TM 3-34.62/MCRP 3-40D.9

EARTHMOVING OPERATIONS

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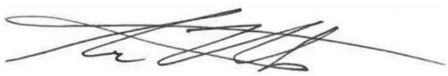
Foreword

This publication has been prepared under our direction for use by our respective commanders and other commands as appropriate.



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Earthmoving Operations

1. This change updates several administrative errors throughout this Technical Manual.

2. An asterisk (*) marks changed material.

3. TM 3-34.62/MCRP 3-40D.9, 29 July 2026, is changed as follows:

Change Version Pages	Change Description
Cover Page	Adds HQ, USMC
Foreword	Corrects USMC doctrine web address
iv	Corrects case for “Mobile” and “light” and corrects title for figure 2-14
vi	Corrects language in figure B-1 and table 3-1 titles
vii	Corrects case in table 12-2 title
7	Corrects case in figure 2-1 title
22	Adds forward slash between “LM^3” and “LCY” and inserts “semi”
29	Corrects formula
39	Corrects equation and spacing
41	Corrects formula and results
43	Corrects inputs
44	Corrects inputs and equations
45	Corrects language and equation
46	Corrects language
47	Corrects language
48	Corrects language
60	Corrects case in table 4-3 title
103	Adds degree symbol
130	Corrects language
169	Corrects language
173	Corrects hyperlink and language
177	Corrects language
185	Corrects handbook version and date

4. File this transmittal sheet in front of the publication for reference purposes.

5. An updated Authentication Page has amended the prior authentication reflected in the rear of this publication.

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Headquarters
Department of the Army
Washington, D.C., 30 May 2025

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Camp Lejeune, NC, 30 May 2025

EARTHMOVING OPERATIONS

Contents

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Figures

Tables

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Preface

This technical manual is a guide for engineer personnel responsible for planning, designing, and constructing earthworks in the theater of operations. It gives estimated production rates, characteristics, operation techniques, and soil considerations for earthmoving equipment. This guide should be used to help select the most economical and effective equipment for each operation.

This manual discusses the complete process of estimating equipment production rates. However, users of this manual are encouraged to use their experience and data from other projects to estimate production rates.

The material in this manual applies to all construction equipment regardless of make or model. The equipment used in this manual are examples only. Information for production calculations should be obtained from the operator and maintenance manuals for the make and model of the equipment being used.

Appendix A contains an English-to-metric measurement conversion chart.

The proponent of this publication is HQ TRADOC. Send comments and recommendations on Department of the Army (DA) Form 2028 (Recommended Changes to Publications and Blank Forms) directly to United States Army Engineer School (USAES), ATTN: ATSE-DOT-DD, Directorate of Training, 320 Engineer Loop Suite 2617, Fort Leonard Wood, Missouri 65473-8929; by email to usarmy.leonardwood.mscoe.mbx.engrdoc@army.mil or submit an electronic DA Form 2028.

The Commanding Officer of the Marine Corps Engineer School is appointed as the author and manager of Marine Corps content in this publication. Marine Corps personnel can submit suggestions and changes by e-mail to MCES_S3_Doctrine_SMB@usmc.mil or by mail to the Commanding Officer (ATTN: S-3), Marine Corps Engineer School, PSC Box 20069, Camp Lejeune, NC 28542-0069.

Unless this publication states otherwise, masculine nouns and pronouns do not refer exclusively to men.

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Chapter 1

Managing Earthmoving Operations

Earthmoving involves various activities such as site preparation, excavation, embankment construction, backfilling, dredging, preparing base course, subbase, and subgrade, compaction, and road surfacing. The amount of work required to complete these tasks is influenced by the types of equipment used and the environmental conditions. It's important to consider the best method of operation and the type of equipment to be used before making estimates. Each piece of equipment is designed for specific mechanical tasks, so the selection of equipment should be based on efficient operation and availability.

PROJECT MANAGEMENT

1-1. Project managers must follow basic management phases to ensure that construction projects successfully meet deadlines outlined in project directives. Additionally, managers must ensure conformance to safety and environmental protection standards. The basic management phases, as discussed in TM 3-34.42/MCRP 3-40D.6, are—

- Planning.
- Organizing.
- Staffing.
- Directing.
- Controlling.
- Executing.

EQUIPMENT SELECTION

1-2. Proper equipment selection is crucial for achieving efficient earthmoving and construction operations. When selecting a machine for a particular task, consider the operational capabilities of the machine and equipment availability. The manager should visualize the best way to use the available equipment based on soil considerations, zone of operation, and project-specific requirements. The manual discusses equipment production-estimating procedures to help quantify equipment productivity.

PRODUCTION ESTIMATES

1-3. Production estimates, production control, and production records form the foundation for management decisions. Therefore, it is beneficial to have a standardized method for recording, directing, and reporting production. (Refer to the specific equipment production-estimating procedures in the relevant chapters of this manual.)

PRODUCTION-RATE FORMULA

1-4. The most convenient and useful unit of work done and unit of time to use in calculating productivity for a particular piece of equipment or a specific job depends on the specific work-task being analyzed. To make accurate and meaningful comparisons and conclusions about production, it is best to use standardized terms.

$$Production\ rate = \frac{unit\ of\ work\ done}{unit\ of\ time}$$

- **Production rate.** The entire expression represents a time-related production rate, such as cubic yards per hour, tons per shift (including the shift duration), or feet of ditch per hour.
- **Unit of work done.** This represents the amount of production completed, such as the volume or weight of material moved, the number of material pieces cut, the distance traveled, or any similar production measurement.
- **Unit of time.** This represents an arbitrary time unit, such as a minute, an hour, a 10-hour shift, a day, or any other convenient duration in which the unit of work is completed.

TIME-REQUIRED FORMULA

1-5. The inverse of the production-rate formula is sometimes used in project scheduling to calculate the time needed to complete a specific amount of work.

$$Time\ required = \frac{unit\ of\ time}{unit\ of\ work\ done}$$

Note. Express the time required in units such as hours per 1,000 cubic yards, hours per acre, days per acre, or minutes per foot of ditch.

MATERIAL CONSIDERATIONS

1-6. Depending on where a material is located in the construction process, such as during excavation versus after compaction, the same material weight will occupy different volumes (see figure 1-1). Material volume can be measured in one of three states:

- **Bank cubic yard (BCY).** A BCY represents one cubic yard of material in its natural or undisturbed state.
- **Loose cubic yard (LCY).** A LCY is one cubic yard of material after it has been disturbed by an excavation process.
- **Compacted cubic yard (CCY).** A CCY refers to one cubic yard of material after compaction.

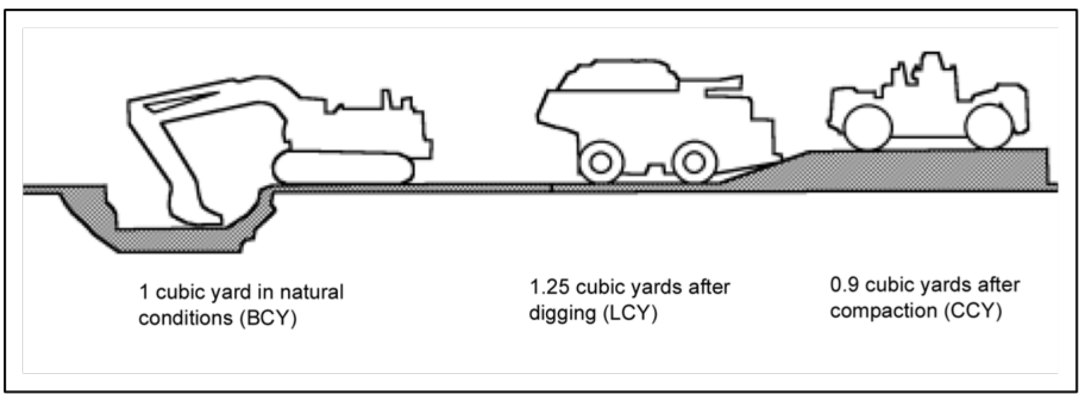

Figure 1-1. Material-volume changes caused by construction processes

1-7. When manipulating materials in the construction process, their volume changes. (Refer to table 1-1 and table 1-2, page 3, for material-volume conversion and load factors.) The primary concern for an earthmover is understanding the physical properties of the material, such as how easy it is to move. In earthmoving operations, materials are typically categorized as rock, soil (common earth), and unclassified.

- **Rock.** Rock cannot be removed by ordinary earthmoving equipment; it requires drilling and blasting. After blasting, excavators are used to load the rock fragments into haul units for removal.
- **Soil.** Soils are classified based on their particle-size distribution and cohesiveness. For example, gravel and sands have blocky-shaped particles and are noncohesive, while clay has small, platy-shaped particles and is cohesive. While ripping equipment may be necessary to loosen consolidated deposits, soil removal does not require the use of explosives.
- **Unclassified.** The combination of rock and soil, known as unclassified material, is widely found across the world.

SOIL PROPERTIES

1-8. In an earthmoving operation, it is essential to thoroughly analyze the properties of the material such as loadability, moisture content, percentage of swell, and compactability, and to incorporate this information into the construction plan. Soil preparation and compaction requirements are discussed in chapter 11.

Loadability

1-9. Loadability is a general material property or characteristic. If a material is easy to dig and load, it has high loadability. On the other hand, if a material is difficult to dig and load, it has low loadability. Certain types of clay and loam are easy to excavate or load into a scraper in their natural state.

Moisture Content

1-10. Moisture content is a crucial factor in earthmoving operations because it affects the unit weight and handling properties of the soil. All soil naturally contains some moisture, and the amount retained depends on weather, drainage, and the retention properties of the soil. Mechanical or chemical treatment can alter the moisture content of soil. For more information on how to increase or decrease soil moisture content, please refer to chapter 11.

Table 1-1. Material volume conversion factors

Material Type	*Converted From*	*Converted To*		
		Bank (In Place)	*Loose*	*Compacted*
Sand or gravel	Bank (in place) Loose Compacted	— 0.90 1.05	1.11 — 1.17	0.95 0.86 —
Loam (common earth)	Bank (in place) Loose Compacted	— 0.80 1.11	1.25 — 1.39	0.90 0.72 —
Clay	Bank (in place) Loose Compacted	— 0.70 1.11	1.43 — 1.59	0.90 0.63 —
Rock (blasted)	Bank (in place) Loose Compacted	— 0.67 0.77	1.50 — 1.15	1.30 0.87 —
Coral (comparable to lime rock)	Bank (in place) Loose Compacted	— 0.67 0.77	1.50 — 1.15	1.30 0.87 —

Table 1-2. Material weight, swell percentages, and load factors

Material Type	*Loose (Pounds per Cubic Yards)*	*Swell (Percent)*	*Load Factor*	*Bank (Pounds per Cubic Yard)*
Cinders	800 to 1,200	40 to 55	0.65 to 0.72	1,100 to 1,860
Clay, dry	1,700 to 2,000	40	0.72	2,360 to 2,780
Clay, wet	2,400 to 3,000	40	0.72	3,360 to 4,200
Earth (loam or silt), dry	1,900 to 2,200	15 to 35	0.74 to 0.87	2,180 to 2,980
Earth (loam or silt), wet	2,800 to 3,200	25	0.80	3,500 to 4,000
Gravel, dry	2,700 to 3,000	10 to 15	0.87 to 0.91	2,980 to 3,450
Gravel, wet	2,800 to 3,100	10 to 15	0.87 to 0.91	3,080 to 3,560

Table 1-2. Material weight, swell percentages, and load factors (continued)

Material Type	*Loose (Pounds per Cubic Yards)*	*Swell (Percent)*	*Load Factor*	*Bank (Pounds per Cubic Yard)*
Sand, dry	2,600 to 2,900	10 to 15	0.87 to 0.91	2,860 to 3,340
Sand, wet	2,800 to 3,100	10 to 15	0.87 to 0.91	3,080 to 3,560
Shale (soft rock)	2,400 to 2,700	65	0.60	4,000 to 4,500
Trap Rock	2,700 to 3,500	50	0.66	4,100 to 5,300
Note. The above numbers are averages for common materials. Weights and load factors vary with such factors as grain size, moisture content, and degree of compaction. If an exact weight for a specific material must be determined, run a test on a sample of that particular material.				

Percentage of Swell

1-11. Many earth and rock materials expand when they are excavated due to the creation of voids. After determining the type of soil, you can estimate the percentage of expansion, known as swell, by referring to a table of material properties. For instance, dry clay typically swells by 40 percent, meaning that 1 cubic yard of clay in its natural state will expand to fill a space of 1.4 cubic yards when excavated. You can estimate the swell of a soil by using a table of material properties, such as table 1-2.

Compactability

1-12. During earthmoving work, it is typical to compact soil to a higher density than its natural state. This is done because higher density is linked to increased strength, reduced settlement, improved bearing capacity, and lower permeability. The density requirements will be specified in the project guidelines.

Soil Weight

1-13. The performance of equipment is influenced by the weight of the soil. To accurately estimate the equipment needed for a job, it is important to know the unit weight of the material being moved. The weight of the soil affects how dozers push, graders cast, and scrapers load the material. For example, if a scraper has a volumetric capacity of 25 cubic yards and a rated load capacity of 50,000 pounds, the material being carried will exceed the volumetric capacity of the scraper before reaching the gravimetric capacity if it is relatively light, such as cinder. Conversely, if the load is gravel, which may weigh more than 3,000 pounds per cubic yard, it will exceed the gravimetric capacity before reaching the volumetric capacity. You can refer to table 1-2 for the unit weight of specific materials.

> ***Note.*** The same amount of material will take up different amounts of space in BCY, LCY, and CCY. When it comes to earthmoving, BCY is typically used as the standard unit of comparison. It's important to consider the material in its loose state, which refers to the volume of the load. You can find average material conversion factors for earth-volume changes in Table 1-1 on page 3.

Load Factor

1-14. To convert the volume of LCY to BCY, use a load factor from table 1-2 (*LCY x load factor = BCY*). Similar factors should be used when converting material to a compacted state, with the specific factors depending on the degree of compaction. Compute the load factor as follows:

$$If\ 1\ cubic\ yard\ of\ clay\ (bank\ state) = 1.4\ cubic\ yards\ of\ clay\ (loose\ state)$$
$$then\ 1\ cubic\ yard\ of\ clay\ (loose\ state) = \frac{1}{1.4}\ or\ 0.72\ cubic\ yard\ of\ clay\ (bank\ state).$$

1-15. In this case, the load factor for dry clay is 0.72. This means that if a scraper is carrying 25 LCY of dry clay, it is carrying 18 BCY (25 x 0.72).

ZONES OF OPERATION

1-16. The selection of earthmoving equipment is influenced by the specific zones of operation. A mass diagram provides a visual representation of how materials should be moved and is a useful tool for identifying these zones. You can find detailed explanations of mass diagrams in TM 3-34.48-1. When working on a construction project, it is important to consider three zones of operation.

POWER ZONE

1-17. In the power zone, maximum power is necessary to overcome challenging site or job conditions. These conditions may include rough terrain, steep slopes, pioneering operations, or extremely heavy loads. Work in these areas requires crawler tractors that can generate high drawbar pull at slow speeds. In such adverse conditions, the more traction a tractor can produce, the more likely it is to reach its full potential.

SLOW-SPEED HAULING ZONE

1-18. The slow-speed hauling zone is comparable to the power zone because power, rather than speed, is the crucial factor. Site conditions are slightly better than in the power zone, and the hauling distance is short. The improved conditions give the dozer more power, and the distances are too short for most scrapers to build up sufficient momentum to shift into higher speeds, so both machines achieve the same speed. Considerations that determine a slow-speed hauling zone are as follows:

- The ground conditions do not allow for fast travel, and the distance the material needs to be moved makes economical dozing operations unfeasible.
- The distances for hauling are not long enough to allow scrapers to travel at high speeds.

HIGH-SPEED HAULING ZONE

1-19. In the high-speed hauling zone, construction has progressed to the point where ground conditions are good, or where long, well-maintained haul roads are established. It is important to achieve this condition as soon as possible because production increases when the scraper is working at its maximum speed. The following considerations determine a high-speed hauling zone:

- Good hauling conditions exist on both grade and haul-road surfaces.
- Haul distances are long enough to permit acceleration to maximum travel speeds.
- Push tractors (also referred to as pushers) are available to assist in loading.

CAUTION

Operate equipment at safe speeds to prevent personal injury or premature failure of the major components of the machine. Ensure that hauling operations are conducted safely and efficiently.

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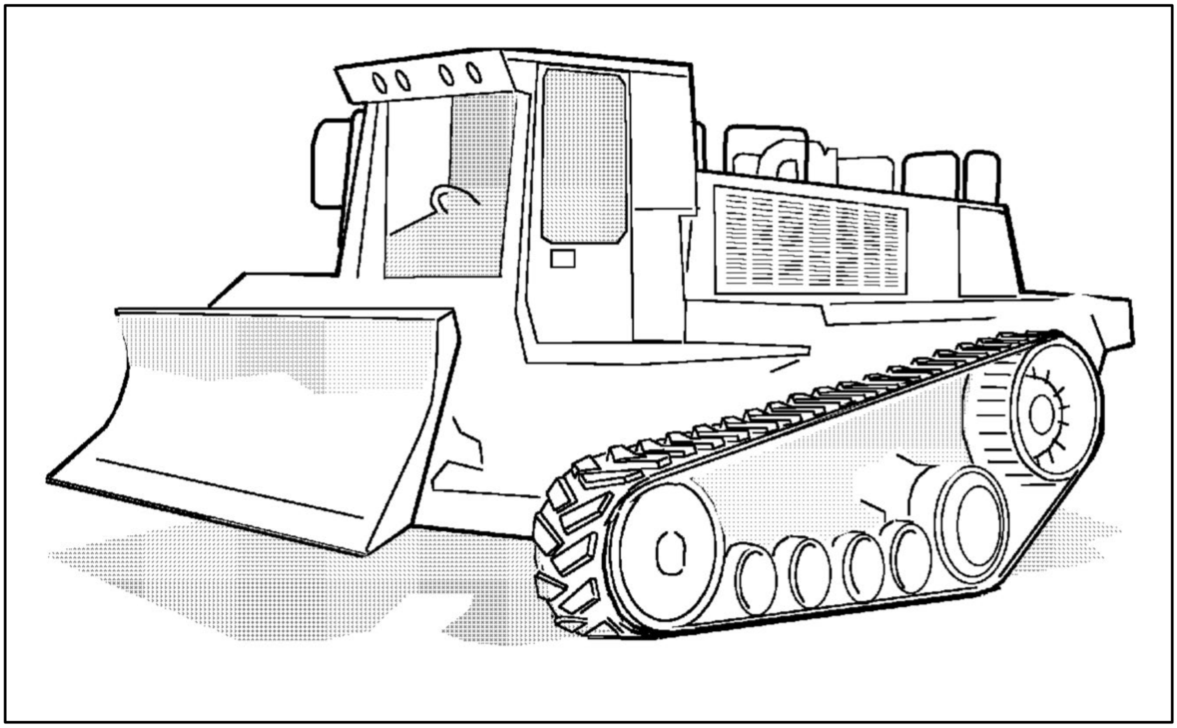
Chapter 2
Dozers

Dozers, also known as tracklaying crawlers or wheel tractors equipped with a blade, are essential and versatile pieces of equipment in the construction industry. They are designed to provide high drawbar pull and traction effort, making them standard equipment for tasks such as land clearing, dozing, and assisting in scraper loading. Dozers can also be equipped with rear-mounted winches or rippers. Crawler tractors exert low ground-bearing pressure, which adds to their versatility. When moving dozers between projects or within a project, it is best to transport them on heavy trailers to avoid excessive track wear and to prolong the operational life of the machine.

DESCRIPTION

2-1. A crawler dozer consists of a power plant, typically a diesel engine, mounted on an undercarriage that rides on tracks extending the full length of the dozer. There are two classifications of military dozers based on weight and pounds of drawbar pull. DEUCE is considered a light-class dozer (see figure 2-1), while the medium crawler tractor (MCT) and D7 are examples of a medium-class dozer (see figure 2-2, page 8).



* **Figure 2-1. Deployable universal combat earthmover (DEUCE), light-class dozer**

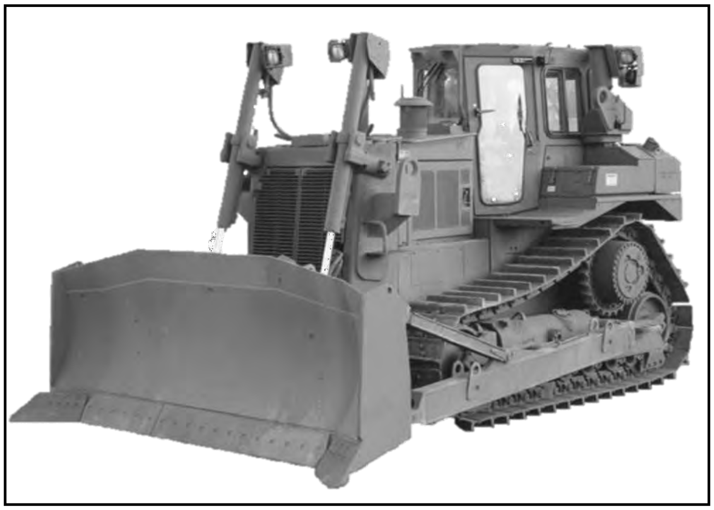


Figure 2-2. Medium-class dozer

BLADES

2-2. A dozer blade is made up of a moldboard with replaceable cutting edges and side bits. The blade is connected to the tractor either by push arms and tilt cylinders or a C-frame. Blades come in different sizes and designs for specific work applications. The hardened-steel cutting edges and side bits are bolted on because they experience the most abrasion and wear out quickly, allowing for easy replacement. Machine designs allow either edge of the blade to be raised or lowered in the vertical plane of the blade (tilt). The top of the blade can be pitched forward or backward, varying the angle of attack of the cutting edge (pitch). Blades mounted on a C-frame can be turned from the direction of travel (angling). Not all blades have these features, but a single mount may incorporate any two of these features.

STRAIGHT BLADE

2-3. When using straight blades for pushing material and cutting ditches, it is important to keep in mind that the blade is mounted in a fixed position, perpendicular to the line of travel. It can be tilted and pitched either forward or backward within a 10° arc. Tilting the blade allows the concentration of dozer driving power on a limited length of the blade. Pitching the blade provides increased penetration for cutting or less penetration for back dragging.

ANGLE BLADE

2-4. Angle blades, which are 1 to 2 feet wider than straight blades, are most effectively used for side casting material when backfilling or making sidehill cuts. They are also suitable for rough grading, spreading piles, or windrowing material. The angle blade can be angled up to a maximum of 25° left or right of perpendicular to the dozer or used as a straight blade. When angled, the blade can be tilted, but it cannot be pitched.

SPECIAL-PURPOSE BLADE

2-5. There are special blades (see figure 2-3), such as the Rome K/G, designed specifically for clearing brush and trees, rather than for earthmoving. The Rome K/G blade is fixed at a permanent angle and has a stinger on one end. This stinger includes a vertical splitter and stiffener, as well as a triangular-shaped horizontal part called the web. One side of the triangular web is adjacent to the bottom of the vertical splitter, while the other side is adjacent to the cutting edge of the blade. The abutting sides of the web are each about 2 feet in length, depending on how far the stinger protrudes from the blade. This blade is intended to cut down brush and trees at, or a few inches above, ground level rather than uprooting them. When cutting a large-diameter tree, the stinger should be used to split the tree first in order to weaken it; then the tree can be cut off and pushed over with the blade. It is important to keep both the stinger and the cutting edge sharp. Efficient operation of this blade requires well-trained operators. Additionally, there are other special-purpose blades that can be mounted on dozers, although they are not discussed in this manual.

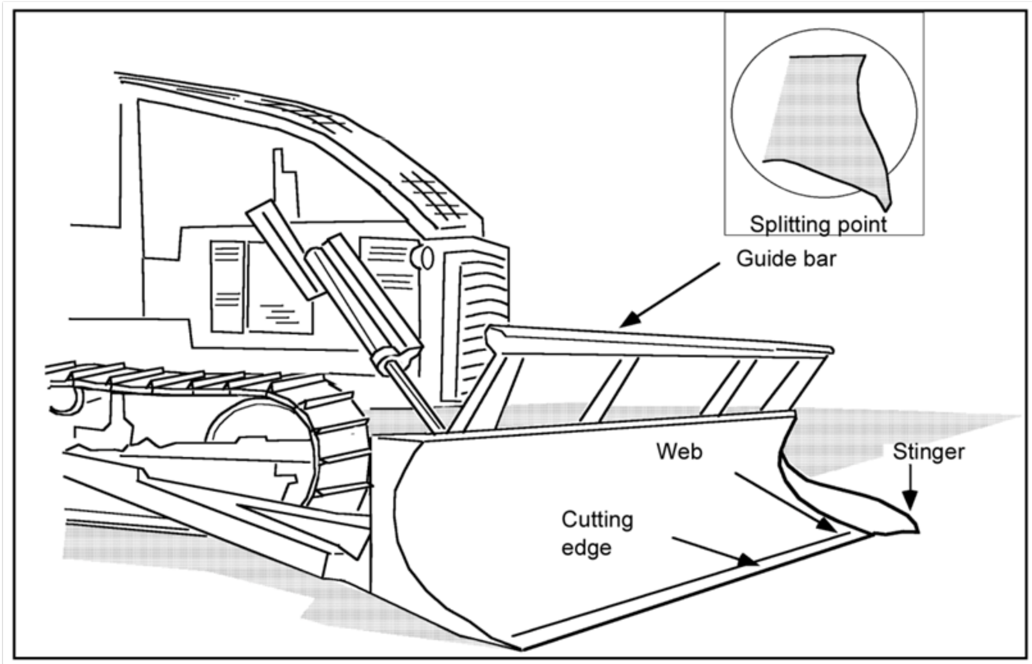


Figure 2-3. Special purpose clearing blade

CLEARING AND GRUBBING OPERATIONS

2-6. Before shaping the ground, it is usually necessary to clear vegetation and trees. This involves removing surface boulders and other embedded materials and disposing of the cleared material. It is important to address environmental-protection considerations before starting the clearing operations. Depending on project specifications, vegetation and trees may be sheared at ground level or it may be necessary to remove stumps and roots from below the ground. Plan the clearing operations to allow for disposal of debris in one handling and try to travel in one direction to avoid damaging the trees. Clearing techniques vary based on the type of vegetation, soil type, and moisture condition. Table 2-1 shows average clearing rates for normal area-clearing jobs. If the project requires strip-type clearing, increase the values in Table 2-1 by 60 percent. Tactical land clearing is performed by engineers as a combat support function to enhance and complement mobility, firepower, surveillance, and target acquisition.

Table 2-1. Quick production estimates for normal area clearing

Equipment	***Equipment (Hours Per Acre)***		
	Light (12 Inches or Less*)	***Medium (12 to 18 Inches*)***	***Heavy (18 Inches*)***
Bulldozer:			
Medium tractor	2.5	5.0	10.0
Heavy tractor	1.5	3.0	8.0

Table 2-1. Quick production estimates for normal area clearing (continued)

Equipment	*Equipment (Hours Per Acre)*		
	Light (12 Inches or Less)*	*Medium (12 to 18 Inches*)*	*Heavy (18 Inches*)*
Shear blade:			
Medium tractor	0.4	0.8	1.3
Heavy tractor	0.3	0.5	0.8
*Maximum tree size ***Note.*** These clearing rates are average for tree counts of 50 trees per acre. Adverse conditions (slopes, rocks, soft ground) can reduce these rates significantly.			

BRUSH AND SMALL TREES

2-7. When operating the dozer with the blade slightly below ground level, you can typically remove small trees and brush. The blade will cut, break off, or uproot most of the tree and bend the rest, making it easier to remove on the return trip. A medium tractor with a dozer blade can clear and pile approximately 0.25 acres of brush or small trees per hour.

MEDIUM TREES

2-8. To remove a medium-sized tree (7 to 12 inches in diameter), first, raise the blade of the bulldozer as high as possible to gain added leverage. Then, push the tree over slowly. As the tree starts to fall, quickly back the dozer to avoid the rising roots. Lower the blade and drive the dozer forward to lift out the roots. On average, it takes 2 to 9 minutes for a medium tractor with a dozer blade to clear and pile medium trees.

LARGE TREES

2-9. When removing large trees (12 to 30 inches in diameter), the process is slower and more difficult compared to clearing brush and smaller trees. First, carefully probe the tree for dead limbs that could fall and determine the natural direction of lean of the tree, if any. This direction is the best for pushing the tree over. Then, position the blade high and center it on the tree for maximum leverage. If possible, push the tree over the same way as a medium tree. However, if the tree has a massive, deeply embedded root system, use the following method (see figure 2-4):

- ***Step 1.*** Start on the side opposite the proposed direction of fall and make a cut deep enough to sever some of the large roots. Make the cut like a V-ditch, tilted downward laterally toward the roots.
- ***Step 2.*** Cut side two.
- ***Step 3.*** Cut side three.
- ***Step 4.*** Build an earth ramp on the same side as the original cut to get better leverage for pushing. Once the ramp is in place, push the tree over. As the tree starts to fall, quickly reverse the dozer to avoid the rising root mass. After the tree is down, fill the stump hole to prevent water from collecting.

2-10. The average time for a medium tractor with a dozer blade to clear and pile large trees is 5 to 20 minutes per tree. However, the time required to clear and pile massive trees, which require a four-step procedure, will often be more than 20 minutes each.

Note. The roots on the fourth side may also need to be cut.

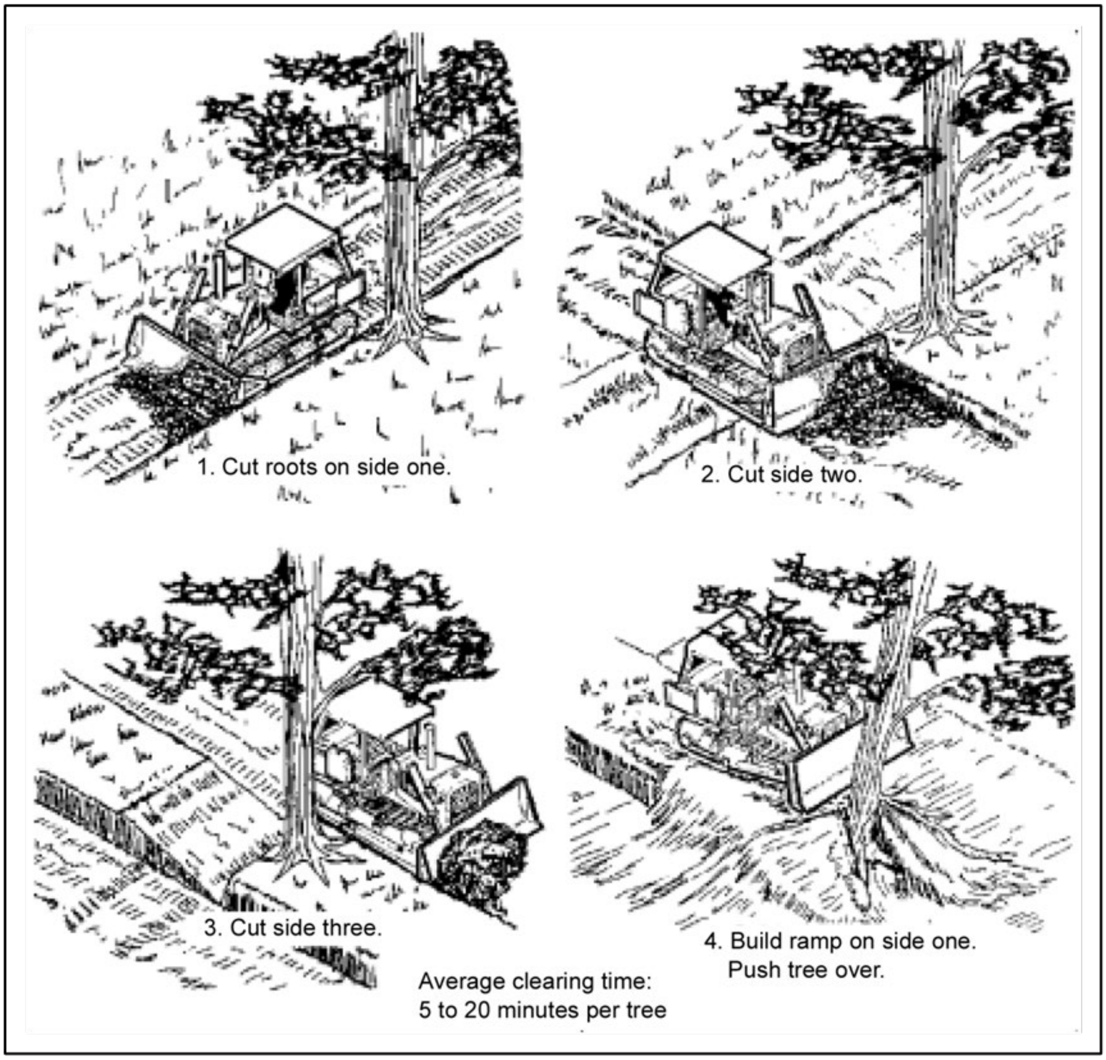


Figure 2-4. Four steps for removing a large tree with a massive, deeply embedded root system

ROOTS

2-11. Mount a rake on the dozer in place of the blade to remove roots and small stumps. As the dozer moves forward, it forces the teeth of the rake below the surface of the ground. The teeth will catch the belowground roots and the surface brush left from the felling operation, while the soil remains or passes through.

SAFETY PRECAUTIONS

2-12. Never operate clearing tractors too close together. Do not follow a tree too closely when pushing it, because when it begins to fall, its stump and roots may catch under the front of the dozer. Clean out accumulated debris in the belly pan of the dozer often to prevent fires in the engine compartment.

PRODUCTION ESTIMATES

2-13. The two methods used to estimate production for clearing and grubbing projects are the quick method and the tree-count method.

Quick Method

2-14. Table 2-1, page 10, displays quick estimates for normal area clearing. The quick method should only be used when a detailed reconnaissance and tree count are not feasible.

- ***Step 1.*** Determine the size of the area to clear (in acres).

$$Acres\ to\ be\ cleared = \frac{width\ (feet) x\ length\ (feet)}{43{,}560\ square\ feet\ per\ acre}$$

- ***Step 2***. Determine the size and number of dozers available.
- ***Step 3***. Determine the maximum size of the trees to clear.
- ***Step 4***. Determine the time required (hours per acre) for clearing, based on dozer size and tree size (see table 2-1, page 10).
- ***Step 5.*** Determine the efficiency factor for the work. Operators require breaks, and there are always secondary delays for minor equipment repairs. Therefore, actual production time per hour is something less than 60 minutes. In the case of a well-managed job, expect 50 minutes of production time per hour.

$$Efficiency\ factor = \frac{actual\ working\ minutes\ per\ hour}{60 - minute\ working\ hour}$$

- ***Step 6.*** Determine the operator factor using table 2-2.
- ***Step*** *7*. Determine the total time (in hours) required to complete the mission.

$$Total\ time\ (hours) = \frac{D\ x\ A}{E\ x\ O\ x\ N}$$

where—

D=time required, in hours per acre

A= total area, in acres

E= efficiency factor

O= operator factor

N= number of dozers available

Table 2-2. Operator factors for track dozers

Operator Ability	***Daylight***	***Night***
Excellent	1.00	0.75
Average	0.75	0.56
Poor	0.60	0.45
Note. These factors assume good visibility and a 60-minute working hour efficiency.		

