specifies that a particular asphalt binder must pass these tests at specific temperatures that are dependent upon the specific climatic conditions in the area of use.

Therefore, a binder used in the Sonoran Desert of California/Arizona/Mexico would have different properties than one used in the Alaskan tundra. This concept is not new—selection of penetration- or viscosity-graded asphalt binders follows the same logic—but the relationships between asphalt binder properties and conditions of use are more complete and more precise with the Superpave PG system. Information on how to select a PG asphalt binder for a specific condition is contained in the Superpave mix design method.

Superpave PG is reported using two numbers: the first being the average seven-day maximum pavement temperature in degrees Celsius (°C), and the second being the minimum pavement design temperature, also measured in °C, likely to be experienced. Thus, a PG 58–22 is intended for use where the average seven-day maximum pavement temperature is 58° C and the expected minimum pavement temperature is –22° C.

Notice that these numbers are pavement temperatures and not air temperatures. As a general rule-of-thumb, PG binders that differ in the high- and low-temperature specification by 90° C or more generally require some sort of modification.

Asphalt cutbacks

The special equipment needed to heat asphalt cements is not always available. Since asphalt must be in a fluid condition to be sprayed or mixed with aggregate, the solid asphalt cement would not be suitable. A more fluid asphaltic material requiring less heating than AC to secure proper spraying, and mixing consistencies is obtained by combining asphalt cement with any of a number of petroleum distillates. The distillate used is called a *cutter stock*, and the product of the combined materials is called an *asphalt cutback*.

On exposure to atmospheric conditions, the cutter stocks evaporate leaving the asphalt cement to perform its function. This rate of evaporation determines the type of asphalt cutback. Asphalt cutbacks can be classified as shown in the following table:

Cutback	Volatility	Viscosity Grades
Rapid curing (RC)	AC mixed with naphtha- or gasoline-type cutter stock of high volatility.	70, 250, 800, and 3,000.
Medium curing (MC)	AC mixed with a kerosene-type cutter stock of medium volatility.	30, 70, 250, 800, and 3,000.
Slow curing (SC)	AC mixed with a low-volatile fuel, such as diesel or motor oil.	70, 250, 800, and 3,000.

The lower numbers have more cutter stock added, making them more fluid. An MC–30, for instance, contains about 50 percent asphalt cement and 50 percent kerosene and is very fluid. An RC–3,000, however, contains about 85 percent asphalt and 15 percent naphtha or gasoline and is quite thick.

All cutbacks are fluid at room temperature and are usually more convenient to use than asphalt cements. But, cutbacks are not without drawbacks. Probably their biggest disadvantage stems from the fact that they contain petroleum products used as cutter stocks that may render them environmentally unacceptable in some areas. As the cutter stock evaporates, it releases harmful volatile organic compounds (VOC) into the environment. The EPA regulates these emissions and has eliminated their use in some states.

Asphalt emulsions

Asphalt emulsions are mixtures of the three basic ingredients: AC, water, and an emulsifying agent. Asphalt does not readily mix with water, but by the addition of a small amount of chemical (emulsifying agent), it is possible to make a temporary mixture in the form of emulsion. Some examples of emulsifying agents that can be used include salt, soap, and detergent. Most commercial asphalt emulsions normally have 55–70 percent asphalt cement, 0.5–3.0 percent emulsifying agent, and the remainder being water. The larger the amount of asphalt cement, the thicker the solution.

Asphalt emulsions can be sprayed and mixed with the aggregate without heating. After spraying, the water and asphalt separate; the water evaporates and leaves the AC behind.

Emulsions are classified on the basis of how quickly the asphalt will coalesce—that is, revert to AC. The relative terms rapid setting (RS), medium setting (MS), and slow setting (SS) have been adopted to simplify and standardize this classification.

The tendency to coalesce is closely related to the mixing of an emulsion. An RS emulsion has little or no ability to mix with an aggregate, an MS emulsion is expected to mix with coarse but not fine aggregate, and an SS emulsion is designed to mix with fine aggregate. A quick-set (QS) type of emulsion has been developed for slurry seals. Its use is rapidly increasing as the unique, quick-setting property solves one of the major problems of slurry seals.

Weather also affects the use of asphalt emulsions. Since the emulsion mixture contains water, you cannot use it if the temperature drops below the freezing mark. But, since the mixture contains an emulsifying agent that allows the AC to mix with water, you can use the asphalt emulsion with damp aggregate. The emulsifying agent allows the mixture to bond to the aggregate. As with asphalt cutbacks, when the water evaporates it still gives off VOCs and may be regulated by the EPA where you are stationed.

432. Preparing a base for an asphalt surface

Just as in rigid pavement, you must prepare your area for bituminous materials. You must choose your materials carefully and apply them at the specified rate. In addition, you must follow procedures closely to prevent costly repairs later.

Before bituminous materials are mixed and placed on the road or runway, the base on which the mix is to be placed must be prepared properly. The base must be graded to the proper shape and elevation and compacted to the specified density. For the purpose of this lesson, we will assume the base course has been graded and compacted properly.

Surface conditions

Bituminous surfaces must be constructed on bases that are reasonably dry and free from caked mud or dust. Dust, if present on the base, must be removed before bituminous construction starts. Otherwise, you may have trouble getting a good bond between the base course and the pavement. If there isn't a good bond, the pavement becomes unstable when traffic travels over it. Dust can be removed by cleaning the base with a rotary sweeper. Washing or flushing with water may be needed to remove coatings of mud or dust. If all else fails, you may have to regrade the area, regain the proper elevation and recompact.

Weather limitations

Bituminous construction should not be tried during cold or prolonged wet weather. Temperatures below 50°F normally mean bituminous construction must stop. However, satisfactory hot-mix bituminous pavements may sometimes be constructed at temperatures below 50°F if the mix has been adapted for cooler temperatures. In such cases, operations must be coordinated properly to prevent excessive heat loss in the spreading and rolling operations. If the mix cools to the point where proper spreading and rolling cannot be done, the pavement can be expected to fail.

A bituminous pavement may be put over an old road or runway as a resurfacing project, or it may be placed directly over the base course on a new road or runway. In either case, the surface must be prepared properly before the paving mixture is placed. The surface must be clean and free of dust or foreign material and must be treated with a tack or prime coat. The application of a tack or prime coat is a preliminary step that must be used with any bituminous construction method.

How to apply a tack coat

A tack coat may be defined as a liquid bituminous material applied to a nonabsorbent surface (usually over asphalt binder course, overlays, or concrete overlays).

Purpose

The purpose of the tack coat is to ensure a good bond and seal between the old underlying surface and the new overlaying surface. It acts as the bonding agent, or in simpler terms, the glue.

Materials used

Materials recommended for tack coats are diluted asphalt emulsions. These materials are used because very little penetration is desired.

Application

After the surface is swept free of foreign matter, a very thin, uniform layer of tack-coat material is applied with a distributor in large areas and with hand spreaders in the smaller areas. The application rate is 0.05–0.15 gallon per square yard.

You should never apply more tack-coat material than you can cover in a day's work. Be extremely careful not to overtack the area. Overtacking causes the pavement to shove, slip, corrugate, and bleed.

Use care to control the drying or curing period so that the coating reaches a tacky or sticky condition before the surface course is laid. If not enough time elapses, the tack coat acts as a lubricant and prevents a bond with the surface course. As a result, the purpose of the tack coat is completely defeated. If too much time elapses, the tack coat becomes hard or acquires foreign matter, conditions that also defeat its purpose.

You should make every effort to keep nonessential traffic off the area. This keeps the tack coat from being picked up by tires and keeps foreign material off the tack coat.

As with all hazardous materials we use in our career field, make sure you know the regulations involved with its use. Also, contact environmental before using any product that may be regulated.

Prime coat

A prime coat is the light application of a liquid bituminous material to an absorbent surface. This material can be applied to stone, gravel, or other similar surfaces.

Purpose

The following five important reasons to apply a prime coat are that the prime coat:

1. Waterproofs the surface.
2. Keeps water from seeping up by plugging the voids.
3. Bonds loose soil particles.
4. Hardens the surface.
5. Adheres the base course to the asphalt mat overlay.

Materials used

Because of environmental concerns, the best materials for prime coats are emulsions. The types of emulsions used as a primer on dense, well-compacted bases are much the same as with tack coats.

Application

Because a prime coat produces an effective bond, it is seldom necessary to provide this adhesive course as with a tack coat. Tack coats are applied to primed bases only when the prime coat is exceptionally hard or dusty. Ordinarily, the heat of hot-laid asphalt softens the hardened prime to give the desired adhesion (bonding capability).

For large areas, the primer is applied with a distributor, at an approximate rate of 0.10–0.25 gallon per square yard. Hand spreaders are normally used for smaller areas where a distributor would be impractical. Generally, most of the primer should reach full penetration into the surface within 2–3 hours, and the normal drying or curing period should be approximately 24–48 hours. It is better to underprime rather than overprime. The new pavement takes up any unabsorbed material, and pavement failure or surface bleeding may result. If a free film of prime material remains after 48 hours, spread a light, uniform layer of clean, dry sand over the surface to absorb the excess primer.

If possible, traffic should not be permitted on the primed surface. The reason is to prevent loss of the primer and to prevent dust or mud from collecting on the surface. When traffic cannot be excluded, spread medium-fine sand over the surface to protect it. The sand blots any excess bituminous material and prevents it from being picked up by traffic. Before the bituminous surface is placed, any loose sand should be lightly broomed from the base.

Depending on the state where you are located, the use of primers may be limited or even prohibited due to environmental concerns. Know the local laws before you proceed with tacking or priming.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

431. Bituminous materials overview

1. How are ACs produced?

2. What are the five types of asphalt cement and their grades?

3. What is the current way to grade asphalt cement?

4. What are the ingredients of asphalt emulsions?

432. Preparing a base for an asphalt surface

1. What action may be necessary to remove coatings of mud or dust from a base?

2. What precautions must you take if you place hot-mix at temperatures below 50°F?

3. What is the purpose of a tack coat?

4. How much tack-coat material should you apply?

5. What will overtacking cause a pavement to do?

6. What is a prime coat?

7. When are tack coats applied to primed bases?

4–2. Asphalt Construction

The need for compaction cannot be overstated. You must select the proper equipment and follow established procedures to get the proper density of an asphalt mat. A well-constructed and properly compacted bituminous pavement not only will provide a smooth riding surface but will also provide motorists with safe paths to travel for years to come.

Asphalt pavements are made up of bituminous materials (5–10 percent) and aggregates (90–95 percent). This mixture provides a firm, stable pavement that needs a minimum of maintenance if properly constructed. Depending on foundation strength and expected wheel loads, this pavement may be as thin as 1 inch or as thick as 1 foot or more. Generally, the stronger the foundation structures (subbase and base course), the thinner the pavement can be.

ACC (flexible) pavement structure is much like a rigid pavement structure in many aspects. Also, there are some minor differences in each basic-type structure.

When you sketch a simple diagram of a rigid (concrete) and a flexible pavement structure, you draw identical diagrams; both consist of the following three parts:

- Pavement.
- Base course.
- Subgrade.

The foundation that comprises the compacted subgrade and base course is topped with a pavement, which consists of aggregate (sand and gravel or crushed stone) and binder (cement). The binder in a rigid pavement is Portland cement. The binder in a flexible pavement is AC. Both binders serve the same function: to bind well-graded, quality aggregate into a uniform, dense mass called concrete.

There are differences between the two types of pavements. The differences, though, are not substantial but a matter of degree. The riding surface of one is rock hard, the other resilient. Rigid pavements can span some weak spots in the foundation. Flexible pavements follow the settling of the foundation material and reflect weak spots on the surface. There are advantages and disadvantages in both cases. Weaknesses in the base cause rigid pavements to break up, requiring extensive repairs. On the other hand, as a base settles, flexible pavement follows and relatively minor maintenance will bring the pavement to strength and grade.

Water in the pavement structure is probably the greatest enemy to well-made pavement structures.

Asphalt cement is a natural waterproofing agent. The probability of water entering a rigid pavement structure from the surface is greater than entering flexible pavement. Other qualities of Portland cement and asphalt cement have been previously covered in this CDC.

433. Types of asphalt pavement construction

When speaking of concrete, people usually think only in terms of PCC. However, both pavements are concrete pavements. This lesson concerns the various types of asphalt pavement construction. With that in mind, the Asphalt Institute, which is the petroleum industry's authority on asphalt construction, defines asphalt concrete as, "high-quality, thoroughly controlled hot mixture of asphalt cement; well-graded, high-quality aggregate, thoroughly compacted into a uniform, dense mass..." In that definition, if you were to simply strike off "hot" and replace "asphalt" with "Portland," you would have a fairly good definition of PCC.

