

Chapter 11

Soil-Processing and Compaction

Horizontal construction projects such as roads and airfields are constructed using a variety of soil types. The suitability of these materials for construction applications depends on their gradation, physical characteristics, and load-bearing capacity. While some soil types are suitable for structural purposes in their natural state, others require processing such as adjusting the moisture content by mixing and blending. Because there is a direct relationship between increased density and increased strength and bearing capacity, the engineering properties of most soils can be improved simply by compaction. Soil properties and compaction requirements are discussed in FM 5-410.

SOIL PROCESSING

11-1. The amount of water present in a soil mass affects the ease of compaction operations and the achievable soil density. The water-content ratio is the standard measure of water in a soil mass. The water-content ratio compares the weight of the water present in a soil mass to the weight of the soil solids in the same mass. Each soil has its particular optimum moisture content (OMC) at which a corresponding maximum density can be obtained for a given amount of compactive input energy. Trying to compact a soil at a water content either higher or lower than optimum can be very difficult. The OMC varies from about 12 to 25 percent for fine-grained soils and from 7 to 12 percent for well-graded granular soils. Since it is difficult to attain and maintain the exact OMC, normal practice is to work within an acceptable moisture range. This range, which is usually ± 2 percent of optimum, is based on attaining the maximum density with the minimum compactive effort. Determination of the OMC is a laboratory test procedure. For a detailed description of the moisture-density relationships of various soils, refer to FM 5-410.

INCREASING THE MOISTURE CONTENT

11-2. If the moisture content of a soil is below its optimum moisture range, add water to the soil before compaction. When it is necessary to add water, the project officer must consider the following:

- The amount of water required.
- The rate of water application.
- The method of application.
- The effects of the weather.

Add water to the soil at the borrow pit or in place (at the construction site). When processing granular materials, adding water in place usually gives the best results. After adding water, thoroughly and uniformly mix it with the soil.

Amount of Water Required

11-3. It is essential to determine the amount of water required to achieve a soil water content within the acceptable moisture range. Compute the amount of water to add or remove in gallons per station (100 feet of length). Use the following formula, based on the compacted volume, to compute the amount of water to add or remove from the soil. The volume in this formula is for only one station of project length. The computation is based on the dry weight of the soil.

$$\begin{aligned} \text{Gallons per station for one lift} &= \text{desired dry density of soil in pounds per cubic foot (pcf)} \\ &\times \frac{\text{desired moisture content (percent)} - \text{moisture content of borrow (percent)}}{100} \\ &\times \frac{\text{compacted volume of soil (cubic foot)}}{8.33 \text{ pounds per gallon}} \end{aligned}$$

where—

8.33 = the weight of a gallon of water

NOTE: Normally, it is a good practice to adjust the desired moisture content to OMC +2 percent, but this depends on the environmental conditions (temperature and wind) and the soil type. A negative answer indicates that water removal from the borrow material is necessary before compacting the material on the fill.

EXAMPLE

Prepare to place soil in 6-inch (compacted) lifts. The desired dry unit weight of the embankment is 120 pcf. The OMC (desired moisture content) of the soil is 12 percent, but the soils technician has determined that the moisture content of the borrow material is only 5 percent. The roadway section to be placed is 40 feet wide. Compute the amount of water (in gallons) to add per station for each lift of material.

$$\begin{aligned} \text{Gallons per station for one lift} &= 120 \text{ pcf} \times \frac{12 \text{ percent (OMC)} - 5 \text{ percent (borrow)}}{100} \\ &\times \frac{40 \text{ feet} \times 100 \text{ feet} \times 0.5 \text{ foot}}{8.33 \text{ pounds per gallon}} \\ &= 120 \text{ pcf} \times 0.07 \times \frac{2,000 \text{ cubic feet}}{8.33 \text{ pounds per gallon}} \\ &= 2,017 \end{aligned}$$

NOTE: If the road width is constant, determine the total amount of water required for the job by multiplying the gallons per lift times the number of lifts, times the road length (in stations).

Rate of Water Application

11-4. After determining the total amount of water required, determine the rate of application. Use the following formal to determine the water application rate in gallons per square yard.

$$\begin{aligned} \text{Gallons per square yard} &= \text{desired dry density of soil (pcf)} \\ &\times \frac{\text{percent of moisture added or removed}}{100} \times \text{lift thickness (feet)} \\ &\times \frac{9 \text{ square feet per square yard}}{8.33 \text{ pounds per gallon}} \end{aligned}$$

where—

9 = factor used to convert square feet to square yards

8.33 = the weight of a gallon of water

EXAMPLE

Using the data from the previous example, determine the required application rate in gallons per square yard.

$$\begin{aligned} \text{Gallons per square yard} &= 120 \text{ pcf} \times 0.07 \times 0.5 \text{ foot} \times \frac{9 \text{ square feet per square yard}}{8.33 \text{ pounds per gallon}} \\ &= 4.5 \text{ gallons per square yard} \end{aligned}$$

Method of Application

11-5. After calculating the application rate, determine the method of application. Regardless of the method of application, it is important to achieve the proper application rate and the uniform distribution of water.

11-6. **Water Distributor.** The most common method of adding water is with a water distributor. Water distributors are designed to distribute the correct amount of water evenly over the fill. The truck-mounted, 1,000-gallon water distributor (*Figure 11-1, page 11-4*) can distribute water under various pressures or by gravity feed. It distributes the water through a 12-foot folding, rear-mounted spray bar. The spray bar is adjustable, in 1-foot increments, from 4 to 24 feet. The water application rate can be maintained by controlling the forward speed of the vehicle and the water distribution pressure. A cab-mounted odometer shows the vehicle speed in fpm. The project officer should provide the water-distributor operator with the application rate in gallons per square yard. With this information, the operator can determine the appropriate spray-bar length, pumping pressure, and vehicle speed to achieve the required application rate. Refer to the vehicle's technical manual for specific information regarding application rates.