EXAMPLE

Calculate the amount of time needed to clear an area that is 500 feet wide and 0.5 mile long. Two medium bulldozers are available for the task. The largest trees in the area have a diameter of 14 inches and the ground is mostly level. The operators are of average ability and will work only during daylight hours. The expected efficiency is 50 minutes per hour.

Step 1. $Total\ area\ in\ acres = \frac{width\ (feet)\ x\ length\ (feet)}{43{,}560\ quare\ feet\ per\ acre}$

$$= \frac{500\ feet\ x\ (0.5\ mile\ x\ 5{,}280\ feet\ per\ mile)}{43{,}560} = 30.3\ acres$$

Step 2. Dozer size = medium

Number of dozers available = 2

Step 3. Maximum tree size = 14 inches

Step 4. Time required = 5 hours per acre (table 2-1, page 10)

Step 5. $Efficiency\ factor = \frac{50\ minutes\ per\ hour}{60\ minute\ working\ hour} = 0.83$

Step 6. Operator factor = 0.75 (Table 2-2)

Step 7. $Total\ time\ (hours) = \frac{5\ hours\ per\ acre\ x\ 30.3\ acres}{0.83\ x\ 0.75\ x\ 2}$ = 121.6 or 122 hours

Tree-Count Method

2-15. Use this method when a detailed reconnaissance and a tree count are possible. The tree-count method allows for a better production estimate.

- ***Step 1.*** Determine the size of the area to clear (in acres). Refer to step 1 of the quick method.
- ***Step 2.*** Determine the size and number of dozers available.
- ***Step 3.*** Determine the average number of each size of tree per acre. This will require a field reconnaissance.
- ***Step 4.*** Determine the basic production factors (hours per acre) based on the dozer size and the size of the trees to clear (see table 2-3).
- ***Step 5.*** Determine the time required to clear one acre.

$$D = H([A\ x\ B] + [M_1\ x\ N_1] + [M_2 + N_2] + [M_3\ x\ N_3] + [I\ x\ F])$$

where—

D = clearing time of one acre, in minutes

H = hardwood factor affecting total time—

H = 1.3 if hardwoods are 75 to 100 percent

H = 1 if hardwoods are 25 to 75 percent

H = 0.7 if hardwoods are 0 to 25 percent

A = tree-density and presence-of-vines factor affecting total time

A = 2 if density is more than 600 trees per acre (dense)

A = 1 if density is 400 to 600 trees per acre (medium)

A = 0.7 if density is less than 400 trees per acre (light)

A = 2 if heavy vines are present

A = 3 if very heavy vines are present

B = base time per acre determined from dozer size, in minutes

M = time required per tree in each diameter range, in minutes

N = number of trees per acre in each diameter range, from reconnaissance

I = sum of diameter of all trees per acre greater than 6 feet in diameter at ground level (in foot increments), from reconnaissance

F = time required per foot of diameter for trees greater than 6 feet in diameter, in minutes

Note. When it is necessary to grub roots and stumps, increase the time per acre by 25 percent.

- ***Step 6.*** Determine the total time (in hours) required to complete the mission.

$$Total\ time\ (hours) = \frac{D\ x\ A}{N}$$

where—

D = time required to clear one acre (from step 5), in hours

A = total area

N = number of dozers

Table 2-3. Production factors for felling with a clearing blade

Tractor	***Base Minutes Per Acre B***	***Tree Diameter Range***				
		1-2 Feet M_1	***2-3 Feet M_2***	***3-4 Feet M_3***	***4-6 Feet M_4***	***More Than 6 Feet F***
Medium	23.48	0.5	1.7	3.3	10.2	3.3
Heavy	18.22	0.2	1.3	2.2	6.0	1.8
Note. These times are based on working on reasonably level ground with good footing and an average mix of soft and hardwoods.						

Note. The tree-count method has no correction factor for efficiency or operator skill. The values in table 2-3 are based on normal efficiency and average operator skill.

SIDEHILL EXCAVATIONS

2-16. One of a more important uses of the dozer is making sidehill cuts, which includes pioneering road cuts along hillsides. An angle blade is preferred for this operation because of its side-casting ability.

CREATING A SLOPE

2-17. To start the cut, it is best to begin at the top of the hill and create a bench that is several dozer lengths long. You can do this by working up and down the slope perpendicular to the long direction of the project (refer to figure 2-5[A], page 15). When designing the benches, make sure that water runs off without causing damage to the slope. If possible, start the bench at the highest point of the cut and then widen and deepen the cut until the desired road profile is achieved. It is important to start the bench far enough up the slope to allow room for both the inner slope and the roadway.

Note. When working on extremely steep slopes, a winch line may be necessary to stabilize the dozer (see paragraph 2-37, page 22).

2-18. Short perpendicular passes make it difficult for the dozer to get a full blade load. After creating the initial bench, turn the dozer and work in the long direction of the project (see figure 2.5[B]). Get a full blade load and then turn the dozer to push the material over the side. Once the bench is developed, use a dozer or a scraper to finish the cut. Keep the inside (hillside) of the roadway lower than the outside to allow the dozer to work effectively on the edge and reduce erosion of the outer slope. It is important to maintain the proper slope on the inside of the cut because it is very difficult to change the cut slope after construction. Maintain the proper bench slope by moving out from the inside slope on each successive cut. Determine the slope ratio by measuring the distance moved away from the slope for each successive cut and the depth of each cut. When cutting the cross slope on the road, work from the toe of the bench to the outside edge of the road.

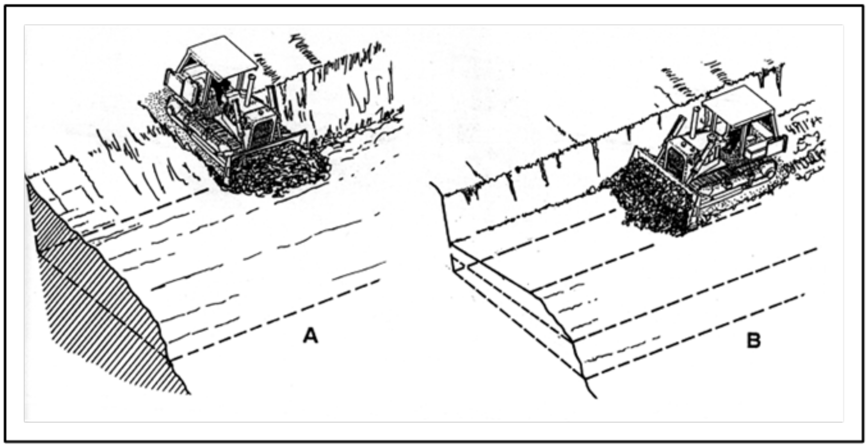


Figure 2-5. Sidehill cut

FINISHING A SIDE SLOPE

2-19. There are two methods for finishing a side slope—working perpendicular to the slope and working diagonally up the slope.

Working Perpendicular To The Slope

2-20. The bulldozer shown in figure 2-6, page 16, is finishing a side slope by working perpendicular to the slope. Begin by starting the dozer at the top of the embankment. As the dozer moves, earth will fall to the lower side of the blade, forming a windrow. On subsequent passes, pick up this windrow and use it to fill holes and other irregularities in the terrain. It is important to be cautious and prevent the blade corner from digging in too deep, as this could steepen the slope beyond job specifications.

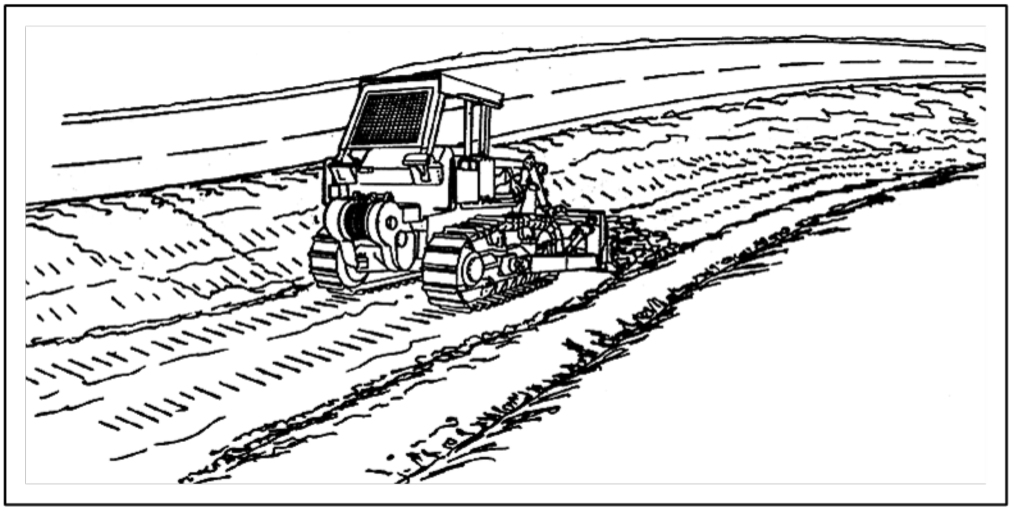


Figure 2-6. Finishing a side slope working perpendicular to the slope

Working Diagonally Up The Slope

2-21. The dozer depicted in figure 2-7 is completing the side slope by starting at the bottom and working diagonally up the slope. The windrow that forms is continually pushed to one side, which helps to fill low spots, holes, and irregularities. This is one of the few instances where a bulldozer is effective in pushing uphill.

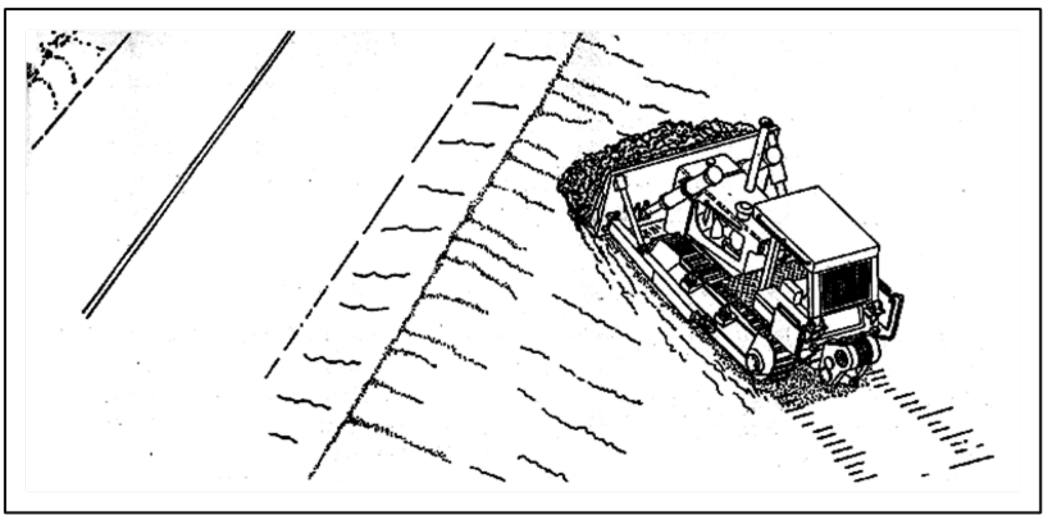


Figure 2-7. Finishing a side slope working diagonally up the slope

OPERATION TECHNIQUES

2-22. Dozers work best when the ground is firm and free of potholes, sharp ridges, or rocks. Uneven surfaces make it difficult to keep the blade in contact with the ground, which can result in burying vegetation in hollows rather than removing it. To save time and increase output, use the following techniques when conditions permit.

DOZING

2-23. When straight dozing, if the blade digs in and the rear of the machine rises, raise the blade to continue an even cut. If moving a heavy load causes the travel speed to drop, shift to a lower gear and/or raise the blade slightly. When finishing or leveling, a full blade handles easier than a partially loaded blade.

Side-By-Side Dozing

2-24. Side-by-side dozing can increase production by 15 to 25 percent when moving material a distance of 50 to 300 feet (see figure 2-8). However, if the distance is less than 50 feet, the extra time needed to maneuver and position the dozers will offset the increased production.

Figure 2-8. Side-by-side dozing

Slot Dozing

2-25. Slot dozing involves using spillage from the first few passes to create a windrow on each side of the path of the dozer (see figure 2-9). This creates a trench, which helps prevent spillage from the blade on subsequent passes. To boost productivity, make cuts parallel and leave a narrow uncut section between the slots. Then, remove the uncut section through regular dozing. When the grade and soil conditions are favorable, slot dozing can increase output by as much as 20 percent.

Figure 2-9. Slot dozing

Downhill Dozing

2-26. Stack multiple loads at the top of the hill, and then push them all down in one go. When pushing downhill, go all the way to the bottom with each load. Whenever you can, push downhill as it boosts productivity.

Hard-Materials Dozing

2-27. When rippers are not available, use the dozer blade to loosen hard material. Tilt the blade to force one corner into the material. You can tilt the blade by using blade control, driving one track onto a ridge of material bladed up for this purpose, or by placing a rock or log under the track. To maximize the driving force of the blade, only hook the tilted end under the material. Use the dozer to break a thin layer by turning on it. Turning causes the track grousers (cleats) to break through the top layer. When dealing with a thin layer of frozen material, it is best to break through at one point. By lifting and pushing, the blade breaks through the top frozen layer as shown in figure 2-10.

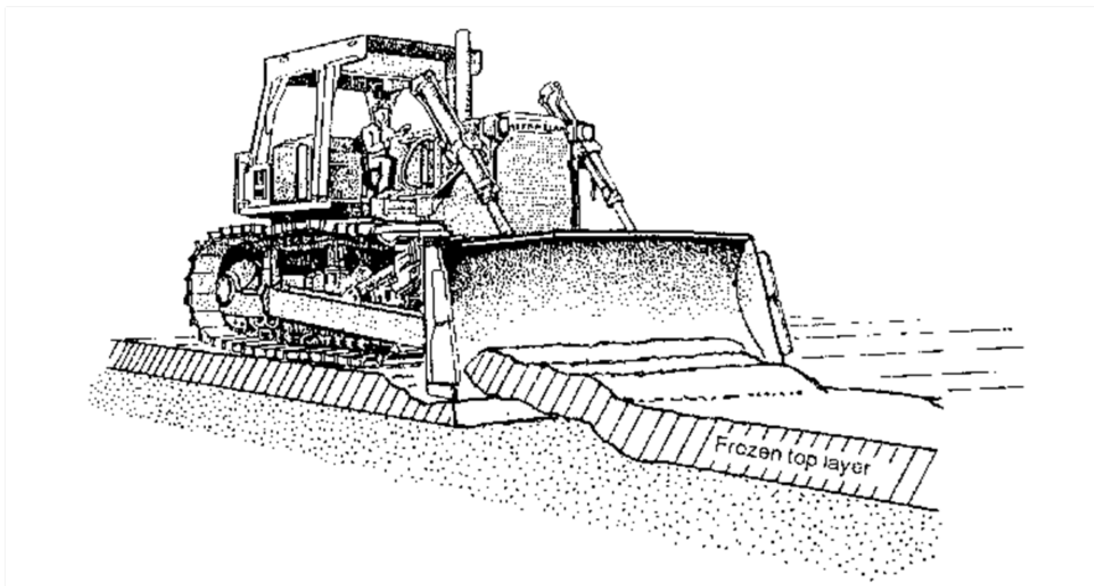


Figure 2-10. Dozing hard materials or frozen ground layers

Rock Dozing

2-28. To remove small rocks, use a rake. The rake allows the soil to remain or pass through while taking out the rocks from the earth. When removing large, partially buried boulders, tilt the dozer blade and excavate the earth from around three sides of the boulder. Lower the blade enough to get under the fourth side. Raise the blade as the dozer moves forward to create a lifting and rolling action of the boulder. If the dozer cannot push the boulder, lift it upward with the blade and have someone place a log or another object under the boulder so the dozer can get another hold. The rolling action removes the boulder as the dozer moves forward. Dozer work in rocky areas increases track wear. If possible, install rock shoes or rock pads to reduce this wear.

Wet-Materials Dozing

2-29. When the material is wet, it can be challenging to move with a dozer. Additionally, the wet ground might be too soft to withstand the weight of the dozer. If this is the case, ensure that each pass goes through the full depth of the wet material. This will provide the dozer with a more stable base. If possible, use wider tracked shoes to improve flotation. When working in mud, push the mud far enough so that it does not flow back into the cut. Make sure to have plans in place for recovery operations in case the dozer gets stuck. It is beneficial to use machines equipped with a winch.

DITCHING

2-30. To create shallow ditches, it is best to use a grader, but rough ditching can also be done using dozers. When using a dozer, tilt the blade to cut shallow V-ditches (see figure 2-11). For larger ditches, push the material perpendicular to the center line of the ditch. Once the desired depth is reached, push the material along the length of the ditch to smooth the sides and bottom. Often, irregularities in a ditch need to be corrected. Try to remove humps or fill holes in a single pass, but if necessary, use multiple passes to correct the grade.

Figure 2-11. Tilt dozer ditching

CONSTRUCTING A STOCKPILE

2-31. A dozer is a great machine for creating stockpiles of materials, which can then be easily loaded into haul units by either a loader or a hydraulic excavator. Follow these steps to construct a stockpile:

- ***Step 1.*** On the first pass, push the material from the beginning of the excavation to the stockpile area. Make sure the distance is no more than 75 feet from the start point. Do not excavate deeper than 6 to 8 inches and maintain a smooth cut.

WARNING

Before putting the machine in reverse, and while backing, the operator must be satisfied that no one will be endangered.

- ***Step 2.*** Begin raising the blade one dozer length from the stockpile, allowing the material to form a ramp as it drifts under the blade upon reaching the stockpile area.

CAUTION

Keep the bulldozer under control at all times. Do not shift the transmission into neutral to coast. Choose the appropriate gear range before descending. Avoid changing gears while going downhill.

- ***Step 3.*** Push the material on successive cuts in the same manner, working the dozer from the starting point all the way around the work area while stockpiling, and overlap cuts by about one-third of the width of the blade to pick up windrows.

Note. Do not stop the forward motion or cause the tracks to spin while pushing material.

- ***Step 4.*** Make successive cuts as in step 2 to build the stockpile higher with each pass until it reaches the desired height.

SPREADING A STOCKPILE

2-32. Large piles should be worked from the side, cutting material away from the stockpile, using one-third of the blade. Use the following steps to spread a stockpile:

- ***Step 1***. Lower the blade to the desired height while moving forward.
- ***Step 2.*** Adjust the blade height and move the dozer into the side of the pile making the cut with only one-third of the blade.

Note. When using the left side of the blade, continue working to the left. When using the right side of the blade, continue working to the right.

- ***Step 3.*** Cut into the stockpile. The blade should be as full as possible without stalling the dozer or spinning the tracks. Raise and lower the blade to maintain a smooth pass.

WARNING

When spreading materials that are higher than the midpoint of the rollover protective structure (ROPS), adjust the height of the cut to eliminate the danger from collapsing material.

- ***Step 4.*** Spread the blade load after cutting the pile by continuing to move forward and slowly raising the blade until all material is evenly feathered.
- ***Step 5.*** Feather the blade load and reverse the dozer. Raise the blade about 12 inches off the ground, back the dozer to the stockpile, and reposition for another cut.
- Repeat the above steps until the stockpile has been leveled and spread over the designated area. Do not back blade to level the stockpile.

BACKFILLING

2-33. To effectively backfill, use an angle blade to push material sideways, allowing forward motion parallel to the excavation. If using a straight blade, approach the excavation at a slight angle and then turn in toward the excavation at the end of the pass. Ensure that no part of the tracks hang over the edge. Adjust the length of the push based on soil conditions. For soft material or unstable slopes, let the second bladeful push the first bladeful over the edge. Be careful to keep oversize materials out of the backfill.

RIPPING

2-34. Figure 2-12 illustrates various ripping operations. For ripping operations, use first gear. When performing one-shank ripping, always utilize the center shank. If possible, use additional shanks to enhance production. When ripping for scraper loading, rip in the same direction that the scrapers are loading, if feasible. It is generally preferable to rip as deeply as possible. However, at times it's better to rip the material in its natural layers, even if this is less than the full shank depth. Place the ripped material on top of the unripped formation to cushion the machine and provide traction. When a relatively small final material size is required, space passes close together. Cross rip only when necessary to achieve the required breakage. Follow these steps to rip material:

- ***Step 1.*** Position the dozer on the uphill side if operating on a slope, about half the length of the dozer from the start of the area to be ripped.
- ***Step 2.*** Place the transmission shift lever in forward, first gear.
- ***Step 3.*** Lower the rippers to the ripping depth as the dozer begins to cross the area to be ripped.

> **WARNING**
>
> **Maintain a straight line while ripping. Turning the dozer with the rippers in the ground will cause damage to the dozer.**

- ***Step 4.*** Raise the rippers out of the ground and then stop at the end of the pass.
- ***Step 5.*** Place the transmission in reverse and back the dozer to the start points.
- ***Step 6.*** Position the dozer to overlap the previous ripping pass.
- Repeat steps 1 through 6 until the area is completely ripped.

PACKED SOIL, HARDPAN, SHALE, AND CEMENTED GRAVEL

2-35. Three shank ripping is effective in these materials; use as many shanks as possible to achieve the desired material size.

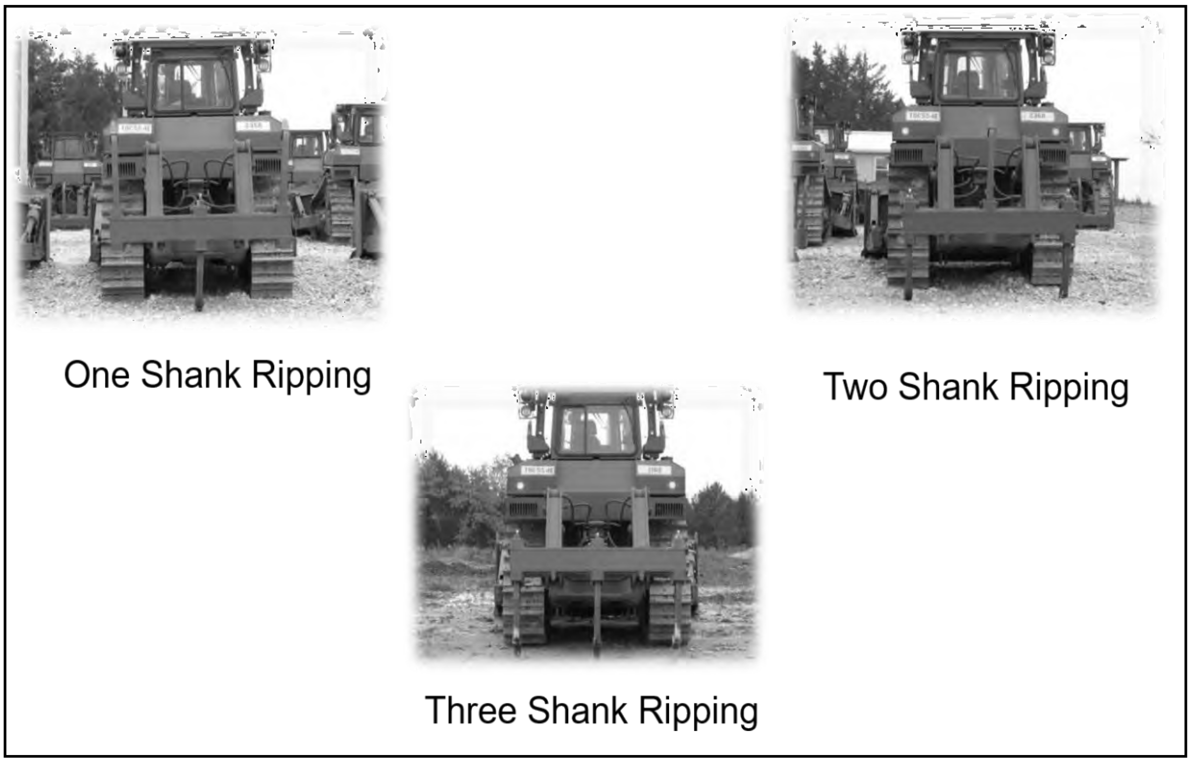


Figure 2-12. Ripping operations

ROCK WITH FRACTURES, FAULTS, AND PLANES OF WEAKNESS

2-36. Use two shanks for ripping in areas with small rocks, and switch to the center shank if the machine stalls or tracks spin.

- **Asphalt.** Raise the ripper shank to lift out and break the material.
- **Concrete.** Use one-shank ripping to sever reinforcing rods or wire mesh effectively.

SOLID ROCK, GRANITE, AND HARD-TO-RIP MATERIAL

2-37. Use one shank in hard-to-rip material or material that tends to break out in large slabs or pieces.

WINCHING

2-38. When using a winch, make sure to keep personnel clear of the cable, as cables can break and cause severe injury. Exercise caution with suspended loads, as if the engine speed is too low, the weight of the load may exceed the engine capacity and cause the load to drop, even if the winch is in the reel-in position.

CAUTION

Always ensure that the winch cable is kept in a straight line behind the machine. For safety and to maximize the service life of the winch component, decelerate the engine before moving the winch control lever. When shifting, control the cable speed by adjusting the engine speed. When the machine is stationary, operate the winch loads at low engine speed. When moving away from a load, use low gear to prevent the winch components from overspeeding. Avoid operating the winch for extended periods.

DOZER PRODUCTION ESTIMATES

* 2-39. Dozer production curves give maximum-production values (in Lm^3/LCY per hour) for straight and semi-universal blades based on the following conditions:

- A 60-minute working hour (100 percent efficiency).
- Power-shift machines with 0.05-minute fixed times are being used.
- The dozer cuts 50 feet, then drifts the blade load to dump over a high wall.
- The soil density is 2,300 pounds per LCY.
- The coefficient of traction equals 0.5 or better for crawler machines and 0.4 or better for wheel machines.
- Hydraulic-controlled blades are being used.

3-40. Use the following steps to estimate dozer production:

- ***Step 1***. Determine the maximum production by referring to either figure 2-13 or figure 2-14, depending on the type of dozer being used. Locate the dozing distance on the bottom horizontal scale in the relevant figure. Then, read vertically until you intersect the production curve for the specific dozer, and finally, read the vertical scale on the left to determine the maximum production in LCY per hour.
  - Use figure 2-13 to determine the estimated maximum production for D6T through D7E tractors with straight blades. The DEUCE has the same production capability as the D5. Marines should use D7 data in figure as equivalent to the medium crawler tractor (MCT).
  - Use figure 2-14 to determine the estimated maximum production for D7R or D8R tractors with semi-universal.

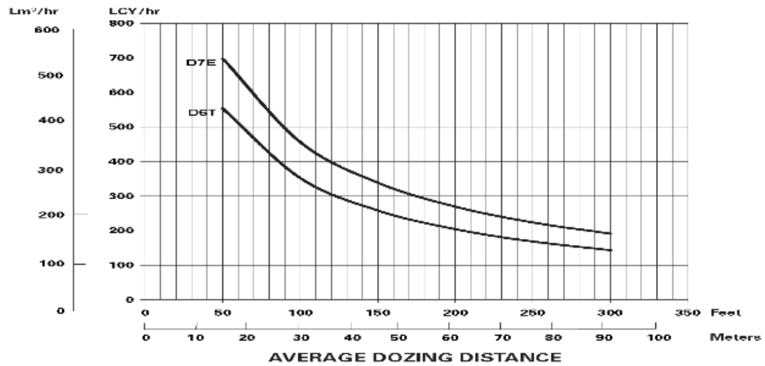


Figure 2-13. Estimated maximum production for D6T and D7E tractors with straight blades (Metric/English)

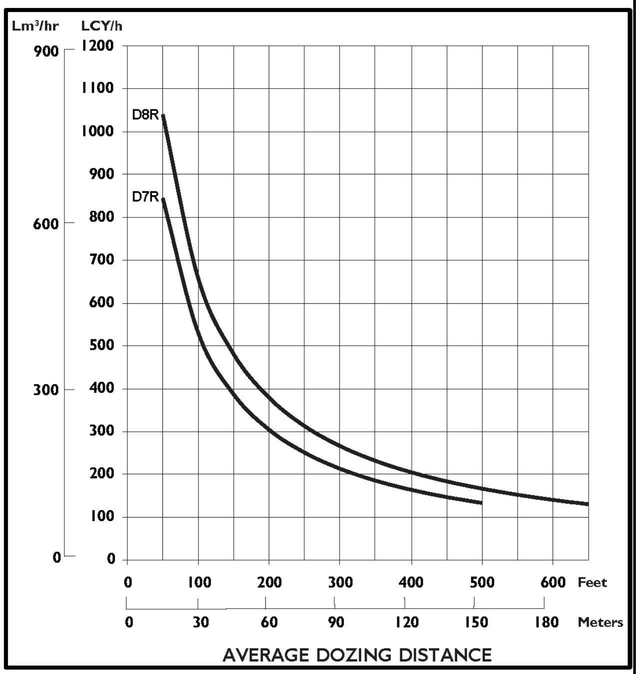


Figure 2-14. Estimated maximum production for D7 or D8 tractors with semi-universal blades (Metric/English)

- ***Step 2.*** Determine the grade correction factor (-) favorable or (+) unfavorable. Find the percent grade on the bottom horizontal scale of figure 2-15. Read up vertically and intersect the grade correction curve, then read to the left horizontally and locate the grade correction factor on the vertical scale.

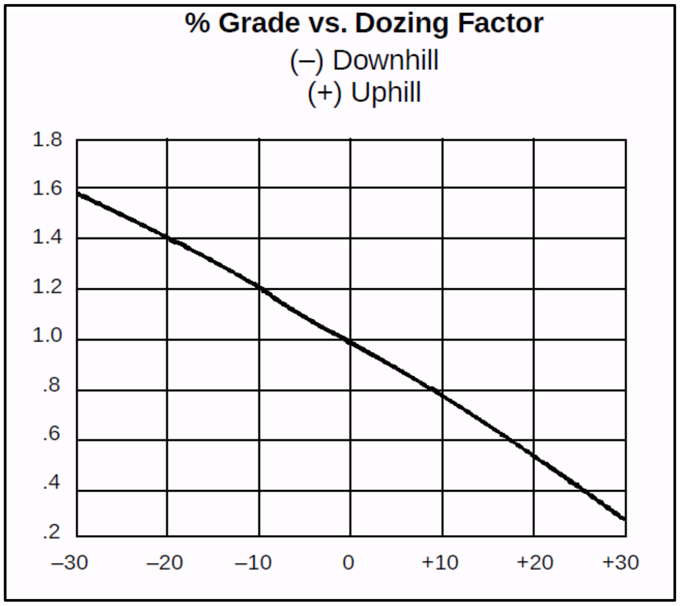


Figure 2-15. Dozer-production grade correction factors

- ***Step 3.*** Determine the material-weight correction factor. If the actual unit weight of the material to be excavated is not available from soil investigations, you can use the average values found in table 1-2, page 3. To find the correction factor, divide 2,300 pounds per LCY by the LCY weight of the material. The assumed soil density of 2,300 pounds per LCY is a constant used to calculate the maximum production.

$$Material - weight\ correction\ factor = \frac{2300\ pounds\ per\ LCY\ (standard\ material\ unit\ weight)}{actual\ material\ LCY\ weight}$$

where—

2,300 = standard material unit weight per LCY

- ***Step 4.*** Determine the material-type correction factor. Dozer blades are designed to cut material and give it a rolling effect in front of the blade. This results in a production factor of 1. Table 2-4 gives the correction factors to account for how different materials behave in front of the blade.

Table 2-4. Material-type correction factors

Material State	***Factor for Crawler Tractors***
Loose, stockpile	1.2
Hard to cut; frozen, with tilt cylinder Hard to cut; frozen, without tilt cylinder	0.8 0.7
Hard to drift; dead (dry, noncohesive) material or very sticky material	0.8
Rock (ripped or blasted)	0.6 to 0.8

- ***Step 5.*** Determine the operator correction factor (see table 2-2, page 12).
- ***Step 6.*** Determine the operating-technique correction factor from table 2-5.

Table 2-5. Operating-technique correction factors

Operating Technique	*Factor for Crawler Tractors*
Slot dozing	1.2
Side-by-side dozing	1.15 to 1.25

- ***Step 7.*** Determine the efficiency factor. In the case of a well-managed job, expect 50 minutes of production time per hour.

$$Efficiency\ factor = \frac{actual\ working\ minutes\ per\ hour}{60\text{–}\ minute\ working\ hour}$$

- ***Step 8***. Determine dozer production.

$$Production\ (LCY\ per\ hour) = maximum\ production\ x\ the\ product\ of\ the\ correction\ factor$$

- ***Step 9.*** Determine the material conversion factor, if required. To determine the total time required (step 10) and the total number of bulldozers needed to complete a mission within a specified time (step 11), adjust the volume of material being moved and the equipment production rate per hour so that they both represent the same material state. When referring to material and production states, use terms such as LCY, BCY, and CCY. If necessary, refer to table 1-1 on page 3 to find the material conversion factor. To find the production per hour in a different state, multiply the conversion factor by the production per hour.

Note. This conversion will not change the dozer production effort.

2-41. Example:

Determine the average hourly production (in CCY) of a straight-blade D7 (with tilt cylinder) moving hard-packed clay an average distance of 200 feet, down a 10 per cent grade, using slot dozing. Estimated material weight is 2,500 pounds per LCY. The operator is of average ability and will work during daylight hours. Expected efficiency is 50 minutes per hour.