Central plant mix

Asphalt paving mixtures prepared in a central mixing plant are known as plant mixes. Asphalt concrete is considered the highest quality-type of plant mix. It consists of well-graded, high-quality aggregate and AC. The PC asphalt binder and aggregate are heated separately from 275–350°F, carefully measured, and then mixed until the aggregate particles are coated with PC asphalt binder.

Central plant mix is the most widely utilized flexible pavement construction material. Central plants produce paving mixes that are much more accurately produced than mixes by other methods. This is true because central plants are set up to screen, grade, accurately weigh the aggregate, and to add the exact amount of bituminous material. Other methods of construction do not share these advantages.

Most central plants are set up to produce two general types of bituminous mixtures—hot-mix and cold-mix. Each type has its own unique characteristics and its own advantages and disadvantages.

Hot-mix

Hot-mix is the most common material used for flexible pavement construction and maintenance. It is produced in a heated condition and must be placed and compacted while still hot. The bituminous material used in hot-mix is normally PG asphalt cement binder. Mixes made in this way produce pavements that are stronger and many times more durable than mixes produced by other methods.

The mix design of HMA has changed greatly over the years. Each state has its own performance-grade requirements to meet geographic conditions. Simply broken down, this means how the PG AC and aggregate mix together reacts to local environments dictates mixture design. Here are a few examples of how the new PG standards apply to four areas in the United States.

- Mobile, Alabama (AL) requires a PG 58–10.
- Juneau, Alaska (AK) requires a PG 40–16.
- Dallas, Texas (TX) requires a PG 64–10.
- Salt Lake City, Utah (UT) requires a PG 58–16.

Now you might be asking what the numbers mean. Remember that each area has different requirements when it comes to the type of HMA. A simple way of looking at it is that Juneau, AK HMA would have a colder climate and traffic condition pavement surface than Dallas, TX would.

Binder course

On larger HMA projects, the first layer of asphalt placed is called “binder course.” Depending on the project design, there may be multiple layers of binder course asphalt placed. Binder course is HMA that is mixed with large-size aggregates that provides stronger structural support for the foundation of the paved area.

Wear course

The final layer of HMA on a pavement project is called the “wear course.” The wear course acts as a sealer for the underlying HMA binder course and foundation. The HMA is made using small-size aggregates that compact better together to provided tighter interlocking of aggregates. The end product provides for a smoother riding surface for vehicle and aircraft. Using this type of construction allows for the wear course to be milled and replaced without replacing the binder course HMA.

Single-course asphalt mats can also be accomplished when conditions are favorable and equipment is available, such as properly sized rollers. A single-course asphalt mat is more economical compared to a binder course, as it takes fewer man-hours to construct. However, a single course may not be able to be compacted enough to meet stringent density criteria.

Cold mix

Cold-mix materials are mainly for patching and sometimes for minor construction work. They are made in either a hot state or a cold state; however, because of the SC asphalts employed, they need not be used while hot. Mixes of this type are satisfactory for very small jobs, but they lack the mix stability (strength) to support heavy wheel loads. They do, however, have an advantage over hot mixes in that they can be stored for up to 24 months and used on an as-needed basis. They are used for emergency maintenance of roads and parking lots.

434. How to compute asphalt

To find the amount of hot- or cold-mix material needed for a specific job, you must be able to compute both area and volume in US and Metric standards. (Much of this discussion is a review of material presented in an earlier volume of this course. It’s important material that you need to know before working problems involving tonnage.)

Area

As a review, area is defined as any plane surface within boundaries. To compute the area of a square or rectangle, you must multiply the length by the width. Because it is always easier to work with one unit of measurement, always remember to first convert the inches to feet when faced with measurements that aren’t in whole feet (simply divide the number of inches by 12).

Applying simple math skills can be used when computing these types of areas. However, as a construction employee you will find that all work sites are not squares or rectangles. Let’s say your next project is circular. This will introduce a different formula from the ones used in computing materials for rectangles and squares.

The formula for computing the area of a circle is Pi (π) times the radius squared (r^2), or πr^2. The number 3.14 represents Pi. The radius of a circle is half of the diameter.

Volume

Volume can be defined as the amount of anything in three dimensions. The third measurement is depth. To compute the volume of a square or rectangle, simply multiply:

Length × width × depth.

This will give you cubic feet (cu. ft.). To calculate the volume of a circular object, compute the area as described earlier and then multiply that by the depth. This will give you the desired volume in cubic feet.

Unlike base course and concrete, bituminous materials are ordered in quantities of tons.

Computing asphalt

Since asphalt is ordered in tons instead of cubic yards, you need to know how much the material weighs. The weight of asphalt is calculated using a measurement of one cubic foot and can vary throughout the world. One cubic foot of compacted HMA may weigh 120 lbs. in one region of the United States and 150 lbs. somewhere else. The difference arises from different weights of materials used in the design of the mix. There are different designs for different uses. For example, a large-aggregate mix used on a runway would weigh a different amount than a basic parking-lot mix with much smaller aggregate. It's all about the weights of the materials that make up the specific mix you are using at the time.

A difference of a few pounds is no big deal when you are only talking about a few tons of material; however, when you have several miles of paving, the difference adds up quickly. Either you order entirely too much asphalt, or you don't order nearly enough. Either way, it is not an effective or efficient way to construct asphalt pavements.

There are several ways to calculate the weight of the material required. The easiest and most accurate way is to contact the company that will be providing the asphalt and ask them what weight to use. They must conform to guidelines and strict regulations regarding mix design, so they will have these numbers readily available. Most municipalities and local governments require it.

For simplicity sake, however, let's assume that the asphalt we are using weighs 140 pounds per cubic foot, compacted. Therefore, our formula for volume will have this weight added to change the answer from a volume measurement to a weight measurement.

Length × width × depth = ft^3 (volume in cubic feet).

Volume × 140 pounds/ft^3 = pounds.

Once we know how many pounds are represented by our volume measurement, we can convert it into tons. There are 2,000 pounds in one US ton, so it is simply a matter of dividing the total weight (of our area) by 2,000.

Total weight (lbs.) ÷ 2,000 = Tons.

There will be many times in which you will encounter low spots in the base course. You may need a little more HMA to compensate. Once you have computed the total tons required for the job, it is best to order a little extra (normally 5 percent). We can calculate the excess needed by multiplying:

Tons × 1.05 (5%)

This will give you enough material to complete the job if you do the project in the United States. But as said before when deployed, your unit of purchase could be the metric ton. It is simply a matter of converting tons into metric tons.

NOTE: One US ton equals 0.907 metric ton.

Let's look at an example of a simple parking lot measuring 300 feet long and 60 feet wide. Let's assume there will be one 2-inch lift.

300 (L) × 60 (W) × 0.167 (D in inches) ×140 ÷ 2000 × 1.05 =

420,840 ÷ 2000 × 1.05 =

210.42 × 1.05 = 220.941 tons (round up to 221 tons).

Let's now look at using 150 pounds per cubic foot for the weight of the asphalt and see what happens to our calculations for the parking lot.

300 (L) × 60 (W) × 0.167 (D in inches) ×150 ÷ 2000 × 1.05 =

450,900 ÷ 2000 × 1.05 =

225.45 × 1.05 = 236.72 tons (round up to 237 tons).

As you can see, just by changing the weight by 10 pounds, we came up with a difference of 16 tons for the same exact parking lot. We could go the opposite direction and see what happens if we use 120 pounds per cubic foot instead.

300 (L) × 60 (W) × 0.167 (D in inches) ×120 ÷ 2000 × 1.05 =

360,720 ÷ 2000 × 1.05 =

180.36× 1.05 = 189.38 tons (round up to 190 tons).

This calculation netted 47 tons difference! That equates to thousands of dollars wasted if you ordered the asphalt using the 150 pounds per cubic foot and the actual weight of the material was 120 pounds per cubic foot.

The steps for computing cold-mix asphalt are the same as the ones used for computing hot-mix except for the weight of the material. Cold-mix material does not need to be used right away and can be stored for future use. For this reason, we can use 90 pounds per cubic foot as a general average for the weight. If needed, we can plug the 90 into our asphalt formula to come up with an amount required for a specific project. However, cold-mix asphalt is normally not used for any kind of construction that an HMA would be used for. It is normally exclusively for quick, expedient repairs like filling potholes and building up shoulders. We usually order several tons at a time and stockpile it for future use.

435. How to inspect and place asphalt

Critical factors in any asphalt project is the condition of your asphalt mix upon arrival to the work site and the method it is placed. In this lesson you will learn how to inspect asphalt for deficiencies to ensure you are receiving a good mix. You will also learn the different methods of placement and will notice the pros and cons of each method. Lastly you will have a firm grasp on the sequence of placing asphalt.

Visual inspection of the mix

After trucks arrive on your job site, a visual inspection of the material is required to ensure the material will not have any deficiencies before dumped into a lay-down machine or spread by hand at the job location. The following paragraphs provide a relatively small list and descriptions of deficiencies to be cognizant of when working on an asphalt project.

Temperature

Generally a load that appears stiff or has an unusually high peak may be too cool to meet specifications. The temperature should be checked. If it is below the optimum placement temperature, but within the acceptable temperature range, immediate steps should be taken to offload it. If you have trucks waiting with different temperatures within the acceptable range, get the truck with the lowest temperature to offload first. Reject any loads that are below the required minimum temperature. Accepting substandard material is unacceptable as it will produce a substandard product.

Mix slumped in truck

Normally the material in the truck is in the shape of a dome. If a load lies flat or nearly flat, it may contain too much asphalt or excessive moisture. This is called a “rich” mix and has very different density characteristics than an ideal mix. You will have to adjust roller weights, rolling patterns, and cure times to compensate for rich mixes. Close inspection should be made at once. Excess asphalt also may be detected under the screed as excessive shininess on the mat surface. A mix containing a large amount of coarse aggregate might be mistaken for a rich mix because of its shiny appearance. Such a mix, however, usually will not slump in the haul truck.

Lean, dull appearance

A mix that contains too little asphalt can generally be detected immediately in the truck or in the spreader hopper by its lean (dry), granular appearance, improper coating of the aggregate, and a lack of typical shiny black luster. Lack of sufficient asphalt in the mix can be detected on the road by its lean, brown, dull appearance on the surface and unsatisfactory compaction under the roller. Excess fine aggregate can cause a mix to have the same look as a mix with too little asphalt. Excess fines can be detected by inspecting the mix texture and by watching for shifting of the mix under the roller.

Rising steam

Excess moisture often appears as steam rising from the mix when it is dumped into the hopper of the paver. The HMA may be bubbling and popping as if it were boiling in a pot on a stove. Excessive moisture may also cause the mix to appear and act as though it contains excessive asphalt.

Rising smoke

Blue smoke indicates the mix is burnt and must be rejected immediately. Because the asphalt has partially burnt away, it has the appearance of being lean. Check the temperature immediately as this is usually a telling sign of being burnt. The asphalt plant sometimes tries to compensate for long travel distances by pushing the temperature as high as they can. Another sign is the pungent aroma coming from the asphalt. Whenever petroleum products burn, especially bituminous products, they give off a very distinctive smell.

Segregation

Segregation of the aggregate in the mix may occur during paving because of improper handling or it may have happened at some point prior to the mix reaching the paver. In any case, corrective action should be taken immediately. The cause of the segregation should be corrected at its source.

Contamination

Mixes can become contaminated by a number of foreign substances, including spilled gasoline, kerosene, oil, rags, paper, trash, and dirt. The contamination can be removed if it is not too extensive; however, a load that has been thoroughly contaminated should be rejected.

Bleeding

Nonpetroleum-based relief agents are recommended for spraying truck beds while actively hauling HMA. This poses no concerns to the asphalt; however, if someone were to use diesel fuel (as was common in the past), there could have adverse effects. The fuel dilutes the asphalt and causes it to bleed to the surface. Hot-mix contaminated with diesel fuel should be removed and replaced.

When inspecting the HMA and any of the above deficiencies are noted, do not allow dumping of the mix. Inform the driver of the truck of your inspection findings and have the truck return to the plant.

Spreading materials

The material that arrives at the road or runway construction site from the central plant must be spread. It must cover the entire width of the road being paved. It is then struck off to the desired shape and thickness and compacted. The general methods of spreading and shaping the materials include both hand spreading and mechanical spreading.

Hand spreading

The most labor-intensive method used to spread and shape the mixed material is by hand. For this method, the mix is dumped directly from the trucks into or near the area to be repaired. After placement, the asphalt is raked smooth (luted) and compacted with a roller or plate compactor.

Because of the high cost of labor and the inability to get a perfectly smooth and even-textured surface, hand spreading is not used to any great extent. It is used mainly to supplement the other spreading methods or for small jobs. For example, in street work on a base facility, hand spreading is used effectively adjacent to curbs and around manholes. It is also useful at the curved corners of intersections.