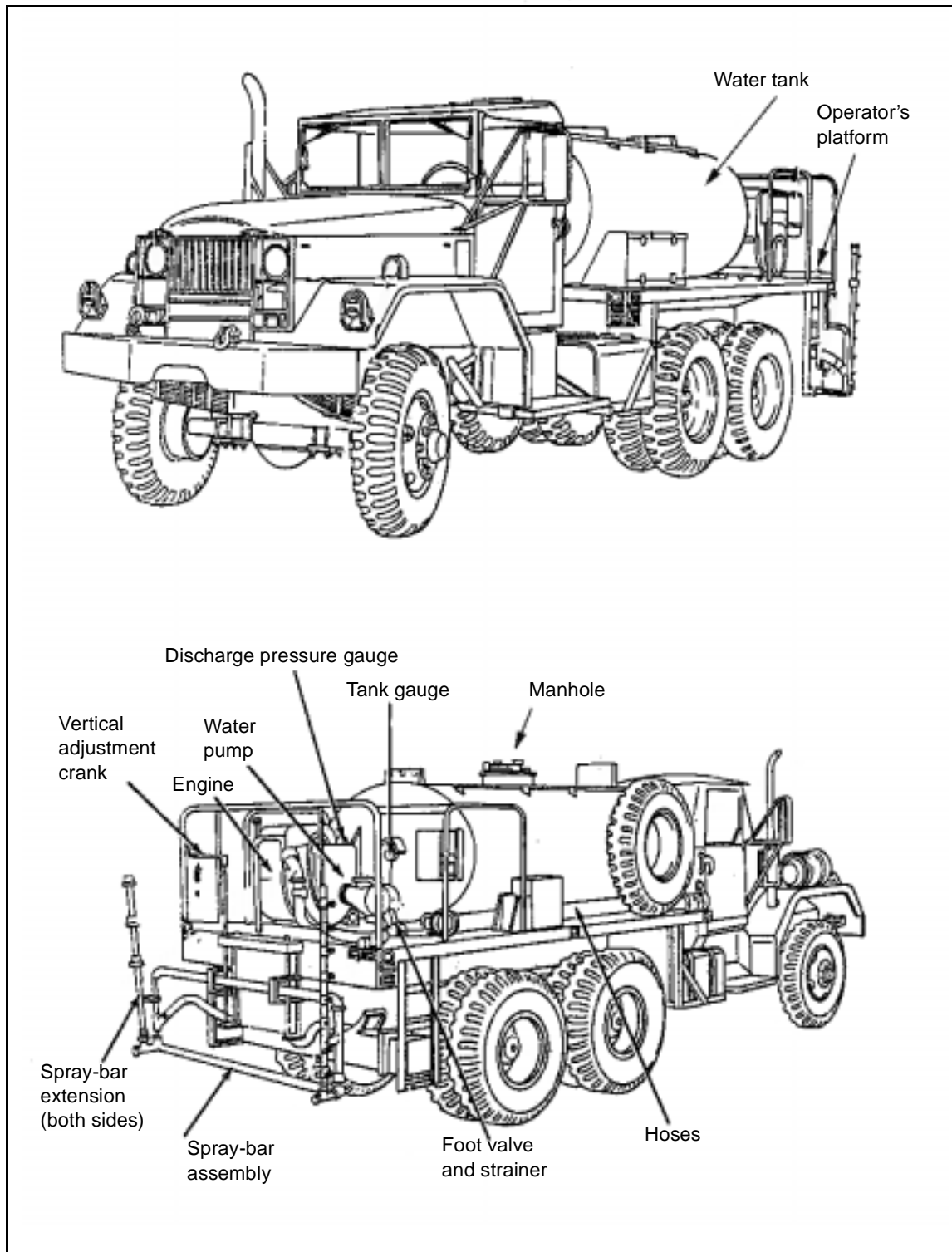


Figure 11-1. Truck-Mounted, 1,000-Gallon Water Distributor

11-7. **Ponding.** If time is available, add water by ponding the area until achieving the desired depth of penetration. It is difficult to control the application rate with this method. Ponding usually requires several days to achieve a uniform moisture distribution.

Effects of the Weather

11-8. Weather substantially affects the soil's moisture content. Cold, rainy, cloudy, or calm weather will cause a soil to retain water or even increase its moisture content. Hot, dry, sunny, or windy weather is conducive to drying the soil by evaporating the moisture. In a desert climate, evaporation claims a large amount of water intended for the soil lift. Thus, for a desert project the engineer might go as high as 6 percent above the OMC as a target for all water application calculations. This allows the actual moisture content to fall very near to the desired content when placing and compacting the material.

REDUCING THE MOISTURE CONTENT

11-9. As previously stated, soil that contains more water than desired (above the optimum moisture range) is correspondingly difficult to compact. Excess water makes achieving the desired density very difficult. In these cases, take action to reduce the moisture content to within the required moisture range. Drying actions may be as simple as aerating the soil. However, they may be as complicated as adding a soil stabilization agent that changes the physical properties of the soil. Lime or fly ash are the typical stabilization agents for fine-grained soils. Excess moisture, caused by a high water table, will require some form of subsurface drainage to reduce the soil's moisture content. The most common method of reducing the moisture is to scarify the soil prior to compaction. Accomplish this by using the scarifying teeth on a grader or a stabilizer mixer or by disking the soil. Another method is to use the grader's blade to toe the soil over into furrows to expose more material for drying.

MIXING AND BLENDING

11-10. Whether adding water to increase the soil's moisture content or adding a drying agent to reduce it, it is essential to mix the water or drying agent thoroughly and uniformly with the soil. Even if additional water is not necessary, mixing may still be essential for a uniform distribution of the existing moisture. Accomplish mixing by using graders, stabilizer mixers, or farm disks.

Grader

11-11. Use conventional graders to mix or blend a soil additive (water or stabilizing agent) by windrowing the material from one side of the working lane to the other. For a detailed description of grader operation, refer to *Chapter 4*.

Stabilizer Mixer

11-12. The stabilizer mixer is an extremely versatile piece of equipment designed specifically for mixing, blending, and aerating materials (*Figure 11-2, page 11-6*). The stabilizer consists of a rear-mounted, removable-tine, rotating tiller blade covered by a removable hood. In place, the hood creates an enclosed mixing chamber, which enhances thorough blending of the soil (*Figure 11-3, page 11-6*). The tiller blade lifts the material in the direction of travel and

throws it against the leading edge of the hood. The material deflecting off of the hood falls back onto the tiller blades for thorough blending. As the stabilizer moves forward, it ejects the material from the rear of the mixing chamber. As the material is ejected, it is struck off by the trailing edge of the hood, resulting in a fairly level working surface. With the trailing edge of the hood fully opened, churned soil has a very high void content, which exposes the soil to the drying action of the sun and wind. Models equipped with a spray bar are used to add water or stabilizing agents to the soil during the blending process. The stabilizer mixer's use is limited to material less than 4 inches in diameter. The tines on the Army's mixer are designed to penetrate up to 12 inches below the existing surface. This unit is used for scarifying and blending in-place (in situ) material as well as fill material.