- Step 1. Uncorrected maximum production = 300 LCY per hour (figure 2-14, page 23)
- Step 2. Grade correction factor = 1.15 (figure 2-15, page 24) Step 3. Material-weight correction factor

$$= \frac{2{,}300\ pounds\ per\ LCY\ (standard\ material\ unit\ weight)}{2{,}500\ pounds\ per\ LYC\ (actual\ material\ unit\ weight)}$$

= 0.92

- Step 4. Material-type correction factor (a hard-to-cut-material) = 0.8 (table 2-4)
- Step 5. Operator correction factor = 0.75 (table 2-2, page 12)
- Step 6. Operating-technique correction factor = 1.2 (table 2-5)
- Step 7. Efficiency factor = (50 working minutes per hour)/(60-minute working hour) = 0.83
- Step 8. Dozer production

= 300 LCY per hour x 1.15 x 0.92 x 0.8 x 0.75 x 1.2 x 0.83

= 190 LCY per hour per dozer

- Step 9. Material conversion factor 0.63

Dozer production in CCY = 0.63 x 190 LCY per hour = 120 CCY per hour

- ***Step 10.*** Determine the total time required in hours.

$$Total\ time\ (hours) = \frac{Q}{P\ x\ N}$$

where—

Q = quantity of material to be moved

P = hourly production rate per dozer

N = number of dozers

2-43. Example:

Determine the total time to move 3,000 CCY of hard-packed clay, using one D7 dozer with a production rate of 120 CCY per hour.

$$\frac{3{,}000\ CCY}{120\ CCY\ per\ hour\ x\ 1\ dozen} = 25\ hour$$

- ***Step 11.*** Determine the total number of dozers required to complete the mission within a given time.

$$Total\ number\ of\ dozers\ = \frac{Q}{P\ x\ T}$$

where—

Q = quantity of material to be moved

P = hourly production rate per dozer

T = maximum allowable duration, in hours

2-44. Example:

Determine how many D7 dozers (with a production rate of 120 CCY per hour) would be needed to move 3,000 CCY of clay in seven hours.

$$\frac{3{,}000\ CCY}{120\ CCY\ per\ hour\ x\ 8\ hours} = 3.6\ D7\ dozers\ (round\ up\ to\ 4\ dozers)$$

RIPPING PRODUCTION ESTIMATES

2-45. The most accurate way to estimate ripping production is by working a test section, recording the time required, and the production achieved. However, it is often not possible to conduct such investigations, so estimates are usually based on historical production charts. Ripping applications will increase the maintenance requirements of the machine by 30 to 40 percent.

QUICK METHOD

2-46. A quick method to determine an approximate production rate is to time several passes of a ripper over a measured distance. The timed duration should include the turnaround time at the end of the pass. Determine an average cycle time from the timed cycles. Determine the quantity (volume) from the measured length multiplied by the width of the ripped area and the depth of penetration. If measurements are in feet, divide the number of feet by 27 to convert cubic feet to cubic yards.

$$Volume\ BCY = \frac{length\ (feet) x\ width\ (feet) x\ penetration\ depth\ (feet)}{27}$$

where—

27 = factor used to convert cubic feet to cubic yards

2-47. Experience has shown that the production rate calculated by this quick method is about 20 percent higher than an accurately cross-sectioned study. Therefore, the formula for estimating ripping production is—

$$Ripping\ production\ (BCY\ per\ hour) = \frac{V}{T\ x\ 12}$$

where—

V = measured volume in BCY

T = average time in hours

1.2 = method correction factor

SEISMIC-VELOCITY METHOD

2-48. Most ripping-production charts are based on the relationship between the ripability and the seismic-wave velocity response of a material. Figure 2-16, page 28, features a ripping performance chart for a 300-horsepower dozer. This chart helps the estimator determine the performance capability of the machine based on seismic velocity and general rock classifications.

2-49. Once the seismic velocity is established, production can be estimated using the production chart in figure 2-17, page 29. This chart provides a range of production rates representing ideal-to-adverse rock conditions based on specific assumptions:

- The efficiency factor is 100 percent (60-minute working hour).
- The power-shift machines used have single-shank rippers.
- The machine rips full-time, no dozing.
- The upper limit of the band reflects ripping under ideal conditions only. If conditions such as thick laminations, vertical laminations, or other rock structural conditions exist which would adversely affect production, use the lower limit.

2-50. Regardless of the seismic velocity, tooth penetration is the key to ripping success. This is particularly true for homogeneous materials such as mudstone, clay stone, and fine-grained caliches.

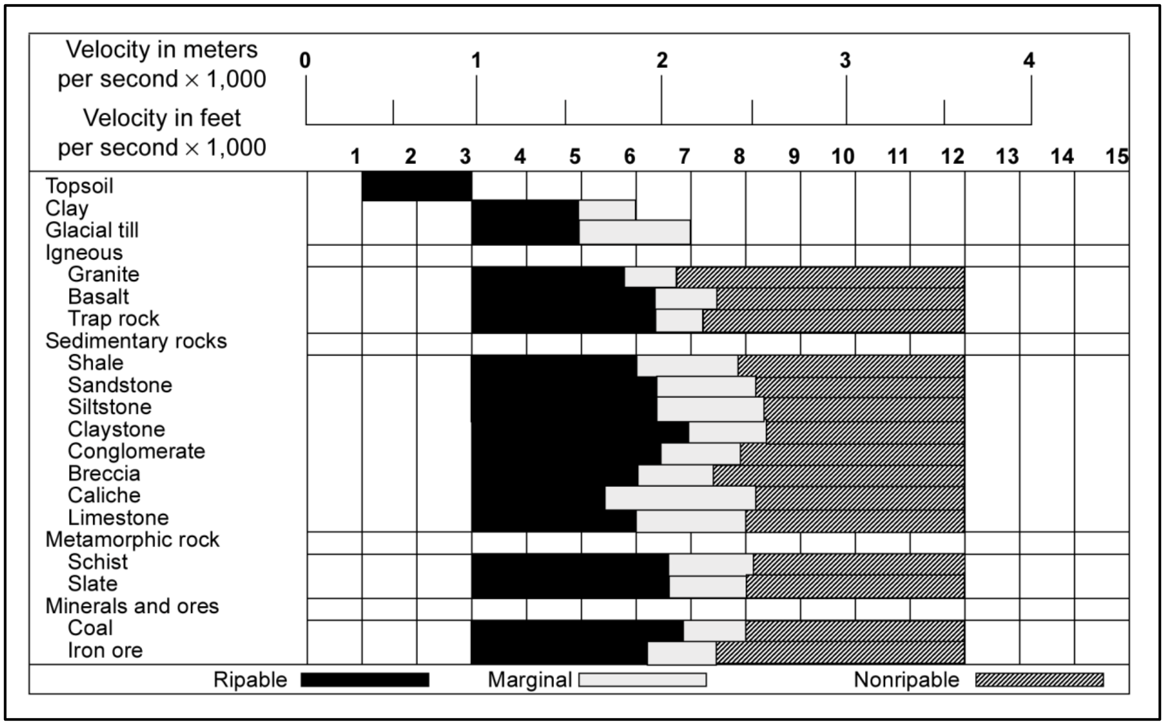


Figure 2-16. Ripping performance for a 300-horsepower dozer with a single- or multishank ripper

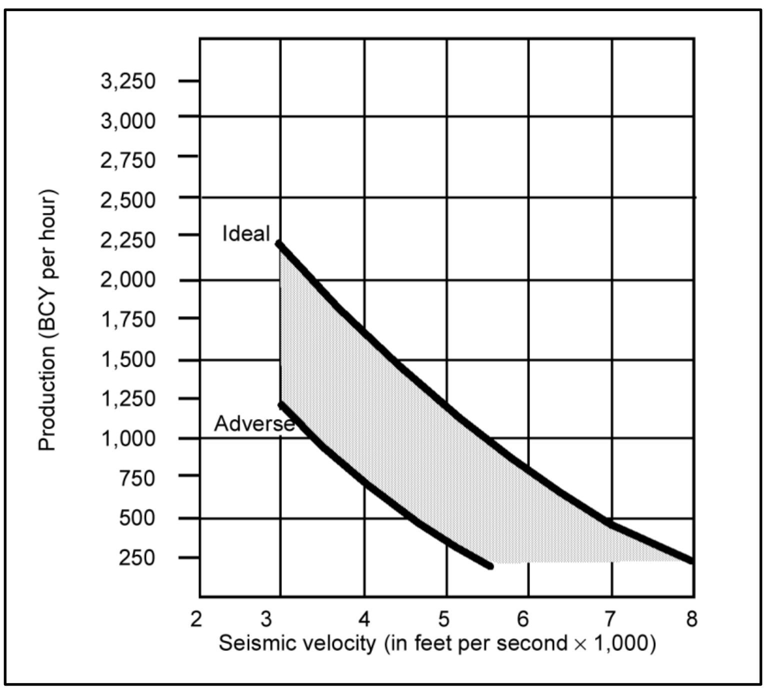


Figure 2-17. Estimated ripping production for a 300-horsepower dozer with a single-shank ripper

$$Production\ (BCY\ per\ hour\ per\ dozer) = P\ x\ E$$

where—

P = maximum production for a 300-horsepower dozer (figure 2-17)

E = efficiency factor

Note. Before referring to figure 2-17 for determining a probable production rate, refer to figure 2-16 to verify the ripability with the equipment available.

2-51. Example:
Determine how many 300-horsepower dozers are needed to rip 9,000 BCY of limestone having a seismic velocity of 4,000 feet per second in 7 hours. The limestone is bedded in thin laminated layers. Efficiency will be a 45-minute working hour.
Maximum production for ideal conditions (thin layers) is 1,700 BCY per hour (figure 2-17).
Efficiency adjusted production

$$= 1{,}700\ BCY\ per\ hour\ x\,\frac{45}{60}$$
$$= 1{,}275\ BCY\ per\ hour$$

*

$$\boldsymbol{\frac{9{,}000\,BCY}{1.275\,BCY\ per\ hour\ x\ 7\ hours} = 1.3 - horsepower\ dozer}$$

=

SAFETY PRECAUTIONS

2-52. Listed below are some specific safety precautions for dozer operators:

- Never carry personnel on the tractor drawbar.
- Never turn around on steep slopes; back up or down instead.
- Keep the machine in low gear when towing a heavy load downhill.
- Always lower the attachments when the machine is parked.
- Ensure that only one person is on the machine while it is in operation.

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Chapter 3

Scrapers

The design of scrapers, specifically tractor scrapers, allows for loading, hauling, dumping, and spreading loose materials. Scrapers are ideal for medium-haul earthmoving operations and for moving ripped materials and shot rock. The primary factors to consider when deciding whether to use a scraper on a particular job are the haul distance (zone of operation), the load volume, and the type and grade of surface traveled on. For small- and medium-size scrapers, the optimum haul distance is 3,000 feet or less.

DESCRIPTION

3-1. Figure 3-1 shows a 621G single-powered-axle wheel scraper. The 621 is designed to operate using a push tractor for loading assistance. The air-droppable 613B wheel scraper has a chain-elevator loading mechanism that allows it to load without the assistance of a push tractor. The basic operating parts of a scraper are as follows:

- **Bowl**. The bowl is the loading and carrying component. It has a cutting edge, which extends across the front bottom edge. Lower the bowl until the cutting edge enters the ground for loading, raise it for carrying, and lower it to the desired lift thickness for dumping and spreading.
- **Apron**. The apron is the front wall of the bowl. It is independent of the bowl, and when raised, it opens for loading and spreading. Lower the apron during hauling to prevent spillage.
- **Ejector**. The ejector is the rear wall of the bowl. Keep the ejector in the rear position when loading and hauling materials. Activate the ejector to move forward during spreading to provide a positive discharge of materials.

CAPACITY

3-2. *Struck* capacity means the bowl has a full load of material that is level with its sides. *Heaped* capacity means the material is heaped in the bowl and slopes down on a 1:1 repose slope to the sides of the bowl. The material load capacity of a scraper is typically measured in LCY due to how the scraper loads. The volume of material moved, expressed in BCY, depends on both the size of the bowl and the type of material being loaded. The Army 621G scraper has a rated volumetric capacity of 15.7 cubic yards when struck and 22 cubic yards when heaped. The capacity of the 613B scraper is 11 cubic yards when heaped. Elevating scrapers like the Army 613 do not have struck capacity ratings.

Figure 3-1. 621G wheel scraper

OPERATING RANGE

3-3. The optimum haul distance for the small- and medium-size scrapers is 300 to 3,000 feet. There are larger scrapers that are effective up to 5,000 feet.

SELECTION

3-4. A scraper is a machine designed for medium-distance movement of materials, serving as a compromise between a machine designed exclusively for either loading or hauling. It is more efficient than a dozer due to its travel-speed advantage and faster than a truck, with a typical load time of less than a minute. Additionally, the scraper can spread its own load and quickly complete the dump cycle, providing another advantage.

PRODUCTION CYCLE

3-5. The production cycle for a scraper involves six operations: loading, haul travel, dumping and spreading, turning at the dump site, return travel, and turning and positioning to load. Figure 3-2 illustrates the functions of the apron, bowl, and ejector during loading, hauling, and dumping.

LOADING

3-6. The 621G scraper loads with push-tractor assistance. It can load to a limited extent without assistance but requires push loading to achieve maximum production. Pusher assistance is necessary to reduce loading time and wheel spinning, which in turn increases tire life. However, the scraper should not rely solely on the pusher to do all the work. Additionally, do not spin the wheels of the scraper to pull away from the pusher. Use pusher assistance for straight, downhill, or straddle loading. Always load the scraper in the direction of haul. Avoid turning the scraper at the same time it is accelerating from the loading operation. It is important to note that the 613 is a self-loading machine and pushing during loading will damage the loading elevator of the scraper.

Figure 3-2. Functions of the apron, bowl, and ejector

Downhill Loading

3-7. Downhill loading enables a scraper to obtain larger loads in less time. Each 1 percent of favorable grade is equivalent to increasing the loading force by 20 pounds per ton of gross scraper weight.

Straddle Loading

3-8. Straddle loading, as shown in figure 3-3 involves making three cuts with a scraper. The first two cuts should be parallel, leaving a ridge of earth between them. The scraper is then used to make the final cut while straddling this ridge. It is important to ensure that the ridge is no wider than the distance between the wheels of the scraper. This technique allows for time savings on every third trip, as the center strip loads with less resistance compared to a full cut.

Figure 3-3. Straddle loading with pusher assistance

Push-Loading

3-9. **Back-track**. Use the back-track push-loading technique (see figure 3-4, page 34) where it is impractical to load in both directions. However, this method is inefficient due to the time spent in backing up and repositioning for the next load.

3-10. **Chain.** Use the chain push-loading technique (see figure 3-4) where the cut is fairly long, making it possible to pick up two or more scraper loads without backtracking. The pusher pushes one scraper, then moves behind another scraper that is moving in the same direction in an adjacent lane.

3-11. **Shuttle**. Use the shuttle push-loading technique (see figure 3-4) for short cuts where it is possible to load in both directions. The pusher pushes one scraper, then turns and pushes a second scraper in the opposite direction.

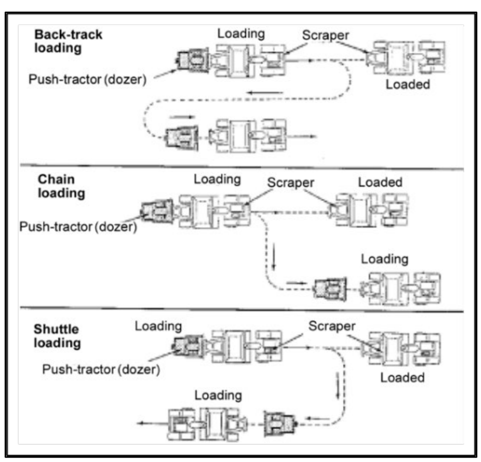

Figure 3-4. Push-loading techniques

Cut-and-Load Sequence

3-12. The scraper loading sequence is as follows:

- ***Step 1.*** Use the service brake to reduce scraper travel speed when close to the cut (loading lane), and downshift to first gear for loading.
- ***Step 2.*** Move the ejector to the rear.
- ***Step 3***. Open the apron partway.
- ***Step 4***. Lower the bowl to an efficient cut depth after the scraper enters the cut. Continue moving forward until the dozer contacts the scraper and begins pushing. If the scraper tires spin before the dozer makes contact, stop and allow the dozer to assist. When the dozer makes contact, push down the differential lock pedal and the transmission hold button and proceed in second gear. The cut should be as deep as possible, but it should allow the scraper to move forward at a constant speed without lugging the engine. Decrease the cut depth if the scraper, pusher lugs, or drive wheels slip. Use the router bits on the vertical side of the bowl to gauge the depth of cut. Once an efficient depth of cut is determined, use that same depth on successive passes.

Note. 621G will remain in drive with the transmission limiting switch activated.

- ***Step 5.*** Mark the cut. When cutting—
  - Regulate the apron opening to prevent material from piling up in front of the lip or falling out of the bowl.
  - Keep the machine moving in a straight line while maintaining pusher and scraper alignment.
  - Do not overload the scraper. Overloading lowers efficiency and places unnecessary stresses on the machine.
  - Raise and lower the bowl rapidly when loading loose material such as sand.

Note. When a push tractor is used, it should be waiting about 45° off of the lane to be cut. This allows the loading unit to come in with the least delay and difficulty.

- ***Step 6.*** Raise the bowl slowly when full, while at the same time closing the apron to prevent spillage.
- ***Step 7.*** Allow the pusher to help the machine out of the cut area, if necessary.

Note. After finishing the cut, release the transmission hold and/or the differential lock if engaged. Accelerate to travel speed as quickly as possible. Drive a short distance before raising the bowl to the carrying position. This will help spread any loose material that has accumulated in front of the bowl and enable the following scraper to maintain its speed.

Materials

3-13. Materials include—

- **Loam and clay.** Loam and most clay soils cut easily and rapidly with minimum effort. However, loosen very hard clay with a dozer ripper before loading.
- **Sand**. Since sand has little or no cohesion between its particles, it tends to run ahead of the scraper blade and apron. The condition is worse for finer and drier particles. When loading sand, the best method is as follows:
  - ***Step 1***. Enter the loading area fast, lowering the bowl slowly, and pick up as much material as possible using the momentum of the scraper unit. This will fill the hard-to-reach rear area of the bowl.
  - ***Step 2.*** Shift to a lower gear once the momentum is lost and allow the pusher to assist.

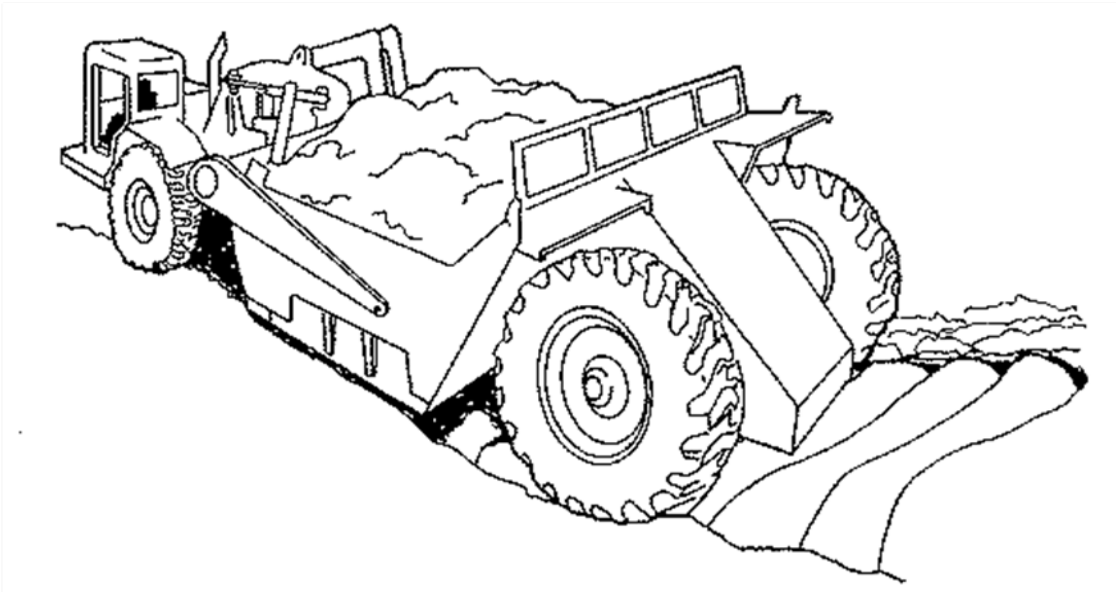

Figure 3-5. Pumping a scraper bowl to load sand

- *Step 3.* Pump the bowl up and down (see figure 3-5). For best pumping results, drop the bowl as the scraper's rear wheels roll into the depression of the previously pumped area and raise the bowl as the wheels are climbing out of the depression.
- ***Step 4.*** Drop the bowl sharply two or three times at the end of the loading area to top out the load. Then close the apron, raise the bowl, and exit the cut area.

- **Rock and Shale**. Loading rock and shale with a scraper can be tough on the equipment, causing wear and tear. To make the task easier, start by ripping the material before using the scraper. When ripping, make sure the depth exceeds the depth of the scraper cut. After ripping, leave a loose layer of material under the tires to improve traction and reduce wear on the tracks and tires. If the rock or shale is soft, ripping may not be necessary. When loading stratified rock, start the cutting edge of the scraper in dirt if possible and catch the blade in planes of lamination to force material into the bowl. Lastly, pick up loose rock or shale on level ground or on a slight incline, with the blade following the lamination planes.

Load Time

3-14. It is crucial to minimize loading time to achieve maximum scraper production. Ideally, push loading should take less than one minute over a distance of 100 feet, although these values may change depending on the material being loaded. Studies have shown that around 85 percent of the scraper's load capacity is reached within the first 0.5 minute of loading during normal operation. Further loading for an additional 0.5 minute will only result in about a 12 percent increase in load volume. Therefore, any extra loading time beyond one minute is not worthwhile, as it will only lead to decreased production due to increased total cycle time.

Borrow-Pit Operation

3-15. The borrow-pit area requires highly competent personnel. Implementing traffic control within the area will minimize waiting time and unnecessary travel for earthmoving support units. Proper drainage maintenance throughout the borrow pit will decrease downtime due to inclement weather.

HAULING

3-16. Hauling, or travel time, includes the haul time and the return time. Here, the power and traction characteristics of the scraper become very important. The following factors can greatly affect travel time.

Haul-Route Location

3-17. Lay out the haul routes to eliminate unnecessary maneuvering. Plan the job to avoid adverse grades that could drastically reduce production. Remember that, where grades permit, the shortest distance between two points is always a straight line.

Road Maintenance

3-18. Keep haul roads in good condition. A well-maintained haul road permits traveling at higher speeds, increases safety, and reduces operator fatigue and equipment wear.

- **Ruts and rough surfaces.** Use a grader or dozer to eliminate ruts and rough (washboard) surfaces. (See chapter 4 for haul-road maintenance with a grader.)
- **Dust.** Use water distributors to reduce dust. Reducing the amount of dust helps alleviate additional mechanical wear, provides better visibility, and lessens the chance of accidents. Keeping roads moist (but not wet) allows them to pack into hard, smooth surfaces permitting higher travel speeds.

Travel Conditions

3-19. When driving on the haul road, the scraper should use the highest safe gear suitable for the road conditions. Whenever possible, keep the scraper bowl relatively close to the ground, at about 18 inches. This helps to lower the scraper's center of gravity and reduces the risk of overturning.

- **Lugging.** Avoid unnecessary lugging of the engine. Downshift when losing momentum. Lugging the engine usually results in a slower speed than the top range of the next lower gear. Although the machine can handle it, it is best to downshift and accelerate faster. Lugging causes a decrease in engine revolutions per minute (rpm), thereby reducing hydraulic pressure, which can result in a loss of steering control.
- **Coasting.** Never coast on a downgrade. When approaching a downgrade, slow down and downshift the transmission. Use the transmission hold on a downgrade to prevent unwanted upshifting. Also, use it when approaching an upgrade or in rough underfooting. To control speed on a downgrade, use the retarder and service brakes. Engine speed should not exceed the recommended rpm of the manufacturer.

DUMPING AND SPREADING

3-20. When dumping, lower the bowl to the desired lift height and open the apron at the beginning of the dump area. Dump and spread in the highest gear permitted by haul-road conditions and fill-material characteristics. Maintaining a constant speed, along with the appropriate bowl height, will help to ensure a uniform depth of the material being lifted. Slowly dribbling the load at low speed will slow down the dumping cycle.

Dumping Procedure

- ***Step 1.*** Move steadily across the spreading area.
- ***Step 2.*** Open the apron fully as the scraper reaches the location to begin dumping. Move the ejector forward to push the material out of the bowl.
- ***Step 3.*** Maintain a straight path through the spread area.
- ***Step 4.*** Close the apron when all the material is out of the bowl and return the ejector to the rear of the bowl.
- ***Step 5***. Raise the bowl slowly to clear obstacles (12 to 18 inches) during the return trip to the loading area.

Spreading Sequence

- ***Step 1.*** Dump and spread the first load at the front of the fill.
- ***Step 2.*** Travel with subsequent loads over the previous fill, provided the lifts are shallow.
- ***Step 3.*** Start each following dump at the end of the previous fill.
- ***Step 4.*** Finish dumping and spreading one full lane before starting a new one so that rollers can start compaction.

- ***Step 5.*** Repeat this method in the next lane. Do not waste time on the fill. The scraper should return to the cut area as fast as possible after dumping the load. Plan the egress from the fill area to avoid soft ground or detours around trees or other obstacles.

Note. Route the scrapers to compact the fill. Overlap wheel paths to aid in compaction of the entire area and to reduce compaction time for rollers.

CAUTION

Do not try to force wet or sticky material out of the bowl too fast. This will cause the material to roll up in front, which can damage the hydraulic system.

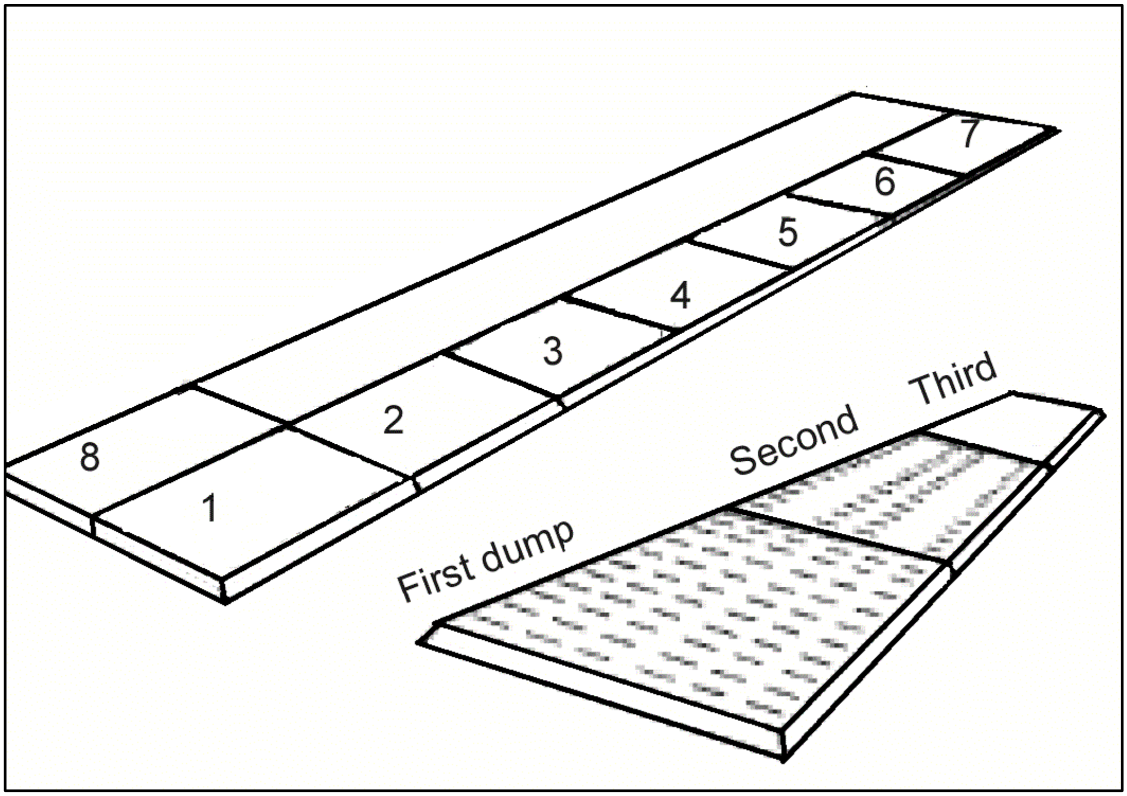

Figure 3-6. Spreading sequence

Fill Slope

3-21. To maintain the desired fill slope, make the fill high on the outside edges. This will prevent the scraper from sliding over the slope and damaging the slope. If there is rain, build up the low center for drainage, or use a grader to cut the outside edge down, creating a crown in the middle of the area.

Materials

3-22. Different materials require different dumping and spreading procedures.

- **Sand**. Spread sand as thin as possible to allow better compaction and to make traveling over the fill easier.

- **Wet or sticky material.** Wet or sticky material may be difficult to unload or spread. When operating in these material types—
  - Do not try to spread the material too thin.
  - Keep the bowl high enough to allow the material to pass under the scraper. Material not having enough room to pass under the scraper will roll up inside the bowl into a solid mass that is difficult to eject.
  - Bring the ejector forward about 12 inches at a time.
  - Back the ejector about 6 inches after each forward movement. This breaks the suction between the material and the bowl.
  - Repeat this procedure until the bowl is empty.

PRODUCTION ESTIMATES

3-23. The following provides a step-by-step explanation of production estimating using the 621G scraper. When gathering data for production estimates, take into account all factors that affect production. This includes considering the scraper's weight, the load's weight, and the average grade and rolling resistance of both the haul and return routes to determine cycle time. These steps can be applied to other makes and models of scrapers by utilizing the appropriate tables and charts for those specific scrapers.

- ***Step 1.*** Determine the vehicle weight, empty and loaded.
  - **Empty vehicle weight (EVW), in tons.** Using table 3-1, first determine the EVW from the EVW column based on the specific make and model of the scraper.
  - **Weight of load, in tons.** Determine the weight of the load in pounds by determining the scraper load volume in cubic yards (this is in LCY of the material) and the material unit weight (in pounds per LCY). If no specific material-weight data is available, use the information in table 1-2, page 3, as an estimate. Multiply the scraper load volume by the unit weight in pounds per LCY of the material to be excavated. Then, convert the resulting weight into tons by dividing the amount by 2,000.

$$Weight\ of\ load\ (pounds) = scraperload\ volume\ (LCY) x\ material\ unit\ weight\ (pounds\ per\ LCY)$$

$$Weight\ of\ load\ (tons) = \frac{weight\ of\ load\ (pounds)}{2{,}000}$$

Table 3-1. Scrapers specifications

Model	***Heaped Capacity (Cubic Yards)***	***EVW (Tons)***
613B	11	15.6
621G	22	37.5

  - **Loaded or gross vehicle weight (GVW).** Determine the GVW by adding the EVW (tons) and the weight of load (tons).

$$GVW\ (tons) = EVW (tons) +\ weight\ of\ load\ (tons)$$

3-24. Example:

Determine the GVW of a 621G single-powered scraper with a 20 LCY load of dry loam.

From table 1-2, page 3, dry loam is 1,900 to 2,200 pounds per LCY. Use an average value of 2,050 pounds per LCY.

$$Weight\ of\ load\ (tons) = \frac{20\ LCY\ x\ 2{,}050\ pounds\ per\ LCY}{2{,}000\ pounds\ per\ ton} = 20.5\ tons$$

* $$EVW = 37.5\ tons$$

* $$GVW = 37.5\ tons + 20.5\ tons = 58\ tons$$

- ***Step 2.*** Determine the average grade (in percent) and the distance (in feet) for both the haul and return routes. Uphill grades are positive (+) and downhill grades are negative (-). Obtain this information from a mass diagram or a haul-route profile.

* **3-25. Example:**

The project mass diagram indicates that there is a 5 percent downhill grade from cut to fill and that the one-way distance is 800 feet. The same route will be used for both the haul and the return.

Haul:

Average grade = -5 percent
Distance = 800 feet

Return:

Average grade = +5 percent
Distance = 800 feet

$$RR_{Haul} = (40 + [30\ x\ TP])x\ GV$$

$$RR_{Return} = (40 + [30\ x\ TP])x\ EVW$$

where—

RR_{Haul} = haul rolling resistance, in pounds

RR_{Return} = return rolling resistance, in pounds

40 = constant that represents the flexing of the driving mechanism, in pounds per ton

30 = constant that represents the force required to climb out of the rut, in pounds per ton per inch

TP = tire penetration, in inches (may be different for the haul and the return)

3-26. Example:

Determine the rolling resistance (haul and return) for a 621G scraper carrying a 20.5-ton load if the tire penetration during the haul is 3 inches and the tire penetration on the return is 1 inch.

* RR_{Haul} = (40 + [30 x 3 inches]) x 53.8 tons = 7,540 pounds

RR_{Return} = (40 + [30 x 1 inch]) x 37.5 tons = 2,625 pounds

Figure 3-7. Rolling resistance

Table 3-2. Representative rolling-resistance values

Road Condition	***Resistance Value (Pounds Per Ton)***
Hard, smooth surface with no tire penetration (well maintained)	40
Firm, smooth surface, flexing slightly under load (well maintained)	65
Flexible dirt roadway (irregular surface): With about 1 inch of tire penetration With up to 4 inches of tire penetration	 100 150
Soft, muddy roadway (irregular surface or sand) with over 6 inches of tire penetration	220 to 400

- ***Step 4.*** Determine the grade resistance or the grade assistance. Grade resistance is the force that opposes the motion of a vehicle when moving uphill, while grade assistance is the force that helps the vehicle move downhill. When facing uphill (adverse) grades, the vehicle requires more power to overcome both rolling and grade resistance. Conversely, when encountering downhill (favorable) grades, the force of gravity aids in propelling the vehicle. Adverse grades are indicated by a plus (+) and favorable grades by a minus (-). In earthmoving, grades are measured as a percentage of slope, representing the ratio between the vertical rise or fall and the horizontal distance over which the rise or fall occurs. For example, a rise of 1 foot in a 20-foot horizontal distance results in a +5 percent grade (**1/20x100**). The grade resistance or assistance can be determined using the following formula:

$$GR(+) or\ GA(-) 20\ x\ percent\ grade\ x\ vehicle\ weight\ (tons)$$

Therefore:

$$GR(+)_{Haul}\ or\ GA(-)_{Haul} = 20\ x\ percent\ grade\ x\ GVW\ (tons)$$

$$GR(+)_{Return}\ or\ GA(-)_{Return} = 20\ x\ percent\ grade\ x\ EVW\ (tons)$$

where—

GR(+) = grade resistance, in pounds

GA(-) = grade assistance, in pounds

20 = constant that represents 20 pounds per ton of vehicle weight per degree of slope

Note. Enter the percent grade as a percent not as a decimal.

3-27. Example:

Determine the grade resistance and grade assistance for a 621G scraper carrying a 20.5-ton load on a -5 percent grade from cut to fill.

* GA(-)Haul = 20 x (-5 percent) x 58 tons (GVW) = -5,800 pounds

GR(+)Return = 20 x (+5 percent) x 37.5 tons (EVW) = +3,750 pounds

- ***Step 5.*** Determine the rimpull required. Rimpull required is a measure of the force needed (in pounds) to overcome the vehicle's rolling resistance and grade assistance/grade resistance. Use the following formula to determine the rimpull required:

$$RPR = RR + GA(-) or\ GR(+)$$

where—

RPR = rimpull required, in pounds

RR = rolling resistance, in pounds

GA(-) = grade assistance, in pounds

GR(+) = grade resistance, in pounds

3-28. Example:

Determine the rimpull required on the haul and return based on the following data:

RR_{Haul} = 6,994 pounds; GA(-) = 5,800 pounds

RR_{Return} = 2,331 pounds; GR(+) = 3,750 pounds

* RPR_{Haul} = 6,994 pounds + (-5,800) pounds = 1,194 pounds

RPR_{Return} = 2,331 pounds + (+3,750) pounds = 6,082 pounds

The available rimpull is the maximum amount of force that the traction of the vehicle can handle. While the engine may be capable of producing this force, it must also be effectively transferred to the ground through the tires. Therefore, the required rimpull must always be less than the available rimpull to avoid tire slippage and ensure that the work can be completed.