When placing the material by hand, be extremely careful to prevent segregation of the mix. Do not throw the material a long distance and don't dump it from too great a height. Dump the material in small piles just ahead of the workers. The material can be leveled with shovels, rakes, and lutes. Use the shovels to move excess material and the lutes and rakes to level it. The material should be as level as possible before you compact it. You can use a straightedge or template to check the surface.

Mechanical spreading

Specialized machines have been developed to spread bituminous paving materials.

Towed

On small paving jobs, it is sometimes cheaper and easier to use a towed-type paver. Towed-type pavers are attached to the rear of a dump truck through locking mechanisms which lock into the wheel hubs. Material is dumped from the bed of the truck and put directly into the hopper of the paver. The material then falls directly to the base. As you move the truck forward, the material is struck off by a blade, a cutter bar, or a screed.

Some towed-type spreaders have floating screeds. To start out spreading at full depth, place blocking under the screed before you put any material into the hopper. Once you set the screed for the proper depth, you should not have to adjust it again. Be sure you keep the hopper full of material during paving operations to assure a full, even spread.

If you are operating the dump truck, always tow the spreader at a uniform speed for any given setting. If your towing speed varies, the spread may vary in thickness as well. With careful set up and operation, you can achieve acceptable results.

Self-propelled

These machines have crawler tracks or wheels and rollers that run on the base or surface. The mix from the central plant is dumped into a hopper at the front of the machine. The spreader, or paver, places the mix evenly on the road behind it. Figure 4–2 shows a pneumatic-tired bituminous paver, while figure 4–3 shows a track paver. Both can handle any type of asphalt mix, cold or hot.

Pavers have several advantages over hand spreading or motor graders for spreading asphalt mixes. Probably the most important advantages are the savings in spreading time, the greater smoothness of the placed mixes, and the ability of the machine to handle the stiffer hot mixes. They can place the mix as rapidly as it is normally delivered from the central plant. Rolling is the only work needed after the surface has been laid with the machine.

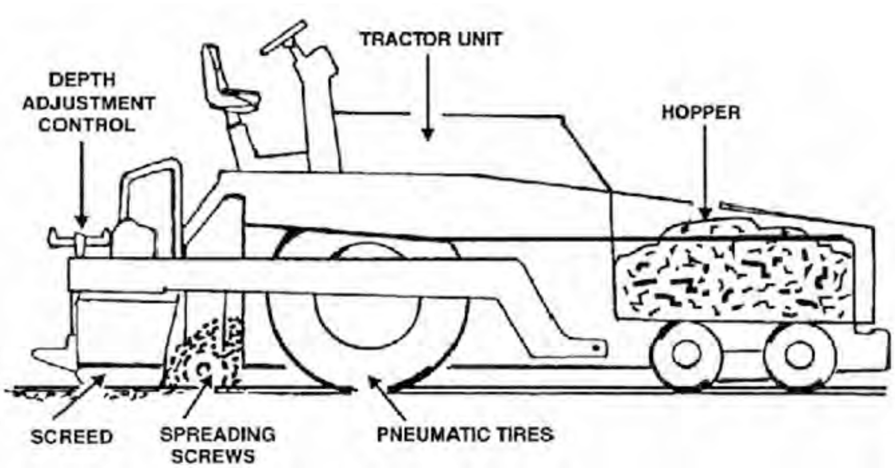


Figure 4–2. Self-propelled bituminous paver (pneumatic-tired).

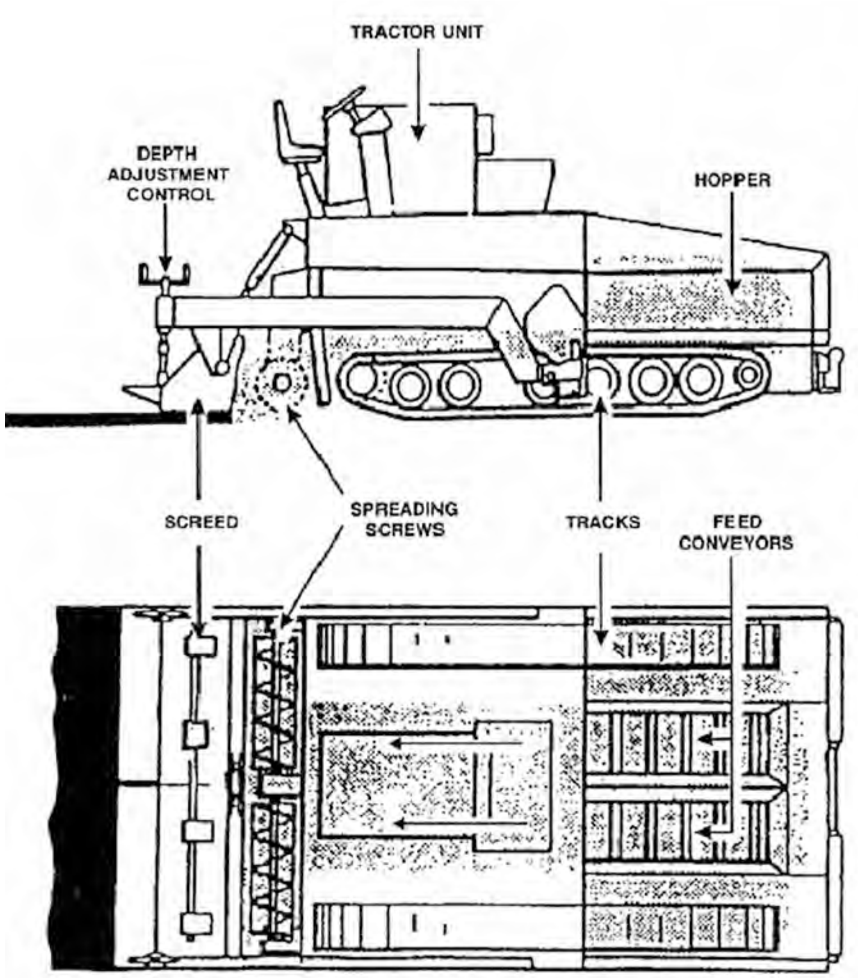


Figure 4–3. Self-propelled bituminous paver (tracks).

436. How to compact asphalt

One of the most important phases in flexible pavement construction is compaction. If the specified density of asphalt pavement mix is not obtained during construction, subsequent traffic will consolidate the pavement further. This consolidation occurs mainly in the wheel paths and appears as channels in the pavement surface.

Fundamental principles

Most mixtures compact quite readily if spread and rolled at temperatures that assure proper asphalt viscosity. Refer to recommended temperature ranges for compaction for the type of asphalt you are working with. Rolling should start as soon as possible after the material has been spread by the paver but should be done with care to prevent unduly roughening of the surface. The vibratory screed on an asphalt paver provides up to 85 percent of the initial compaction to an asphalt mat.

Mix temperature is a principle factor affecting compaction. Delivery temperatures must be no less than 250ºF and no more than 325ºF. Compaction can only occur while the asphalt binder is fluid enough to act as a lubricant. When it cools enough to act as an adhesive, further compaction is extremely difficult to achieve. The best time to roll an asphalt mixture is when its resistance to compaction is the least, while at the same time it is capable of supporting the roller without excessive shoving. The inter-particle friction of the aggregates, the gradation of the mix, and the viscosity of the asphalt influence the best rolling temperature. Therefore, it can change if any of these factors change. The critical mix temperature in an asphalt concrete paving project is the temperature at the time of compaction. If asphalt temperatures dip below 185ºF, the chances of achieving 95 percent compaction are greatly diminished.

A well-compacted asphalt mat should have 95 percent density or higher, depending on its design and expected use. The only way to know for sure is to have it tested. The Engineering Assistants will be able to do the testing or have samples taken to a lab for analysis.

Rolling times

There are many uncontrollable factors that affect how long you must compact asphalt to attain the proper density:

- Ambient temperature.
- Wind.
- Base temperature.
- Cloud conditions.

As mentioned previously, the temperature of the asphalt when it is placed on the surface, along with the other conditions, and the depth of the asphalt determine how long you must compact your asphalt. This time can be as short as a few minutes to over an hour.

Rolling procedure

During rolling, the roller's drums must be kept moist with only enough water to avoid picking up material. Rollers move slowly but methodically with the drive wheels nearest the paver. The speed should not exceed 3 miles per hour (mph) for steel-wheeled rollers or 5 mph for pneumatic-tired rollers. Rollers must be kept in good condition and capable of being placed into reverse without backlash. The line of rolling should not be suddenly changed or the direction of rolling suddenly reversed, thereby displacing the mix. Any pronounced change in direction should be made on stable, compacted material.

If rolling causes material displacement, the affected areas should be loosened at once with lutes or rakes and restored to their original grade with loose material before being re-rolled. Heavy equipment, including rollers, should not be permitted to stand on the finished surface before it has thoroughly cooled or set. Rolling freshly placed asphalt mix is accomplished in the following order:

1. Transverse joints.
2. Longitudinal joints.
3. Initial or breakdown rolling.
4. Second or intermediate rolling.
5. Finish rolling.

Transverse joints

The first pass made will be on the transverse joint with a steel-wheeled roller. The surface is then checked for trueness with a straightedge, and corrections are made if necessary. Continue rolling the joint transversely, with the roller on the previously laid material, except for a 6-inch projection of the wheels when using a tandem roller (fig. 4–4). This operation should be repeated with the successive passes covering 6–8 inches of fresh material until the entire width of the drive wheel is on the new mix. Boards of the proper thickness should be placed at the edge of the pavement to provide for off-pavement movement of the roller. If boards are not used, transverse rolling must stop 6–8 inches short of the outside edge to prevent damage. The outside edge then must be rolled out later when rolling longitudinally.

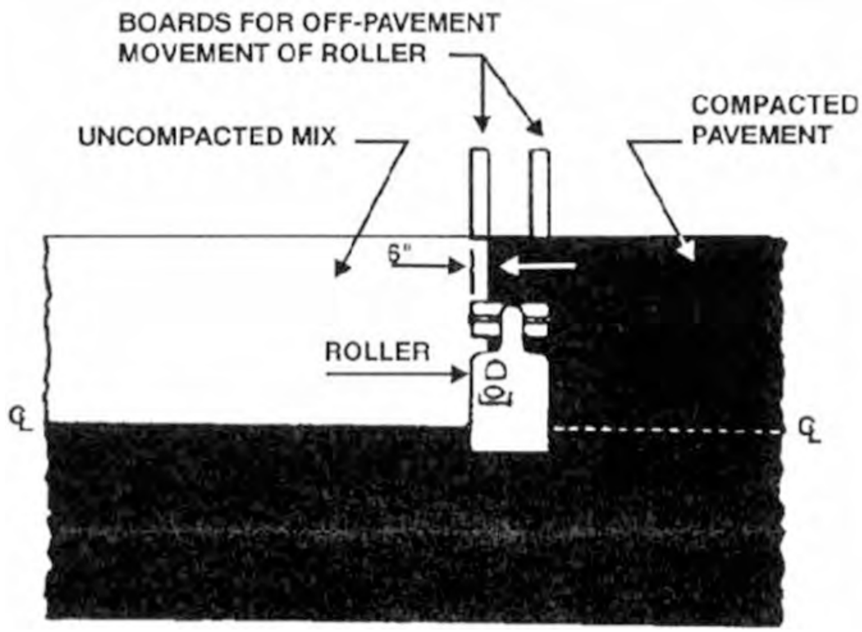


Figure 4–4. Rolling a transverse joint.

Longitudinal joints

Longitudinal joints should be rolled directly behind the paving operation. The roller should be shifted to the previously placed lane so that not more than 6 inches rides on the edge of the fine material left from the joint prepping (fig. 4–5). Joint prepping is simply using a lute to push the material past the joint which may have been left by the paver. It also cleans the joint so the roller can compact the joint cleanly. The roller should continue to roll along this line (called "pinching" the joint), its position being shifted gradually across the joint until a thoroughly compacted, neat joint is obtained.