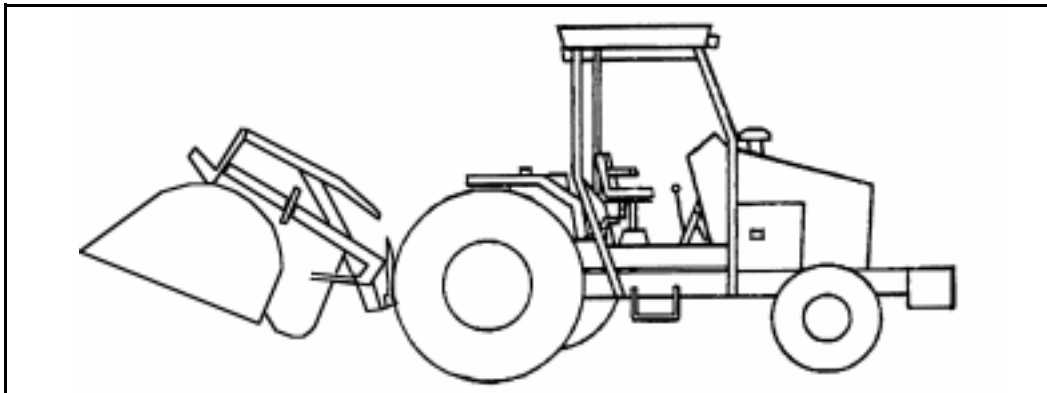


Figure 11-2. Stabilizer Mixer

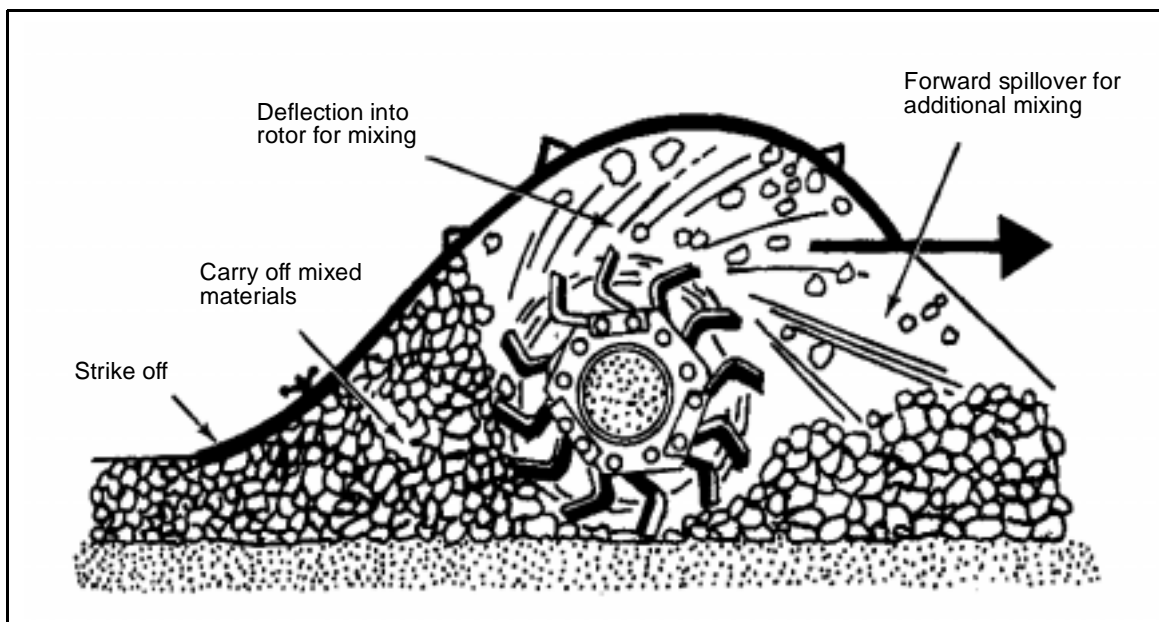


Figure 11-3. Mixing Action in a Stabilizer Mixer

SOIL COMPACTION

11-13. Compaction is the process of mechanically densifying a soil, normally by the application of a moving (or dynamic) load. This is in contrast to consolidation, which is the gradual densification of a soil under a static load. When controlled properly, compaction increases a soil's load-bearing capacity (shear resistance), minimizes settlement (consolidation), changes the soil's volume, and reduces the water-flow rate (permeability) through the soil. Compaction does not affect all soils to the same degree. However, the advantages gained by compaction make it an essential component of the horizontal construction process.

COMPACTIVE EFFORT

11-14. Compactive effort is the amount of energy used to compact a soil mass. Base the appropriate compactive effort on the physical properties of the soil, including gradation (well or poorly graded), the Atterberg limits (cohesive or cohesionless), and the required final density. Compaction equipment uses one or more of the following methods to accomplish soil densification—

- Static weight (pressure).
- Kneading (manipulation).
- Impact (sharp blow).
- Vibration (shaking).

EQUIPMENT SELECTION

11-15. Compaction equipment ranges from handheld vibratory tampers (suitable for small or confined areas) to large, self-propelled rollers and high-speed compactors (ideally suited for large, horizontal construction projects). Consider the following factors when selecting compaction equipment:

- Type and properties of the soil.
- Density desired.
- Placement lift thickness.
- Size of the job.
- Compaction equipment available.

11-16. Soil-compacting equipment normally available to military engineers includes tamping-foot rollers, pneumatic-tired (rubber-tired) rollers, dual-drum vibratory rollers, and smooth-drum vibratory rollers. To select the most appropriate type of compaction equipment, a project officer must know the characteristics, capabilities, and limitations of the different types of rollers. Generally, tamping-foot compactors that produce high unit pressures are best for predominantly fine-grained cohesive materials such as clays and sandy clays. Large, steel-drum rollers are best for larger particle materials such as gravel or cobble. Vibratory rollers are ideal for well-graded or gap-graded materials because the shaking action causes the smaller particles to fill voids around the larger grains. *Table 11-1, page 11-8*, shows the spectrum of capabilities for each type of roller and the type of compactive effort associated with each roller. *Tables 11-2 and 11-3, pages 11-9 and 11-10*, show the major soil-classification categories, the compaction requirements, and the compactive methods compatible with each.

Table 11-1. Compaction-Equipment Capabilities

Spectrum of Roller Capabilities		
Roller Type	Soil Type	Compactive Effort
Sheepsfoot	Fine-grained soils; sandy silts; clays; gravelly clays	Kneading
Tamping foot	All soils except pure sands and pure clays	Kneading
Smooth-drum vibratory	Sand or gravel; gravelly and sandy soils	Vibratory (for granular-type soils)
Pneumatic-tired	Sand or gravel; fine-grained soils; asphalt	Kneading or static (based upon tire pressure)
Dual-drum vibratory	Gravelly soils; asphalt	Static
NOTE: Use a test strip to see which compactor is more efficient.		