- ***Step 6.*** Determine the travel speed.
  - The travel speed of a piece of equipment is the maximum speed at which the vehicle can develop the rimpull required to overcome the opposing forces of grade and rolling resistance. The manufacturer normally provides this information in tables or charts. Figure 3-8 and figure 3-9, page 44, show rimpull charts for the 621G and the 613B.
  - To determine the travel speed, first find the rimpull required for either the haul or return on the left side of the chart. Then, move to the right until you intersect the line representing the highest gear that can achieve that amount of rimpull. Finally, read down from the gear intersect to determine the maximum travel speed.

Note. Determine the travel speed for both the haul and the return.

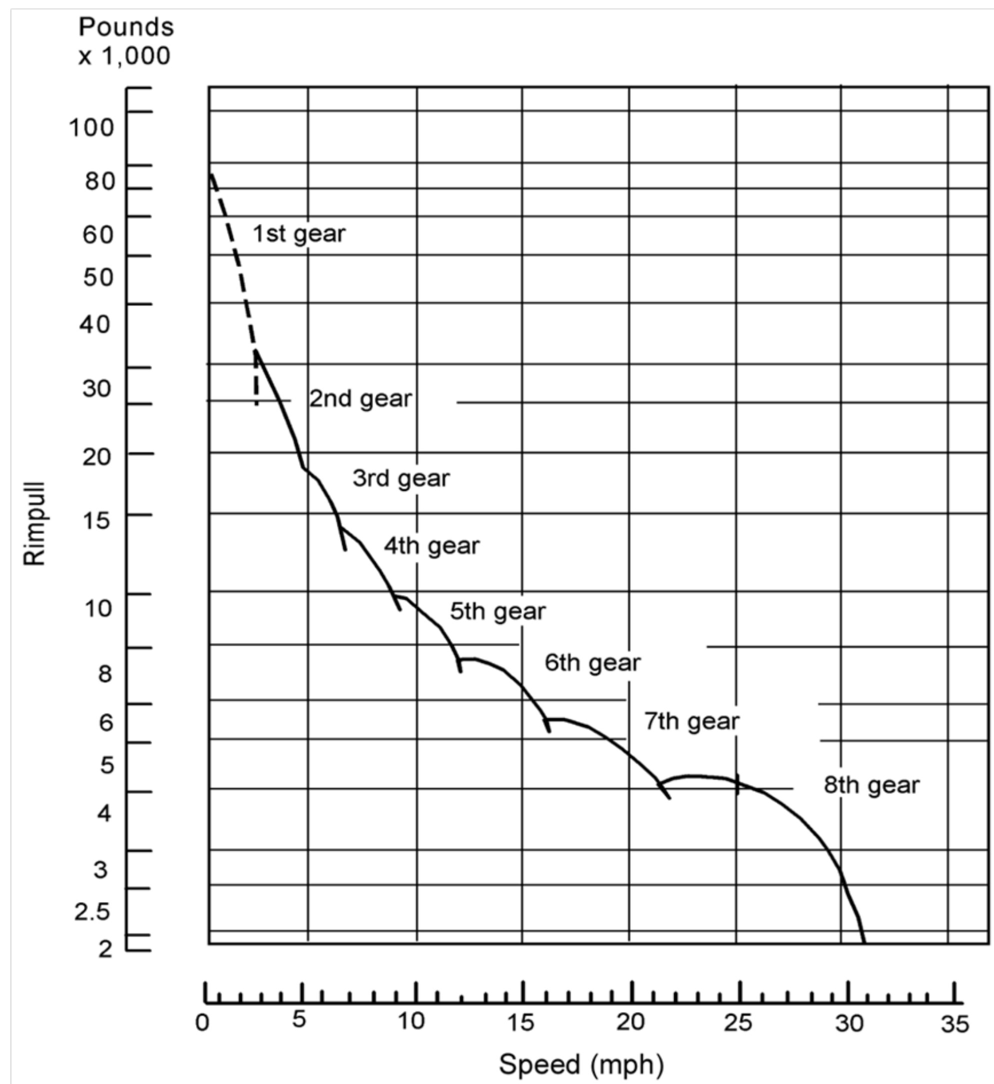

Figure 3-8. Speed chart for the 621G

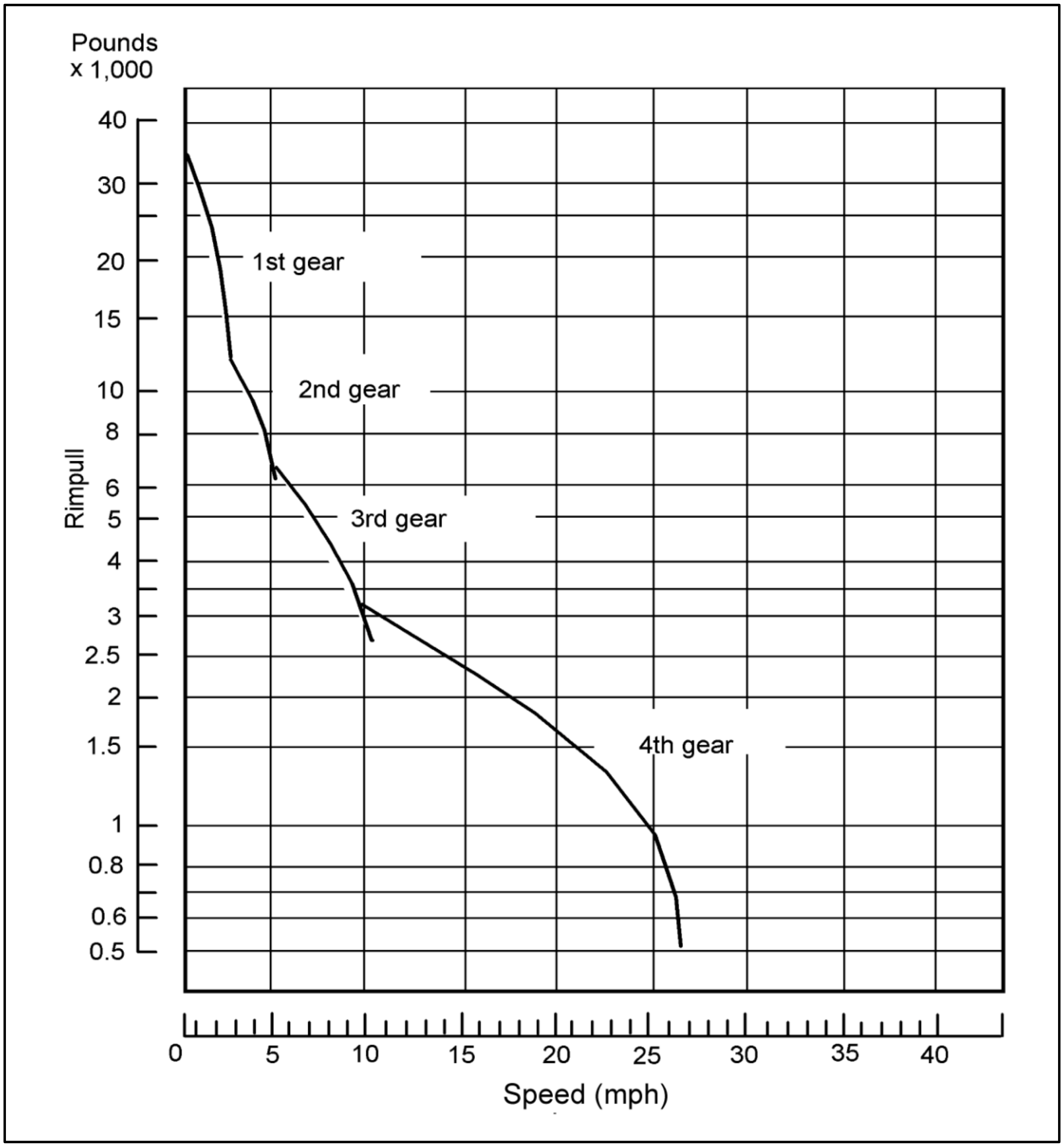

Figure 3-9. Speed chart for the 613B

3-29. Example:

Determine the maximum travel speed for a 621G scraper, based on the following data.

*

RPR_{Haul} = 1,194 pounds

RPR_{Return} = 6,082 pounds

First, to determine the travel speed for the haul, refer to figure 3-8, page 43, and locate 1,614 pounds on the scale. Since this is below the lowest scale number of 2,000 pounds, use the bottom line on the rimpull scale. Read right to determine travel gear (eighth gear) and down to determine travel speed (31 miles per hour [mph]).

* Second, you need to determine the travel speed for the return. To do this, you should refer to figure 3-8, page 43, and locate the point on the rimpull scale corresponding to 6,082 pounds (you will need to interpolate between 6,000 and 8,000). Once you have located this point, read towards the right to determine the travel gear (sixth gear) and downwards to determine the travel speed (16 mph).

Note. If the computed travel speed (either haul or return) exceeds the standing operating procedure (SOP) maximum allowable speed of the unit, the travel time should be determined based on the maximum allowable speed in the SOP.

- ***Step** 7*. Determine the total travel time. Total travel time is the sum of the time it takes the vehicle to complete one haul and one return.

$$Total\ TT = TT_{Haul} + TT_{Return}$$

where—

TT = travel time

- First, determine the haul travel time.

$$TT_{Haul} = \frac{average\ haul\ distance\ (feet)}{88\ x\ travel\ speed\ _{Haul}}$$

where—

TT = travel time, in minutes

88 = conversion factor used to convert mph into feet per minute (fpm)

- Second, determine the return travel time (in minutes).

$$TT_{Return} = \frac{average\ return\ distance\ (feet)}{88\ x\ travel\ speed_{Return}}$$

where—

TT = travel time, in minutes

88 = conversion factor used to convert mph into fpm

Note. The haul and return routes are not always the same. Be sure to use the correct haul distance for each computation.

3-30. Example:

Determine the total travel time for a 621G based on a haul speed of 32 mph, a return speed of 17 mph, and a haul distance of 800 feet. The SOP of the unit limits scraper travel speed to 25 mph.

Determine the haul and return travel time.

* $$l\ \frac{800\ feet}{88\ x\ 25\ mph} = 0.36\ minutes$$

* $$TTR_{eturn}\ \frac{800\ feet}{88\ x\ 16\ mph} = 0.57\ minutes$$

Determine the total travel time.

* $$Total\ TT = 0.36 + 0.57 = 0.9\ minutes$$

*

- ***Step 8.*** Determine the cycle time.
  - The cycle time is the total travel time plus the time required for loading, dumping, turning at the dump site, and turning and positioning to load, along with the time to accelerate/decelerate during the haul and return.
  - The average dumping time for scrapers with a heaped capacity of less than 25 cubic yards is 0.3 minutes. The type or size of the scraper does not significantly affect the turning time. The average turning time in the cut is 0.3 minutes, and 0.21 minutes on the fill. The turning time is slightly higher in the cut due to congestion in the area and the need for positioning for loading. Therefore, for both the 613B and the 621G scrapers, allow 0.81 minutes for dumping, turning at the dump site, and turning at the load site. The loading time is the consequential variable.
  - A good average time for loading the 621G with a D8 or equivalent-size push tractor is 0.85 minutes. If using a smaller push tractor, you can modify the time for loading or the assumed load volume. Expect load times approaching 1 minute when using a D7. The self-loading 613B requires 0.9 minute to load in good material such as loam, loose clay, or sandy material. However, if you encounter tight materials, the loading duration will increase. To determine the turn-and-dump time and the load time for a special piece of equipment, time the equipment as it goes through a few cycles.

*

$$CT = total\ TT + TD + LT$$

where—

CT = total scraper cycle time, in minutes

TT = travel time

TD = total turn and dump time

LT = load time

3-31. Example:

Determine the cycle time for a 621G scraper with a D7 push tractor based on a travel time of 0.9 minute and an average turn and dump and load time.

$$\boldsymbol{CT\ (minutes) = 0.9\ minute + 0.81\ minute + 1\ minute}$$

$$\boldsymbol{= 2.71\ minutes}$$

Step 9. Determine the trips per hour. To calculate the number of trips per hour, divide the number of working minutes per hour by the cycle time. Typically, there are around 50 minutes of productive time per hour on a well-managed scraper job. However, if the work is in a confined area like a ditch, or if the embankment is a narrow bridge header, the estimator should factor in a reduced productive time of 45 minutes per hour.

$$TPH = \frac{working\ minutes\ per\ hour}{CT}$$

where—

TPH = trips per hour

CT = total scraper cycle time, in minutes

3-32. Example:

Determine how many trips per hour a 621G can make based on a 50-minute working hour and a cycle time of 2.71 minutes per trip.

$$TPH = \frac{50\ minutes}{2.71\ minutes\ per\ trip} = 18.5\ trips$$

- ***Step 10***. Determine the hourly production rate. In order to calculate the hourly production rate, it is necessary to know the average size of each load (in LCY) and the number of trips made per hour. The average load size is determined by the scraper's capacity, the type of material, and the loading method.

$$P = TPH\ x\ average\ LCY\ per\ load$$

where—

P = hourly production rate, in LCY per hour

TPH = trips per hour

Note. To convert from LCY to either BCY or CCY, multiply the production rate by a soil conversion factor from table 1-1, page 3.

$$P\ (BCY\ per\ hour\ or\ CCY\ per\ hour) =\ P\ (LCY\ per\ hour)\ x\ conversion\ factor$$

where—

P = hourly production rate

3-33. Example:

Determine the hourly production rate in BCY per hour for a 621G working in loam, making 18.5 trips per hour, with an average load of 20 LCY.

P (LCY per hour) = 18.5 TPH x 20 LCY per load = 370 LCY per hour

P (BCY per hour) = 370 LCY per hour x 0.8 = 296 BCY per hour

- ***Step 11.*** Determine the total time in hours required to complete the mission. To determine the total time required to complete a mission, one must know the total volume to move, the hourly production rate, and the number of scrapers to be used on the job.

$$Total\ time\ (hours) = \frac{Q}{P\ x\ N}$$

where—

Q = total volume to move, in BCY

P = hourly production rate, in BCY per hour

N = number of scrapers

3-34. Example:

Determine how many hours it would take to move 19,440 BCY, using three 621G scrapers, each with an hourly production rate of 296 BCY per hour.

* $$Total\ time\ (hours) = \frac{19{,}440}{296\ BCY\ per\ hour\ x\ 3} = 22\ hours$$

If it is necessary to complete the job in a specified time, use the same basic formula to determine the required number of scrapers.

$$Number\ of\ scrapes\ required\ = \frac{Q}{P\ x\ H}$$

where—

Q = total volume to move, in BCY

P = hourly production rate, in BCY per hour

H = required number of hours

* • ***Step 12.*** Determine the number of push tractors required. The number of push tractors needed is determined by the ratio of the scraper cycle time to the push-tractor cycle time. When using self-loading scrapers like the 613B, a push tractor is not required, so this part of the analysis is unnecessary.

$$N = \frac{CT}{PT}$$

where—

N = number of push tractors required

CT = total scraper cycle time, in minutes

PT = total pusher cycle time, in minutes

- Load time (discussed in step 8). A 621G loading with a D7 push tractor requires about 1 minute to load. This is the time the push tractor is in contact with the scraper.
- Push-tractor cycle time. Once a scraper load time has been determined, use the following formula to determine the push-tractor cycle time.

$$PT = (1.4 \ x \ LT) + 0.25$$

where—

PT = total push-tractor cycle time

1.4 = constant that represents scraper load time and push-tractor travel time between scrapers

LT = load time

0.25 = constant that represents push-tractor positioning time

At this point, the number of scrapers that a single push tractor will support can be determined.

3-35. Example:

Determine how many 621G scrapers a single push tractor can support if the scraper cycle time is 2.71 minutes and the scraper load time is 1 minute.

$$PT = (1.4 \ x \ 1) + 0.25 = 1.65 \ minutes$$

$$Number \ of \ scrapers = \frac{2.71 \ minutes}{1.65 \ minutes} = 1.64 \ scrapers$$

This example shows that the push-tractor cycle time will control the production when using only one push tractor and more than one scraper on the project. The push-tractor production formula is—

$$P = \frac{working \ minutes \ per \ hour}{PT} \ x \ scraper \ load \ (LCY)$$

where—

P = hourly production rate, in LCY per hour

PT = total push-tractor cycle time, in minutes

As was done in step 10, convert the production into BCY or CCY by using the table 1-1, page 3, soil conversion factors.

3-36. Example:

Determine what the production will be in BCY if a single push tractor, with a cycle time of 1.65 minutes supports two 621G scrapers hauling 20 LCY of loam. Assume a 50-minute working hour. The scrapers have a cycle time of 2.71 minutes.

*

$$Number \ of \ scrapers \ one \ pusher \ can \ support = \frac{2.71 \ minutes}{1.65 \ minutes} = 1.64 \ scrapers$$

Therefore, if using only one push tractor, the pusher cycle time will control production

$$P\ (BCY\ per\ hour) = \frac{50}{1.65} x\ 20\ LCY\ x\ 0.8 = 485\ BCY\ per\ hour$$

Note. If the incorrect assumption was made that one pusher could handle two scrapers, the production would have been calculated at 590 BCY per hour.

$$P\ (BCY\ per\ hour) = \frac{50\ minutes}{2.71\ minutes} x\ 2\ scrapers\ x\ 20\ LCY\ x\ 0.8\ = 590\ BCY\ per\ hour$$

where—

P = hourly production rate

Once the number of scrapers that one push tractor can support has been determined, use the following formula to determine how many push tractors are needed to support the job if using additional scrapers.

$$Number\ of\ push\ tractors\ required = \frac{number\ of\ scrapers\ on\ job}{number\ of\ scrapers\ a\ push\ tractor\ can\ support}$$

3-37. Example:

Determine how many push tractors are required on a job that has nine 621G scrapers, if a single push tractor can support 1.64 scrapers.

* $$Number\ of\ push\ tractors\ required = \frac{9\ scrapers}{1.64\ scrapers\ per\ push\ tractors} = 6\ push\ tractors$$

Chapter 4
Graders

Graders are versatile machines used for grading, shaping, bank sloping, and ditching. They are also used for mixing, spreading, side casting, leveling, crowning, general construction, and road and runway maintenance. Graders cannot perform dozer work due to the structural strength and location of their blade. However, they can move small amounts of material. They are capable of working on slopes as steep as 3:1 and cutting ditches to a depth of 3 feet.

GRADER COMPONENTS

4-1. The blade and the scarifier are the main components of the grader that perform the work. The position and pitch of the blade are adjustable and determined by the type of operation being carried out.

BLADE

4-2. The primary part of a grader blade is a moldboard that is controlled hydraulically, to which the cutting edges are attached with bolts. You can use the blade (see figure 4-1, page 52) to move material to the side. The ends of the blade can be raised or lowered together or independently of each other.

Blade Position

4-3. The blade can be positioned perpendicular or parallel to the direction of travel. It can also be shifted to either side or raised vertically (see figure 4-2, page 53).

Blade Pitch

4-4. The blade can be adjusted to pitch forward or backward (see figure 4-3, page 53). It is important to keep the blade near the center of the pitch adjustment in order to keep the top of the moldboard directly over the cutting edge of the blade. When the blade is pitched forward, its cutting ability decreases and dragging action increases. In this position, the blade tends to ride over the material rather than cut and push, and it has less chance of catching on solid obstructions. A forward pitch is ideal for making light, rapid cuts and blending materials. On the other hand, when the blade is pitched to the rear, it cuts readily, but the material tends to boil over itself.

SCARIFIER

4-5. To break up hard material that the blade cannot cut, use a scarifier (see figure 4-1). The scarifier has 11 removable teeth that can be adjusted to cut up to 12 inches deep. When working with hard material, you may need to remove some of the teeth. However, do not remove more than five teeth as this could shear off the remaining ones due to the force against them. When removing teeth, start with the center one and then alternate with the other four teeth. This helps balance the scarifier and distribute the load evenly. With the top of the scarifier pitched to the rear, the teeth lift and tear the material being loosened. Use this position for breaking up asphalt pavement. Adjust the pitch of the scarifier according to the type of material being ripped.

ROAD AND DITCH CONSTRUCTION

4-6. Road grading, embankment finish work, and shallow-ditch construction are basic grader operations.

MARKING FOR A DITCH CUT

4-7. To achieve better grader control and straighter ditches, it is recommended to make a 3- to 4-inch-deep marking cut on the first pass (see figure 4-4, page 54) at the outer edge of the bank slope, which is usually marked by slope stakes. Ensure that the toe of the blade is aligned with the outside edge of the lead wheel. This marking cut will serve as a guide for subsequent operations.

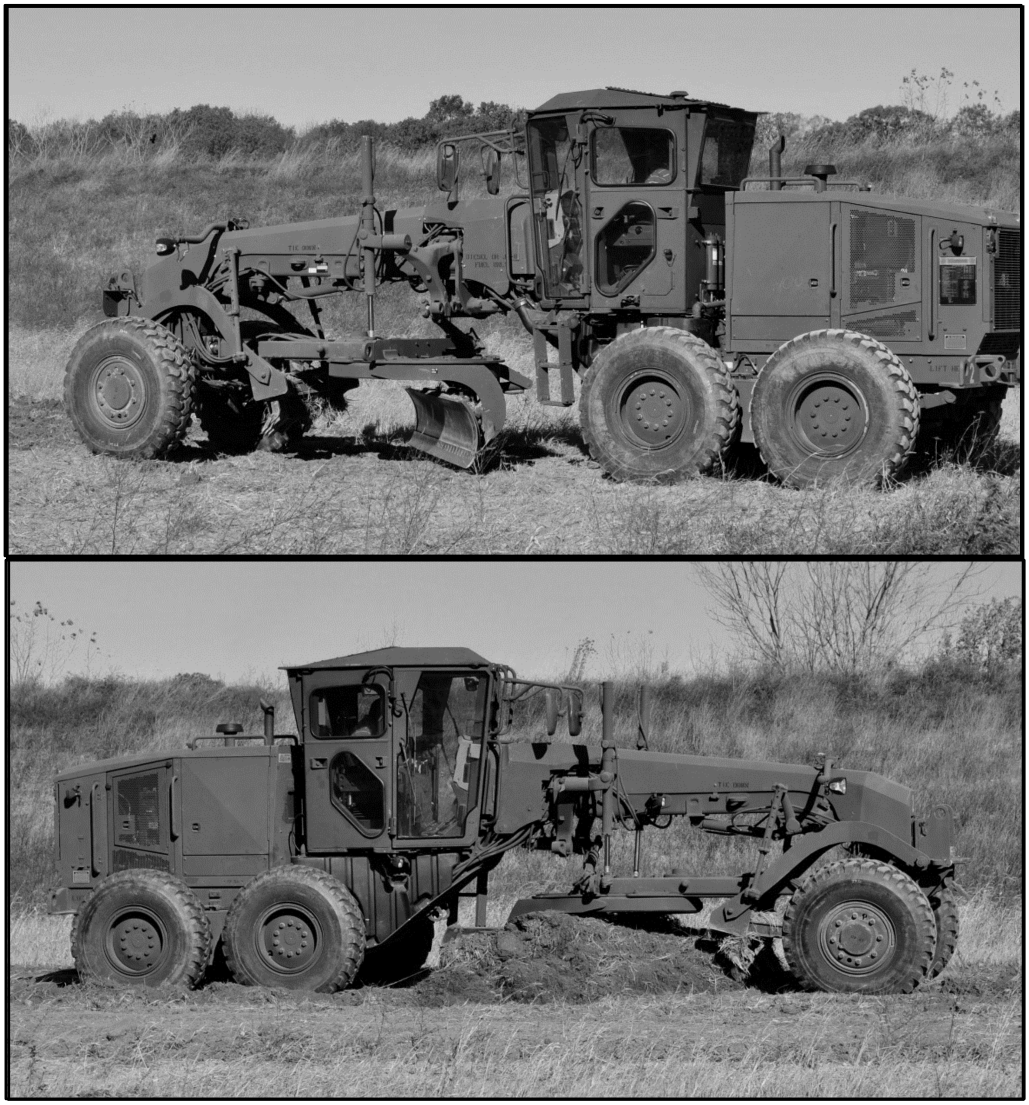

Figure 4-1. Grader

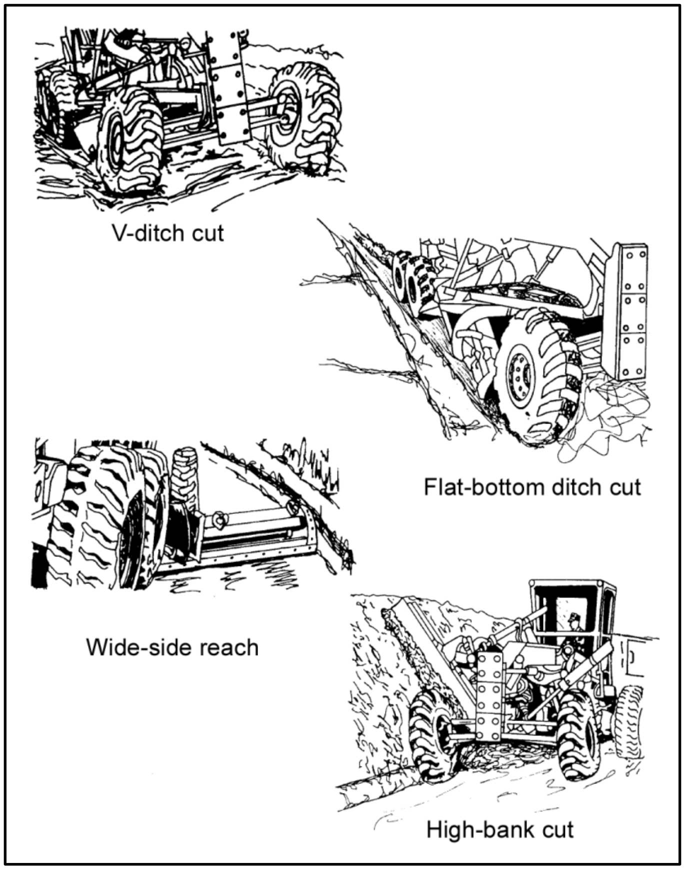

Figure 4-2. Blade positions

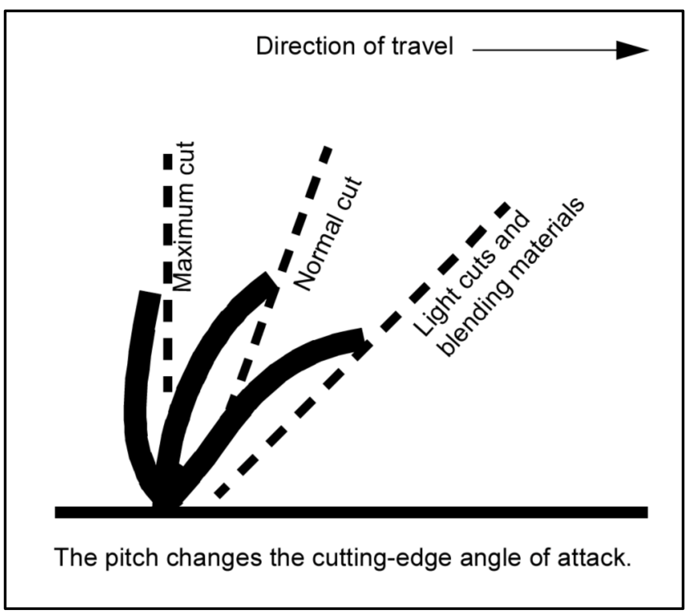

Figure 4-3. Blade pitch

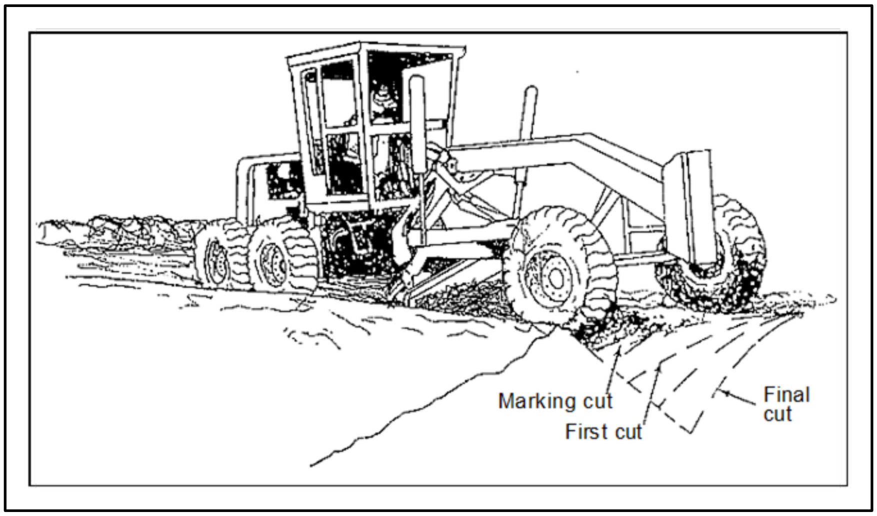

Figure 4-4. Starting a ditch

MAKING A DITCH CUT

4-8. Make each ditch cut as deep as possible without stalling or losing control of the grader. Normally, make ditching cuts in second gear at full throttle. Start with the blade positioned so that the toe is in line with the center of the lead wheel. Bring each successive cut in from the edge of the bank slope so that the toe of the blade will be in line with the ditch bottom on the final cut. Figure 4-5 shows the steps of the V-ditching method for a single roadside ditch. Repeat the steps on the opposite side of the road. The frame of the machine should be articulated when performing steps 4 and 7.

Marking The Cut

- ***Step 1.*** Begin the ditch by establishing a marking cut as follows (ditching is normally done on the right-hand side of the grader):
  - Ensure that the moldboard is high enough off the surface to allow unrestricted movement.
  - Ensure that the blade is pitched halfway.
  - Center shift until the left lift cylinder (heel) is straight up and down.
  - Rotate the moldboard so that the toe is just behind the outside edge of the right front wheel (about a 45° angle to the frame).
  - Side shift the blade if necessary to extend the edge of the moldboard to the outside edge of the right front wheel.
  - Raise the left lift cylinder all the way.
  - Lean the front wheels to the left. The grader is now in the ditching position.
- ***Step 2***. Move the grader forward. As the right front wheel passes over the starting point of the ditch, lower the toe of the moldboard. Apply enough pressure on the toe to penetrate the surface of the ground about 3 to 4 inches.

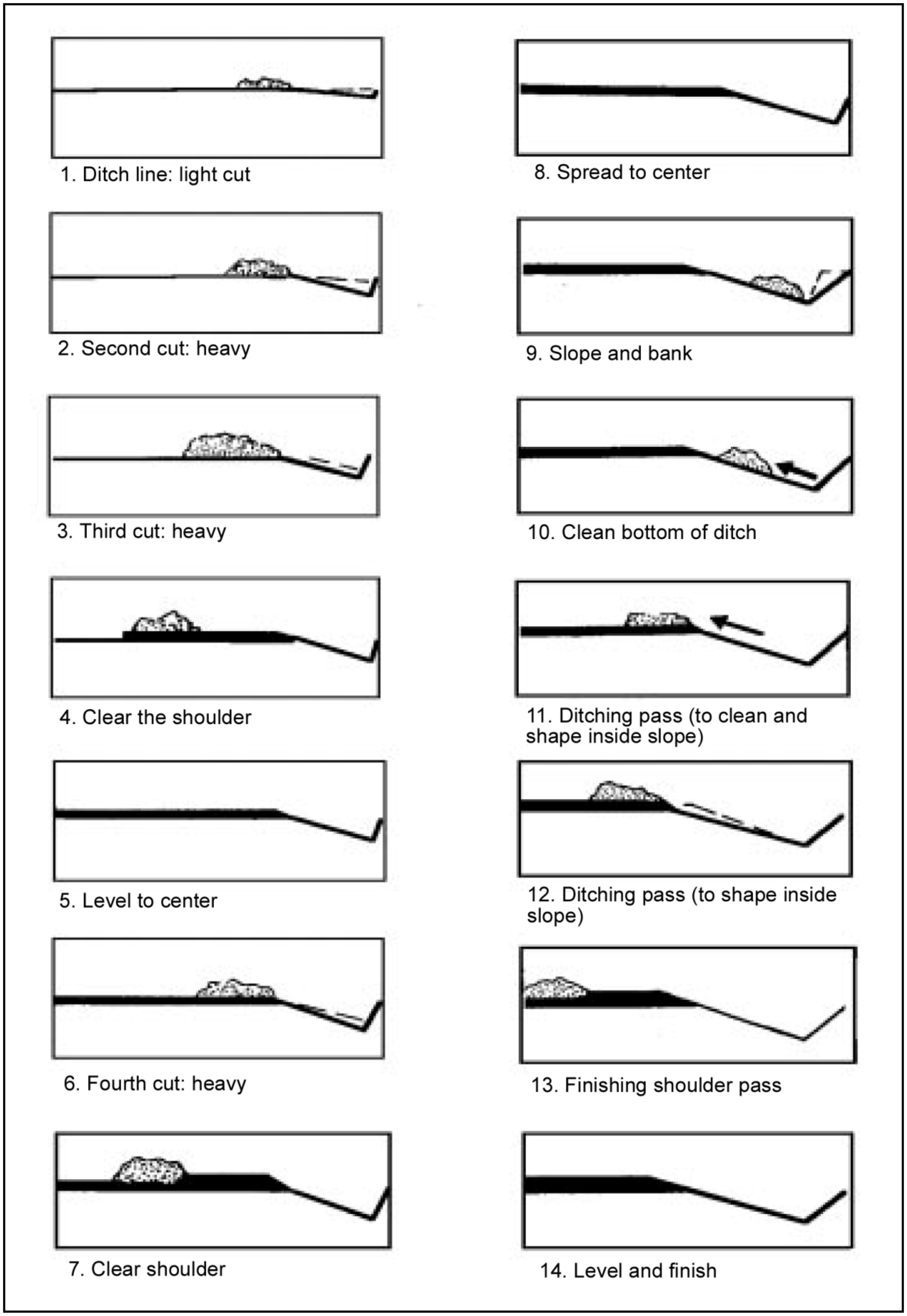

Figure 4-5. V-Ditching method

- ***Step 3.*** Feather the material and raise the moldboard toe clear of the ground at the completion of the marking cut. Continue moving forward until the rear wheels pass over and off the marking cut.