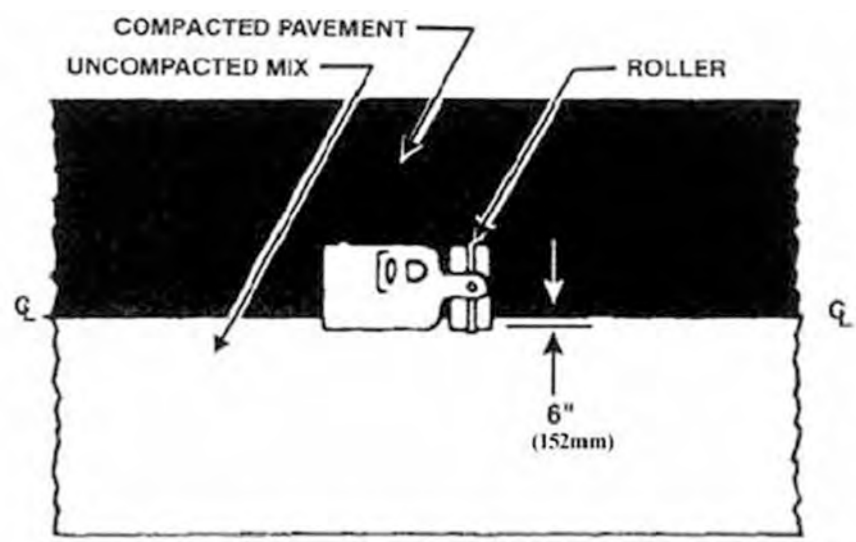


Figure 4–5. Rolling a longitudinal joint.

An alternative method, used mainly with vibratory rollers, has the roller making the first pass to the paver with the drum on the hot material about 3 inches away from the first placed lane. This leaves a narrow ridge of hot, unrolled mix (fig. 4–6, A). On the return pass, the first placed lane is overlapped about 3 inches (fig. 4–6, B). Good density should result. This method prevents roller bounce and washboarding at the joint caused by vibration.

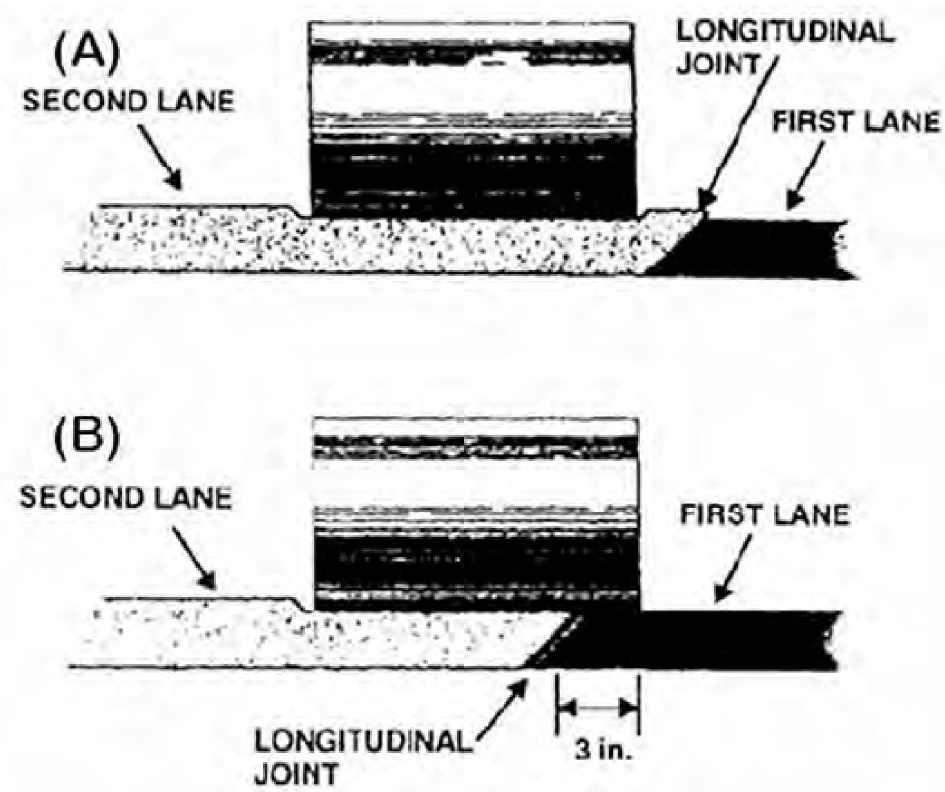


Figure 4–6. Joint rolling with vibrating roller.

Breakdown rolling

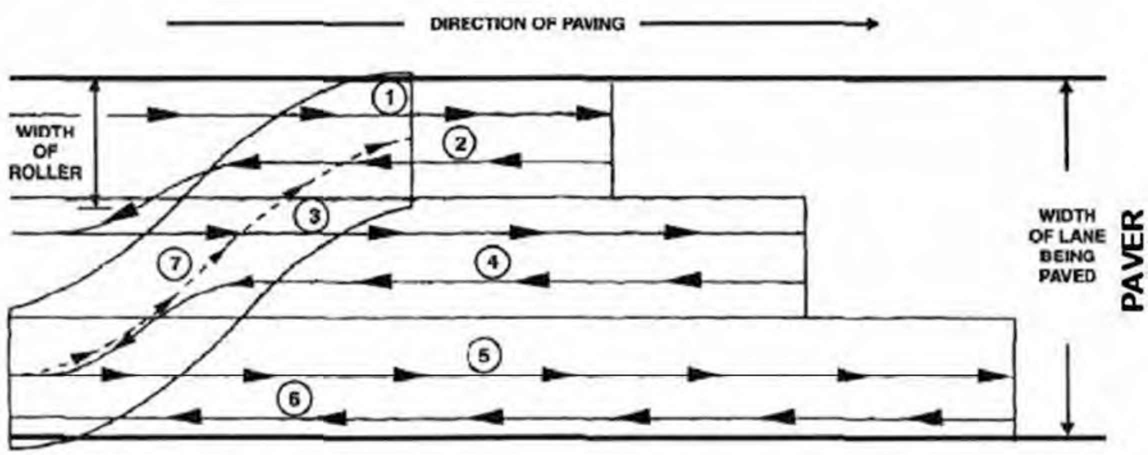
Breakdown rolling is best done with steel-wheeled rollers. Vibratory or static-weight tandem rollers are recommended. Pneumatic-tired rollers, however, also have been successful for breakdown rolling but normally should be limited to binder courses made with bituminous materials.

The weight of the roller used for breakdown rolling depends to a large degree on the temperature, thickness, and stability of the mix being placed. Generally, a roller weighing from 8–12 tons is used for this operation. You may have to adjust the weight of your rollers to correlate to the mix.

After joints have been pinched, start the rolling operation on the low side of the spread, usually the outside of the lane being paved, and progress toward the high side. The reason for this is that the asphalt mixtures, when hot, tend to migrate towards the low side of the spread under the action of the roller. If rolling is started on the high side, this migration is much more pronounced.

A rolling pattern that provides the most uniform coverage of the lane being paved should be used. Rollers vary in widths, and a single recommended pattern that applies to all rollers is impractical. For this reason, the best rolling pattern for each roller being used should be worked out and followed to get the most uniform compaction across the lane.

The rolling pattern includes not only the number of passes, but also the location of the first pass, the sequence of succeeding passes, and the overlapping between passes. One coverage will include all the passes necessary to compact the entire width of the mat, one time. Rolling speed should not exceed 3 mph. Also, sharp turns and quick starts and stops should be avoided. For thin lifts, a recommended rolling pattern for static steel-wheeled rollers is shown in figure 4–7.



This is a recommended rolling pattern. Every pass of the roller should proceed straight into the compacted mix and return in the same path. After the required passes are completed, the roller should move to the outside of the pavement on cooled material and repeat the procedure.

Figure 4–7. Rolling pattern.

The rolling operation (fig. 4–7) should start from the edge of the spread on the low side with the roller moving forward as close behind the paver as practical (after the joints have been pinched). The second movement of the roller should be to reverse in the same path until the roller has reached previously compacted material. At this point it should swing over and move forward along the path number three, again going as close as possible behind the paver. The fourth movement is reversed in the third path and a repetition of the previous operation. After the entire width of the mix being placed has been covered in this fashion, the roller should swing across the spread to the low side and repeat the process. With this pattern, the lap of the roller with succeeding passes need not be more than 3–4 inches.

For thick lift construction, the rolling process should start 12–15 inches from the lower unsupported edge until the center part of the spread is compacted to some degree of stability. Succeeding passes of the roller should then gradually progress toward the edges of the spread. The uncompacted edge provides initial confinement during the first pass, thus minimizing lateral movement of the mix. After the central part of the spread has been compacted, the mix will support the roller and allow the edge to be compacted without lateral movement.

With steel-wheeled rollers, the operation should always progress with the drive wheel forward in the direction of paving. This is especially important in breakdown rolling because 80–90 percent of compaction occurs in breakdown rolling. The main reason why breakdown rolling should be done with the drive wheel forward is that there is more direct vertical load applied by this wheel than by the tiller wheel (fig. 4–8).

If the breakdown pass is made with the tiller wheel forward, the pushing force and the weight of the roller is slightly ahead of vertical, causing material to push up in front of the wheel. The greater weight of the drive wheel carries out the compaction while the turning force tends to tuck the material under the front of the wheel.

There are exceptions to rolling with the drive wheel forward, however. They usually occur when construction occurs on a hill or extreme grades. The exceptions occur when, due to these extreme grades, the drive wheel of the roller begins to chatter on the mat, causing displacement of the mix and a very rough surface. In these cases, the roller must be turned around to allow the tiller wheel to partially compact the material so that the drive wheel can proceed over it.

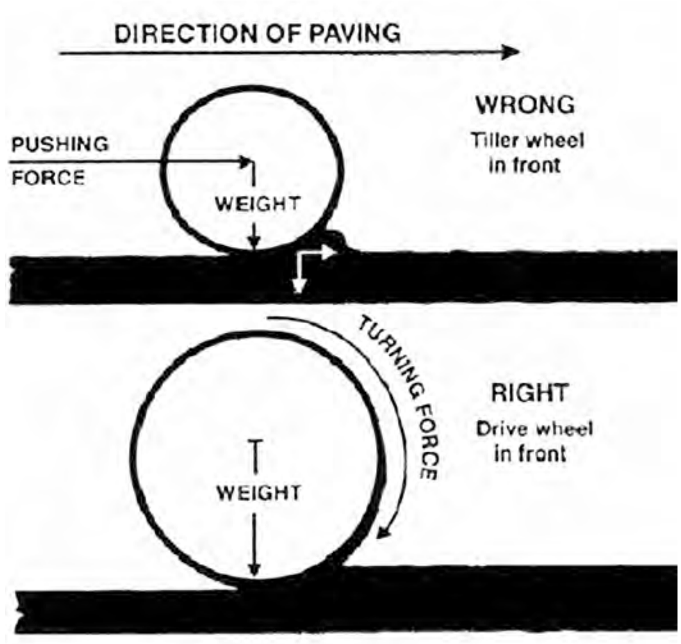


Figure 4–8. Forces acting when tiller wheel or drive wheel is forward.

Intermediate rolling

The second or intermediate rolling should closely follow breakdown rolling while the asphalt mix is still plastic and at a temperature that will result in maximum density.

Pneumatic-tired or vibratory tandem rollers may be used for intermediate rolling. When using pneumatic-tired rollers, keeping the tires hot is the most effective means of preventing the material from being picked up. Applying a small amount of nonfoaming detergent or water-soluble oil on the wetting nap (cocoa pads) of a pneumatic-tired roller at the beginning of the rolling operation will help prevent asphalt from sticking to the tires until they warm up. Pneumatic-tired rollers are preferred for intermediate rolling for several reasons, including the following:

- They provide a more uniform degree of compaction than steel-wheeled rollers.
- They improve the seal near the surface, decreasing the permeability of the layer.
- They orient the aggregate particles for greatest stability, as high-pressure truck tires do after using the asphalt surface for some time.

Tire contact pressures should be as high as possible without causing displacement of mix that cannot be remedied in the final rolling.

Intermediate rolling should be continuous after breakdown rolling until all of the mix has been compacted thoroughly. At least three complete coverages should be made. Like the steel-wheeled roller, turning of the pneumatic-tired roller on the paving mix should not be permitted as it could cause displacement.

Vibratory tandem rollers—of proper static weight, vibration frequency, and amplitude—provide required densities with fewer passes than static-weight tandem or pneumatic-tired rollers (or a combination of the two).

Regardless of the type of roller used, the rolling pattern should be developed in the same way as for the initial, or breakdown, rolling. This pattern should be continued until the desired compaction is obtained.

Finish rolling

Finish rolling is done solely for the improvement of the surface. It should be done with steel-wheeled tandem roller, static-weight, or vibratory roller while the material is still warm enough for removal of roller marks.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

433. Types of asphalt pavement construction

1. What are the two general types of central plant mixes?

2. Normally, what is the bituminous material used in hot-mix?

3. What is the advantage of cold-mix over hot-mix?

434. How to compute asphalt

1. Due to geographic differences, what is the easiest and most accurate way to calculate the weight of the HMA required?

2. How many tons of hot-mix is needed to build a parking lot that measures 400 feet long by 45.5 feet wide by 3 inches deep, using 140 pounds per cubic foot material weight, including 5 percent for low spots?