Tamping-Foot Roller

11-17. The self-propelled, tamping-foot roller (*Figure 11-4, page 11-11*) has feet that are square or angular and taper down away from the drum. This design allows the roller to achieve better penetration on the initial pass, resulting in a thorough, uniform compaction throughout a lift. This roller compacts the material from the bottom of the lift to the top, and walks out after achieving the desired density. It is suitable for compacting all fine-grained materials, but is generally not suitable for use on cohesionless granular materials. The lift thickness for the tamping-foot roller is limited to 8 inches in compacted depth. If the material is loose and reasonably workable (permitting the roller's feet to penetrate into the layer on the initial pass), it is possible to obtain a uniform density throughout the full depth of the lift. Thoroughly loosen material that has become compacted by the wheels of equipment during spreading or wetting before compaction. The tamping-foot roller does not adequately compact the upper 2 to 3 inches of a lift. Therefore, follow up with a pneumatic-tired or smooth-drum roller to complete the compaction or to seal the surface if not placing a succeeding lift. The self-propelled tamping-foot roller can achieve a working speed of as high as 8 mph. The tamping-foot roller compacts from the bottom up and is particularly appropriate for plastic materials. It is ideal for working soils that have moisture contents above the acceptable moisture range since it tends to aerate the soil as it compacts.

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Table 11-2. Soil Classification

Major Soil Categories		Symbol and Description		Value as a Base, Subbase, or Subgrade	Potential Frost Action
Coarse-grained soils (50% or more larger than a #200 sieve opening)	Gravel and/or gravelly soils	GW	Well-graded gravels or gravel-sand mixture with 5% or less of fines	Fair to good for base; good to excellent for subbase and subgrade	None to very slight
		GP	Poorly graded gravels or gravel-sand mixture with little or no fines	Fair to good for all	None to very slight
		GM	Silty gravel and poorly graded gravel-sand-silt mixtures	Not suitable for base (15% or less of fines with PI of 5 or less); fair to excellent for subbase and subgrade (50% or less of fines)	Slight to medium
		GC	Clayey gravel and poorly graded gravel-sand-clay mixture	Not suitable for base (15% or less of fines with PI of 5 or less); poor to good for subbase and subgrade	Slight to medium
	Sand and/or sandy soils	SW	Well-graded sands or gravelly sand mixture with 5% or less of fines	Poor for base; fair to good for subbase and subgrade	None to very slight
		SP	Poorly graded sands or gravelly sand mixture with 5% or less of fines	Poor to not suitable for base; poor to fair for subbase and subgrade	None to very slight
		SM	Silty sands, sand-silt mixture	Not suitable for base; poor to good for subbase and subgrade	Slight to high
		SC	Clayey sands, sand-clay mixture	Not suitable for base; poor to fair for subbase and subgrade	Slight to high
Fine-grained soils (more than 50% smaller than a #200 sieve opening)	Silt and clays with liquid limits less than 50	ML	Inorganic silt of low plasticity, silty fine sands	Not suitable for base or subbase; poor to fair for subgrade	Medium to very high
		CL	Inorganic clay of low to medium plasticity, lean clays	Not suitable for base or subbase; poor to fair for subgrade	Medium to high
		OL	Organic silt and organic silt-clay of low plasticity	Not suitable for base or subbase; poor to very poor for subgrade	Medium to high
	Silt and clays with liquid limits greater than 50	MH	Inorganic silt micaceous or diatomaceous soil	Not suitable for base or subbase; poor to fair for subgrade	Medium to very high
		CH	Inorganic clay of high plasticity, fatty clays	Not suitable for base or subbase; poor to fair for subgrade	Medium
		OH	Organic clay of medium to high plasticity	Not suitable for base or subbase; poor to very poor for subgrade	Medium
Highly organic soils		Highly organic soils (peat) are not defined by numerical criteria; these soils are identified by visual and manual inspection.			

Table 11-3. Average Compaction Requirements

		Soil Classification Symbol													
		GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	MH	CH	OH
Sheeps-foot, Standard With Ballast (Towed by Dozer)	Lift Thickness Compacted (Inches)	*	*	*	6	*	*	*	6 (Best)	6	6 (Best)	6	6	6 (Best)	6
	Rolling Speed (mph)	NA	NA	NA	3	NA	NA	NA	3	3	2	2	2	2	2
	Number of Passes	NA	NA	NA	10	NA	NA	NA	10	10	12	12	12	14	14
Self-Propelled Vibratory Roller	Lift Thickness Compacted (Inches)	18 (Best)	18 (Best)	12	12	18 (Best)	18 (Best)	12	12	8	8	*	*	*	*
	Rolling Speed (mph/vpm)	4/1,400 or more	4/1,400 or more	4/1,100	4/700 to none	4/1,400 or more	4/1,400 or more	4/1,100	3/700 to none	3/700 to none	3/700 to none	NA	NA	NA	NA
	Number of Passes	8	8	6	6	8	8	6	7	7	7	NA	NA	NA	NA
Tamping-Foot Roller, Self-Propelled (Not Recommended for Finishing Grade)	Lift Thickness Compacted (Inches)	12	12	9	9	12	12	9	9	6	6	6	6	6	6
	Rolling Speed (mph)	10	10	10	8	10	10	10	8	8	4	4	4	3	3
	Number of Passes	5	5	6	7	5	5	6	6	5	5	5	6	6	6
13-Wheel Pneumatic Compactor with Ballast (Wheel Towed), 100 psi	Lift Thickness Compacted (Inches)	6	6	6	6	6	6	6	6	4	4	4	4	4	4
	Rolling Speed (mph)	5	5	4	4	5	5	4	3	3	3	3	3	2	2
	Number of Passes	10	10	10	10	10	10	10	12	7	7	7	8	9	9
9-Wheel Pneumatic, Self-Propelled with Ballast, 100 psi	Lift Thickness Compacted (Inches)	6	6	6	6	6	6	6	6	4	4	4	4	4	4
	Rolling Speed (mph)	6	6	6	5	6	6	6	5	4	4	4	4	3	3
	Number of Passes	6	6	7	7	7	7	8	8	6	6	6	6	6	6
Smooth-Drum Vibratory Roller	Lift Thickness Compacted (Inches)	12	12	9	9	12	12	9	9	6	6	*	*	*	*
	Rolling Speed (mph/vpm)	4/1,400 or more	4/1,400 or more	4/1,100	4/700 to none	4/1,400 or more	4/1,400 or more	4/1,100	3/700 to none	3/700 to none	3/700 to none	NA	NA	NA	NA
	Number of Passes	8	8	8	9	8	8	8	10	10	10	NA	NA	NA	NA
NOTES: This chart should be used as a planning guide when a test strip cannot be performed. The above symbols are based on the United Soil Classification System (USCS). *Not recommended.															