Note. Feathering is achieved by gradually raising the moldboard in 1/2- to 1-inch intervals while moving forward. It is recommended to wait two or three seconds between each upward adjustment until all the material in front of the moldboard passes under it.

- ***Step 4.*** Straighten the front wheels and steer the grader to the right (about a 45° angle to the ditch).
- ***Step 5.*** Back the grader along the outside edge of the windrow.
- ***Step 6.*** Reposition the grader at the start point.
- ***Step 7.*** Lean the front wheels to the left.

Establishing The Depth of The Ditch

- ***Step 1***. Place the grader in forward motion and apply as much downward pressure to the toe of the blade that the grader will handle.
- ***Step 2***. Continue along the ditch line until the grader has reached the finishing point, and then follow the exit procedures previously discussed under marking the cut.

Note. When making ditch cuts, windrows form between the heel of the blade and the left rear wheel. It is important to move or level these windrows when the ditch is at the planned depth or when the windrow becomes higher than the road clearance of the grader. This material will form the shoulder of the road.

Establishing The Shoulder of The Ditch

4-9. This task is accomplished by placing the grader in the wide-side reach position.

- ***Step 1***. Adjust the moldboard as follows:
  - Rotate the moldboard to a 90° angle (perpendicular) with the frame (straight across) and adjust the height of the blade to about 4 to 6 inches above the surface.
  - Center shift the blade all the way to the right.
  - Readjust the height of the blade to about 2 inches above the surface.
  - Side shift the blade all the way to the right.
  - Lean the front wheels to the left.
  - Circle the moldboard counterclockwise until the toe is about 12 to 15 inches from the outside edge of the front right wheel.

Note. Do not adjust the moldboard height, especially the left lift cylinder.

- ***Step* 2**. Move the grader forward and maintain a position and course so that the toe of the moldboard passes directly over the center of the ditch.
- ***Step 3.*** Apply enough downward pressure to skim the material from the shoulder; do not cut the shoulder.
- ***Step 4.*** Continue forward as the grader passes the finishing point of the ditch until all the material in front of the moldboard passes under it or is windrowed off the heel.
- ***Step 5.*** Continue forward until enough space is available to position the grader to back up and straddle the windrow.

Note. Place the grader in the right-hand general grade position, and the moldboard will be positioned to execute the next maneuver. Avoid backing the grader in the wide-side reach position.

- ***Step 6.*** Ensure that the front wheels are straight up and down before backing the grader.
- ***Step 7.*** Back the grader to the starting point of the project and, after stopping, lean the wheels to the left.

- ***Step 8.*** Lower the toe and heel of the moldboard to the surface.
- ***Step 9.*** Raise the heel about 2 to 3 inches and ensure that the toe is just touching the surface. With the heel raised about 3 inches, the loose material from the ditch should pass under and off the heel of the moldboard.
- ***Step 10.*** Move the grader forward. Maintain a straight course by keeping the grader centered on the windrow.
- ***Step 11.*** Skim the shoulder of the road with the toe and spread the windrow to form the surface of the road.
- ***Step 12.*** Ensure that the material is feathered at the end of the pass before stopping the grader.
- ***Step 13.*** Straighten the front wheels and raise both lift cylinders all the way.
- ***Step 14.*** Reposition the grader at the finishing end of the project. The grader should be positioned to establish a V-ditch (going the opposite direction) on the other side of the project area.

Note. Sometimes, when excavating ditches, more material than necessary is produced for the roadbed and shoulders. In such cases, the excess material can be used as fill at other locations within the project. To do this, blade the excess material into a windrow and then transport it to the appropriate location.

CREATING A BANK SLOPE

4-10. To prevent slope-sloughing failures and excessive erosion of the bank, slope the bank on a road cut. This will also prevent the roadside ditch from filling up. Start by casting the material cut from the outer slope into the bottom of the ditch and remove it later. Figure 4-6 shows a grader sloping a high-bank cut.

CLEANING A DITCH

4-11. To remove unwanted material that was pushed into the ditch during the bank slope operation, place the blade in the same position as used for the ditching cuts. This casts the material onto the shoulder.

FINISHING A SHOULDER

4-12. Move the windrow (formed by cleaning the ditch) onto the road at the same time the shoulder is being finished to the desired slope.

FINISHING A CROWN OR A CROSS SLOPE

4-13. The final operation is to spread all the material brought from the ditch onto the roadway. Use this material to bring the roadway to the desired crown or a cross slope.

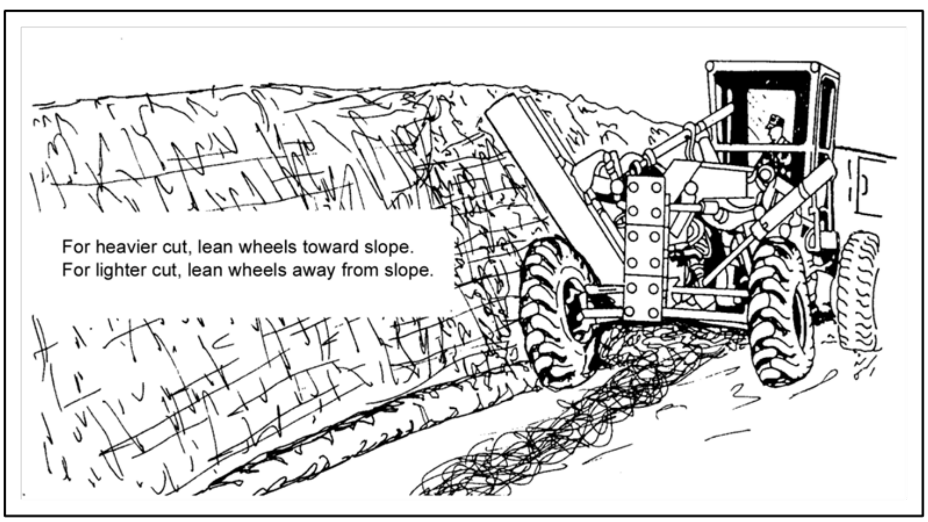

Figure 4-6. Sloping a high bank

EARTH- AND GRAVEL-ROAD MAINTENANCE

LEVELING AND MAINTAINING SURFACES

4-14. To maintain a smooth road or runway surface, typically you would work the material across the surface from one side to the other. However, to keep the surface in good condition during dry weather, you should move the eroded material from the edges and shoulders of the road towards the center. It is important to be careful when disturbing dry road surfaces because traffic or wind can cause the loss of binder material. The surface is easier to work with when it's damp, so it's best to perform surface maintenance after a rain. You may need to use a water truck to dampen dry material.

- ***Step 1***. Rotate the moldboard so that the toe is on the right side of the grader at about a 50° to 60° angle to the frame.
- ***Step 2***. Ensure that the blade is pitched halfway.
- ***Step 3.*** Center shift the blade until the left lift cylinder is straight up and down.
- ***Step 4.*** Lean the front wheels to the left.
- ***Step 5.*** Lower the moldboard until the toe and heel slightly touch the ground.
- ***Step 6.*** Place the grader in motion and, as the moldboard crosses the project start line, apply enough downward pressure on both the heel and the toe to penetrate the surface on a level plain about 1/2 inch.
- ***Step 7.*** Maintain a straight course, adjusting the moldboard slightly to carry the material the length of the project.
- ***Step 8.*** Feather the material at the end of the pass.
- ***Step 9.*** Stop the grader and straighten the front wheels after the material is feathered to a smooth termination.
- ***Step 10.*** Raise both lift cylinders all the way.
- ***Step 11.*** Position the grader to straddle the windrow just made, and back the grader to the starting point while ensuring the windrow is between the wheels (do not drive on top of the windrow).
- ***Step 12.*** Stop the grader just outside of the project boundary line.
- Repeat this process until the entire area is leveled.

SMOOTHING PITTED SURFACES

4-15. When there is binder present and the moisture content is appropriate, rough or badly pitted surfaces can be smoothed out. The material from the cut surface is then spread over the smooth base. It is best to reshape earth and gravel roads after a rain. If the roads are dry, they should be moistened using a water distributor to ensure that the material has enough moisture to compact properly.

CORRECTING CORRUGATED ROADS

4-16. When repairing corrugated roads, it is important to be cautious in order to avoid making the situation worse. Making deep cuts on a washboard surface can lead to blade chatter, which will only emphasize the corrugations instead of correcting them. Severely corrugated surfaces may need to be scarified. With the right moisture content, level the surface by cutting across the corrugations. Change the blade angle so that the cutting edge does not follow the rough surface. Cut the surface to the bottom of the corrugations, and then reshape the surface by spreading the windrows evenly across the road. Once the road is reshaped, traffic will help compact it. However, rolling the surface after shaping will provide better and longer-lasting results.

SCARIFYING ROADS OR AREAS

- ***Step 1***. Position the grader outside the working area.
- ***Step 2***. Ensure that the moldboard is high enough off the ground to allow unrestricted movement.
- ***Step 3.*** Rotate the moldboard so that it is perpendicular with the frame and adjust the height to 12 inches off the surface (level).
- ***Step 4.*** Center shift the blade until the lift cylinders are centered on the grader.
- ***Step 5.*** Pitch the blade halfway.
- ***Step 6.*** Ensure that the front wheels are vertical.
- ***Step 7.*** Move the grader forward.

- ***Step 8.*** Lower the scarifier as it crosses the starting point and penetrate the surface.
- ***Step 9.*** Scarify the entire length of the area to a minimum depth of about 6 inches.
- ***Step 10.*** Raise the scarifier at the finish point.
- ***Step 11.*** Exit the project area and stop the grader.
- ***Step 12.*** Rotate the moldboard to a 50° angle and adjust the center shift to straighten the heel cylinder.
- ***Step 13.*** Return to the starting point and reposition the grader for a second scarifying pass.

SNOW REMOVAL

4-17. Graders remove snow similarly to snowplows. When removing snow from uneven pavements or portable runway surfaces, be sure to raise the blade by 0.5 to 1 inch. Improper adjustment can cause damage to the grader and may gouge the surface.

ASPHALT MIXING

4-18. Asphalt can be mixed in place or mixed with imported aggregate. Chapter 12 provides additional information on asphalt mixing.

MIXED-IN-PLACE ASPHALT

4-19. For mixed-in-place asphalt, spread the asphalt directly on the road surface, either before or after scarifying the surface. After applying the asphalt, mix it with the surface soil by scarifying and/or windrowing with the blade.

IMPORTED AGGREGATE

4-20. When using imported aggregate for a pavement—

- ***Step 1***. Shape the existing base and prepare it by blading, rolling, and curing as necessary.
- ***Step 2***. Dump the aggregate mix and blade it into uniform windrows. If the aggregate is too wet, blade the windrows to allow evaporation of the excess moisture.
- ***Step 3.*** Flatten the windrow and apply the asphalt.
- ***Step 4.*** Mix the asphalt with the aggregate using the grader. Move the windrow from side to side across the road by making successive passes with the blade. Several graders can operate, one behind another (tandem), on the same windrow. If rain moistens the mixture, continue mixing until dry.
- ***Step 5.*** Blade the material back into a windrow after mixing and before spreading.

LARGE-AREA MIXTURES

4-21. Mark the edges of the spread width for each windrow with stakes. When spreading mixtures over large areas, use blue-top hubs (blue tops) to indicate the final pavement elevation. The blue tops are typically placed 20 feet apart in a grid pattern. Remove the blue tops before rolling the pavement. Usually, one pass of the grader will flatten the windrow, after which it can be spread to each side in increments. This will create a layer of uniform thickness with proper lateral and longitudinal slopes. A skilled grader operator is essential at this phase.

OPERATION TECHNIQUES AND TIPS

4-22. Graders can be used for spreading, leveling, side casting, and planning materials. Different procedures are required to achieve a desired result.

SPREADING AND LEVELING

4-23. To spread windrows of loose material (see figure 4-7), use a grader. If there is enough space to work around the sides of the windrows, extend the blade to the side and reduce the windrow by making a series of side cuts. Spread the windrows as much as possible. The grader's power and traction will limit the load that can be pushed. While graders have less power and traction compared to dozers, they move the load faster. The grader blade is lower and more concave than the dozer blade, providing increased rolling action to the load, allowing a large quantity to be pushed without spilling over the top. Leveling large windrows may require two or more side cuts with a grader (see figure 4-8).

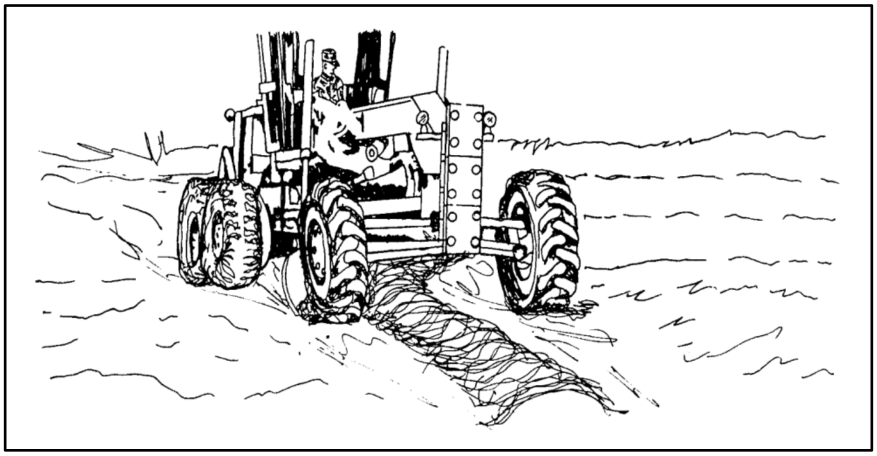

Figure 4-7. Spreading windrowed material

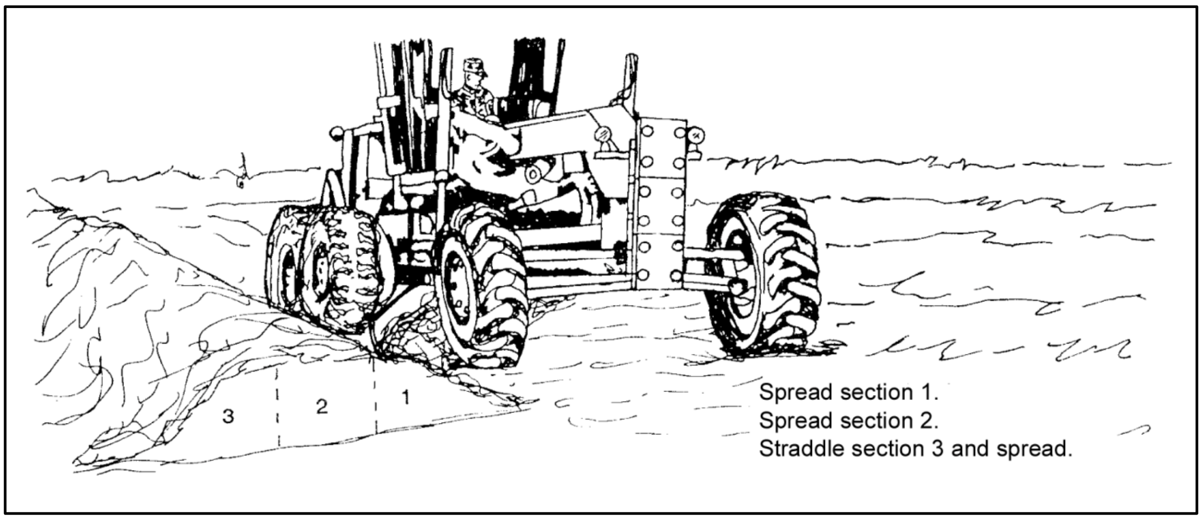

Figure 4-8. Leveling large windrows

SIDE CASTING

4-24. Set the blade at an angle so that the load being pushed will drift off the trailing end (see figure 4-9, page 61). The rolling action caused by the blade curve helps with this side movement. When the blade is angled more sharply, the speed of the side drift increases, which means the material is not carried as far forward, allowing for deeper cuts. To shape and maintain most roads, set the blade at a 25° to 30° angle. Decrease the angle for spreading windrows, and increase the angle for hard cuts and ditching.

Note. A blade that is angled straight across (perpendicular to the direction of movement) is at 0°.

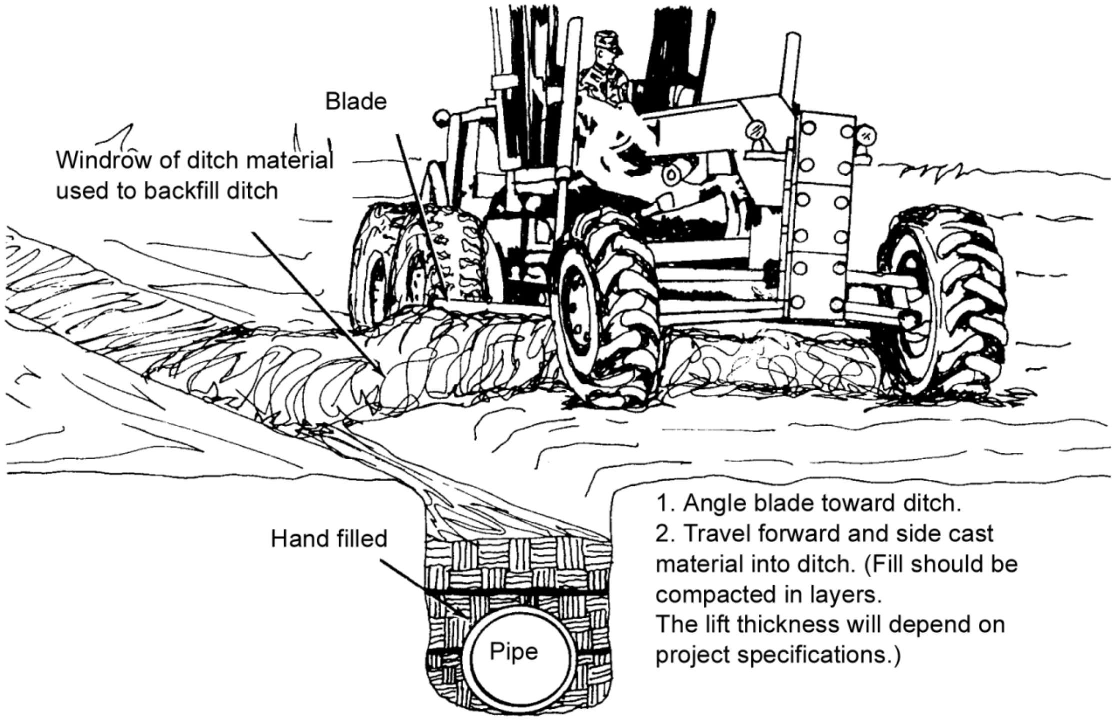

Figure 4-9. Backfilling a ditch by side casting

PLANNING

4-25. To plane off irregular surfaces, set the blade at an angle and use the material to fill the hollows. Always cut enough material to keep some in front of the blade. Move the loosened material forward and sideways to distribute it evenly. On the next pass, pick up the material left at the trailing edge of the blade. On the final pass, make a lighter cut and lift the trailing edge of the blade enough to allow the surplus material to go under rather than around the end to avoid leaving a ridge. Avoid piling windrows in front of the rear wheels, as it will adversely affect traction and grader control.

WORKING SPEEDS

4-26. Always operate the grader as fast as the skill of the operator and the road conditions permit. Operate at full throttle in each gear. Use a lower gear if less speed is required, rather than operating at less than full throttle. Table 4-1 lists the proper gear ranges for various grader operations under normal conditions. Table 4-2 lists the road speeds for the Army's 120M grader, and table 4-3 lists the road speeds for the Marine Corps' 120M grader.

Table 4-1. Proper gear ranges for grader operations

Operation	*Gear*
Maintenance	Second to third
Spreading	Third to fourth
Mixing	Fourth to sixth

Table 4-1. Proper gear ranges for grader operations (continued)

Operation	*Gear*
Ditching	First to second
Bank sloping	First
Snow removal	Fifth to sixth
Finishing	Second to fourth

Table 4-2. Road speeds for the Army's 120M grader

Model	*Road Speed: mph at rated rpm*							
	Forward Gears						*Reverse Gears*	
	First	*Second*	*Third*	*Fourth*	*Fifth*	*Sixth*	*Low*	*High*
120M	2.3	3.7	5.9	9.7	15.5	24.5	Same as forward	

* **Table 4-3. Road speeds for the Marine Corps' 120M grader**

Road Speed: mph at rated rpm								
GEAR	*First*	*Second*	*Third*	*Fourth*	*Fifth*	*Six*	*Seventh*	*Eight*
FORWARD	2.4	3.3	4.75	6.5	10.2	13.8	19.00	27.7
REVERSE	2.0	3.8	5.6	8.6	16.1	23.5		

BLADE SETTING AND GRADER SPEED

4-27. Each job requires a specific blade setting and grader speed for optimum production. Deviations from these settings and speeds will cause machine inefficiency.

TURNING

4-28. When making multiple passes over a short distance (less than 1,000 feet), it is usually more efficient to back the grader to the starting point instead of turning it around. Avoid making turns on a newly-laid bituminous road or runway surface.

NUMBER OF PASSES

4-29. The efficiency of grading is directly related to the number of passes made. Operator skill, combined with good planning, is crucial for minimizing unnecessary passes. For instance, if a job can be completed in four passes, any additional passes will increase the time and cost of the job.

TIRE INFLATION

4-30. Keep the tires properly inflated for best results. Overinflated tires lead to reduced contact between the tires and the road surface, which can cause a loss of traction. Differences in air pressure in the rear tires can result in tire slippage and grader bucking. The correct tire inflation pressure can be found in the operator's manual.

WET AND MUDDY CONDITIONS

4-31. Wet and muddy conditions can lead to poor traction, which in turn may reduce the efficiency of the grader. Despite this reduced efficiency, the grader remains the best machine to use under these conditions. For example, it can effectively cast surface mud to the side on a haul road.

HAUL-ROAD MAINTENANCE

4-32. Ensure that the haul roads are kept in good condition. This will enhance the efficiency of scrapers or dump trucks during large earthmoving operations. To maintain haul roads, graders are the most suitable machines for the job. The most effective method for road maintenance is to use enough graders to complete one side of a road with a single pass of each grader (known as tandem operation). With this method, maintenance of one side of the road is completed while the other side remains open to traffic.

TANDEM OPERATIONS

4-33. Using graders in tandem expedites such operations as leveling, mixing, spreading, and haul-road maintenance.

PRODUCTION ESTIMATES

4-34. A grader can be used in a variety of applications. Therefore, there are many ways to measure its operating capacity, or production. One method expresses a grader's production in relation to the area covered by the moldboard, over a specified period (usually an hour). The formulas below depict this method using the Metric and English equivalent unit of measure. An example of how to apply this formula is provided after paragraph 4-38.

Formula:

$A = S \times (L_e - L_o) \times 1000 \times E$ (Metric)

$A = S \times (L_e - L_o) \times 5280 \times E$ (English)

where A = hourly operating area (m^2/hr or ft^2/hr*)

S = operating speed (km/hr or mph*)

L_e = effective blade length (m or ft*)

L_o = width of overlap (m or ft)

1000 = number of meters per kilometer

5280 = number of feet per mile

E = job efficiency

* m^2= square meters, ft^2= square feet, m= meter, hr = hour, ft = feet, km/hr= kilometers per hour, mph= miles per hour

OPERATING SPEEDS

4-35. Typically, the operating speed for a grader can vary by application. Table 4-4 gives the operating speed for common grader tasks in Metric and English units of measurement.

Table 4-4. Grader operating speed by application

Task	Metric	English
Finish grading	0-4 km/hr	0-2.5 mph
Heavy blading	0-9 km/hr	0-6 mph
Ditch repair	0-5 km/hr	0-3 mph
Ripping	0-5 km/hr	0-3 mph
Road maintenance	5-16 km/hr	3-9.5 mph
Haul road maintenance	5-16 km/hr	3-9.5 mph
Snow plowing	7-21 km/hr	4-13 mph
Snow winging	15-28 km/hr	9-17 mph

EFFECTIVE BLADE LENGTH

4-36. Since the moldboard is usually angled when the grader is moving material, an effective blade length must be computed to account for this angle. Effective blade length is the amount of blade coverage the grader can move when the blade is at a given angle. Figure 4-10 illustrates the relationship between moldboard angle and a grader's effective blade length. Table 4-5 shows the effective blade length for various moldboards when the blade is operated at 0-to-45-degree angles. The effective length of the moldboard becomes shorter as the moldboard angle increases.

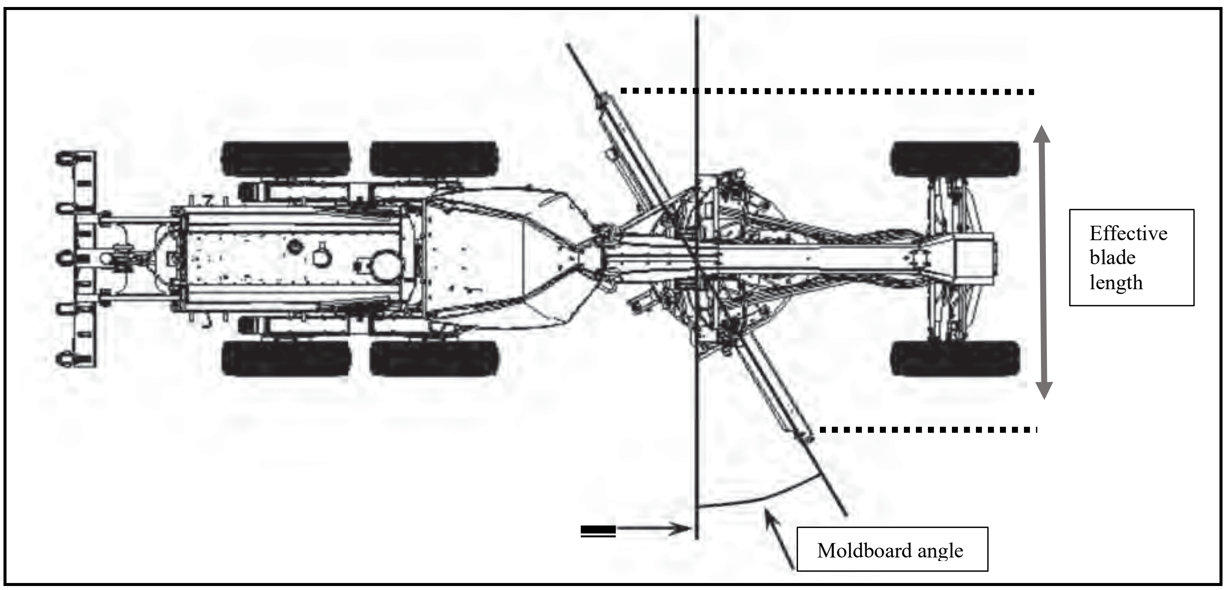

Figure 4-10. Relationship between moldboard angle and effective blade length.

Table 4-5. Effective blade length for angles 0-45 degrees

		Moldboard							
		3.66m (12 ft)		4.27m (14 ft)		4.88m (16 ft)		7.32m (24 ft)	
Angle^0		meters	feet	meters	feet	meters	feet	meters	feet
	0^0	3.66	12	4.27	14	4.88	16	7.32	24
	5^0	3.64	11.95	4.25	13.95	4.86	15.94	7.29	23.91
	10^0	3.60	11.82	4.20	13.79	4.80	15.76	7.21	23.64
	15^0	3.53	11.59	4.12	13.52	4.71	15.45	7.07	23.18
	20^0	3.44	11.28	4.01	13.16	4.58	15.04	6.87	22.55
	25^0	3.32	10.88	3.87	12.69	4.42	14.50	6.63	21.75
	30^0	3.17	10.39	3.69	12.12	4.22	13.86	6.33	20.78
	35^0	3.00	9.83	3.50	11.47	4.00	13.11	5.99	19.66
	40^0	2.80	9.19	3.27	10.72	3.74	12.26	5.61	18.39
	45^0	2.59	8.49	3.02	9.90	3.45	11.31	5.17	16.97

WIDTH OF OVERLAP

4-34. The width of overlap is generally 0.6 meters (2.0 feet) This overlap accounts for the need to keep tires out of the windrow on the return pass.

JOB EFFICIENCY

4-35. Job efficiency can vary based on job conditions, operator skill, etc. A good estimation for efficiency is approximately 0.70 to 0.85, but actual operating conditions should be used to determine the best value.

4-36. Due to the long passes involved in road maintenance – fewer turnabouts are needed– a higher job efficiency of 0.90 is chosen.

43,560 square feet = 1 acre   10,000 square meters = 1 hectare
5280 feet = 1 mile   1000 meters = 1 kilometer

Solution:

From the data in table 4-4, the effective blade length is 3.17 m (10.4 ft)

Metric/ Production,

A = 13 km/hr x (3.17 m – 0.6 m) x 1000 m x 0.90
= 30,069 m^2/hr divided by 10,000 m^2
= 3.07 hectares/hr

English
Production,

A = 8 mph x (10.4 ft – 2.0 ft) x 5280 ft x 0.90
= 319,069 ft^2/hr divided by 43,560 ft^2
= 7.33 acres/hr

4-37. Example:

An Army 120M motor grader with a 3.66 m (12 ft.) moldboard is performing road maintenance on a township road. The machine is working at an average speed of 13Km/H (8mph) with a moldboard carry angle of 30 degrees. What is the motor grader's production based on coverage area?

Note: Due to the long passes involved in road maintenance—fewer turnabouts—a higher job efficiency of 0.90 is chose.

43,560 square feet = 1 acre   10,000 square meters = 1 hectare

5,280 feet = 1 mile   1000 meters = 1 kilometer

Metric
Production, A = 13 km/h x (3.17 m – 0.6 m) x 1000 x 0.90)
= 30,069 m^2/hr divided by 10,000 m^2
= (3.07 hectares/hr)

English
Production, A = 8 mph x (10.4 ft. – 2.0 ft.) x 5,280 ft. x 0.90
= 319,069 ft^2/hr divided by 43,560 ft.
= (7.33 acres/hr)

Solution: From the table 4-5, the effective blade length is 3.17 m. (10.4ft.)

SAFETY

4-39. Listed below are specific safety rules for grader operators:

- Always display a red flag or a flashing light on a staff at least 6 feet above the left rear wheel when operating a grader slowly on a highway or roadway.
- Never allow other personnel to ride on the blade or rear of the grader.
- Always engage the clutch gently, especially when going uphill or pulling out of a ditch.
- Always reduce speed before making a turn or applying the brakes.
- Always keep the grader in low gear when going down steep slopes.
- Always take extra care when working on hillsides to drive slowly and to be observant of holes or ditches.
- Never use graders to pull stumps or other heavy loads.
- Always keep the blade angled well under the machine when it is not in use.
- Never allow more than one person on a grader while it is in operation. If it has a buddy seat, ensure that no more than two people are on the machine while it is in operation.

Chapter 5

Loaders

Loaders are extensively used in construction operations to handle and transport materials, load haul units, excavate, and charge aggregate bins at asphalt and concrete plants. The loader is a versatile piece of equipment designed to excavate at or above wheel or track level. The hydraulic-activated lifting system exerts maximum breakout force with an upward motion of the bucket. Large rubber tires on wheel models provide good traction and low ground-bearing pressure. A wheel loader can attain high speeds, which permit it to travel from one job site to another under its own power.

DESCRIPTION

5-1. Military loaders are diesel-driven, rubber-tired machines (see figure 5-1). They come in various sizes and capacities. Equipped with a power-shift transmission and a torque converter, these loaders have fast movement capability in both forward and reverse, with minimal shock. This allows the machines to maintain a high production rate. The hydraulic system provides the operator precise control of attached equipment and also assists with steering. Most loaders are equipped with pintles or towing hooks for towing small trailers or light loads.

Figure 5-1. 924H wheel loader

ATTACHMENTS

5-2. The most common loader attachments are a shovel-type bucket or a forklift (see figure 5-2, page 66). The hydraulic system of the loader provides the power necessary for operating these attachments. Hooks (designed for lifting and moving sling loads) and snowplows are other available attachments.

BUCKET

5-3. Buckets can be general-purpose (one-piece, conventional) or multipurpose (two-piece, hinged-jaw) (see figure 5-2). The bucket is connected to the tractor unit by lift arms. They are constructed from heavy-duty, all-welded steel and come in sizes ranging from 2.5 to 5 cubic yards. Bucket teeth are either bolted or welded onto replaceable cutting edges. For excavation of medium-type materials, bolt-on, replaceable teeth are provided. The multipurpose bucket allows the loader to be used as a dozer and to grab material.

FORKLIFT

5-4. A forklift can be attached to the tractor unit instead of a bucket. Designed for material handling, the fork attachment is made of steel and has two movable tines.

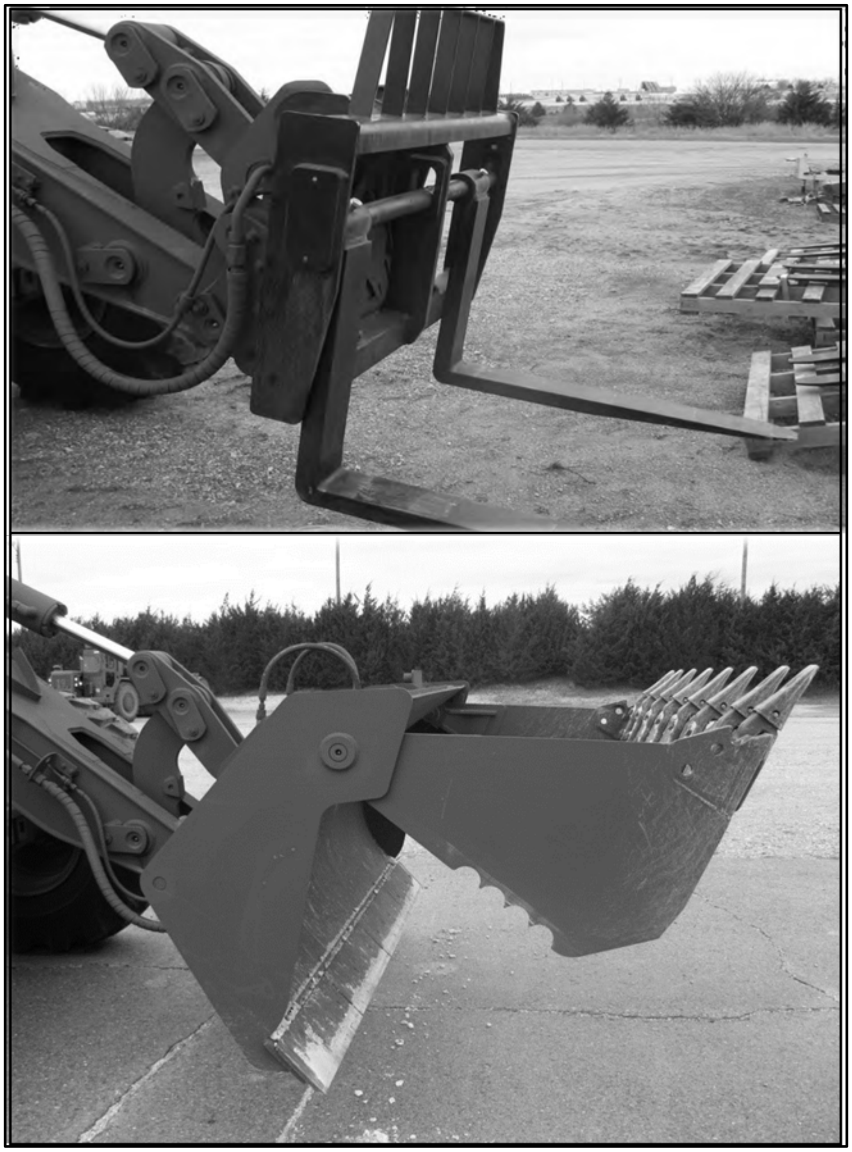

Figure 5-2. 924H loader attachments

USE

5-5. A loader is commonly used for various tasks such as loading trucks, stockpiling materials, digging basements or gun emplacements, backfilling ditches, and lifting and moving construction materials. When equipped with rock-type-tread tires, it can operate in and around rock quarries. In addition, loaders can be used for miscellaneous construction tasks including stripping overburden, charging hoppers and skips, lifting and moving forms for concrete work, moving large concrete and steel pipes, assisting with plant erection and maintenance, and towing small trailers and light loads.