3. Let's now assume that after talking to the asphalt plant, the material weight is actually 153 pounds per cubic foot. How much HMA will we need?

4. How much does one cubic foot of cold-mix weigh?

435. How to inspect and place asphalt

1. What type of inspection needs to be completed before dumping the HMA in the laydown machine?
2. What are some advantages of using bituminous pavers over motor graders?
3. What is the only work required after the surface has been laid with the paving machine?

436. How to compact asphalt

1. What is the sequence of rolling freshly placed asphalt?
2. Briefly explain procedures for rolling asphalt with vibratory rollers.
3. On what does the weight of the roller used for breakdown rolling depend?
4. Why is it important to start the rolling operation on the low side of the spread?

Answers to Self-Test Questions

431

1. By refining crude petroleum.
2. AC–2.5, Soft; AC–5, Semi-Soft; AC–10, Medium; AC–20, Semi-Hard, and AC–40, Hard.
3. Performance grading.
4. AC, water, and an emulsifying agent.

432

1. Washing or flushing with water.
2. Operations must be properly coordinated to prevent excessive heat loss during the spreading and rolling operations.
3. To ensure a good bond and seal between the old underlying surface and the new overlaying surface. It acts as the bonding agent, or in simpler terms, the glue.
4. Never apply more tack coat material than you can cover in a day’s work.
5. Shove, slip, corrugate, and bleed.
6. The light application of a liquid bituminous material to an absorbent surface.
7. Only when the prime coat is exceptionally hard or dusty.

433

1. Hot-mix and cold-mix.
2. PG asphalt cement binder.
3. It can be stored for up to 24 months and used on an as-needed basis.

434

1. Contact the company that will be providing the asphalt and ask them what weight to use.
2. 335 tons.
3. 366 tons.
4. Approximately 90 lbs.

435

1. Visual.
2. The savings in spreading time, the greater smoothness of the placed mixes, and the ability of the machine to handle the stiffer hot mixes.
3. Rolling.

436

1. Transverse joints, longitudinal joints, initial or breakdown rolling, second or intermediate rolling, and finish rolling.
2. The roller makes the first pass to the paver with the drum on the hot material about 3 inches away from the first placed lane. On the return pass, the first placed lane is overlapped about 3 inches.
3. The temperature, thickness, and stability of the mix being placed.
4. Asphalt mixtures, when hot, tend to migrate towards the low side of the spread under the action of the roller.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

64. (431) Today's asphalt cements are graded according to
    a. volatility.
    b. setting rate.
    c. performance.
    d. evaporation rate.

65. (431) Which type of asphalt emulsion is developed for slurry seals?
    a. Quick-set (QS).
    b. Slow setting (SS).
    c. Rapid setting (RS).
    d. Medium setting (MS).

66. (431) Which of these materials can be used with damp aggregate?
    a. Road tar.
    b. Asphalt cement.
    c. Road tar cutback.
    d. Asphalt emulsion.

67. (432) Bituminous surfaces *must be* constructed on bases that are reasonably dry and free from
    a. excessive wheel loads.
    b. too great compaction.
    c. optimum moisture.
    d. caked mud or dust.

68. (432) Bituminous construction *normally* should be suspended when the temperature falls below
    a. 35°F.
    b. 40°F.
    c. 45°F.
    d. 50°F.

69. (432) What is the purpose of a tack coat?
    a. Acts as a barrier for concrete.
    b. Waterproofs and hardens the surface.
    c. Acts as glue between two layers of asphalt.
    d. Keeps water from seeping up by plugging the voids.

70. (433) Each state has its own performance grade requirements to meet what conditions?
    a. Geographic.
    b. Geometrical.
    c. Geopolitical.
    d. Geophysical.

71. (433) On larger hot-mix asphalt (HMA) projects, what is the first layer of asphalt called?
    a. Wear course.
    b. Binder course.
    c. Station course.
    d. Branch course.

72. (434) Can you use the same weight of asphalt for multiple mixes when computing requirements?
    a. Yes, all asphalt weighs the same.
    b. No, asphalt weight varies by mix design.
    c. Yes, use the weight from your last assignment.
    d. No, asphalt weight increases with elevation and location.

73. (434) How many tons of hot-mix asphalt will be required to construct an area that measures 60 feet long by 35 feet wide by two inches deep, using 137 pound/ft^3 asphalt, and including five percent extra for low spots?
    a. 25.22.
    b. 26.55.
    c. 27.14.
    d. 28.87.

74. (435) What shape should an asphalt mix have it is slumped in the bed of a dump truck?
    a. Crater.
    b. Dome.
    c. Cone.
    d. Flat.

75. (435) When inspecting a truck of asphalt, blue smoke indicates the mix is
    a. Evaporating all the moisture in the load.
    b. Ready for laying.
    c. Too cold.
    d. Burnt.

76. (435) One advantage of a bituminous paver over a motor grader is that the bituminous paver
    a. does *not* handle the stiffer hot mixes.
    b. provides a rougher surface.
    c. requires more manpower.
    d. saves spreading time.

77. (436) The *maximum* speed of steel-wheeled rollers should *not* exceed how many miles per hour (mph)?
    a. 3.
    b. 5.
    c. 7.
    d. 9.

78. (436) How far from the lower unsupported edge should the rolling process start for thick lift construction?
    a. 3 to 6 inches.
    b. 6 to 9 inches.
    c. 9 to 12 inches.
    d. 12 to 15 inches.

79. (436) At least how many coverages should be made with the pneumatic-tired roller during the intermediate rolling?
    a. 2.
    b. 3.
    c. 4.
    d. 5.

80. (436) Finish rolling is done solely to
    a. seal the surface.
    b. knead the surface.
    c. improve the surface.
    d. waterproof the surface.

Please read the unit menu for unit 5 and continue ➔

Unit 5. Asphalt Cement Concrete Pavement Maintenance

THERE ARE OVER 4 MILLION miles of paved roads in the United States requiring maintenance. The original investment in these structures was in the billions of dollars and their maintenance now costs millions of tax dollars annually. Obviously, good quality and timely maintenance are imperative. "Maintenance" is the preservation and upkeep of a paved surface in its originally constructed condition or in its subsequent, improved condition. Routine maintenance is assumed in selecting the design life of a pavement. If maintenance is not done, the pavement will not adequately perform throughout its design life. Maintenance should be done with minimum expense and interruption to traffic.

5–1. Identifying Pavement Defects

This section will help you better the identify types of ACC pavement defects, which is also the first step in maintaining flexible pavements. You will look specifically at the types of defects and learn to identify them as well as what may have cause the defect in the first place.

437. Types and causes of asphalt cement concrete pavement defects

In this lesson, we introduce the topic, the types, and causes of defects within flexible pavement. These defects can be placed into one of the following five categories:

- Cracking.
- Distortion.
- Disintegration.
- Slippery surfaces.
- Surface treatment problems.

Cracking

How to repair a crack properly depends on the type of crack, the cause, its size, as well as the size of the area to be repaired. The common types of cracks you will find are referred to as alligator, edge, longitudinal, transverse and diagonal, reflection, block, and slippage.

Alligator cracks

Alligator cracks are interconnected cracks forming a series of small, many-sided blocks resembling an alligator's skin or chicken wire. Alligator cracking usually is caused by failure of the base or subgrade and is aggravated by traffic and water. Normally, the affected area is not large. When it does occur on a large scale, the cracking is most likely due to repeated loads above the pavement's designated strength. Aging and a poor mix can contribute to the problem. Alligator cracking is considered a major structural stress (fig. 5–1).

Edge cracks

Edge cracks are longitudinal cracks 1–2 feet from the edge of the pavement. They can have transverse cracks branching in towards the shoulder. Normally, edge cracks are caused by a concentration of traffic loads near the edge, aggravated by a lack of side or shoulder support. They may also be caused by settlement or yielding of the base material underlying the cracked area. This, in turn, may be a result of poor drainage, frost heave, or shrinkage from the drying out of the surrounding earth (fig. 5–2).

Figure 5–1. Alligator cracks.

Figure 5–2. Edge cracks.

Edge-joint cracks

An edge-joint crack is a longitudinal separation along the seam between the pavement and the shoulder. It is caused by poor construction practices or by trucks straddling the joint where the pavement and the shoulder meet (fig. 5–3).

Lane-joint cracks

Lane-joint cracks are longitudinal separations along the seam between two paving lanes. A weak seam usually causes this type of crack or a poor bond between adjoining spreads in the pavement. Transverse cracks are from shrinkage as the asphalt ages, and diagonal cracks are a reflection of an underlying crack in an asphalt overlay (fig. 5–4).

Figure 5–3. Edge-joint cracks.

Figure 5–4. Lane-joint cracks.

Reflection cracks

Reflection cracks occur most frequently in asphalt overlays of a PCC pavement. These cracks reflect the pattern in the pavement structure underneath. Reflection cracks are caused by thermal expansion and contraction of the PCC pavement. Asphalt and PCC have different rates of expansion and contraction (fig. 5–5).

Shrinkage cracks

These interconnected cracks form a series of large blocks, usually 1–10 feet square with sharp corners or angles. They usually occur over the entire surface and are worse in low-traffic areas. The cause is the aging of the asphalt pavement where the asphalt has lost its flexibility, hardens, and shrinks. Lack of traffic hastens shrinkage cracks in these pavements (fig. 5–6).

Figure 5–5. Reflection cracks.

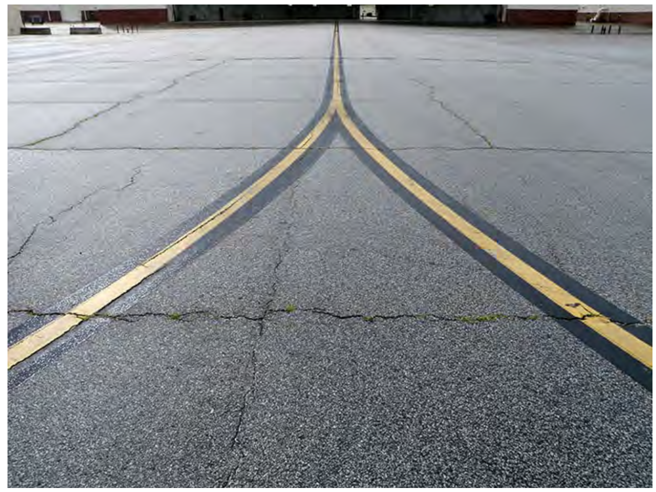


Figure 5–6. Shrinkage cracks.

Slippage cracks

Slippage cracks are crescent-shaped with the ends of the cracks pointing away from the direction of traffic, resulting from horizontal forces induced by traffic. They are caused by a lack of bond between the surface layer and the course beneath. Lack of bond may be due to dust, dirt, oil, or the absence of a tack coat (fig. 5–7).

Distortion

Pavement distortion is any change in your asphalt pavement surface. It is the result of subgrade weakness where compaction or movement of the subgrade soil has taken place or where base compaction has occurred. Another possible cause is the mix itself. It may or may not be accompanied by cracking. This distress creates a traffic hazard, lets water accumulate, and eventually makes matters worse. Distortion takes a number of different forms, such as channeling, corrugations and shoving, grade depressions, utility cut depressions, and upheaval or swelling.

Channeling or ruts

Channeling, also referred to as grooving or rutting, is made up of channelized depressions that develop in the wheel tracks of flexible pavements. Channeling may result from consolidation or lateral movement under traffic in one or more of the underlying courses or by displacement in the bituminous surface itself. It may develop under traffic in new flexible pavements that had too little compaction during construction or from plastic movement in a mix that does not have enough stability to support traffic (fig. 5–8).

Figure 5–7. Slippage cracks.

Figure 5–8. Channeling or rutting.

Corrugations

A corrugation, or washboarding, is a form of plastic movement typified by regularly spaced ridges and valleys running perpendicular to the direction of traffic. The spacing between the ridges is usually 5 feet or less. Normally, the cause is traffic action (braking, acceleration, or bouncing) on an unstable asphalt pavement surface of poorly compacted base (fig. 5–9).

Shoving

Shoving is the plastic movement of the pavement resulting in localized bulging or longitudinal displacement of the pavement. Shoving normally occurs at points where traffic starts and stops or on hills where vehicles brake on the downgrade or where it adjoins a PCC pavement. As the PCC expands, the asphalt gives way and shoves upward away from the base course.

Usually, both corrugations and shoving occur in flexible pavement mixtures that lack stability. This may be the result of too much binder, too much fine aggregate, or round or smooth textured coarse aggregate (fig. 5–10).