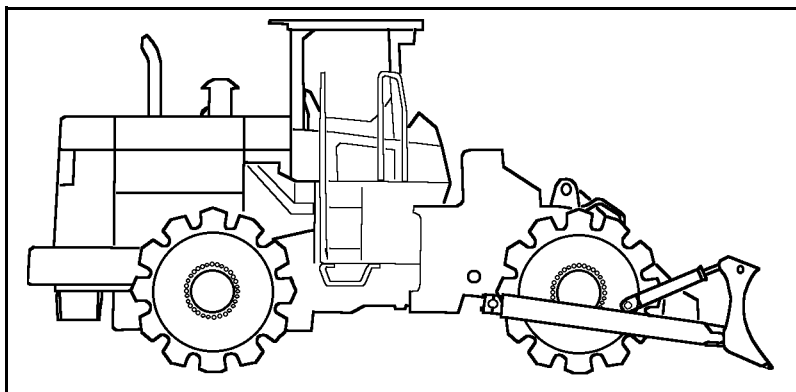


Figure 11-4. Self-Propelled, Tamping-Foot Roller

Pneumatic-Tired Roller

11-18. Pneumatic-tired rollers (towed and self-propelled) are suitable for compacting most granular materials. They are not effective in compacting fine-grained clays. Pneumatic-tired rollers compact using two types of compactive effort—static-load and kneading. The Army currently has a towed, 13-wheel, pneumatic-tired roller (*Figure 11-5*) and a variable-pressure, self-propelled, nine-wheel, pneumatic-tired roller (*Figure 11-6, page 11-12*). The nine-wheeled model is capable of varying the contact pressure to achieve the desired compactive effort. The contact pressure is controlled by adjusting the tire pressure and the wheel load. The towed, 13-wheel model exerts about 210 pounds of contact pressure per inch of rolling width. Contact pressure is affected by tire pressure and wheel load.

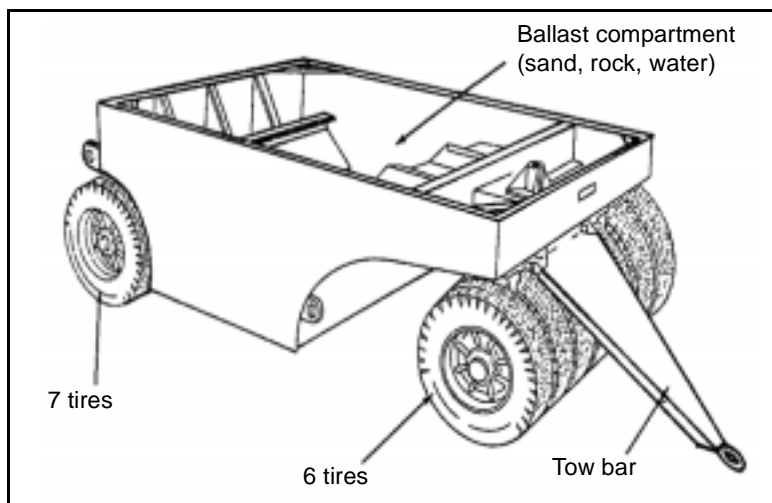


Figure 11-5. Towed, 13-Wheel, Pneumatic-Tired Roller

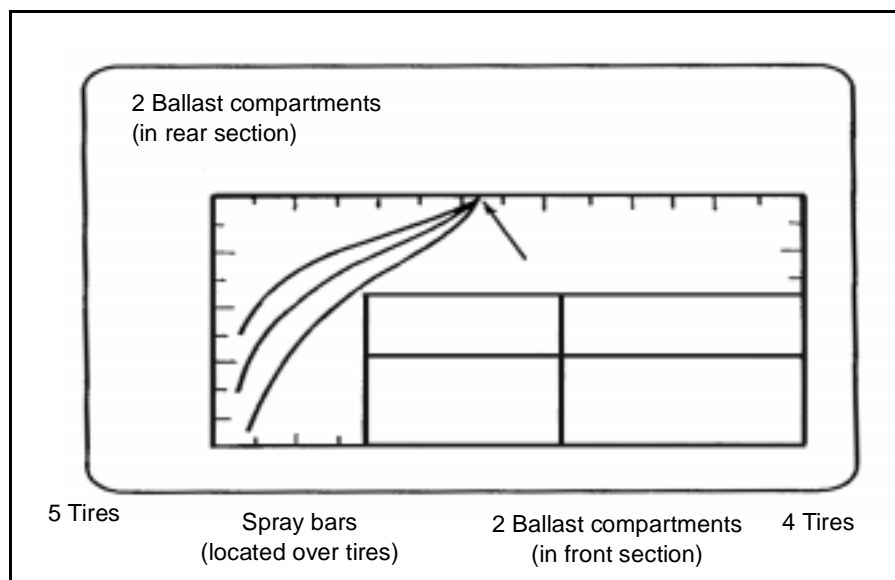


Figure 11-6. Self-Propelled, Nine-Wheel, Pneumatic-Tired Roller

- Contact pressure.** The contact pressure of these rollers is determined primarily by the tire pressure. Within the rated load limits, the same load and tire pressure give about the same contact area for any tire. The tire sidewalls carry about 10 percent of the load, and the trapped air essentially supports 90 percent of the load. Consequently, the tire will deflect until the contact area is adequate and the ground pressure on the tire is equal to the tire pressure. For example, the contact area for a tire with a 50-psi internal tire pressure and a 5,000-pound wheel load is 100 square inches. If the wheel load is doubled to 10,000 pounds, the tire will deflect until 200 square inches are in contact with the ground. Since the sidewalls carry 10 percent of the load, the contact area is—

$$\text{Contact area} = \frac{0.9 \times \text{wheel load}}{\text{tire pressure}}$$

Generally, the analysis of contact pressure neglects the raised portions of the tread. Use the gross contact areas, including the areas between the raised portion, to determine contact pressure.

$$\text{Contact pressure} = \frac{\text{wheel load}}{\text{contact area}}$$

- Wheel load.** The wheel load is significant for compacting at the required depth or in test rolling to detect subsurface defects. Researchers have built test sections in 6-inch compacted layers with wheel loads of 10,000; 20,000; and 40,000 pounds to determine if increased wheel loads would increase density. In the tests, the tire's inflation pressure was maintained at a constant 65 psi. *Figure 11-7* shows the vertical pressure distribution for the tire loadings. As shown, the effective pressure varies with the depth. However, at shallow depths, the pressure difference among the three loads was not

enough to produce additional density. These and other tests have indicated that an increase in wheel load is advantageous in compacting thick lifts.