SELECTION

5-6. When choosing a loader, it is important to consider the type and volume of material it will be handling. Loaders work well for excavating soft to medium-hard material, but their production rates decrease when excavating medium to hard material. Another important factor is the height at which the material needs to be raised. For effective loading into trucks, the loader must be able to dump over the side of the dump bed of the truck. The loader achieves its highest production rate when working on a flat, smooth surface with enough space to maneuver. In poor underfoot conditions or when there is limited space in which to efficiently operate, other equipment may be more effective.

OPERATION

LOADING THE BUCKET

5-7. When loading the bucket, keep it parallel to the ground so that its cutting edge can skim the travel surface and remove ruts, obstacles, and loose material on the forward pass. As the cutting edge contacts the bank or stockpile, move the loader forward at a slow speed and increase the power. While penetrating the material, raise the bucket. Crowd the material into the bucket and roll the bucket back to prevent spilling. Maintain the bucket in an upward position while backing away to prevent spilling.

POSITIONING OF HAUL UNITS

5-8. Proper positioning of the equipment that will receive material from the loader is necessary for maximum production. This cuts down on maneuver time.

V-LOADING METHOD

5-9. When loading trucks from a bank or a stockpile with a single loader, use the V-loading method. Use the following steps for the V-loading method (see figure 5-3, page 68).

- ***Step 1***. With the bucket lowered 1 to 2 inches off the ground, head the loader toward the bank or stockpile in low gear.
- ***Step 2.*** Move the loader into the stockpile and manipulate the lift and tilt control levers, simultaneously curling back the bucket and raising the boom slightly until the bucket is full and completely rolled back. Maintain power without spinning the tires.
- ***Step 3.*** Hold the bucket in the upright and curled position, and back away from the stockpile or bank.
- ***Step 4.*** Approach the haul unit at a 90° angle, lifting the bucket high enough to clear the haul unit.
- ***Step 5.*** Proceed slowly forward until the bucket is over the haul unit. **Do not** touch the haul unit with the front tires.
- ***Step 6.*** Dump the bucket by rolling the bucket slowly forward. **Do not** let the bucket hit the haul unit.
- ***Step 7***. Back away from the haul unit while simultaneously lowering the boom and leveling the bucket.
- ***Step 8.*** Repeat the above steps until the haul unit is loaded.

Note. While these loaders are flexible and can dig under very awkward conditions, the best production is achieved by keeping both the angle of turn and the travel distance to a minimum.

CLAM LOADING METHOD

5-10. The clam loading procedure can be used with the multipurpose bucket for handling rocks, timbers, or stockpiles of loose material:

- ***Step 1***. Center the front of the bucket on the middle of the first load to be picked up. At approximately 5 feet from the load, begin to open the bucket.
- ***Step 2.*** Move the loader forward and make contact with the load. About two-thirds of the opened bucket should penetrate into the material to be loaded.
- ***Step 3.*** Close the bucket to secure the load.
- ***Step 4.*** Position the load 10 to 14 inches above the ground.

> **CAUTION**
>
> Remember to keep the loader bucket as low as possible. A lower bucket position offers better balance and visibility for the operator. When traveling over rough terrain or terrain that can cause the loader to slide with a full bucket, always operate at a low speed. Failing to do so can lead to loss of control, resulting in serious injury, loss of life, and property damage.

- ***Step 5.*** Maneuver the loader to the desired location for load placement.
- ***Step 6.*** Open the bucket fully.
- ***Step 7.*** Raise the bucket high enough to clear any previously dumped material. Ensure that all of the material is out of the bucket.
- ***Step 8.*** Close the bucket.
- ***Step 9.*** Place the bucket in the traveling position (10 to 14 inches above the ground).
- ***Step 10.*** Repeat the above steps until the task is complete.

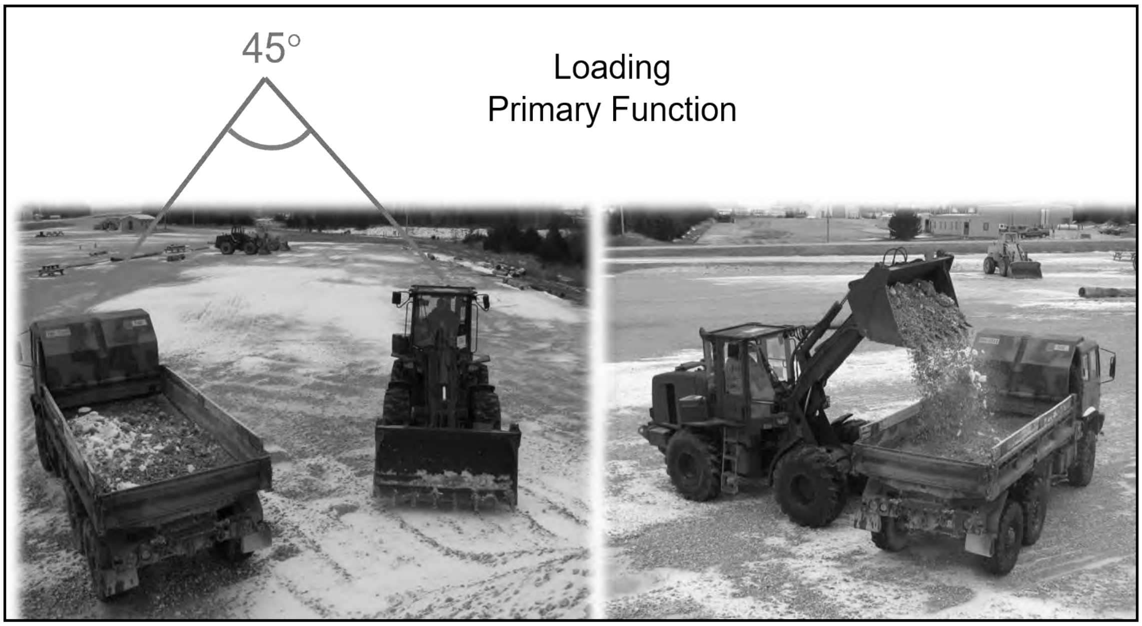

Figure 5-3. Loading trucks with a loader (V-loading method)

EXCAVATING BASEMENTS AND GUN EMPLACEMENTS

5-11. A loader can dig excavations such as basements or gun emplacements if the material is not too hard. The operator should first construct a ramp into the excavation (see figure 5-4). Because the loader works best when excavating above wheel level, the ramp allows the loader to work in that manner and later provides an exit to bring out the material. The following procedures are used to construct a ramp.

- ***Step 1.*** Determine a starting point for the ramp.
- ***Step 2.*** Position the bucket so that it is pitched forward.
- ***Step 3.*** Move the loader forward, gradually penetrating the earth by lowering the lift control lever.
  - Keep the loader in as high a gear as possible without causing the tires to excessively spin.
  - Use the lift control lever to regulate the depth of cut.
- ***Step 4.*** Retract the bucket fully.
- ***Step 5.*** Place the lift control lever in the raised position until the bucket is high enough to clear the surrounding area.

- ***Step 6.*** Dump the loaded bucket onto a stockpile or into a haul unit.
- ***Step 7.*** Repeat the above steps until the excavation is complete.

WORKING IN DIFFICULT MATERIAL

5-12. The multipurpose bucket is better at handling sticky materials that tend to cling to the bucket, while the general-purpose bucket may struggle with this. A clam-type digging motion is most effective when working with difficult material. For medium to hard materials, it is more efficient to first break or loosen the material before digging.

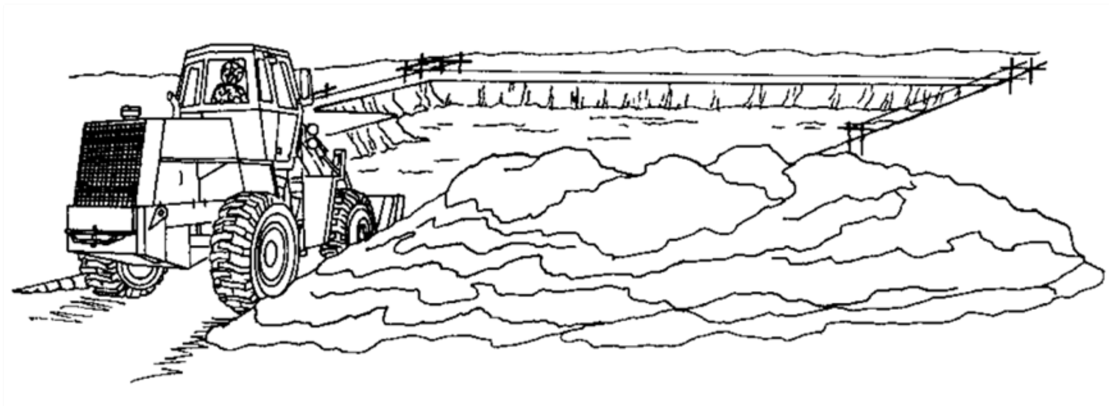

Figure 5-4. Constructing a ramp into an excavation

BACKFILLING

5-13. When filling trenches, lower the bucket to ground level and use the forward movement of the machine to push the piled earth into the trench (see figure 5-5, page 70). This type of work is best suited for the loader when the bucket is as wide as, or wider than, the wheels or tracks of the loader. Using a narrow bucket can cause the wheels to ride up the stockpile, raising one corner of the bucket and requiring more passes. The following steps are used to carry out backfilling operations:

- ***Step 1.*** Align the loader with the stockpile (either to the left or right side) while approaching at a 45° angle so that one-third of the bucket will contact the stockpile.

Note. This technique will not work when pushing a large stockpile. When pushing a large stockpile, work from the edges.

- ***Step 2.*** Adjust the bucket by moving the lift control lever to lower the bucket to just off of the natural ground. If using a multipurpose bucket, move the bucket control lever to open the bucket to the clam position.
- ***Step 3.*** Move the loader forward and gradually move the material. Keep the loader in as high a gear as possible without causing the tires to excessively spin.
- ***Step 4.*** Move the lift control lever to lower or raise the bucket to cut and spread the material the length of the trench.
- ***Step 5.*** Move the lift control lever to raise the bucket 10 to 14 inches off the ground before reversing direction.
- ***Step 6.*** Reverse the loader and return to the stockpile.
- ***Step 7.*** Repeat the above steps until the operation is complete.

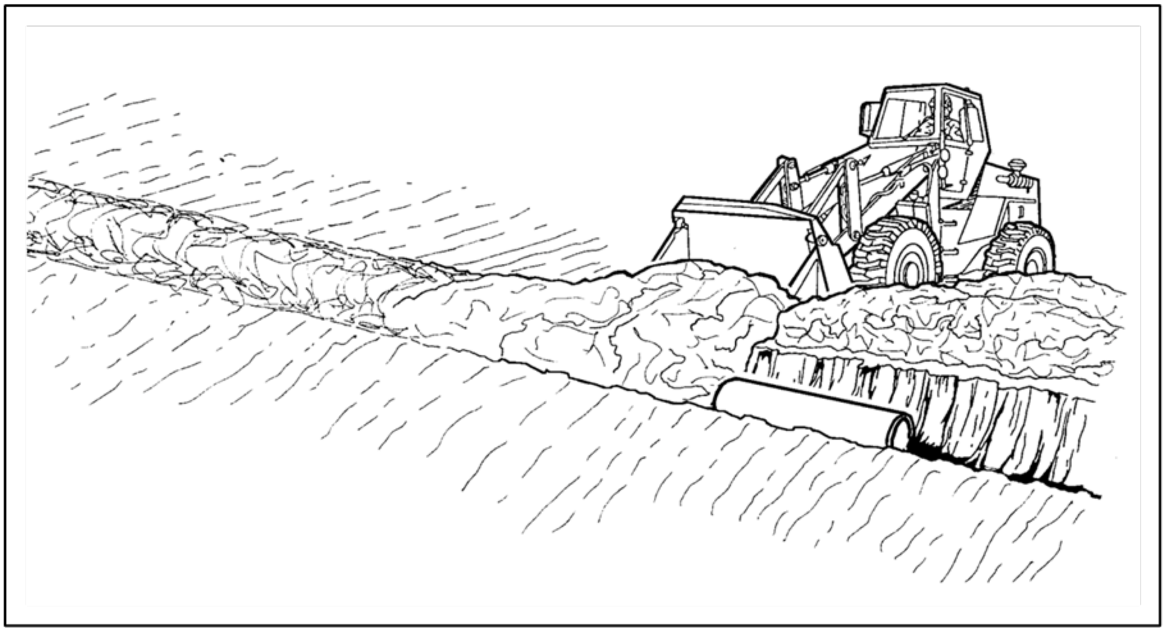

Figure 5-5. Backfilling a trench with a loader

CONSTRUCTING A STOCKPILE

5-14. A stockpile can be constructed from the material excavated in any of the previously described operations. Use the following dump steps when constructing a stockpile:

- ***Step 1.*** Move the loader forward until the front tires contact the bank.
- ***Step 2.*** Move the lift control lever to raise the bucket all the way.
- ***Step 3.*** Move the tilt control lever to slowly tilt the bucket to the dump position.
- ***Step 4.*** Pull the tilt control lever to tilt the bucket back to the standard bucket position.
- ***Step 5.*** Back the loader from the stockpile and lower the bucket to about 10 to 14 inches off the ground.
- ***Step 6.*** Back the loader to the start of the work area.
- ***Step 7.*** Repeat the above steps until all of the material is stockpiled.

PRODUCTION ESTIMATES

5-15. Several factors influence loader production, including the skill of the operator, how much the material has been loosened beforehand, the slope and height of the operating area, the climate, and the positioning of the haul unit. Table 5-1 provides bucket fill factors for converting rated heaped-bucket capacity to LCY volume based on the type of material being handled. Table 5-2 gives average cycle times for wheel loaders to excavate and load with no extra travel required. Use the provided formulas and the step-by-step method to estimate loader production.

Table 5-1. Bucket fill factors for wheel loaders

Material	*Wheel Loader Fill Factor**
Loose material: • Mixed moist aggregates • Uniform aggregates: up to 1/8 inch ▪ 1/8 to 3/8 inch ▪ 1/2 to 3/4 inch ▪ 1 inch and over	 0.95 to 1.00 0.95 to 1.00 0.90 to 0.95 0.85 to 0.90 0.85 to 0.90
Blasted rock: • Well blasted • Average • Poor	 0.80 to 0.95 0.75 to 0.90 0.60 to 0.75
Other: • Rock-dirt mixtures • Moist loam	 1.00 to 1.20 1.00 to 1.10
Soil	0.80 to 1.00
*Decimal of heaped-bucket capacity, for adjustment to LCY	
Legend: LCY loose cubic yard	

Table 5-2. Average cycle times for wheel loaders

Loader Size, Heaped-Bucket Capacity (Cubic Yards)	*Wheel-Loader Cycle Time (Minutes)*
1.00 to 3.75	0.45 to 0.50
4.00 to 5.50	0.50 to 0.55
Note. Includes load, maneuver with four reversals of direction (minimum travel), and dump.	

CUBIC-YARD ESTIMATES

- ***Step 1***. Determine the material type and the rated heaped-bucket capacity of the loader.
- ***Step 2***. Select the bucket fill factor from table 5-1 based on the material type.
- ***Step 3.*** Determine the average cycle time from table 5-2 based on the size of wheel loader.

Note. If needed, include the round-trip travel time to the cycle time found in table 5-2 (such as when charging aggregate bins at a plant). Calculate the total travel time using the formula in chapter 3, paragraph 3-28, step 7. Determine the speed based on the gear capabilities of the loader matched to the travel conditions of the site. For travel distances of less than 100 feet, a wheel loader (with a loaded bucket) should be able to travel at about 80% of its maximum speed in low gear and return (with an empty bucket) at about 60% of its maximum speed in second gear. Expect slightly higher speeds for longer travel distances.

- ***Step 4***. Determine the maximum production rate using the following formula.

$$Maximum\ production\ rate\ (LCY\ per\ hour) = \frac{heaped - bucket\ capacity\ x\ bucket\ fill\ factor\ x\ 60\ minutes}{loader\ cycle\ time\ (minutes)}$$

- ***Step 5***. Determine an efficiency factor. Efficiency depends on both the job conditions and management. A good, average loader efficiency is 50 minutes of work per hour. However, the estimator must always subjectively evaluate all of the conditions that impact efficiency, such as—
  - Work-site dimensions, the depth of cut, and the amount of movement required.
  - Surface conditions and weather, including the season of the year and drainage.
  - Equipment condition.
- ***Step 6***. Determine the net production rate in LCY per hour. Multiply the maximum production rate (LCY per hour) by the efficiency factor:

$$Net\ production\ rate\ (LCY\ per\ hour) = maximum\ production\ rate\ (LCY\ per\ hour) x\ efficiency\ factor$$

5-16. Example:

What is the net production rate (LCY per hour) for a 2.5 cubic-yard wheel loader loading moist loam? Assume average working conditions.

$\boldsymbol{Material\ type} = \boldsymbol{moist\ loam}$

$\boldsymbol{Rated\ heaped - bucket\ capacity} = \boldsymbol{2.5\ cubic\ yards}$

$\boldsymbol{Bucket\ fill\ factor\ for\ moist\ loam\ (table\ 5-1)} = \boldsymbol{1\ to\ 1.1\ use\ an\ average\ of\ 1.05}$

$\boldsymbol{Cycle\ time\ for\ a\ 2.5\ cubic\ yard\ wheel\ loader\ (table\ 5-2)}$

$$\boldsymbol{= 0.45\ to\ 0.5\ minute, use\ an\ average\ of\ 0.475\ minute}$$

$$\boldsymbol{Maximum\ production\ rate\ (LCY\ per\ hour) = \frac{2.5\ x\ 105\ x\ 60\ minutes}{0.475\ minute}}$$

$$\boldsymbol{= 332\ LCY\ per\ hour}$$

$$\boldsymbol{Net\ production\ rate\ (LCY\ per\ hour) = 332\ LCY\ per\ hour\ x\ \frac{50\ minutes}{60\ minutes}}$$

$\boldsymbol{= 227\ LCY\ per\ hour}$

TONNAGE ESTIMATES

5-17. Determine the net production rate in tons per hour. Multiply the net production rate (LCY per hour) by the material weight (tons per LCY). Divide the material weight by 2,000 to convert pounds per LCY to tons per LCY.

$$Material\ weight\ (tons\ per\ LCY) = \frac{weight\ (pounds\ per\ LCY)}{2{,}000\ pounds\ per\ ton}$$

$$Net\ production\ rate\ (tons\ per\ hour) = Net\ production\ rate\ (LCY\ per\ hour)\ x\ Material\ weight\ (tons\ per\ LCY)$$

5-18. Example:

What is the net production rate in tons per hour of a wheel loader working in loam (2,200 pounds per LCY) with a net production rate of 263 LCY per hour?

$$Material\ weight\ (tons\ per\ LCY) = \frac{2{,}200 \text{ pounds per LCY}}{/2{,}000 \text{ pounds per ton}} = 1.1\ tons\ per\ LCY$$

$$Net\ production\ rate\ (tons\ per\ hour) = 263\ LCY\ per\ hour\ x\ 1.1\ tons\ per\ LCY$$
$$= 289\ tons\ per\ hour$$

OTHER ESTIMATES

- Determine a soil conversion factor if necessary (see table 1-1, page 3).
- Determine the total time required. The formula used to determine dozer production (chapter 2, paragraph 2-39, step 10) is applicable.
- Determine the total number of wheel loaders required to complete the mission in a given time. The formula used to determine dozer production (chapter 2, paragraph 2-39, step 11) is applicable.

SAFETY

5-19. Operate wheel loaders carefully because they are easy to overturn. Do not extend any portion of your body between the cab and the lift arms. Operators should adhere to the following safety practices:

- Block the bucket when working on the machine.
- Use caution when removing and replacing the lock rings.
- Do not work between the wheels and the frame while the engine is running.
- Use caution when operating close to the edge of a trench or when working under overhangs created by digging into banks or stockpiles.
- Travel with the bucket at or below axle height.
- Do not carry or lift personnel in the bucket.
- Ground the bucket, and set the parking brake before leaving the machine.

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Chapter 6
Forklifts

Forklifts are effective on unprepared or unstable surfaces and work well in rough terrain where high-flotation tires are needed. Most forklifts are four-wheel-steering machines. The Army uses forklifts for loading, unloading, and transporting crates and palletized loads. Examples of such situations include working on a beach, in the surf, and in deep sand, snow, or mud. A forklift can move at high speeds between construction sites when not carrying a load.

USE

6-1. Forklifts (figure 6-1) were once restricted to use in warehouses or terminals. The Army now uses them for various activities, including—

- Loading and unloading flatcars, trucks, flat trailers, aircraft, and naval landing craft.
- Stocking and transporting heavy crates and palletized loads.

Figure 6-1. Forklift

OPERATION TECHNIQUES

POSITIONING TO LOAD

6-2. When positioning a forklift to pick up a load, make sure to bring it in square to the load. Then, use the side shift to align the forks instead of trying to align the entire vehicle. Extend the boom as necessary when lifting a load, and retract the boom against the frame when transporting loads. Use oscillation to easily pick up loads at an angle.

TRANSPORTING A LOAD

6-3. When transporting a load, tilt the mast as far back as the load will permit and raise the load only high enough (4 to 6 inches) to clear obstructions. Always change speed gradually, as sudden starts and stops will cause the load to shift. Gradual starts and stops also prevent rapid wear of machine components. Use four-wheel steering for normal material handling and two-wheel steering for high-speed runs.

Operating In Sand Or Mud

6-4. Lower the tire pressure when operating in sand or mud. Check the operator's manual for appropriate pressures.

Transporting On Ramps And Grades

6-5. When using a forklift to transport cargo up ramps or other grades, carry the load on the upgrade end of the machine. When carrying cargo downgrade, back the forklift down the grade with the load on the upgrade end. Carry all loads with the tines tipped back.

Operating In Water

6-6. For operating in water, disconnect the fan and use four-wheel drive. (Check the operator's manual for servicing requirements after operating in salt water.)

SAFETY

6-7. Operators must always face in the direction of travel. Carry the load so that it does not obstruct the operator's vision in the direction of travel. When forklifts are not in operation, lower the forks and rest them flat on the ground or floor.

Overhead Safety Guards

6-8. Equip forklifts of all types with steel overhead safety guards. Permit exceptions only when the overhead safety guards either increase the overall height of the forklift or restrict the freedom of movement of the operator.

Load Capacity

6-9. In the Army, the load capacity and gross weight must be stenciled on the machine and be in plain view of the operator. The Marine Corps does not require this information to be stenciled onto forklifts. Operators should never exceed the load capacity of their forklift. Do not counterweight the machine to increase lifting capacity. The capacity rating is based on the load center specific to the fork carriage being used, which is not always 24 inches from the heel of the forks.

Hoisting Personnel

6-10. Use a forklift to hoist personnel only after obtaining a supervisor's approval and under the following conditions:

- Allow only skilled personnel to perform tasks requiring elevation of personnel by forklift.
- Use special personnel pallets (guardrails on all four sides).
- Face all personnel away from the mast with their hands clear of the hoisting mechanism during the actual raising and lowering.

Chapter 7
Cranes

Cranes are used to lift and position loads. There are more than three types of crane mountings, such as portal, rail, and barge (floating) mounts. Truck, crawler, and rough-terrain cranes offer increased maneuverability at the work site. However, while truck and rough-terrain mounts provide mobility, they do not offer the same stability as crawler mounts. Additionally, by attaching accessory equipment to a crane's superstructure and boom, the basic crane can be utilized for tasks like pile driving or excavation.

BASIC CRANE UNIT

7-1. The basic crane unit (see figure 7-1) consists of a substructure mount and a fully revolving superstructure. The upper revolving superstructure remains largely consistent regardless of the substructure mount. By installing various attachments, the crane can be used for tasks beyond just hoisting. Figure 7-2, page 78, illustrates several crane attachments, including a hook block, clamshell, pile driver, and dragline.

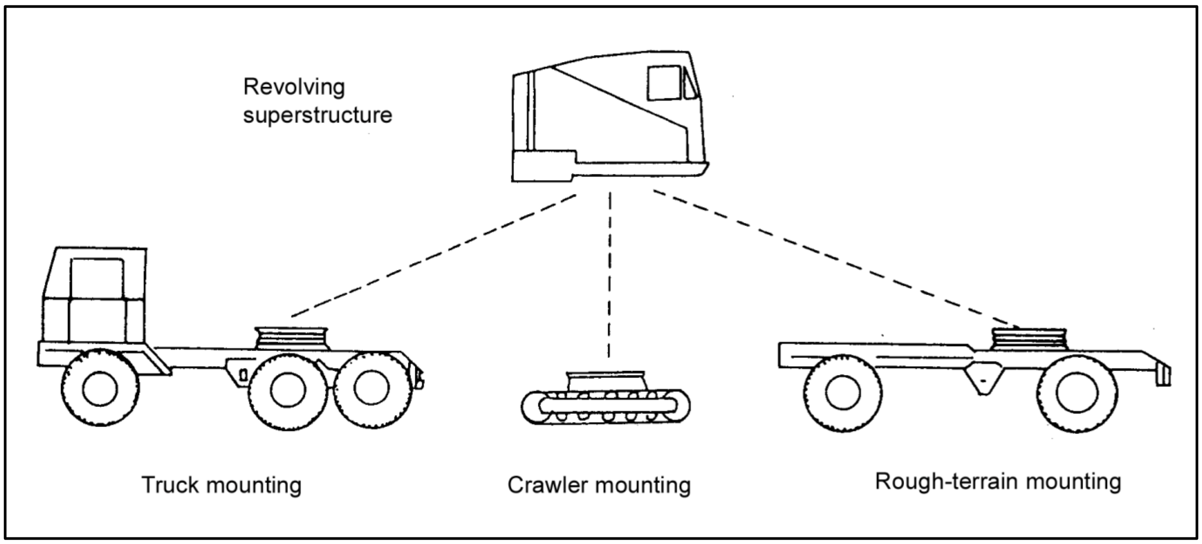

Figure 7-1. Basic crane unit

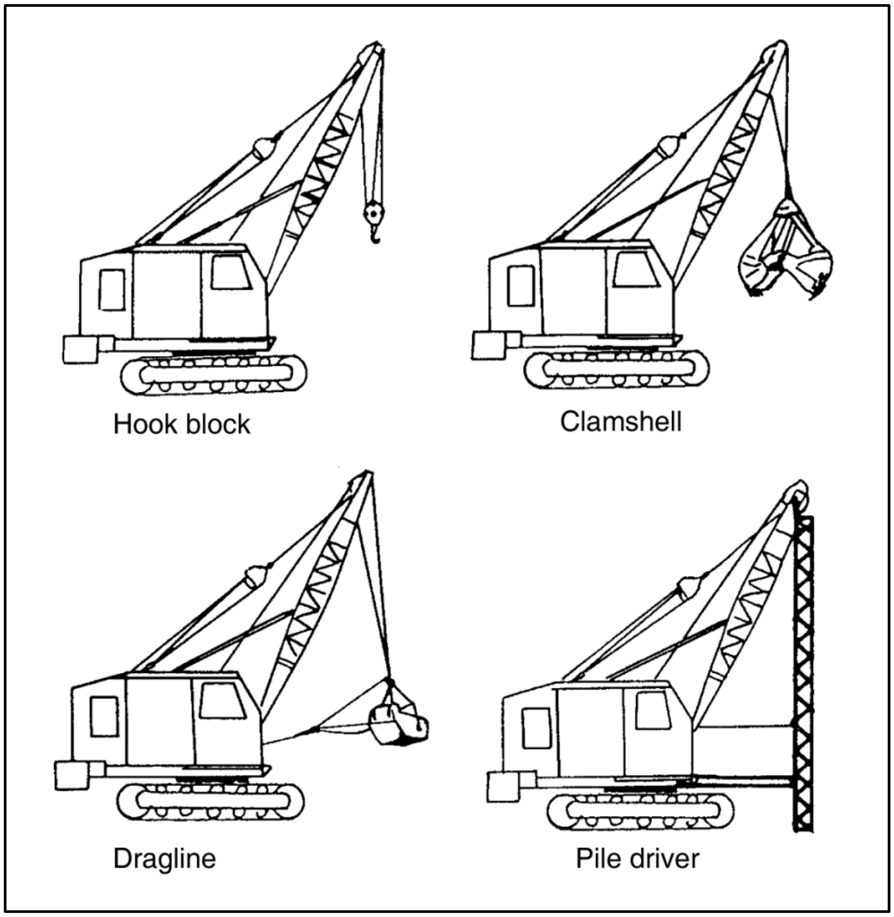

Figure 7-2. Crane attachments

SUBSTRUCTURE

7-2. The substructure can be a truck, a crawler, or a rough-terrain mount. Each mount has different stabilization and terrain capabilities.

Truck Mount

7-3. Truck cranes are equipped with specially designed heavy-duty mounts that enhance mobility between projects. The 20-ton and 25-ton truck cranes can operate various attachments, including a hook block, a 0.75-cubic-yard clamshell, a diesel pile driver with a 7,000-foot-pounds-per-blow capacity, or a dragline. Figure 7-3 illustrates a 25-ton truck crane featuring a hydraulic telescopic boom.

- **Stability.** These cranes have outriggers on each side. Always employ the outriggers when operating the crane or attachments. Fully extend the outriggers and secure the jacks on the base plates so that the crane is completely off of the tires. Some models are equipped with hydraulic outriggers.
- **Terrain capability.** Because of its limited stability, the truck mount restricts the efficient movement of these cranes to firm, level terrain.

7-4. **Towing.** A pintle hook is located on the rear of the truck, while towing eyes are situated at the front. The pintle hook allows the truck to tow an attachment trailer for transporting necessary equipment to the job site. If the truck becomes inoperable or gets stuck, the towing eyes can be used to connect it to a towing vehicle. These towing eyes are designed to withstand twice the dead-weight pull of the truck.

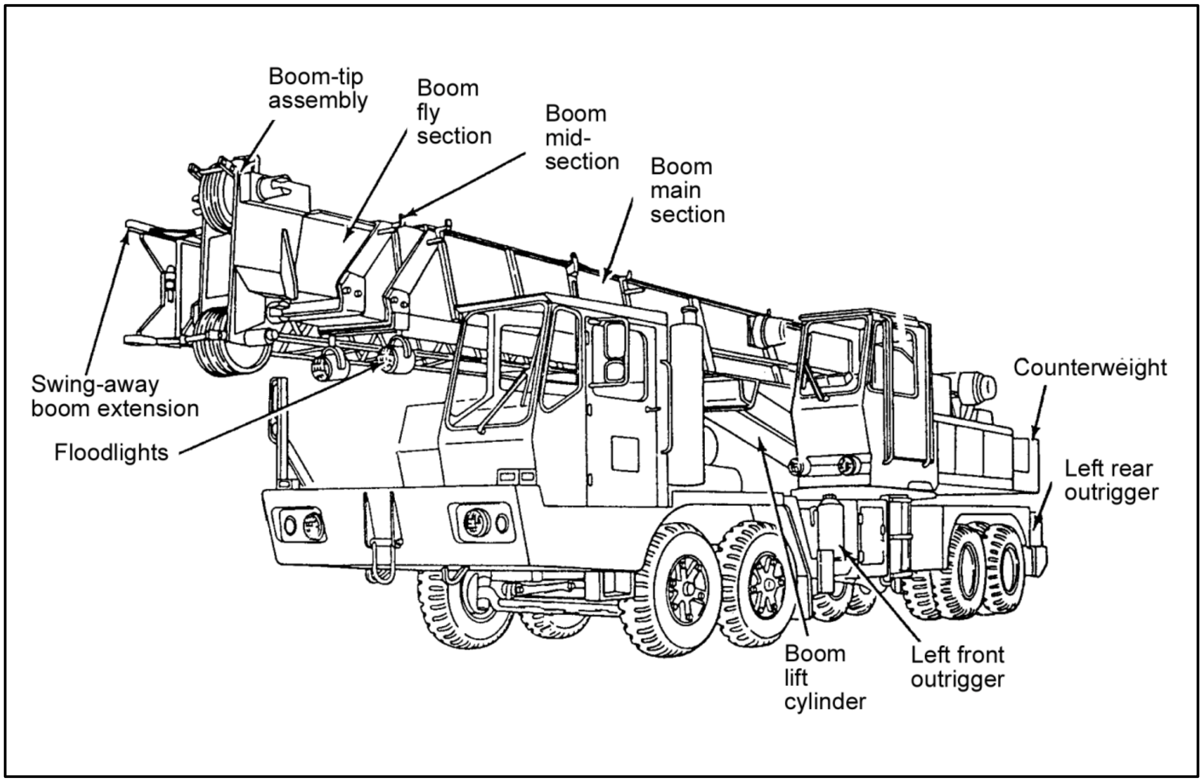

Figure 7-3. Truck crane (25-ton) with a hydraulic telescopic boom

7-5. Operating Hints. These are standard operating procedures to ensure safe operations**.**

- Be sure the crane is level prior to operating.
- Do not hoist loads over the front. Generally, perform all heavy hoisting over the rear of the truck since the truck's cab and engine provide additional counterweight for the load. When using a load chart, ensure that the capacity reflects the quadrant of the proposed hoist. For example, over the side, over the rear of the mount, or over the front of the mount.
- Use the outriggers.
- Check the base plates periodically to ensure that good soil bearing is being maintained.
- Place the truck's transmission in neutral when operating the superstructure. This prevents possible damage to the gears by any rocking movement of the truck.