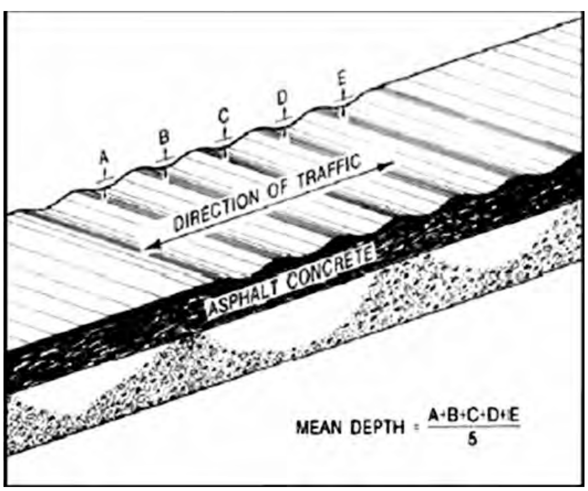


Figure 5–9. Corrugations.

Figure 5–10. Shoving.

Grade depressions

Grade depressions are localized areas of low elevation noticeable by standing water (bird baths) after a rainfall or stained areas where water had dried. It may or may not be accompanied by cracking. Water collects in depressions, which becomes not only a source of pavement deterioration, but also a hazard to motorists. Depressions are caused by traffic heavier than that for which the pavement was designed, poor compaction of the surface or base, poor construction methods, or by consolidation deep within the subgrade (fig. 5–11).

Utility cut depressions

These depressions in the pavement develop from a cut for utility installation or repair. These are caused by inadequate compaction of the backfill material.

Upheaval

Upheaval is the localized upward displacement of the pavement due to swelling of the subgrade or some part of the pavement structure. It is most commonly caused by ice expansion in the granular courses beneath the pavement or in the subgrade. Upheaval may also be caused by the swelling effect of moisture on expansive soils (fig. 5–12).

Figure 5–11. Grade depressions.

Figure 5–12. Upheaval.

Disintegration

The breaking up of a pavement into small, loose fragments is termed disintegration. This includes the dislodging of aggregate particles. If not stopped in its early stages, disintegration can progress until the pavement requires complete rebuilding. Potholes and raveling are two common types of early-stage disintegration.

Potholes

Potholes are bowl-shaped holes of various sizes in the pavement resulting from localized disintegration under traffic. They are usually caused by weakness in the pavement resulting from too little binder, too thin a surface, too many fines, or poor drainage, creating a weakened base or subgrade.

Raveling

Raveling is the progressive loss of surface material caused by weather or traffic abrasion (fig. 5–13).

Slippery surfaces

Few dry pavements are slippery, but there are many things that can make a pavement slippery when wet. One of the most common causes of a slippery flexible pavement is a thin film of water over a smooth surface. This can cause a vehicle to hydroplane. Other causes of slippery surfaces in flexible pavements are bleeding and polished aggregates.

Bleeding

Bleeding is the upward movement of bituminous material in a flexible pavement, resulting in the formation of a film of bituminous material on the surface. The most common cause of bleeding is too much asphalt in one or more of the pavement layers. This is usually the result of a too rich a plant mix or a too heavy prime or tack coat. Bleeding normally occurs in hot weather (fig. 5–14).

Figure 5–13. Raveling.

Figure 5–14. Bleeding.

Polished aggregate

Polished aggregates are those that have been worn smooth under traffic. Using the wrong type of aggregate in the pavement mix causes polished aggregates (fig. 5–15).

Figure 5–15. Polished aggregate.

Surface treatment problems

Because of the method of construction, surface treatments may develop some defects that do not occur in other types of flexible pavement surfaces. These include loss of cover aggregates, longitudinal streaking, and transverse streaking.

Loss of cover aggregates

Loss of cover aggregates is the whipping-off of aggregate under traffic from a surface-treated pavement. Several things can cause loss of cover aggregates, such as the following:

1. Aggregate spread after the bituminous material has cooled too much.
2. Aggregate too dusty or wet when spread.
3. Aggregate not rolled or seated immediately after spreading.
4. Steel-wheel roller bridged over low spots.
5. Traffic allowed on new surface treatment too soon.
6. Not enough or wrong grade of asphalt on an absorbent surface.

Longitudinal streaking

Longitudinal streaking is alternating lean and heavy lines of bituminous material running parallel to the centerline of the road. Several things can cause longitudinal streaking. Most can be pinpointed to improper operation of the asphalt distributor.

Transverse streaking

Transverse streaking is the same as longitudinal streaking except that the lean and heavy lines of bituminous material run perpendicular to the road. The cause of transverse streaking is an asphalt distributor that is not running or being operated properly.

438. Inspecting asphalt cement concrete pavements

Frequent and careful inspections of bituminous surfaces are a vital part of maintenance. During your inspection, you should look closely for signs of cracking, distortion, disintegration, slippery surfaces, and surface treatment problems.

Inspection requirements

You should use the procedures in UFC 3–270–06, *Paver Asphalt Surfaced Airfields Pavement Condition Index (PCI)*, to accomplish the inspections. The information from the inspection can be used with the PAVER program to plan maintenance.

Just like the rigid pavement PCI surveys, you will have to accurately identify flexible pavement distress types, quantity, and severity level. The steps for computing the PCI for flexible pavement is done the same as described earlier for rigid pavements with the exception that square footage is used as sample units instead of predetermined slab numbers (5,000 sq. ft. [flexible] vs. 20 slabs [rigid]).

Also as discussed earlier, you can spot obvious failures and deficiencies with riding inspections. These inspections are made from a vehicle, and failures are noted on a street map. The sweeper operator is the ideal person to note failures and deficiencies when sweeping on base streets and airfields. The failures noted on this type of inspection must be taken care of as soon as possible. Otherwise, what may be a relatively minor repair job could soon become a major one.

A walking inspection can lead to finding more detailed problems. A close examination is needed to detect conditions that may lead to a failure. While performing the walking inspection, look for the following types of things:

- Poor drainage—drainage should be checked right after a heavy rain.
- Cracks and weathering—this condition is very evident after a light rain.
- Porous areas.

All potential trouble spots should be marked for further attention later. If preventive maintenance is accomplished in time, most failures can be reduced or eliminated. However, there are certain times when inspections are particularly important, such as in the spring and fall. A carefully repaired pavement will survive cold, wet weather without any major damage. In the spring, check for weather damage and for elevation of the shoulders where they join the pavement. High shoulders trap water at the edge of the pavement; the water seeps under the pavement and causes cracks and edge breakup. Failures discovered during an inspection can be corrected by good pavement maintenance practices.

Finding the cause of the failure

During the inspection, try to determine the cause of the failure. If you make the repairs without removing the cause, the pavement will fail again, continuing to result in the loss of valuable maintenance dollars.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

437. Types and causes of asphalt cement concrete pavement defects

1. What are the five categories of flexible pavement defects?

2. Match the defect in column B with its description in column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) Longitudinal cracks about 1–2 feet from the edge of the pavement.	a. Lane-joint crack.
____ (2) Longitudinal separations along the seam between two paving lanes.	b. Potholes.
____ (3) Interconnected cracks forming a series of large blocks, usually 1–10 feet square with sharp corners or angles.	c. Bleeding.
____ (4) Channelized depressions that develop in the wheel tracks of flexible pavement.	d. Longitudinal streaking.
____ (5) Bowl-shaped holes of various sizes in the pavement resulting from localized disintegration under traffic.	e. Edge cracks.
____ (6) The upward movement of bituminous material in a flexible pavement, resulting in the formation of a film of bituminous material on the surface.	f. Channeling or ruts.
____ (7) Alternating lean and heavy lines of bituminous material running parallel to the centerline of the road.	g. Shrinkage crack.

3. Match the defect in column B with its cause in column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) Failure of the base or subgrade.	a. Upheaval.
____ (2) Thermal expansion and contraction of the PCC pavement.	b. Raveling.
____ (3) Lack of bond between the surface layer and the course beneath.	c. Corrugations.
____ (4) Traffic action (braking, acceleration, or bouncing) on the unstable asphalt pavement surface or poorly compacted base.	d. Alligator crack.
____ (5) Ice expansion in the granular course beneath the pavement or in the subgrade.	e. Reflection crack.
____ (6) Weather and traffic abrasion.	f. Slippage crack.

438. Inspecting asphalt cement concrete pavements

1. What would you look for during a walking inspection?

2. What is the result of high shoulders?

3. What will happen if you make repairs without removing the cause?

5–2. Repairing Defective Pavement

Care and good judgment are necessary in applying suitable methods and in selecting proper materials for maintenance and repairs of bituminous surfaces. Both methods and materials vary considerably with local conditions, but the principle of bituminous work remains the same. This section considers effectively sealing cracks within the pavements. It also discusses removing defective areas in the event sealing is untenable. Finally, it discusses the proper replacement of the pavement itself. In the previous section, we discussed the causes for failures. Once the cause of failure has been determined, repairs must start at the source of the failure.

439. Sealing cracks in asphalt cement concrete pavements

Cracking takes many forms. Simple crack filling may be the right treatment in some cases. In others, complete removal of the affected area and the installation of drainage structures may be necessary before effective repairs can be carried out. This lesson discusses the appropriate materials, preparing the area for repair, and properly sealing the crack.

Materials used

Materials used to fill cracks depend on the type of pavement, how much and what type of traffic the pavement receives, the size of the cracks, and even the overall condition of the pavement.

The sealer used should meet federal specifications for the type of pavement and the service it will be subjected to. Get with your major command (MAJCOM) pavements engineer to determine the best product for the specific sealing application. You can also use a rubberized asphalt sealant, if it is approved by your pavements engineer. Large cracks have been filled successfully with a slurry seal mixture or a heated mixture of sand and asphalt. If the cracks are large enough, consider replacing the entire area.

Area preparation

As stated before, flexible pavement crack repairs depend on the cause of failure, amount of area to be repaired, and the size of the cracks. The categories cracks are grouped into for sealing purposes include hairline, small, medium, and large cracks. The following paragraphs provide the normal types of repair procedures when the areas to be repaired are not large.

Hairline

Hairline cracks that are less than ¼ inch require no preparation unless they cover 80 percent or more of the pavement area. Repairs would be made using a surface-type treatment unless on the airfield.

Small cracks

Small cracks are ¼–¾ inch and should be widened to a nominal width of ⅛ inch greater than the existing nominal or average width. This will help eliminate the potential for raveling of the pavement along the edges of the crack and will provide a sealant reservoir with vertical faces. The depth of the routed crack should be approximately ¾ inch. A backer-rod material should be placed in cracks that are greater than ¾ inch in depth.

Medium cracks

Medium cracks are ¾–2 inches. Cracks that fall into this range are prepared by simply cleaning the crack the same way as you would prepare concrete cracks of the same size. There are a couple of exceptions: you can use a rotary impact router with carbide-tipped bits, or you can use a wire-brush attachment for a saw. These machines will clean the crack, but you still must use high-pressure air to blow all loose material out of the cracks. You should sweep up all debris from the immediate area before you try to fill the crack.

Large cracks

Large cracks are 2 inches or wider and should be prepared in the same manner as a pothole repair. A saw should be used to cut away damaged pavement to provide vertical faces. The area should be cleaned and filled with asphalt instead of sealant.

Crack filling

Hairline cracks, such as shrinkage cracks, are not sealed individually. Generally, you should seal the entire area having hairline cracks. Spray or spread the material over the entire area. Use either a fog seal (asphalt emulsion diluted with water) or a slurry seal mixture (asphalt emulsion, fine sand, and water). Small and medium cracks are sealed individually with a prepared joint sealer.

Remember that the type of sealer selected depends on several factors mentioned previously. There are several ways of applying this material. The best way is to use the same kettle with a pressure-injection wand that is used for concrete. Another way is to use pour pots and squeegees. Use the squeegee to force the sealing material into the cracks. If you use a hot-joiner sealer, apply it at the maximum recommended temperature to ensure good penetration into the crack. Large cracks are filled with sand asphalt or well-graded asphalt.

440. Removing defective areas of asphalt cement concrete pavement

This lesson is concerned with properly removing areas within pavements that have been identified as defective, in order to properly make repairs. A key aspect of your job is to make sure defects in pavements are identified and repaired as soon as possible. Repairs are done in a step-by-step process.

Mark the area

The first step in removing a defective area is to mark out the area you want to remove. If you are going to use a pavement saw to cut the pavement, make sure your marks are heavy and easy to see. The marks should be made with a waterproof material, such as a spray paint or crayon, to prevent it from being washed off by water from the saw. You already have learned you should mark the area at least 2 inches into solid rigid-type pavement to make sure the entire defect is removed. Since flexible or ACC pavements lack the beam strength of rigid pavements, you must make your marks at least 1 foot (12 inches) into sound pavement. This is strictly a preventive measure to ensure the entire defect is removed. The shape of the patch is also important; if you expect the patch to be strong enough to support traffic, you must make sure the marked area is square or rectangular with two faces at right angles to the flow of traffic. This will ensure the patch does not shove or corrugate when traffic is released on it.