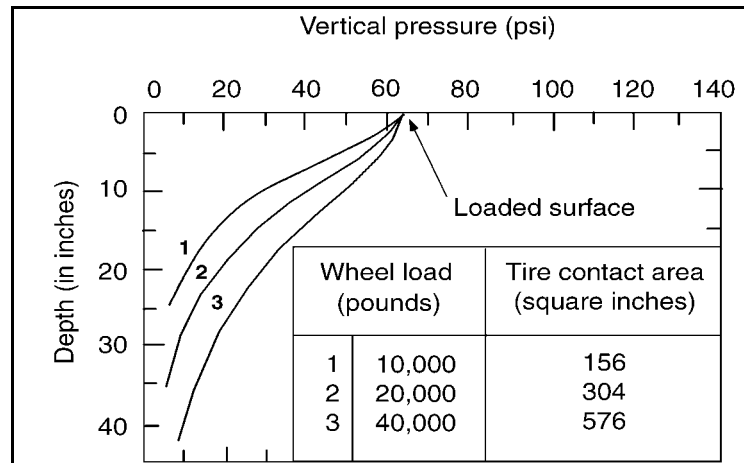


Figure 11-7. Vertical Pressure Distribution Beneath a Wheel Load

- Surface coverage.** The wheel arrangement and the tire deflection determine the surface coverage. *Figure 11-8* shows the results of varying wheel loads and tire pressures on single-pass coverage for a heavy pneumatic-tired roller. Most of the pneumatic-tired rollers use two rows of tires. The tires of one row offset the gaps between the tires of the second row. This ensures complete coverage with one pass. Heavier rollers have only one row of tires and require two passes for complete surface coverage. The additive effects of the pressure bulbs from the wheels on heavier rollers affect the at-depth coverage and the rolling pattern. *Figure 11-9, page 11-14*, shows that at-depth coverage requires considerable overlap with each pass to ensure that the entire area has received the same compactive effort.

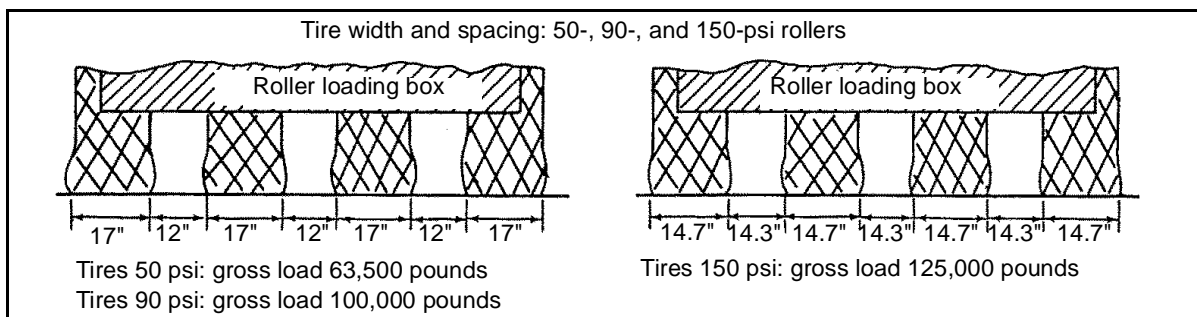


Figure 11-8. Varying Wheel Loads and Tire Pressures

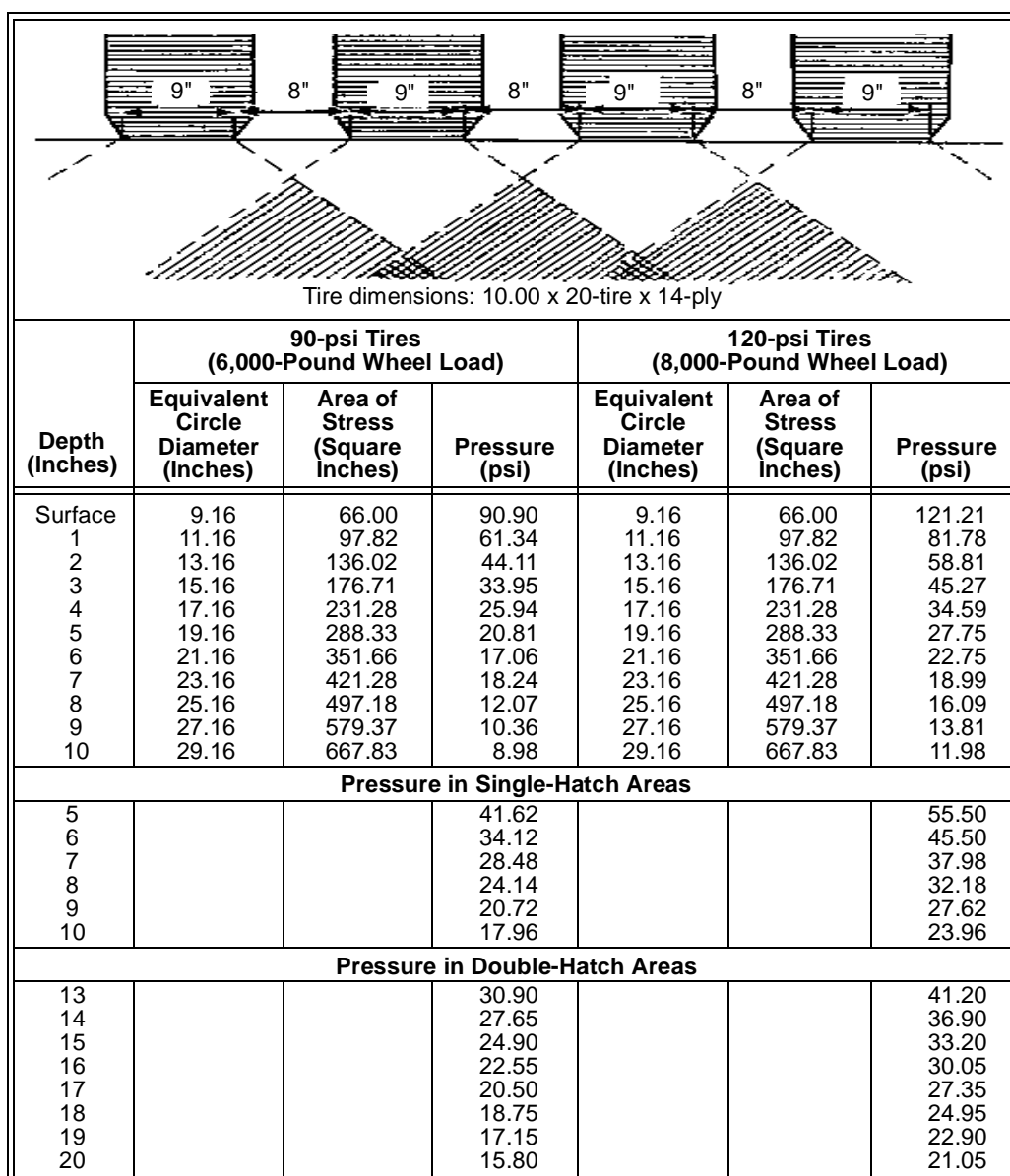


Figure 11-9. Tire Pressures at Various Depths

Dual-Drum Vibratory Roller

11-19. The dual-drum vibratory roller, with its smooth steel drum (*Figure 11-10*), can compact a wide variety of materials from sand to cobble. Use this roller to compact asphalt paving, cohesionless subgrade, base course, and wearing surfaces. It is very effective when used immediately behind a blade to create a smooth, dense, and watertight subgrade finish. Because it has a relatively low unit pressure and compacts from the top down, it is normally used for relatively shallow lifts (less than 4 inches). The smooth steel drum is ideal for base- or wearing-course finish work. Exercise care to prevent excess crushing of the base-course material. This is the roller of choice for asphalt paving.