Crawler Mount

7-6. Transport crawler cranes between projects using transport trucks. Crawler cranes travel at relatively low speeds, and extended travel distances can lead to excessive wear on their tracks. These cranes are best suited for long-duration jobs. Their crawler design provides excellent maneuverability on job sites while maintaining low ground-bearing pressure. The 40-ton crawler crane can operate various attachments, including a hook block, a 2-cubic-yard clamshell, a diesel pile driver with a 24,000-foot-pounds-per-blow capacity, or a dragline. The military typically employs the 40-ton crane for quarry operations.

- **Stability**. The crawler mounting provides a stable base for operating the revolving superstructure. Because of the width and length of the crawler tracks, the weight of the machine spreads over a large area.
- **Terrain capability.** Crawler cranes are designed to operate on level ground. An out-of-level condition of just 3° can lead to a 30 percent reduction in hoisting capacity. Due to their low ground-bearing pressure, crawler cranes can traverse soft ground. In areas where the ground is particularly soft or unstable, it is important to use timber mats to ensure a stable foundation (see figure 7-4). When not lifting a load, the machine is capable of climbing slight grades.

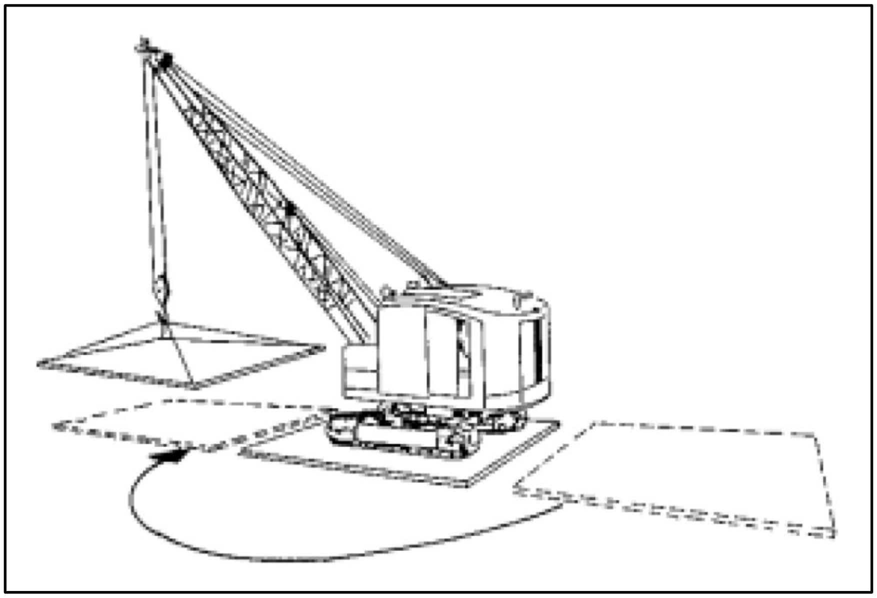

Figure 7-4. Timber mats supporting a crawler crane on soft material

7-7. Crawler cranes can be secured on barges to operate over water. They are capable of working in shallow water, provided that the water does not reach the revolving superstructure. Before moving the machine into the water, it is essential to check the water depth and the conditions of the ground beneath. Be sure to thoroughly clean and service the machine after working in saltwater.

Rough-Terrain Mount

7-8. The 22-ton rough-terrain crane is capable of operating a hook block, a 0.75-cubic-yard clamshell, a diesel pile driver with a force of 7,000 foot-pounds per blow, or a dragline. The main differences between the rough-terrain crane and the truck crane are the larger tires and higher ground clearance. These features allow the rough-terrain crane to operate in areas that are inaccessible to the truck crane.

7-9. **Rough-Terrain Crane (22-Ton).** The rough terrain crane is designed for long-distance highway travel and offers excellent maneuverability at job sites. It features a mount that provides four-wheel-drive capability, conventional two-wheel steering, four-wheel steering, and crab steering. The machine can travel at speeds of up to 55 mph on the highway. This crane is equipped with dual cabs: a lower cab for highway travel and a superstructure cab that includes both the driving and crane controls. Additionally, a pintle hook at the rear of the mount allows it to tow an attachment trailer, although towing the trailer cross-country is not recommended.

- **Stability.** Since the mount is not suspended on springs, the front axle must oscillate. This oscillation helps prevent the mount from tipping or rolling over if one of the front wheels drops into a hole. Before extending the boom, use the outriggers to lift the machine off the ground and to level it. When stabilizing the machine with the outriggers, position safety wedges on the front axle to prevent oscillation. The outriggers operate independently, allowing the superstructure to be leveled effectively. Load ratings are based on the assumption that the crane is in a level position for the full 360° of swing.
- **Terrain capability.** The machine's low ground-bearing pressure lets it travel over relatively soft terrain. It can traverse slopes up to 48 percent if the ground is firm and dry.

SUPERSTRUCTURE

7-10. The revolving superstructure rests on the mount and includes the counterweight, the engine, the operating mechanism, the boom, the cab, and sometimes a separate engine.

Counterweight

7-11. The counterweight is normally a cast-steel member attached to the rear of the superstructure to produce a countermoment to the weight and radius of the load. This countermoment prevents the crane from tipping.

Operating Mechanisms

7-12. Two independent cable drums control the operation of various attachments. The drums can be mounted parallel to each other or one behind the other. You can refer to them based on their relative position (*right* or *left*, *front* or *rear*) or by their function (the drag cable drum for dragline operations or the *closing-line cable drum* for clamshell operations). When the drums are used together with a hook block, they should be referred to as the *rear* or *main hoist drum*.

7-13. A third cable drum, known as the *boom hoist drum*, is responsible for raising and lowering the boom on cranes with a lattice boom. Some models feature a two-piece, grooved lagging that allows for quick attachment to the drum shaft. The diameters of the grooved lagging vary based on the make and model of the machine. These differences in lagging diameter affect the operating line speeds. For instance, the lagging used for dragline operations may have a smaller diameter to provide a slower line speed, which results in greater power.

7-14. Clutches and brakes can be powered mechanically, hydraulically, or pneumatically. Some models feature an internally mounted clutch that expands to engage the drum when actuated. Other models have external contracting clutches.

Boom

7-15. **Lattice Boom.** The lattice boom is a structure made up of four main chords connected by lacing. The basic design includes a base section supported by a revolving superstructure and an upper section with a boom head. The two sections are joined using either bolted butt-plate (flange) connections or pin and clevis connections. To increase the length of a lattice boom, there are two common methods: inserting an intermediate section between the upper and base sections, which is the most typical approach, or adding a jib, which is a lighter structural extension. An offset jib allows for a greater load radius compared to an equivalent length of standard boom. Cranes that are not equipped with jib-boom anchor plates can only extend their booms by using intermediate sections. When lengthening lattice booms, it is important to extend the gantry or A-frame to maintain the required lifting angle for the boom lines.

7-16. **Hydraulic Telescopic Boom.** This boom is made up of two or more telescoping boxes constructed from steel plates. Hydraulic cylinders are used to extend or retract these boxes. Only specific attachments can be used with this type of boom. It is commonly found on certain rough-terrain cranes and truck cranes (see figure 7-3, page 79).

HOISTING OPERATIONS

7-17. The hook block (as shown in figure 7-2, page 78) is suitable for hoisting operations and can be used with either a lattice or telescoping boom. Basic crane equipment includes hoist drums, hook blocks to provide the necessary parts of line (reeving), as well as boom-suspension and hoist cables.

FACTORS AFFECTING HOISTING CAPACITY

7-18. Boom length, operating radius or boom angle, type of mount, stability (use of outriggers), amount of counterweight, hook-block size, hoisting position, and maintenance determine the safe hoisting capacity of the crane.

Boom Length

7-19. Increased boom length reduces a crane's hoisting capacity. Use of a jib attachment will further reduce the hoisting capacity. The increased load moment at the greater operating radius and the added weight of the additional boom sections decrease the hoisting capacity.

Operating Radius

7-20. The operating (working) radius (see figure 7-5) is the horizontal distance measured from the axis of rotation of the superstructure to a vertical line extending down from the outer edge of the crane's boom-tip sheave. Cranes are rated based on their hoisting capacities at various radii, taking into account either tipping or structural constraints. When the boom swings, it generates a centrifugal force (illustrated in figure 7-6) that effectively increases the operating radius. Additionally, high winds can push the load, further increasing the operating radius (refer to table 7-1). As the working radius increases, the hoisting capacity decreases. Therefore, it is essential to know the weight of the load before attempting to hoist it.

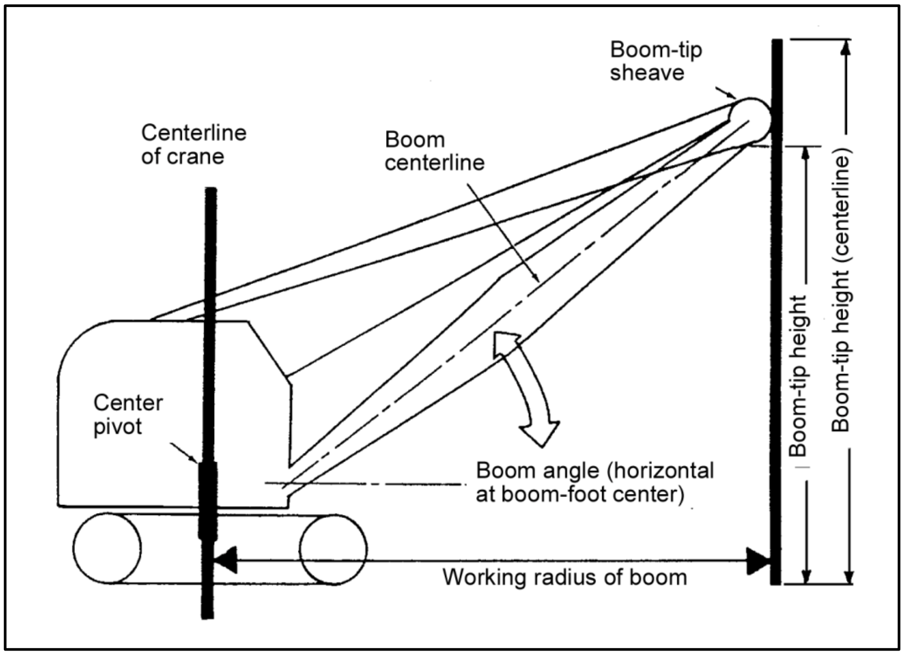

Figure 7-5. Operating radius of a boom

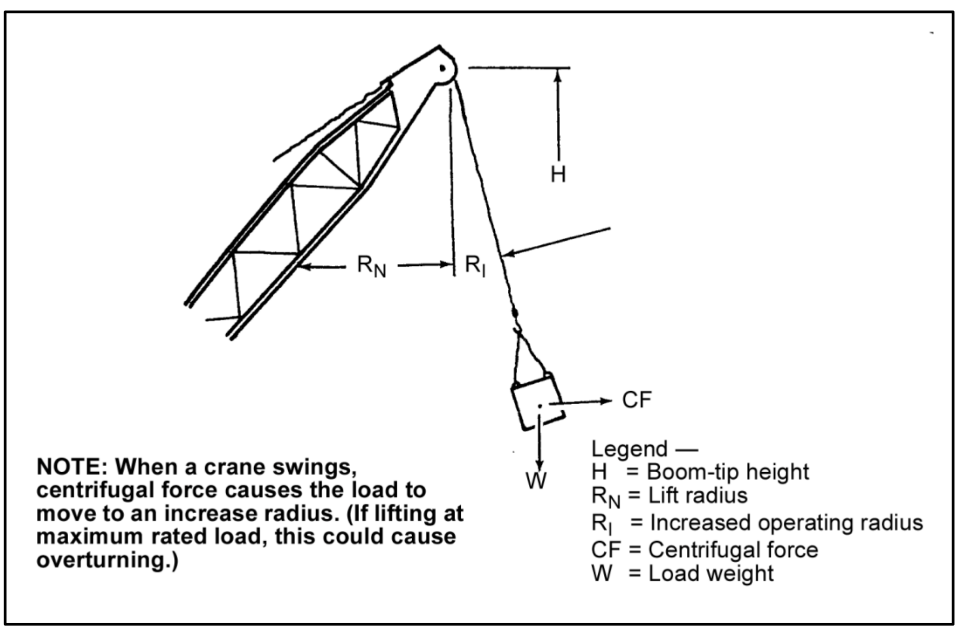

Figure 7-6. Effects of centrifugal force on the operating radius

Table 7-1. Effects of wind on crane operations

Approximate Wind Speed		*Weather Conditions*	*Effects*
mph	*kph*		
0-1	0-1.5	Calm	Smoke rises straight up
1-3	1.5-5	Light air	Smoke drifts
4-7	6-11	Slight breeze	Leaves rustle
8-12	12-19	Gentle breeze	Leaves and small twigs move
13-18	20-29	Moderate breeze	Dust and papers fly; small branches move
19-24	30-39	Fresh breeze	Small trees sway
25-31	40-50	Strong breeze	Large branches move
32-38	51-61	High wind	Walking is difficult; tree trunks bend
39-46	62-74	Gale	Twigs break off
47-54	75-87	Strong gale	Shingles are blown away
55-63	88-100	Whole gale	Trees may be uprooted

Mount Type

7-21. The basis of a crane’s hoisting-capacity rating concerning tipping is as follows (check the operator's manual for the correct table):

- **Crawler mounted.** Power Crane and Shovel Association (PCSA) standards limit the load capacity concerning tipping to 75 percent of the maximum load.
- **Truck and rough-terrain mounted.** PCSA standards limit the load capacity concerning tipping to 85 percent of the maximum load whether on tires or outriggers.
- Capacity at short radii is usually limited by the structural capacity of the components of the machine. In the case of hydraulic cranes, the hydraulic capacity sometimes limits the lifting capability.

Stability

7-22. It is extremely important to position the crane on firm, level ground. If outriggers are available, they should be fully extended and properly bearing weight. If necessary, prepare the operating site for the crane in advance. Following the load chart ratings for the machine is essential to maintain stability. This ensures a proper balance between the load weight, radius, and the machine’s counterweight. Keep in mind that a crane’s hoisting capacity, as indicated in the load chart, assumes the crane is on solid, level ground. Be cautious not to place the crane’s tracks or outriggers over underground utilities, recompacted trench excavations, or too close to excavation edges, as these areas could collapse when lifting a load.

Counterweight

7-23. Do not add additional counterweight or anchor the crane to a *deadman* in an attempt to increase hoisting capacity. These procedures could cause structural damage to the crane.

Hook-Block Size

7-24. The hook block on the crane must be sized according to the crane's specifications. Failure to use the proper rigging and hook capacity may result in damage to the block and the sheave system. Hoisting capacity tables are based on gross capacity, so it is important to consider the weight of the hook block and slings as part of the overall load.

Hoist Position

7-25. The load capacity of a crane is influenced by the position of the boom in relation to the undercarriage of the machine. For a crawler crane, there are three key quadrants to consider: over the side, over the drive end of the tracks, and over the idler end of the tracks. For mobile cranes, the quadrants are typically defined by imaginary lines extending from the superstructure's center of rotation to the position of the outriggers. Always take into account the minimum conditions when swinging the load from the pickup point to its final placement.

Maintenance

7-26. Proper crane maintenance will help to achieve rated, safe hoisting capacity. Check the following items to ensure that the crane can attain its rated hoisting capacity:

- Type, size, and condition of the wire ropes.
- Type, size, and condition of the hook block.
- Structural condition of the boom.
- Mechanical condition of the engine.
- Adjustments and functional qualities of the clutches and brakes.

SAFE HOISTING-CAPACITY CALCULATION

- ***Step 1***. Determine the required clearance (figure 7-7), which includes the:
  - Load height.
  - Hoisting height.
  - Hook-block height.
  - Minimum estimated safe distance between the boom-tip sheave and the hook-block sheave. (This is a judgment call; normally, a 2-foot clearance is satisfactory.)
  - Height of the slings from the load's top to the hook.

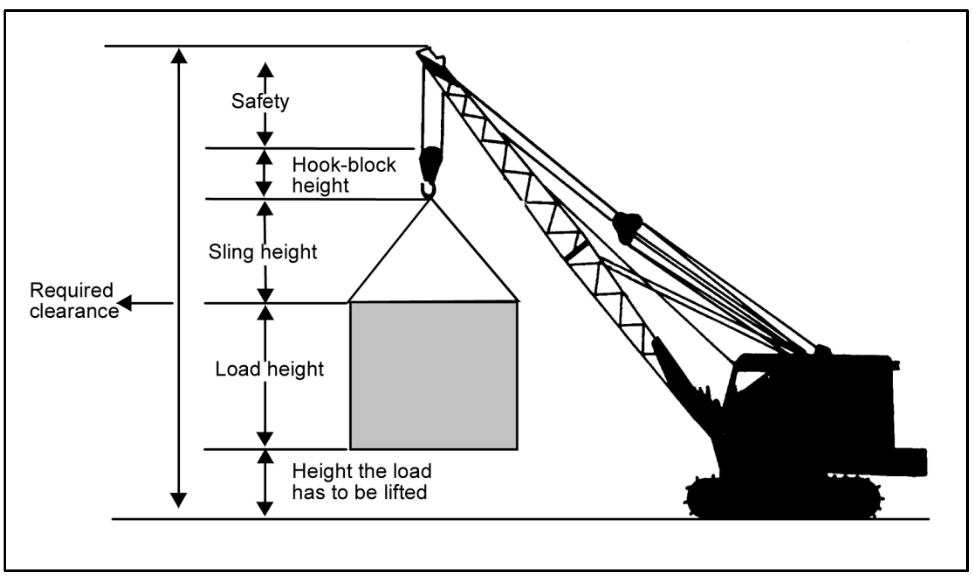

Figure 7-7. Required clearance

- ***Step 2.*** Determine the total weight to hoist, which includes the—
  - Load weight.
  - Hook-block weight.
  - Sling weight.
  - Stowed jib weight (if mounted on the boom).

- ***Step 3.*** Determine the working radius. This is the distance from the crane's center of rotation to the load's center. Always consider the maximum radius that results when swinging the load from point of pick up to final placement.

Note. Remember that centrifugal force (caused by swinging the boom or from the wind) can increase the radius. Refer to figure 7-6, page 83, and table 7-1, page 83, respectively.

- ***Step 4***. Determine if the crane will hoist the load. Use the appropriate equipment-hoisting charts and the following information:
  - Boom length.
  - Boom angle.
  - Boom-tip height.
  - Total hoisted weight.

OPERATION TIPS

- Try to position the crane to eliminate swinging over workers.
- Ensure that the supporting ground has adequate strength.
- Position the crane for the shortest possible boom swing and swing the load slowly when performing repetitive hoisting.
- Ensure that the machine is always level.
- Use tag lines on loads to prevent excessive swaying of the load.
- Use adequate hoist-line lengths to ensure full travel of the block to the lowest point required.
- Organize the work for minimum travel time. When possible, complete all needed hoists in one area before moving to a new position.
- Use the power-down device on the equipment (if available) when performing precise load handling.
- Do not use excessive counterweight or tie-down devices to increase stability.
- Check weather reports or use the indicators given in table 7-1, page 87, to determine approximate wind speed. Wind can affect crane operations and even cause overturning when hoisting close to or at maximum hoisting capacity. Cease work if wind speed exceeds 30 mph.

PILE DRIVER

DESCRIPTION

7-27. The pile driver attachment (refer to figure 7-2, page 78) includes several components: adapter plates, leads, a catwalk, a hammer, and a pile cap. The adapter plates are bolted to the top section of the leads and are secured to the tip of the boom. The leads are attached below the base of the boom. Note that pile leads cannot be connected to a jib boom. The hammer can be either a diesel type or a drop type.

Diesel Hammers

7-28. Diesel-driven pile-driving hammers come in two types: open-top and closed-end. Both types feature self-contained, free-piston engines that operate on a two-cycle compression-ignition principle. Diesel hammers eliminate the need for air compressors or steam boilers to power the hammer. It is important not to use these hammers for pulling piles. They can be used with either lattice or telescopic booms. However, when driving a pile in soft soil, a diesel hammer may not fire due to insufficient soil resistance to support fuel ignition. In such cases, switch to a drop hammer until the pile reaches adequate driving resistance.

Drop Hammers

7-29. Gravity-operated drop hammers are most effective for driving vertical piles. When piles are angled, some of the driving force is lost due to friction with the pile leads. Compared to other types of hammers, drop hammers operate relatively slowly. It is recommended to use a hammer that weighs at least as much as the pile being driven; for optimal results, the hammer should ideally be twice the weight of the pile. Using a heavier hammer with a smaller drop is preferable. Raise and drop the hammer at a consistent speed, with typical drop rates ranging from four to eight blows per minute. The recommended drop height varies depending on the type of pile; for instance, a drop height of 15 feet is recommended for timber piles, while 8 feet is advised for concrete piles.

DRIVING RATE

7-30. Driving time can vary significantly due to factors such as terrain, weather, soil conditions, the type of pile, and the type of hammer used. The only way to accurately determine the driving rate is to drive a pile under the specific conditions of the project. As a guideline for planning, you can estimate approximately 30 minutes to drive a 12-inch diameter pile to a depth of 20 feet. This estimate includes the time needed to set the pile in the leads.

OPERATION TIPS

7-31. Use the following guidelines when operating a pile driver:

- Position the crane so that it will require the minimum time to move between pile locations. Placement is generally parallel to the long axis of the pile group.
- Place the piles close to the driving locations so that the crane only needs to swing to pick up the next pile.
- Make shallow, continuous blows with the hammer. High, infrequent blows cause pile failures.

CLAMSHELL

DESCRIPTION

7-32. The clamshell setup (see Figure 7-2, page 78) includes a clamshell bucket, hoist drum laggings, a tag line, and wire ropes for the boom. The clamshell bucket is comprised of two scoops that are hinged together. It’s important to note that a clamshell cannot be operated from a jib. The drum laggings for the clamshell may either be the same as those used for the crane or may need to be adjusted to meet the specific speed and pull requirements of the clamshell. These requirements can vary based on the equipment’s design, so it is essential to refer to the operator's manual. Typically, the wire ropes used for hoisting can also be used for clamshell operations. However, you will need to add two additional lines: a secondary hoist line and a tag line. The tag line is a small-diameter cable equipped with a spring-tension winder, which helps to prevent the clamshell bucket from twisting during operation. Both the tag line and winder are interchangeable with any make or model within the same size range. The spring-loaded tag line operates independently and does not require the operator’s control, nor does it connect to the crane’s operating drums. The winder is usually mounted on the lower part of the boom.

7-33. The clamshell is a vertically-operated attachment designed for use at, above, and below ground level. To use it, attach the clamshell bucket to the hoist line of the crane. This attachment is effective for digging in loose to medium-stiff soils. The length of the boom affects the maximum height the clamshell can reach, while the capacity of the cable drums limits the depth it can achieve based on the length of the wire rope. A clamshell's hoisting capacity can vary significantly. Factors such as boom length, operating radius, clam bucket size, and the weight of the excavated material all influence its safe hoisting capacity. It is important to refer to the crane’s load-capacity table found in the operator's manual for accurate information.

USE

7-34. The clamshell bucket is ideal for tasks such as excavating vertical shafts or footings, as well as for loading aggregate bins or hoppers. The bucket's movement is controlled by the holding, closing, and tag lines. At the beginning of the digging cycle, the bucket is lowered onto the material to be excavated with its shells open. As the closing line is pulled in, the shells come together, allowing them to penetrate the material. The weight of the bucket, which is the only means of crowding, aids in this penetration. After digging, the holding and closing lines raise the bucket. To dump the material, simply release the tension on the closing line to open the bucket.

Excavating Vertical Shafts or Footings

7-35. Since the dimensions of this type of excavation can vary, it is challenging to determine the most efficient digging position for the clamshell bucket. Two important factors to consider are the amount of wire rope on the machine and the necessity of keeping the outside edge of the cut lower than the center. This practice prevents the bucket from drifting toward the center, which can lead to a V-shaped excavation. In deep excavations, a bucket spotter or signalman typically guides the operator, especially when the bucket is out of the operator's sight. Spotters may also need to use hand tag lines to help direct the bucket effectively.

Charging Aggregate Bins or Hoppers

7-36. Position the crane to avoid having to raise and lower the boom when swinging between the aggregate stockpiles and the bins or hoppers.

PRODUCTION ESTIMATES

7-37. The following factors make it difficult to arrive at dependable clamshell production rates:

- The difficulty of loading the bucket in different soil types.
- The height to hoist the load.
- The slow swing required.
- The method of disposing of the load.

When loading material into a truck, the time it takes to position the bucket over the truck and dump the load is typically longer than when dumping the material directly onto a spoil pile. To estimate the production rate of a clamshell, the most effective method is to observe the equipment in operation at a job site and measure its cycle time. However, this estimate may not provide an exact measure of the clamshell's cycle time due to variations in operator proficiency and fatigue. Based on the cycle time observed at a specific job site, the following page presents an example of how to calculate the clamshell's production rate. This example outlines the formulas used in a five-step method.

7-38. Example:

Determine the number of hours it will take to load 450 LCY of aggregate from a stockpile into haul units with a clamshell.

Bucket size = 0.75 cubic yard

Average cycle time = 40 seconds

Efficiency factor = 50-minute working hour

STEP 1. Determine the bucket size.

$$\boldsymbol{Bucket\ size = 0.75\ cubic\ yard}$$

STEP 2. Determine the working time (in seconds per hour). Convert working minutes per hour to working seconds per hour.

$$\boldsymbol{Working\ time\ (seconds\ per\ hour)}$$
$$\boldsymbol{= working\ minutes\ per\ hour\ x\ 60\ seconds\ per\ minute}$$
$$\boldsymbol{= 50\ working\ minutes\ per\ hour\ x\ 60\ seconds\ per\ minute}$$
$$\boldsymbol{= 3000\ seconds\ per\ hour}$$

STEP 3. Determine the production rate.

$$\boldsymbol{Production\ rate\ (LCY\ per\ hour)}$$
$$= \frac{\boldsymbol{B\ x\ T\ (seconds\ per\ hour)}}{\boldsymbol{CT\ (seconds)}}$$
$$= \frac{\boldsymbol{0.75\ cubic\ yards\ x\ 3000\ seconds\ per\ hour}}{\boldsymbol{40-second\ cycle}}$$

= 56 LCY per hour

Where—

B = bucket size

T = working time

CT = cycle time

Step 4. Determine the soil conversion factor, if needed.

Soil conversion factor = not applicable

Step 5. Determine the total time required to complete job.

$$\boldsymbol{Total\ time\ (hours)} = \frac{\boldsymbol{quantity\ of\ material\ moved\ (LCY)}}{\boldsymbol{production\ rate\ (LCY\ per\ hour)}}$$

$$= \frac{\mathbf{450}\ \boldsymbol{LCY}}{\mathbf{56}\ \boldsymbol{LCY\ per\ hour}}$$

$$= 8 \text{ hours}$$

Operation Tips

- Position the unit on level ground.
- Position the unit so digging operations are at the same radius as the dumping operation. This will avoid wasted production caused by raising and lowering the boom.
- Select the correct bucket size for the machine. Efficient use of the clamshell means an efficient digging, hoisting, swinging, and dumping cycle. Large buckets may increase the cycle time.
- Remove the bucket teeth when working in soft materials.

DRAGLINE

7-39. Dragline components include a drag bucket and a fairlead assembly. Wire ropes are utilized for dragging, hoisting the bucket, and for the dump lines. The fairlead directs the drag cable onto the drum when the bucket is being loaded. The hoist line, which operates over the boom-point sheave, is responsible for raising and lowering the bucket. During the digging operation, the drag cable pulls the bucket through the material. When the bucket is lifted and moved to the dumping point, it is emptied by releasing tension on the drag cable. Dragline buckets are classified by type and class, as follows:

- **Bucket types.** Type I (light duty), Type II (medium duty), and Type III (heavy duty). The Army usually uses Type II buckets.
- **Bucket classes.** Class P (perforated plate) and Class S (solid plate). The Army usually uses Class S buckets.

Use

7-40. The dragline (see figure 7-2, page 78) is a versatile attachment capable of performing a wide range of operations at or below ground level. It can handle materials ranging from soft to medium-hard. One of the greatest advantages of a dragline compared to other machines is its long reach for both digging and dumping. However, a dragline lacks the positive digging force found in shovels or backhoes; its breakout force relies solely on the weight of the bucket. As a result, the bucket may bounce, tip over, or drift sideways when it encounters hard materials. These issues are particularly noticeable when using lightweight buckets.

7-41. Use a dragline for tasks such as trenching, stripping overburden, cleaning and digging roadside ditches, and sloping embankments. The dragline is particularly effective for handling mud due to its design. Its extended reach allows for excavation over a wide area from a single position, and the sliding action of the bucket reduces suction problems.

Note. Do not use the dragline attachment with hydraulic cranes.

CAPACITY

7-42. When operating a dragline, it is important to keep the boom at a safe angle. Angles of less than 35° from the horizontal are generally not recommended, as they increase the risk of tipping the machine. This risk is particularly heightened when excavating wet, sticky material and casting it onto a spoil bank, as the material can stick in the bucket.

Casting Material

7-43. The throw or cast of the bucket increases the dragline's operating radius, which can be up to one-half of the boom height (figure 7-8).

WARNING

Only experienced operators should perform extended casting because of the possible damage to the cables or the boom or the possibility of tipping the machine.

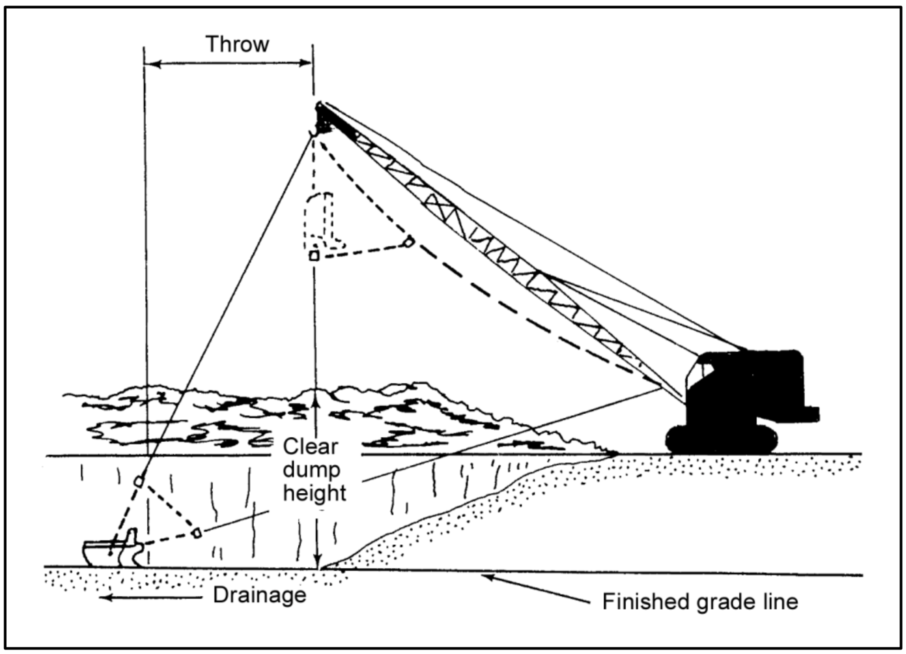

Figure 7-8. Dragline throw

Excavating a Trench

7-44. The dragline carriage should be in line with the trench centerline. This is called the *in-line approach* (figure 7-9). The dragline excavates to the front while moving backwards and dumping on either side of the excavation. To ensure drainage during construction, always start at the lower end of the trench.

Sloping an Embankment

7-45. An effective use of a dragline is to dress the face of an embankment by working from the bottom to the top. Position the machine on the top of the embankment with the tracks parallel to the working face. This is called the *parallel approach* (figure 7-10). This positioning enables the machine to move the full length of the job without excessive turning.

Digging Underwater (Dredging) Or In Wet Materials

7-46. A dragline is ideal for removing materials from areas such as water-filled trenches, canals, gravel pits, or ditches. When digging underwater or in wet materials, the weight of the material increases, which can make it challenging to lift heavily loaded buckets. Therefore, it is important to plan operations so that the material being handled is as dry as possible. Always ensure effective project drainage. Drainage projects that involve ditch excavation through swamps or soft terrain are common. In such conditions, it is advisable to place the excavated material onto a levee or spoil bank. This approach eliminates the need for constructing roads for hauling equipment. However, it may be necessary to build simple service roads to support construction efforts and provide access for fueling the machines.

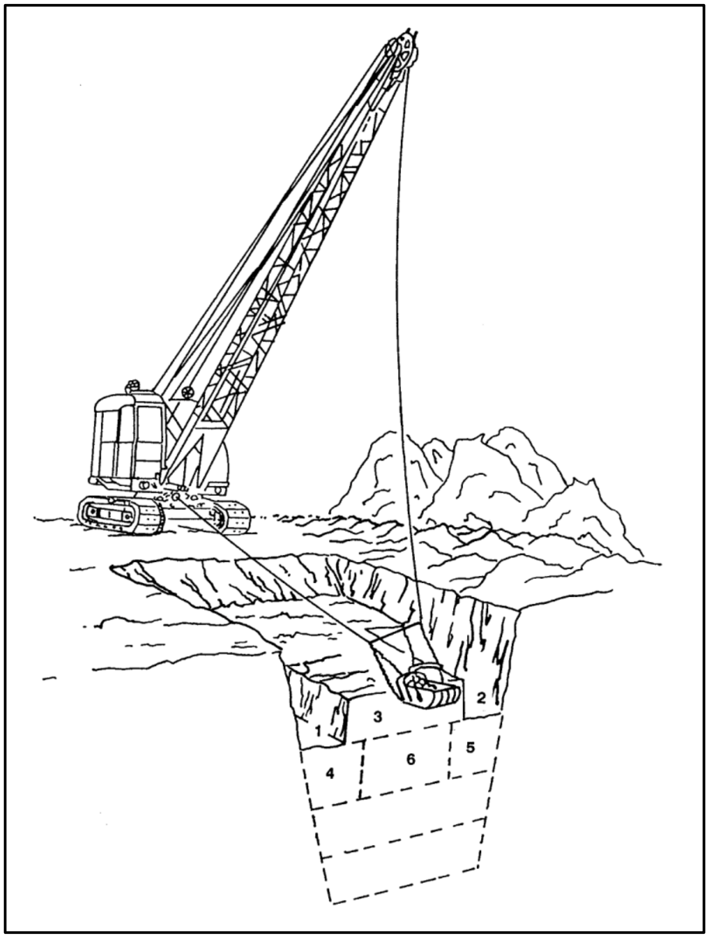

Figure 7-9. In-line approach with a dragline

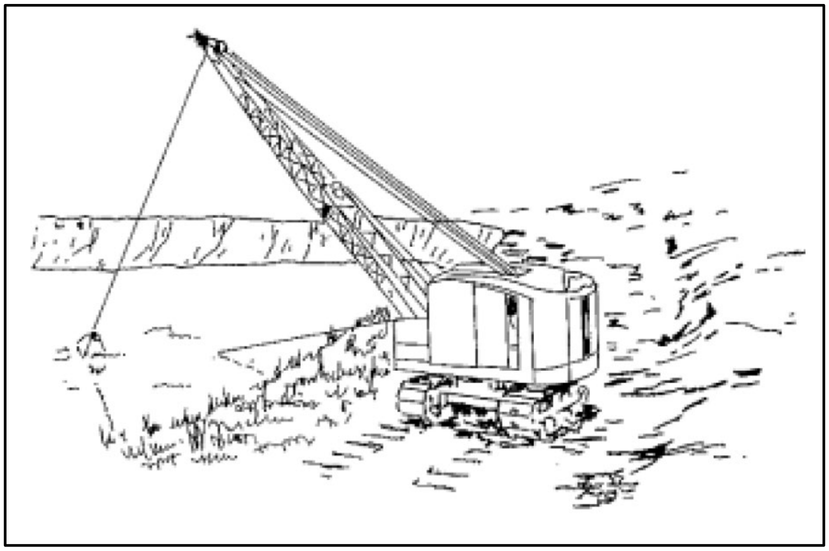

Figure 7-10. Parallel approach with a dragline

Loading Haul Units

7-47. When job conditions require loading excavated material into hauling units, plan the excavation to ensure that loaded trucks can travel on dry ground and over minimal grades when exiting the loading area. Position trucks to minimize boom swing. If possible, place the truck bed directly under the boom tip, aligning the long axis of the truck parallel to the long axis of the boom. However, it is more common to position the truck at a right angle to the boom. Spotting hauling units in the excavation below the dragline will reduce hoist time and increase production efficiency. Since the dragline is not a rigid attachment, it may not dump material as accurately as other excavators, requiring the operator to spend more time positioning the drag bucket before dumping.