Cutting the pavement

After you mark the area you want to remove, you are ready to make your cuts along the marks, and you can accomplish this by using a pavement saw. Before you saw the area, make sure you have the correct type of blade; as with cutting concrete, the best blade is the diamond-tipped blade. This type of blade is water-cooled and will last for several cuts with proper care. If water is not available, you can use a dry abrasive asphalt disk such as what we use on a K–12 saw, or a dry cut asphalt blade. If the saw is not available, you can cut the asphalt using a pneumatic hammer with a 5-inch asphalt-cutting bit. If the pneumatic hammer is used, even though it is fast, it leaves the edges of the patch jagged. When making the cut with either tool, make sure the patch has square edges and is rectangular. The cut should also extend at least a foot into sound pavement.

Removing the pavement

After the outline cuts have been made, you can start to break up the defective material with a pneumatic hammer. Before you use the pneumatic hammer, remember to do a preoperational check of the air compressor and the hammer. Make sure you have the correct bit in the hammer (usually a 5-inch asphalt cutting bit). Break the pavement into pieces that you can remove easily by hand. If the pieces are too large, you may have to use front-end loaders or a skid-steer to remove them. For large areas or where the asphalt is exceptionally thick, you can use a backhoe or excavator to make the job much easier. After the pavement has been broken up, the pieces can then be removed and hauled away.

After you remove the pavement, check the base course to see if it is saturated with water. If so, you must remove the material. If you place your asphalt onto a wet support structure, you will soon find yourself doing the same job over. The removal of the base course should continue until you reach firm, dry material. The sides should be vertical and the bottom as level as possible.

If the base material is good and the asphalt mix was the problem, you still must recompact the base since it was disturbed during removal of the asphalt material.

441. Replacing asphalt cement concrete pavement

This lesson focuses on replacing asphalt pavements, which should be repaired with the same materials used to build them. These materials consist of all forms of bitumen and various grades of aggregate. Find out what is available and exactly how to use them.

Replacing the base course/subgrade

After the area is cut out, clean it with hand brooms. If the top layer of the base course is wet, it must be allowed to dry out. If the base course is saturated, then remove the base course and replace it to match the lower edge of the pavement. After the base course is removed and if the subgrade is found to be unstable, then remove a minimum of 12 inches of the subgrade or until stable material is found. Use caution when removing any material to ensure the area of repair will not be undermined. If undermining occurs, the area of repair will become larger and more time consuming. Fill and compact subgrade and base course in 2- to 3-inch layers (lifts) to the lower edge of the pavement. On large patches, compaction can be done with a roller. Small patches can employ a vibratory tamper or they can be hand-tamped. Also, hand-tamp the edges of each layer as needed. Next, prime the hole with a light application of asphalt, which you can either spray or brush on. The primer must be thin enough so that it can be applied lightly. An excess of bitumen flushes into the patching mixture and causes bleeding. The final step in preparation of the hole is to apply tack coat to the vertical faces (fig. 5–16).

Figure 5–16. Applying a tack coat to the vertical faces.

Remember to get with the environmental flight about the use of primer or tack coats as they may be restricted in your area.

Replacing the bituminous materials

The first step in the replacement of the paving materials is to obtain a sufficient quantity of materials to complete the job. Try to use a hot-mix if possible. Hot-mix is stronger and will last a lot longer.

When you use hot-mix, overfill the area by about 40 percent of the pavement thickness to allow for proper compaction. For example: a 3-inch compacted lift = 4½ inches of material. Experiment with overfilling as 40 percent may be too much for some “tender” mixes. Adjust overfilling to accommodate the mix you are using. If cold-mix is used, spread and roll it in 2- to 3-inch layers. When you spread the cold-mix, keep the material as level as possible to prevent segregation. Both hot- and cold-mixes can be spread by graders spreaders, or by hand, depending on the size of the repair.

Bituminous materials are compacted with steel-wheel rollers and pneumatic-tired rollers on the larger areas, or with vibrator tampers, vibratory patch rollers, and hand tampers on the smaller areas. Compaction is a very important part of the patching operation. The rolling operation on hot-mix should start immediately after the material is placed. Cold-mix should be rolled after proper aeration of the material; aeration exposes the material to the environment which begins the curing process of the material. The edges of the patch should be rolled first, which seals the edges and prevents the material from dishing out and water from infiltrating. You should also seal edges and patches for added protection against water getting into the base. If cold-mix is used, the patch may have a porous surface and need waterproofing. This can be done by applying a sand seal or a thin layer of Portland cement and tamping it in.

Getting a smooth riding surface requires care. Too many people are “mound builders,” which causes a “bump” in the road. A straightedge should be used as a guide to finish the patch, which should not be lower than the existing pavement. While a repair of ⅛ inch higher than the surrounding area is acceptable, you should always strive for a level or flush repair.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

439. Sealing cracks in asphalt cement concrete pavements

1. What factors determine the selection of materials used for filling cracks?

2. Who should you contact to determine the best product for the specific sealing application?

3. What categories are cracks grouped into?

4. How are areas that have small cracks prepared?

5. How is sealing material applied on small and medium cracks?

440. Removing defective areas of asphalt cement concrete pavement

1. Why are flexible pavements marked at least 12 inches into the good pavement?

2. How should you make your cuts in a flexible pavement?

3. What do you do with the defective pavement after it has been broken up into pieces?

441. Replacing asphalt cement concrete pavement

1. How should base-course materials be compacted?

2. What is the first step in the replacement of paving materials?

3. Why should edges of a patch be rolled first?

4. How can you waterproof the porous surface of a cold-mix patch?

5–3. Surface Treatments and Road Shoulder Maintenance

In this section, we will concern ourselves with the subjects of surface treatments and road shoulder maintenance. A surface treatment is the application of asphalt materials to any type of road surface, with or without a cover of mineral aggregate, which produces an increase in thickness, usually less than 1 inch. Surface treatments have a variety of uses; they waterproof, provide a nonskid-wearing surface, and can rejuvenate an old surface. The high cost of replacing a pavement has made surface treatments very popular in today's maintenance programs. We will follow up surface treatments with a short discussion of road shoulders and their maintenance.

442. Surface treatments

This lesson considers the purpose of surface treatments, which are the simplest types of bituminous surfaces that may be placed over prepared surfaces. Surface treatments are applications of bituminous materials to any type of base or pavement surface that, together with an aggregate cover, produce a pavement with a thickness of 1 inch or less. In some cases, multiple treatments that produce thicker pavements are used.

Purposes

Surface treatments are applied for one or more of the following purposes:

- Waterproof the surface.
- Provide a wearing surface.
- Make the surface nonskid.
- Prevent hydroplaning.
- Rejuvenate an old surface.
- Make permanent improvements.

Types

Surface treatments may be applied to the base course of a new road or to the surface of an old road as a method of repair. Surface treatments are grouped into the following categories:

- Sprayed asphalt.
- Sprayed asphalt with surface aggregates (chip seal).
- Slurry seals (asphalt-aggregate mixtures).

Application

Sprayed asphalt treatments contain no aggregates; they are simply applications of different types of asphalt materials to a prepared surface. The categories include fog seals, prime coats, and tack coats.

Fog seal

A fog seal is a very light application of diluted, slow-setting (SS) asphalt emulsion used to renew old asphalt surfaces and seal hairline and small cracks and surface voids. Fog seals are especially useful for pavements carrying a low volume of traffic. A fog seal may also be used to accomplish the following:

- Seal surface voids in new asphalt plant mixes.
- Prevent dust on sprayed asphalt with cover aggregate surface treatments.
- Increase aggregate retention.
- Provide a uniform dark color.
- Protect a pavement from environmental deterioration.

Because fog seals *reduce* skid resistance (surface may become slippery), they should not be used on runways without MAJCOM approval and an engineering design.

The asphalt emulsion used for a fog seal is normally diluted at a rate of one-part emulsion to one-part water (1:1) but can be diluted up to one-part emulsion to five-part water (1:5). The application rate will vary according to the quantity of material the pavements will absorb. The rate should be adjusted so that the treated surface is not slick, unstable, and does not contain excess material after 12–24 hours curing. Normally you should allow the material to cure for 12–24 hours before allowing traffic on the treated surface.

Applying sprayed asphalt with cover aggregate surface treatment

The sprayed asphalt with aggregate cover surface treatments are applications of liquid asphalt followed by an application of aggregate. This can be done in one or more layers of construction. There are two types of sprayed asphalt with cover aggregate surface treatments—single- and multiple-surface treatments.

Single-surface treatments

Single-surface treatments are thin, bituminous aggregate toppings applied to existing bases or surfaces, such as concrete or asphalt. Construction involves applying a sprayed application of asphalt immediately followed by a single application of a uniform size aggregate.

Sequence of operations

The first steps in the sequence of operations are the same as those used for applying the prime coat as previously explained in unit 4. If the area was not previously surfaced, the binder (bituminous material) is applied over the prime coat with a distributor. The aggregate is then spread over the binder by the use of aggregate spreaders. The aggregate cover is spread uniformly immediately behind the distributor; as soon as the aggregate is spread, it is pushed into the soft asphalt by rolling it with a pneumatic-tire roller.

Binder application

When you apply the binder, it should be hot enough to spray properly and cover the surface uniformly. After the binder cools and cures, it should bind the aggregate tightly to prevent it from being dislodged by traffic. Individual aggregate stones should be pressed into the binder, but the binder must not cover them. About half of the individual aggregate stones should be exposed to traffic.

The rate of application will vary according to existing surface conditions, type of, and gradation of the aggregate. For the single-surface treatment, the bitumen must be heated and applied to the surface while hot.

Spread and roll the aggregate (chip seal) before the bitumen cools. Under no circumstances is traffic permitted over the uncovered fresh bitumen. Do not apply bitumen until the aggregate is on hand and ready for application. When the distributor moves forward to spray the asphalt, the aggregate spreader should start right behind it. The asphalt should be covered within one minute, if possible; otherwise, the increase in asphalt viscosity may prevent good binding of the aggregate.

Aggregate application

The size and amount of aggregate you use for surface treatments are important. You must use a size that matches the bitumen application rate. For a single-surface treatment, use ½ inch to sieve number 4. The amount of aggregate should be 25–30 pounds per square yard.

When you distribute the aggregate properly, little hand spreading is needed. At longitudinal joints, the aggregate cover is stopped where the binder is full thickness. This is done to ensure ample overlap of the bitumen coat. Cover all bare spots by hand spreading, and correct any irregularities in distribution with the hand brooms. Immediately remove excess in limited areas with square-pointed shovels. If aggregate spreaders are properly set and operated, handwork is reduced to a minimum.

Do not use drag brooms since they tend to shift smaller pieces of aggregate and upset the larger pieces. Passing traffic then picks up the dislodged aggregate. After rolling, remove any remaining loose aggregate by lightly sweeping with a rotary-powered broom. You should sweep during the cool of early morning after the asphalt binder has firmly set.

Use of rollers

Pneumatic-tire rollers usually roll the aggregate. Steel-wheeled rollers are not recommended by themselves. If used, they should make only one pass (one trip in each direction). The rolling operation should then be completed with the pneumatic-tire roller. Steel-wheeled rollers produce maximum compaction, but they must be used with care to prevent excessive crushing of aggregate particles. In addition, these rollers bridge over the smaller size particles and fail to press the aggregate in these places into the asphalt.

Multiple-surface treatments

A multiple-surface treatment is essentially the same as the single-surface treatment. However, multiple-surface treatments consists of two or more successive layers of binder and aggregate.

This type of treatment does everything a single-surface treatment does (waterproofing and provides a nonskid surface), as well as add some strength, which is something a single-surface treatment does not do. The amount of strength gained depends on the number of aggregate layers and the size of the aggregates used in each layer.

Application of a multiple-surface treatment is performed in stages. Each stage is accomplished in the same manner as a single-surface treatment. The only difference is that each additional layer of aggregate should be about ½ size of the previous layer. This allows the smaller aggregate to interlock with the larger aggregate when rolled.

Applying an asphalt-aggregate mixture surface treatment

An emulsion slurry seal is a mixture of asphalt emulsion, well-graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of old pavements, to restore a uniform surface texture, to stop raveling, to seal the surface to prevent moisture intrusion into the pavement, and to improve the pavement skid resistance. A slurry seal will not increase the strength of the existing pavement.

Slurry seals normally are mixed and applied by a slurry seal machine. These machines can deliver accurately to the mixing chamber predetermined amounts of aggregate, mineral filler, water, and emulsion. After mixing, the material is discharged onto the prepared pavement.