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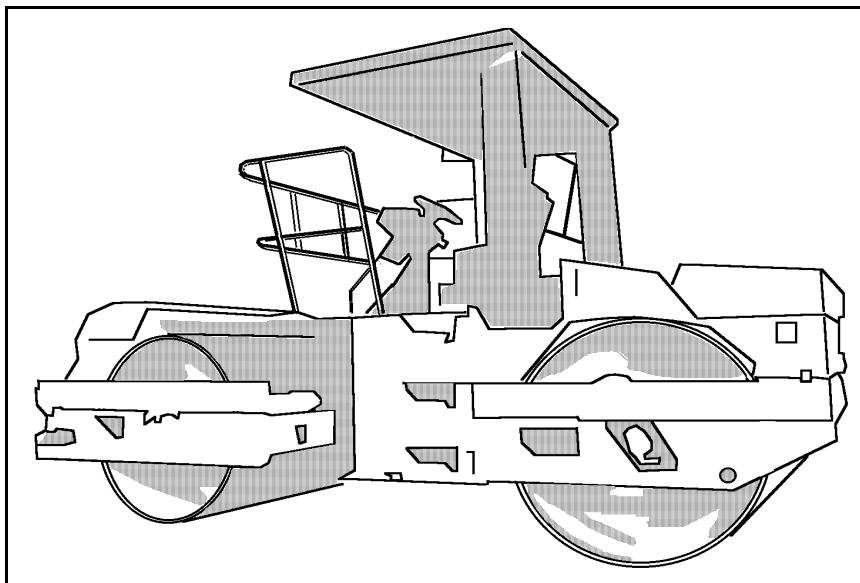


Figure 11-10. Dual-drum vibratory roller

Smooth-Drum Vibratory Roller

11-20. The smooth-drum vibratory roller (*Figure 11-11, page 11-16*) uses a vibratory action in conjunction with the ballast weight of the drum to rearrange the soil particles into a dense soil mass. Vibratory compaction, when properly controlled, can be one of the most effective and economical means of attaining the desired density for cohesionless materials. This roller is very effective in compacting noncohesive/nonplastic sands and gravels, which are often used in subbase and base-course applications. Because this roller is relatively light, the recommended maximum loose-lift depth (the fill material measured before compaction) is 9 inches.

NOTE: Vibration has two measurements—amplitude (the measurement of the movement or throw) and frequency (the number of repetitions per unit of time). The amplitude controls the depth to which the vibration is transmitted into the soil, and the frequency determines the number of blows or oscillations that are transmitted in a period of time.

Jay Tamper

11-21. The jay tamper is a small, self-contained, hand-operated, vibratory compactor. The jay tamper (*Figure 11-12, page 11-16*) resembles a power lawn mower. The jay tamper is ideal for compacting materials in confined spaces such as in a trench against a pipe or inside an existing structure. A gasoline engine powers the unit, so there are no supply lines or other auxiliary items to hinder its operations.

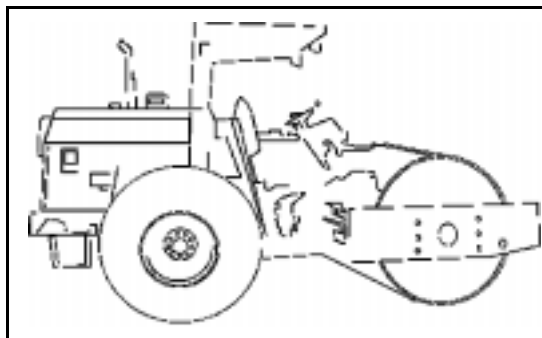


Figure 11-11. Smooth-Drum Vibratory Roller

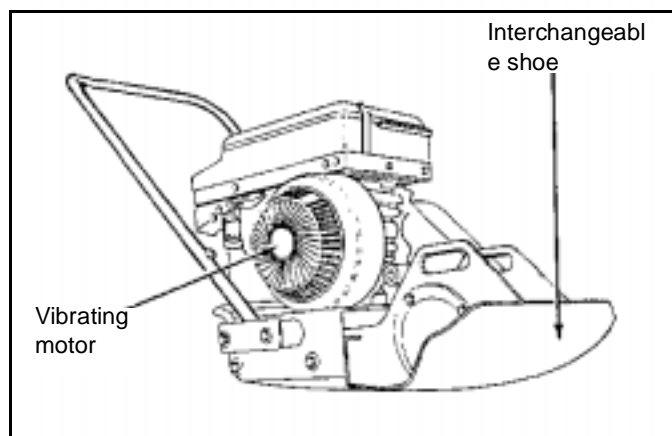


Figure 11-12. Jay Tamper

EQUIPMENT TESTING

11-22. Since the use of several types of compaction equipment overlaps, it is good to use a test strip to make the final determination of the most efficient compactor and compaction procedures. Locate a test strip adjacent to the project site. The test strip provides an evaluation/validation of the proposed construction procedures. Information obtained from a test strip includes the—

- Most effective type of compaction equipment.
- Optimum depth of lift.
- Optimum compactor speed.
- Number of passes required.
- Amount of ballast required.
- Vibration frequency required.

11-23. To make the initial selection of compaction equipment, place a 6-inch (uncompacted depth) lift of the material and run each piece of equipment over a specific length of the strip a predetermined number of passes (usually three). After compacting all the lengths, perform a density test to determine which roller gives the best results. After determining the most effective type of equipment, use additional test strips to determine the most appropriate lift thickness, the required number of passes, the optimum compactor speed and, if using a vibratory roller, the resonant frequency.

PRODUCTION ESTIMATES

11-24. Use the following formula to determine compactor production in CCY per hour.

$$\text{Production (CCY per hour)} = \frac{16.3 \times W \times S \times L \times E}{N}$$

where—

16.3 = constant for converting the factors in feet, mph, and inches to CCY

W = compacted width per pass, in feet

S = compactor speed, in mph

L = compacted lift thickness, in inches

E = efficiency

N = number of passes required

11-25. The accuracy of the compaction estimate depends on the project officer's skill in estimating the speed, the lift thickness, and the number of passes required to attain the required density. Normally, this information is determined from on-site test strips. The efficiency of a daytime compaction effort is typically 50 minutes per hour. Reduce the efficiency to 45 minutes per hour for nighttime compaction. Typical compactor speeds are given in *Table 11-4*. These speeds should be matched with the data in *Tables 11-2 and 11-3, pages 11-8 and 11-9*. When calculating production estimates, use the average speed of the compactor based on the individual speed for each pass.