Another method of mixing slurry is with either a transit mixer or portable concrete mixer. Slurry made in a transit mixer is discharged into a spreader box, which is towed behind the mixer. Portable concrete mixers are used to mix small amounts of slurry.

Slurries must be mixed in a prescribed manner. The first step in mixing the slurry is to pour the water into the mixer; then add the asphalt emulsion. You must be careful when adding the materials to the mixer. They should be added slowly and uniformly to prevent the material from balling and lumping and setting up in the mixer. All materials in the mixer should be blended until all particles are coated and the entire batch is uniform and free flowing.

For coverage of small areas, the slurry is dumped on the surface to be treated and then spread. Long-handled squeegees work best for this. A slurry seal is normally applied ⅛ to ¼ inch thick. If a thicker layer is desired, it should be placed in two thin courses. When you do this, you need to allow enough time between the courses for the slurry to set up.

Before you start to apply your slurry seal, you should repair all potholes and badly distorted areas. Immediately before you apply the slurry, you should thoroughly clean, broom, and moisten the pavement surface with a light application of water to ensure coverage and proper bond.

Keep the traffic off the area until the slurry has had adequate time to set. Such things as temperature, humidity, type of emulsion used, and thickness of the slurry determine the set time. Normally, the area can be opened to traffic within two to three hours.

443. Purpose and maintenance of road shoulders

Road shoulders protect the basic pavement structure by giving lateral support and by protecting the edges from raveling, eroding, undermining, and breaking. Shoulders also provide a safe emergency lane for vehicles to exit the road surface. This is not to say you can use shoulders as a passing lane. Rather, they allow a vehicle to have a place to safely stop, out of traffic, when required.

Types of shoulders

The types of road shoulders you may be required to maintain include the following:

- Earth shoulders.
- Sod shoulders.
- Soil-aggregate shoulders.
- Bituminous shoulders.
- Dual-type shoulders.

Earth shoulders

Earth shoulders are made of unstable native soils without turf cover. You should use this type of shoulder in an area where the soil is naturally well-graded and the rainfall is low. You will find earth shoulders satisfactory for roads carrying light traffic.

Sod shoulders

Sod shoulders are superior to earth shoulders. These shoulders are best used where climate, soil, or traffic conditions permit. They are costly to maintain, partly because they must be mowed and seeded periodically.

Soil-aggregate shoulders

Soil-aggregate shoulders are a combination of the existing soil mixed in a blend with well-graded crushed stone. This shoulder is more stable than earth and sod shoulders.

Bituminous shoulders

Bituminous shoulders are used in areas where complete dust control and maximum safety is a must. This shoulder normally is constructed of HMA. It provides better stability for vehicles and improved erosion control, which makes it a common choice for interstate highways.

Dual-type shoulders

Commonly seen on older highways, dual shoulders are partially paved and exist along narrow pavements, inside curves, and at intersections.

Shoulder maintenance

The purpose of shoulder maintenance is to keep the shoulder in a serviceable condition. The maintenance and repair methods differ according to the type of shoulder. Earth shoulders, for example, are subject to rutting and erosion. You must fill in the ruts and correct the erosion by eliminating the cause. Sod shoulders only require periodic mowing and occasional seeding to keep them in good shape. A soil-aggregate shoulder requires frequent grader maintenance to keep the surface smooth and even. Bituminous and dual-type shoulders require the same maintenance as a flexible pavement.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

442. Surface treatments

1. What are the purposes of a surface treatment?

2. What are the three categories of surface treatments?

3. What will cause the application rate of a fog seal to vary?

4. What size aggregate is used for single-surface treatments?

5. Why are drag brooms *not* recommended on single-surface treatments?

6. What determines the strength gained by applying a multiple-surface treatment?

7. What are the uses of an emulsion slurry seal?

8. Why should the materials for slurry be added to the mixer slowly and uniformly?

9. How long should the slurry materials be blended in the mixer?

10. What is the set time of slurry determined by?

443. Purpose and maintenance of road shoulders

1. What are shoulders used for?

2. Where should you use earth shoulders?

3. What makes sod shoulders costly to maintain?

Answers to Self-Test Questions

437

1. Cracking, distortion, disintegration, slippery surfaces, surface treatment problems.
2. (1) e.
   (2) a.
   (3) g.
   (4) f.
   (5) b.
   (6) c.
   (7) d.
3. (1) d.
   (2) e.
   (3) f.
   (4) c.
   (5) a.
   (6) b.

438

1. Poor drainage, cracks and weathering, and porous areas.

2. They trap water at the edge of the pavement, resulting in water seepage under the pavement, which causes cracks and edge breakup.
3. The pavement will fail again.

439

1. The type of pavement, how much and what type of traffic the pavement receives, the size of the cracks, and even the overall condition of the pavement.
2. Your MAJCOM pavements engineer.
3. Hairline, small, medium, and large.
4. They are widened to a nominal width of ⅛ inch greater than the existing nominal or average width. The depth of the routed crack should be approximately ¾ inch. A backer-rod material should be placed in cracks that are greater than ¾ inch in depth.
5. The best way is to use the same kettle with a pressure-injection wand that is used for concrete. Another way is to use pour pots and squeegees. Use the squeegee to force the sealing material into the cracks. If you use a hot-joiner sealer, apply it at the maximum recommended temperature to ensure good penetration into the crack.

440

1. Flexible or ACC pavements lack the beam strength of rigid pavements.
2. By using a pavement saw to make a fast neat cut or by using a pneumatic hammer with a 5-inch asphalt-cutting bit.
3. Remove it and haul it away.

441

1. Fill and compact subgrade and base course in 2- to 3-inch layers (lifts) to the lower edge of the pavement. On large patches, compaction can be done with a roller, while small patches can employ a vibratory tamper or be hand-tamped. Also, hand-tamp the edges of each layer as needed.
2. Obtain a sufficient quantity of materials to complete the job.
3. To seal the edges and prevent the material from dishing out and water from infiltrating.
4. By applying a sand seal or a thin layer of Portland cement and tamping it in.

442

1. Waterproof the surface, provide a wearing surface, make the surface nonskid, prevent hydroplaning, rejuvenate an old surface, and make permanent improvements.
2. Sprayed asphalt, sprayed asphalt with cover aggregates, and slurry seals (asphalt-aggregate mixtures).
3. The quantity of material the pavements will absorb.
4. One-half inch to sieve number 4.
5. They tend to shift smaller pieces of aggregate and upset the larger pieces.
6. The number of aggregate layers and the size of aggregates used in each layer.
7. To fill cracks and seal areas of old pavements, to restore a uniform surface texture, to stop raveling, to seal the surface to prevent moisture intrusion into the pavement, and to improve the pavement skid resistance.
8. To prevent the material from balling and lumping and setting up in the mixer.
9. Until all particles are coated and the entire batch is uniform and free flowing.
10. Temperature, humidity, type of emulsion used, and thickness of the slurry.

443

1. To protect the basic pavement structure by giving lateral support and by protecting the edges from raveling, eroding, undermining, and breaking. They also provide a safe emergency lane for vehicles to exit the road surface; that is, they allow a vehicle to have a place to safely stop, out of traffic, when required.
2. In an area where the soil in naturally well-graded and the rainfall is low.
3. They must be mowed and seeded periodically.

Complete the unit review exercises.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

81. (437) What types of cracks are interconnected and form a series of small blocks resembling chicken wire?
    a. Edge.
    b. Slippage.
    c. Alligator.
    d. Shrinkage.

82. (437) Normally, edge cracks are caused by a concentration of traffic loads near the edge, aggravated by a lack of
    a. fine aggregate.
    b. proper mixture.
    c. large aggregate.
    d. side or shoulder support.

83. (437) What type of crack in flexible pavement is caused by a lack of bond between the surface layer and the course beneath?
    a. Corner.
    b. Slippage.
    c. Shrinkage.
    d. Longitudinal.

84. (437) The causes of corrugation in flexible pavement is normally the result of
    a. too much binder, aggregate, or smooth textured coarse aggregate.
    b. traffic action, including braking, acceleration and bouncing.
    c. too rich a plant mix or heavy prime or tack coat.
    d. poor compaction of the surface or base.

85. (438) The ideal person to note failures and deficiencies of pavements while conducting their daily duties is the
    a. superintendent.
    b. ops commander.
    c. sweeper operator.
    d. base civil engineer.

86. (439) Large cracks in pavement are prepared for repair in the same way as
    a. potholes.
    b. small cracks.
    c. medium cracks.
    d. surface treatment.

87. (439) Small and medium cracks in flexible pavement can be sealed individually with a
    a. prepared joint sealer.
    b. aggregate seal.
    c. sand seal.
    d. fog seal.

88. (439) What item is used to force sealing material into the cracks in flexible pavements?
    a. Router.
    b. Pour pot.
    c. Squeegee.
    d. Hand broom.

89. (440) Which item should you use to mark defective flexible pavement?
    a. Chalk.
    b. Pencil.
    c. Crayon.
    d. Straightedge.

90. (441) When repairing defective flexible pavement, in how many inch layers should you fill and compact the subgrade and base course materials?
    a. 2–3.
    b. 3–4.
    c. 4–6.
    d. 6–8.

91. (441) When using hot-mix asphalt (HMA) for repairs, how much should you overfill the area to allow for proper compaction?
    a. 10 percent.
    b. 20 percent.
    c. 30 percent.
    d. 40 percent.

92. (442) Surface treatments produce a pavement with a thickness of
    a. 1/2 inch or less.
    b. 1 inch or less.
    c. 2 inches or more.
    d. 4 inches or more.

93. (442) Which of the following is *not* a purpose of a bituminous surface treatment?
    a. Provide a wearing surface.
    b. Make the surface nonskid.
    c. Waterproof the surface.
    d. Strengthen the surface.

94. (442) As soon as the aggregate is spread for a single surface treatment, it is pushed into the soft asphalt by rolling it with a
    a. vibratory roller.
    b. sheepsfoot roller.
    c. steel-wheeled roller.
    d. pneumatic-tire roller.

95. (442) Each additional layer of aggregate for a multiple surface treatment should be about
    a. the same size as the previous layer.
    b. one-half the size of the previous layer.
    c. one-fourth of the size of the previous layer.
    d. three-fourths of the size of the previous layer.

96. (442) One purpose of an emulsion slurry seal is to
    a. increase the strength of the base course.
    b. prevent moisture intrusion into the subgrade.
    c. prevent moisture intrusion into the pavement.
    d. increase the strength of the existing pavement.

97. (442) Immediately *before* you apply slurry, the pavement surface should be thoroughly cleaned, broomed, and
    a. covered with a tack coat.
    b. covered with a prime coat.
    c. moistened with a light application of water.
    d. moistened with a light application of emulsion.

98. (443) Road shoulders protect the basic pavement structure by giving what kind of support?
    a. Lateral.
    b. Flexoral.
    c. Expansive.
    d. Compressive.

99. (443) What do shoulders provide motorists?
    a. An emergency lane.
    b. A passing lane.
    c. A parking area.
    d. A turnaround.

100. (443) What type of road shoulder exists along narrow pavements, inside curves, and at intersections?
    a. Earth.
    b. Dual-type.
    c. Bituminous.
    d. Soil-aggregate.

Glossary

Abbreviations and Acronyms

Acronym	Description
°	degree
A	area
AC	asphalt cement
ACC	asphalt cement concrete
AFCEC	Air Force Civil Engineer Center
AFI	Air Force Instruction
AK	Alaska
AL	Alabama
APE	Airfield Pavement Evaluation
ASTM	American Society for Testing and Materials
B.C.	Before Christ
B.C.E.	Before Common Era
C	Celsius
CDV	corrected deduct value
CE	civil engineering
cu. ft.	cubic feet
cu. yd.	cubic yard
D	depth
DOD	Department of Defense
EPA	Environmental Protection Agency
F	Fahrenheit
ft.	feet
ft^3	cubic feet
FOD	foreign object damage
HMA	hot-mix asphalt
in.	inch
L	length
lb.	pound
MAJCOM	major command
MC	medium curing
mph	miles per hour
MS	medium setting
PC	point of curvature
PCC	Portland cement concrete
PCI	Pavement Condition Index
PI	point of intersection

P/ID	poor/improper design
PG	performance grading
PT	point of tangency
QS	quick-set
r	radius
RC	rapid curing
RS	rapid setting
SC	slow curing
SHRP	Strategic Highway Research Program
sm	square meters
sq. ft.	square feet
SS	slow setting
TDV	total deduct value
TO	technical order
TX	Texas
UFC	Unified Facilities Criteria
UT	Utah
V	volume
VOC	volatile organic compound
W	width
yd^3	cubic yard
π	Pi

Student Notes

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