Table 11-4. Typical Operating Speeds of Compaction Equipment

Compactor	Speed (mph)
Sheepsfoot, crawler, towed	3-5
Sheepsfoot, wheel-tractor, towed	5-10
Tamping foot: First two or three passes	3-5
Walking out	8-10
Heavy pneumatic	3-5
Multitired pneumatic	5-15
Dual-drum vibratory	2-4
Smooth-drum vibratory	2-4
Vibratory: Plate	0.6-1.2
Roller	1

EXAMPLE

Use of a test strip determined that it will take five passes to achieve the required density using a tamping-foot roller. The following speeds were achieved:

First pass = 4 mph

Second pass = 4 mph

Third pass = 5 mph

Fourth pass (walking out) = 8 mph

Fifth pass (walking out) = 9 mph

Determine the average speed.

$$\text{Average speed (mph)} = \frac{4 + 4 + 5 + 8 + 9}{5 \text{ passes}} = 6 \text{ mph}$$

EXAMPLE

What is the estimated production rate (CCY per hour) for a tamping-foot roller with a compaction width of 5 feet? The following information was obtained from a test strip at the project:

Compacted lift thickness = 6 inches

Average speed = 6 mph

Number of passes = 5

Efficiency factor = 0.83

$$\text{Production (CCY per hour)} = \frac{16.3 \times 5 \times 6 \times 6 \times 0.83}{5 \text{ passes}} = 487 \text{ CCY per hour}$$

11-26. Determine the total number of compactors required on the project, using the following formula.

$$\text{Compactors required} = \frac{\text{amount of fill delivered (LCY per hour)} \times \text{soil conversion factor (LCY:BCY)}}{\text{compactor production (CCY per hour)}}$$

NOTE: Refer to Table 1-1, page 1-4, for soil conversion factors.

EXAMPLE

How many compactors are required on the project (previous example) if 1,500 LCY of blasted rock is delivered per hour?

$$\text{Compactors required} = \frac{1,500 \text{ LCY per hour} \times 0.87 \text{ (soil conversion factor)}}{487 \text{ CCY per hour}} = 2.7 \text{ compactors, round up to 3}$$

HORIZONTAL CONSTRUCTION PHASES

11-27. To satisfy the project's density requirement, it is essential to understand the various phases of a horizontal construction project. These include preparing the subgrade; placing and spreading fill material; compacting fill material for the subgrade and base courses; and performing finishing and surfacing operations (discussed in *Chapter 12*).

Preparing Subgrade

11-28. The term subgrade describes the in-place soil on which a road, an airfield, or a heliport is built. Subgrade includes the soil to the depth that may affect the structural design of the project or the depth at which the climate affects the soil. Depths up to 10 feet may be considered subgrade for pavements carrying heavy loads. The quality and natural density of this material dictate what action(s) to take to prepare the subgrade. For example, a highly organic subgrade material may have to be totally removed and replaced with a higher quality, select material. In most situations this is not the case. Often the in-place material is suitable, but requires some degree of compactive effort to achieve the required density.

11-29. Heavy, pneumatic-tired rollers are preferred for subgrade compaction because of their capability to compact the soil to depths up to 18 inches. Often it is necessary to scarify the top 6 inches of the material to adjust the moisture content. Then the material can be recompacted to a higher density than could be achieved at the soil's natural moisture content. This process is known as scarify and compact in place (SCIP). The tamping-foot roller is good for this operation since it loosens the material, yet compacts it as it walks out of the material. The tamping-foot roller also helps to break up oversize material or rock in the area. If using a tamping-foot roller to prepare the subgrade, also use a pneumatic-tired or smooth-drum roller to compact the top 1 to 2 inches of the final material lift or to seal the lift surface if expecting rain.

11-30. Shaping and sealing the surface protects the subgrade from the damaging effects of water infiltration. If a lift has been sealed, scarify the top 1 or 2 inches before placement of a succeeding lift. This ensures a good bond between the lifts. If the subgrade material is sand, a vibratory compactor would provide the most effective compactive effort.

Placing and Spreading Fill Material

11-31. After preparing the subgrade, bring in fill material to form the subbase and base courses for the project. When placing fill, it is important to spread the material in uniform layers and to maintain a reasonably even surface. The thickness of the layers is dependent on the desired compacted lift thickness. The thickness of the uncompacted lift is normally 1 1/2 to 2 times the final compacted lift. For example, place fill in 9- to 12-inch lifts to achieve a compacted lift thickness of 6 inches. Place the fill material with a scraper or a dump truck and spread it with a dozer or grader. When spreading material on a prepared subgrade, spread the material from the farthest point from the source to the nearest or vice versa. The advantages of spreading fill from the farthest point to the nearest are as follows:

- The hauling equipment will further compact the subgrade.
- Previously undetected weaknesses in the subgrade will become apparent.
- Hauling will not hinder spreading or compacting operations.

11-32. On the other hand, spreading from the nearest point to the farthest point has the advantage of haul equipment traveling over the newly spread material. This compacts the material and greatly reduces the overall compactive effort required.

Compacting Fill Material

11-33. Before beginning compaction operations, the project officer must determine the moisture content of the fill and compare it to the acceptable moisture range for that material. If the moisture content is below the acceptable range, add water to the fill. If the moisture content is higher than the acceptable range, use one of the previously discussed methods to dry the soil. After achieving the appropriate moisture content, begin compaction operations. The base course functions as the primary load-bearing component of the road, ultimately providing the pavement (or other surface) strength. Base-course material is, therefore, higher quality material than either the subgrade or the subbase fill. Base course normally consists of well-graded granular materials that have a liquid limit less than 25 percent and a plastic limit less than 6 percent. The thickness of the base course is dependent on the strength of the subgrade. Smooth-drum vibratory rollers are ideal for base-course compaction. A dual-drum roller can also be used for base-course compaction.

OPERATING HINTS

Compacting Against Structures

11-34. Jay tampers and pneumatic backfill tampers are specifically designed for use in confined areas such as against existing structures. If these tampers are not available, use a roller to achieve satisfactory results. If space permits, run the roller parallel to the structure. If it is necessary to work perpendicular to the structure, place fill material (sloped to the height of the roller axle) against the structure. Apply compactive effort against this excess fill material. Take care to avoid damaging the existing structure.

Aerating Materials

11-35. When using the roller to aerate soils, travel at the highest practical speed. High speeds tend to kick up the material, which is the objective in this case instead of density.

Overlapping Passes

11-36. To eliminate noncompacted strips, each pass with the roller should overlap the preceding pass by at least 1 foot.

Turning

11-37. Make gradual turns at the end of each pass. This prevents surface damage to the lift and eliminates the possibility of damaging a towed roller's tongue with the tracks of the towing tractor.