PRODUCTION ESTIMATES

7-48. Table 7-2 presents the hourly production rates for cranes fitted with a dragline attachment. These rates are based on optimal cutting depth, a 90° swing angle, soil type, and maximum efficiency. Table 7-3 provides correction factors for different cutting depths and swing angles. For detailed soil conversion factors, please refer to table 1-1 on page 3. An example illustrating how to calculate the production rate for a crawler-equipped crane with a dragline can be found on page 96. This example outlines a five-step method for determining the production rate.

Table 7-2. Dragline hourly output in bank cubic yard

Material	Dragline Bucket Size (Cubic Yards)								
	3/8	1/2	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/2
Clay or loam (light and moist)	5.0 70.0	5.5 95.0	6.0 130.0	6.6 160.0	7.0 195.0	7.4 220.0	7.7 245.0	8.0 265.0	8.5 305.0
Sand or gravel	5.0 65.0	5.5 90.0	6.0 125.0	6.6 155.0	7.0 185.0	7.4 210.0	7.7 235.0	8.0 255.0	8.5 295.0
Good common earth (soil)	6.0 55.0	6.7 75.0	7.4 105.0	8.0 135.0	8.5 165.0	9.0 190.0	9.5 210.0	9.9 230.0	10.5 265.0
Clay (hard and tough)	7.3 35.0	8.0 55.0	8.7 90.0	9.3 110.0	10.0 135.0	10.7 160.0	11.3 180.0	11.8 195.0	12.3 230.0
Clay (wet and sticky)	7.3 20.0	8.0 30.0	8.7 55.0	9.3 75.0	10.0 95.0	10.7 110.0	11.3 130.0	11.8 145.0	12.3 175.0
Note. The top figures give the optimum depth of cut (in feet). The bottom figures give the estimated BCY per hour.									

Table 7-3. Depth-of-cut and swing-angle correction factors for dragline output

Depth of Cut (in Percent of Optimum)	Swing Angle (Degrees)							
	30	45	60	75	90	120	150	180
20	1.06	0.99	0.94	0.90	0.870	0.81	0.75	0.70
40	1.17	1.08	1.02	0.97	0.930	0.85	0.78	0.72
60	1.24	1.13	1.06	1.01	0.970	0.88	0.80	0.74
80	1.29	1.17	1.09	1.04	0.990	0.90	0.82	0.76
100	1.32	1.19	1.11	1.05	1.000	0.91	0.83	0.77
120	1.29	1.17	1.09	1.03	0.985	0.90	0.82	0.76
140	1.25	1.14	1.06	1.00	0.960	0.88	0.81	0.75
160	1.20	1.10	1.02	0.97	0.930	0.85	0.79	0.73
180	1.15	1.05	0.98	0.94	0.900	0.82	0.76	0.71
200	1.10	1.00	0.94	0.90	0.870	0.79	0.73	0.69

7-49. EXAMPLE:

Determine the hourly output for a ¾-cubic-yard crawler dragline.

$$\textit{Bucket size} = \tfrac{3}{4}\ \textit{cubic yard}$$

$$\textit{Material} = \textit{good common earth}$$

$$\textit{Angle of swing} = 45°$$

$$\textit{Depth of cut} = 9\ \textit{feet}$$

- ***STEP 1.*** Determine the ideal production from *table 7-2, page 78*.
  $\textit{Ideal production} = 105\ \textit{BCY per hour at an optimum of cut of}\ 7.4\ \textit{feet}$
- ***STEP 2.*** Determine the ratio of the actual depth of cut to the optimum depth of cut, expressed as a percent.

$$\textit{Cut ratio}\ (\textit{percent})$$

$$= \frac{actual\ depth\ of\ cut}{optimum\ depth\ of\ cut} x\ 100$$

$$= \frac{9\ feet}{7.4\ feet} x\ 100$$

= 122 percent of optimum

- ***STEP 3.*** Determine the depth-of-cut/swing-angle correction factor from table 7- 3, page 92. In some cases, it may be necessary to interpolate between table 7-3, page 92 values.

  $\boldsymbol{Correction\ factor} = \mathbf{1.17}$
- ***STEP 4.*** Determine an overall efficiency factor based on the job conditions. Drag-lines seldom work at better than a 45-minute working hour.

$$Efficiency\ factor = \frac{45\ minutes}{60\ minutes} = 0.75$$

- ***STEP 5***. Determine the production rate. Multiply the ideal production by the depth-of-cut/swing-angle correction factor and the efficiency factor.

  $\boldsymbol{Production\ rate} = \mathbf{105}\ \boldsymbol{BCY\ per\ hour\ x}\ \mathbf{1.17}\ \boldsymbol{x}\ \mathbf{0.75} = \mathbf{92.1}\ \boldsymbol{BCY\ per\ hour}$
- ***STEP 6***. Determine the soil conversion factor, if needed.

$\boldsymbol{Soil\ conversion\ factor} = \boldsymbol{not\ applicable}$

OPERATION TIPS

- Position the machine to eliminate unnecessary casting and hoisting, although the dragline bucket can easily be cast beyond the length of the boom.
- Use heavy timber mats for work on soft ground. Keep the mats as level and clean as possible.

WARNING

Do not guide the dragline bucket by swinging the superstructure while digging. This puts side stress on the boom, which can cause the boom to collapse. Raise the bucket clear of the ground before swinging the boom.

SAFETY

OPERATOR RESPONSIBILITIES

7-50. Ensure that all crane operators receive comprehensive training in crane safety before they are permitted to operate a crane. Operators must understand the limitations and capabilities of the cranes, as well as how to correctly read a load chart. It is crucial that operators do not operate cranes that are unsafe. They should be able to identify any equipment malfunctions or defects and report them immediately. Operators have the authority to stop operations and refuse to handle loads until they can confirm that safety is assured.

HAND SIGNALS

7-51. Always use a signal person when the point of operation is not completely visible to the equipment operator. When providing hand signals, appoint only one person to communicate with the operator. This signal person must be reliable and fully qualified. They should use a uniform system of signals and remain clearly visible to the operator at all times. Refer to figure 7-11, page 95, for the recommended hand-signal system for directing crane operations. Check the operator's manual for signals related to other equipment. It is essential that both operators and signal persons thoroughly understand the meaning of all signals. For additional crane safety precautions, please see chapter 13.

ACCIDENT PREVENTION

7-52. Common hazards associated with operating hook blocks, clamshells, pile drivers, and draglines are—

- The boom contacting high-voltage electric wires. This is the most hazardous aspect of crane operation.
- The cables breaking.
- The clutch or brake slipping, allowing the boom radius to increase.
- Obstruction of the free passage of the boom or the load.
- Operation on uneven ground.
- Not knowing the actual weight of the load being hoisted.
- Bent or dented chord members on the boom.

7-53. Common operator errors associated with crane operations are—

- Dropping or slipping the load.
- Not using outriggers.
- Not using mousing or safety-type hooks.
- Not being familiar with the equipment.
- Not referring to load charts when using different boom lengths.
- Using the crane hoist cable for towing. The boom is designed for handling vertical loads only.

7-54. Personnel should never attempt to climb on or off of a crane when it is operating. No personnel except the operators and, on occasion, examiners, supervisors, trainees, or repairers, should be on a crane while it is in operation.

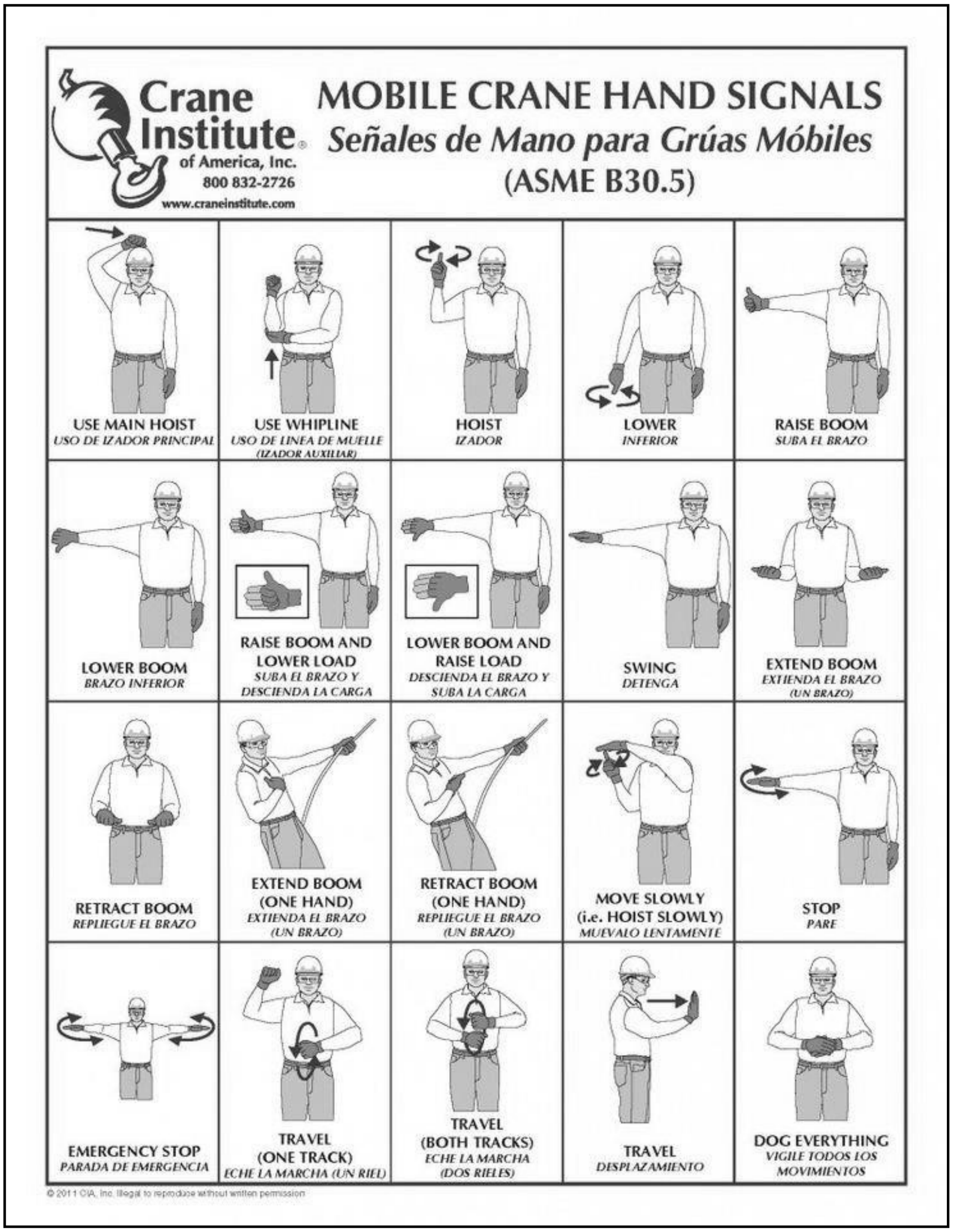

Figure 7-11. Hand signals for crane operations

7-55. When hoisting a load from below water, the crane must account for the additional weight due to the displaced water as the load is lifted. Avoid hoisting unknown weights from the water. Always consider any water contained in the load or inside a waterlogged structure as part of the load's total weight. Before handling any waterlogged loads or loads from water or mud, ensure that the combined weight of the load and the water is within the crane's lifting capacity.

7-56. When lifting a heavy load, raise it slightly to check for any excessive stress on the sling and to ensure that the load is balanced. If you notice any issues, immediately lower the load and do not attempt to move it until you have made the necessary adjustments or repairs.

7-57. Before hoisting a near-capacity load, make sure the hoisting line is vertical. Move the crane instead of lowering the boom, since swinging a capacity load increases the chance of tipping.

7-58. When lowering a boom under load, exercise extreme caution. Pay close attention to the load chart, especially regarding changes in radius, and keep an eye on the radius indicator. These charts are located in the operator's cab. Never lower the hoisting line and the boom at the same time.

7-59. When lowering loads, ensure that you use a low speed that does not exceed the hoisting speed of the equipment for the same load. The typical hoisting speed for a 30-ton, motor-operated crane is approximately 18 feet per minute when carrying a rated load. Stopping the load at these speeds over a short distance can double the stress on both the slings and the crane.

7-60. Be cautious to protect workers, buildings, and scaffolds from injuries caused by swinging loads. Avoid swinging loads over workers whenever possible. If you must move loads over areas where people are present, provide adequate warning (using a bell or siren) so that workers can relocate to safe areas.

7-61. Avoid attempting dual lifts unless absolutely necessary and do so only under competent supervision throughout the operation. Dual lifts are extremely dangerous. If the load shifts, one crane may become overloaded and fail, resulting in the entire load being transferred to the second crane, which could also fail. Before conducting a dual lift, carefully assess the positioning of the cranes and the placement of the slings to ensure the load is balanced properly.

7-62. After repairing or altering a crane or derrick that affects its hoisting capacity or stability, have a qualified individual determine its safe working load. This person should provide a written statement specifying the safe working load.

7-63. Before starting each new shift, test the brakes. Also, check them after a rainstorm or any time the brake linings may be wet. When lifting a heavy load, verify the brakes by stopping the hoist a few inches above the ground and sustaining it with the brake.

7-64. Equip all cranes with appropriate fire extinguishers. Keep the extinguishers maintained and ready for use.

7-65. Never attempt to pull pipes or other objects out of the ground.

PILE-DRIVER SAFETY

7-66. When positioning a crane to drive piles, ensure that you prepare a level work platform and use outriggers to maintain the stability of the crane. During operations, use safety lashings for all hose connections to pile drivers, pile ejectors, or jet pipes. Employ tag lines to control the movement of piles and hammers. When hoisting steel piles, utilize a closed shackle or another reliable means of attachment. Only pile-driving crew members should be allowed in the work areas while driving piles. Pile-driver operators should be aware of the following safety precautions:

- **Repairs.** Never repair any diesel or air equipment while it is in operation or under pressure.
- **Air hoses.** Make frequent inspections of air hoses to locate defects and promptly replace any defective air hoses.
- **Power lines.** Make sure that machines or equipment do not come too close to electric power lines. The machine does not actually have to contact a power line for the machine to be energized.
- **Hammer and driving heads.** When a pile driver is not in use, use a cleat or timber to hold the hammer in place at the bottom of the leads. Secure the driving heads when using the rig to shift cribbing or other material. Never place your head or other parts of your body under suspended hammers that are not dogged or blocked in the leads.
- **Drums, brakes, and leads.** Keep hoisting drums and brakes in the best condition possible and shelter them from the weather. Keep leads well-greased to provide smooth hammer travel.

Chapter 8

Hydraulic Excavators and Backhoes

Hydraulic excavators are specifically designed to dig below the surface on which they are positioned. These machines offer excellent mobility and are ideal for general-purpose tasks, such as excavating trenches and pits. Because of the hydraulic action of their stick and bucket cylinders, they can effectively push the bucket into the material being excavated. The main components of a hydraulic excavator include the boom, the stick (or arm), and the bucket.

DESCRIPTION

8-1. Hydraulic excavators are equipped with fast-acting, variable-flow hydraulic systems and user-friendly controls, allowing for high implement speed and impressive breakout force. This makes them capable of excavating a wide range of materials. The hydraulic hoe is particularly effective for digging below the ground's surface where the machine is positioned. With a diverse selection of booms, sticks, buckets, and attachments, these excavators offer great versatility for tasks such as trench excavation, truck loading, ditch cleaning, concrete breaking, and pipe installation. Additionally, the backhoe loader (BHL), featuring its hoe attachment (see figure 8-1), is well-suited for working in confined spaces and boasts good mobility.

Figure 8-1. Backhoe loader (BHL)

EXCAVATION TECHNIQUES

8-2. The BHL is usually associated with two types of excavations: trenching (linear type) and basement (area type). The operator should judge the length and depth of the cut to produce a full bucket with every pass (figure 8-2, page 98).

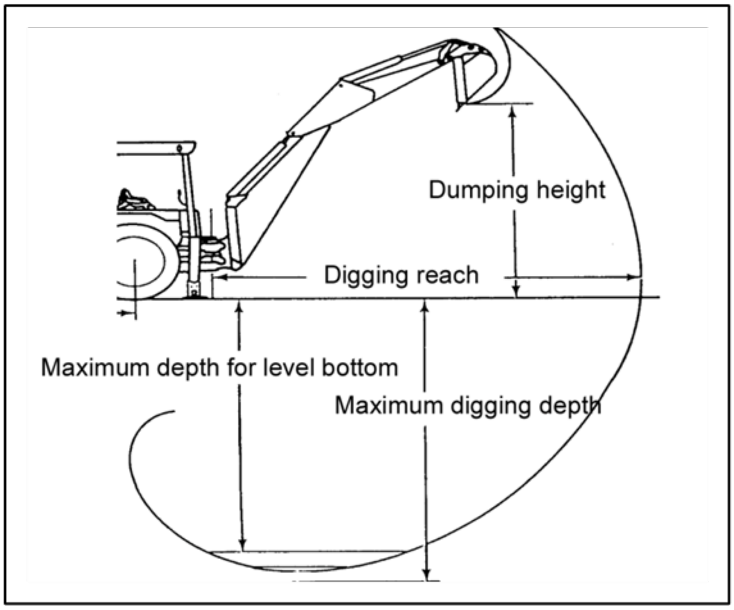

Figure 8-2. Backhoe-bucket operating dimensions

TRENCHING

8-3. There are two methods of trenching: parallel and perpendicular. Figure 8-3 depicts a BHL beginning to construct a trench.

Figure 8-3. BHL excavating

Parallel

8-4. Using the parallel method, position the BHL directly over the trench while ensuring the tractor remains aligned with the centerline of the trench. As digging continues, gradually move the machine away from the excavation. You can either load the excavated material into haul units or stockpile it along the trench's side for later use as backfill.

Perpendicular

8-5. When using the perpendicular method for trench excavation, it is important to dig the trenches in two or more cuts or lifts. Start by excavating the top 35 to 45 percent of the trench depth; for this, position the boom high for the initial cut. After this first cut, move forward about half the length of the machine and lower the boom to finish the cut and remove the remaining material. While this approach may require more and shorter movements, it provides better bucket digging angles and reduces the hoisting distance for the upper lifts.

BASEMENTS

8-6. There are many variations of the two basement excavation sequences illustrated in figure 8-4. The procedures differ based on the design and shape of the excavation, the constraints of surrounding properties, and the requirements for disposing of the excavated material. The initial cut involves digging a trench with vertical outside walls. To reduce the need for manual cleanup, ensure that all exterior wall faces are dug vertically. Plan the starting point and the digging sequence so that the machine can efficiently exit the excavation when completed. When digging trenches for service pipes, do this last and work from the basement outward. Position the machine above the outer edge and dig toward the end and sides of the tractor. Move the machine as indicated by the arrows in the figure.

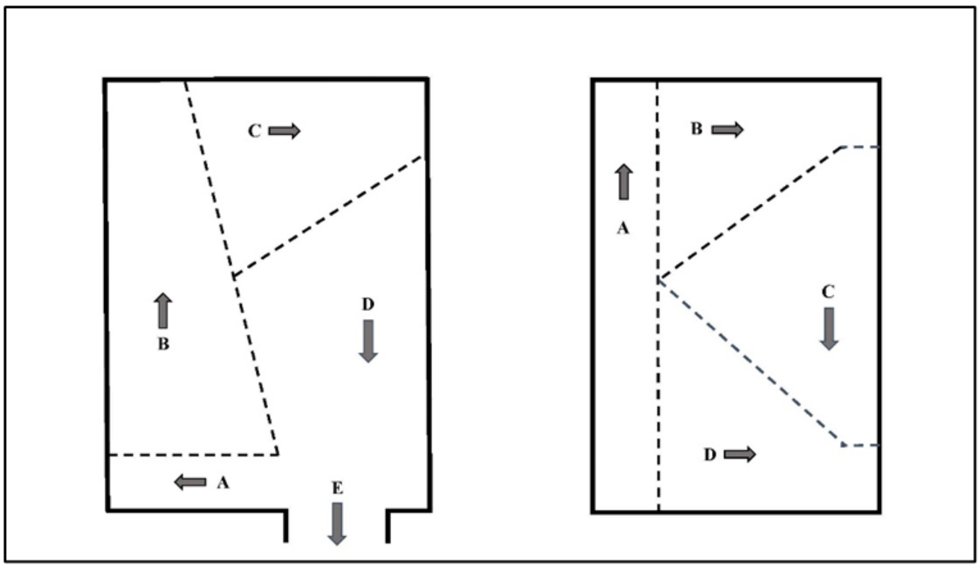

Figure 8-4. Two methods of excavating basements

OPERATION TECHNIQUES

UNDERGROUND UTILITIES

8-7. Survey the area for underground hazards and surface obstacles before digging. This applies particularly to populated areas with multiple underground utilities.

CONFINED QUARTERS

8-8. Working in confined quarters is not efficient from a production standpoint. If expecting considerable close-quarter work, plan to use small machines that can operate efficiently with a minimum work radius.

DRAINAGE DITCHES

8-9. If the job is to continue during wet seasons or in wet areas, give prime consideration to drainage. Begin ditch excavations at the lower end and work toward the upgrade.

HARD MATERIALS

8-10. A hoe can effectively dig into fairly hard materials. However, using blasting or ripping techniques may be more efficient than attempting to break through hardpan and rock layers with a bucket. Once the trench is opened, break the ledge rock by positioning the bucket underneath the layers and pulling it upward. Remove the top layers first, lifting only one or two layers at a time.

BACKHOE LOADER

8-11. The BHL is a pneumatic tired, two-wheel and four-wheel drive (2WD/4WD) front-end loader and backhoe powered by a diesel engine. It is designed for tasks such as excavation of small emplacements, material handling, and general construction. The BHL provides the mobility and operational characteristics required by modern armed forces. Operational features include the capability to function at various humidity levels and ambient temperatures ranging from 25°F to 95°F (32°C to 35°C), as well as at altitudes up to 10,000 feet (3,048 meters). The machine is equipped with a hydraulic front-end loader bucket and a hydraulic backhoe bucket, both controlled from a cab with rollover protective structure (ROPs) and falling object protective structure (FOPs) that houses all operator controls. Power is delivered to the wheels through either an automatic or semi-automatic transmission. Stabilizers are utilized to ensure the BHL remains stable while operating the backhoe.

EXCAVATING

8-12. Under average conditions, small excavators with bucket sizes of less than 1 cubic yard can complete an excavation cycle in 14 seconds. An excavation cycle includes the following steps: loading the bucket, swinging the loaded bucket, dumping the bucket, and swinging the empty bucket. Average conditions are defined as a cut depth between 40 and 60 percent of the machine's rated maximum digging depth, and a swing angle between 30° and 60°. For bucket sizes ranging from 1 cubic yard to less than 2.5 cubic yards, the average cycle time is 15 seconds. It is important to note that greater digging depths or wider swing angles will increase the cycle time.

8-13. Ensure that the hoe is level before operating it. Lower the front loader bucket to the ground, keeping it flat so that the machine’s front wheels are not touching the surface. Move the gearshift and the range-shift levers to their neutral positions, then lower the outriggers. Use the outriggers to level the machine and raise the rear wheels slightly off the ground. Always operate with minimal bucket-arm swing.

8-14. To evaluate heaped capacity, hoe buckets are rated based on an assumed material repose angle of 1:1. As a result, the actual capacity of the bucket varies depending on the type of material being excavated, since each material has its own natural repose angle. Table 8-1 presents the bucket fill factors for hoe buckets according to different material types.

Table 8-1. Bucket fill factors for hoe buckets

Material	*Fill Factor (Percent)*
Moist loam or sandy clay	100 to 110
Sand and gravel	95 to 110
Rock (poorly blasted)	40 to 50
Rock (well blasted)	60 to 75
Hard, tough clay	80 to 90

8-15. **Bucket Cylinder.** When using the bucket cylinder to excavate, follow these steps (see figure 8-5):

- ***Step 1***. Put pressure on the boom to force the bucket teeth or cutting edge into the ground.
- ***Step 2***. Roll the bucket toward the machine until it is full.
- ***Step 3***. Raise the bucket, in a smooth operation, high enough above the trench to clear the spoil pile or the hauling unit and dump the excavated material.

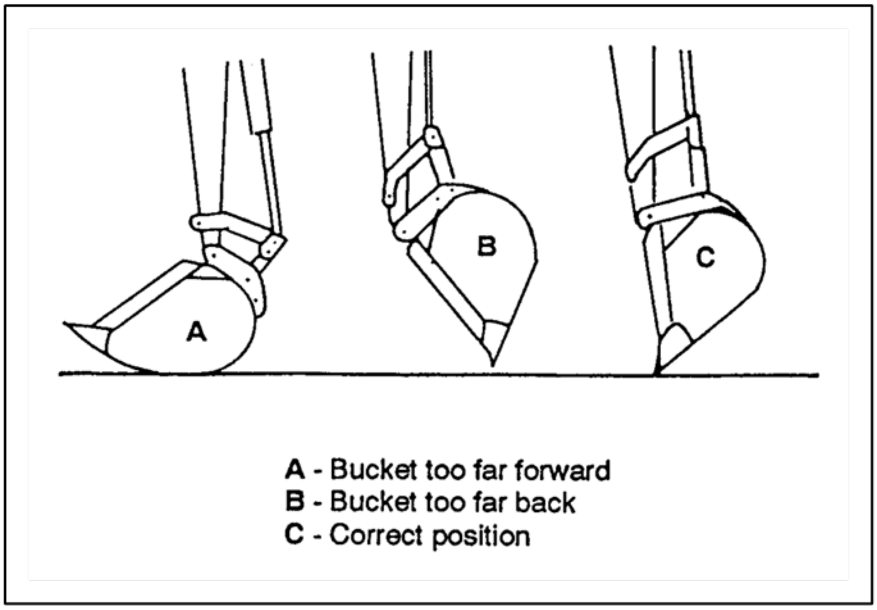

Figure 8-5. Bucket-cylinder operation

8-16. **Dipper Cylinder.** The maximum digging force is developed by operating the dipper cylinder perpendicular to the dipper. As a rule, the optimum depth of cut for a hoe is 30 to 60 percent of the machine's maximum digging depth (figure 8-2, page 98). When using the dipper cylinder to excavate, follow these steps:

- ***Step 1.*** Lower the bucket into the digging position (figure 8-6 [A]).
- ***Step 2.*** Roll the bucket until the bucket teeth or the cutting edge is flat on the ground (figure 8-6 [B]).
- ***Step 3.*** Use the stick cylinder to move the bucket toward the machine until it is half full (figure 8-6 [C]).
- ***Step 4.*** Raise the stick and roll the bucket until it is full (figure 8-6 [D]).

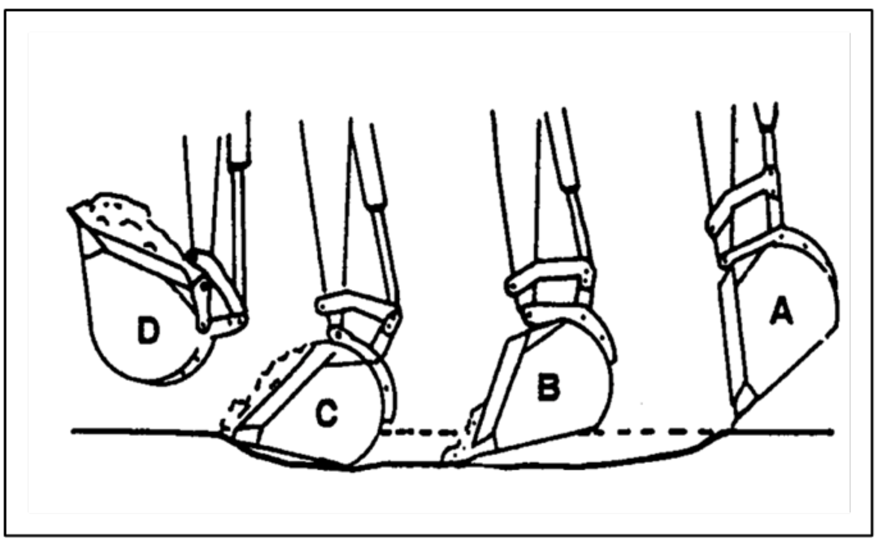

Figure 8-6. BHL digging technique

LOADER BUCKET

8-17. When digging with a loader bucket—

- Use the bucket cylinders to help break the ground loose instead of depending on the forward movement of the machine, as in the loader crowding technique.
- Do not raise the bucket higher than necessary to dump the material.
- Use as flat a ramp as possible when starting an excavation. Plan the job so that most of the hauling from the excavation can be done when driving the unit forward. A steeper ramp can be used when driving forward than when driving in reverse.
- Keep the working area level.

LOADING

8-18. To excavate and load efficiently, the hoe bucket should be lifted through the digging motion and above the haul unit. If feasible, position the truck on the pit floor. This way, once the digging is complete, the bucket will already be above the haul unit, eliminating the need to raise it further before swinging and dumping. This setup can save approximately 12 percent of the total excavation-loading cycle time when loading dump trucks with a hoe. Follow these steps:

- Plan and lay out the area of operation.
- Spot the truck so that the hoe does not have to turn (revolve) more than 90° (V-positioning, discussed in chapter 10, is often appropriate).
- Rotate the bucket over the rear of the dump bed, rather than over the cab of the truck.
- Keep the working area smooth.
- Raise the bucket while moving toward the truck.
- Lower the bucket while moving away from the truck.
- Shake the bucket only when necessary to loosen dirt stuck in the bottom of the bucket.

LEVELING AND GRADING

8-19. Use the loader bucket for leveling and grading, as follows:

- Fill all holes and hollows and loosen up any high spots before attempting to finish the grade (see figure 8-7).
- Spread the dirt evenly by holding the bucket close to the grade (tipped slightly forward) and letting the dirt spill.
- Level and pack the dirt with the loader bucket in a lowered position. To finish, operate the machine in reverse with the bucket dragging (back blading) on the ground.

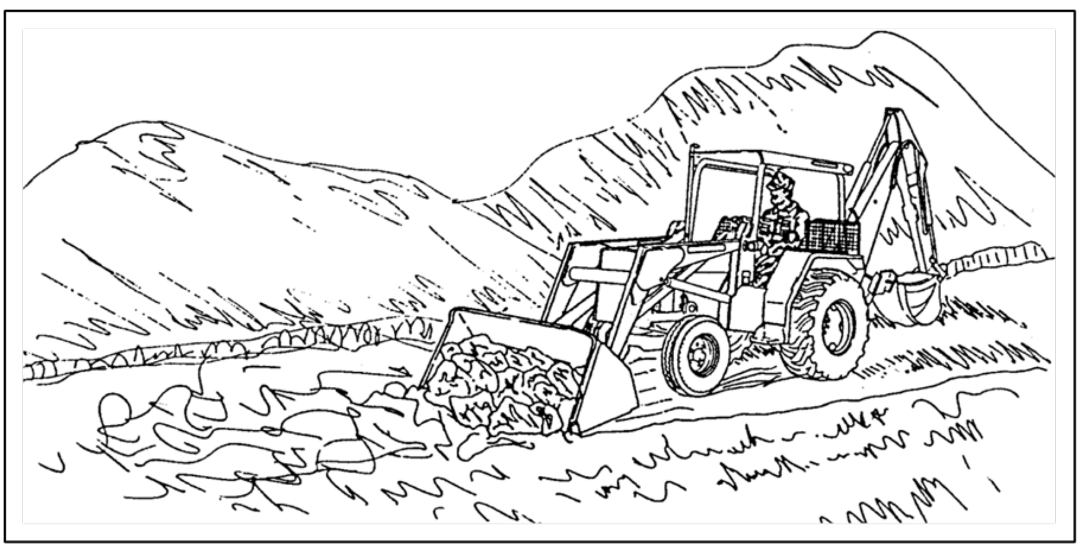

Figure 8-7. Leveling the ground with a loader bucket

TRENCH BACKFILLING

8-20. Use the loader bucket for trench backfilling as follows:

- Position the machine at approximately a 45° angle to the length of the trench and its spoil pile.
- With the bucket raised about 2 inches above the natural ground, use it like a dozer blade to push the material into the trench. Keep the bucket level while pushing the material; do not crowd/curl.
- After the material falls into the trench, reverse the machine and move along the pile to repeat pushing.
- After the last pass, dump the material remaining in the bucket into the trench.

If the material in the spoil pile along the trench is higher than 2 feet or is wet, attack the pile in two passes. Take off the upper half with the first pass and the remainder with a second cleanup pass.

TRACK-MOUNTED EXCAVATOR

8-21. Track-mounted excavators (see figure 8-8) are diesel-powered machines with a maximum digging depth of about 20 feet and a dumping height of approximately 22 feet. These excavators can travel around a job site at a maximum speed of 3 mph in high range. For long-distance travel between projects, they need to be transported. They are commonly used for excavating pipeline trenches, drainage ditches, building footings, creating hasty fortifications, and loading trucks.

Figure 8-8. Track-mounted excavator

EXCAVATING

8-22. Excavators can be fitted with buckets that range in size from 1 to 2.5 cubic yards. Under average conditions, the excavation cycle for this machine takes about 15 seconds, based on a cut depth of 8 to 12 feet and a swing angle of 30° to 60°.

LIFTING

8-23. In utility jobs, excavators often need to lift and swing heavy sections of pipe into trenches. Additionally, these machines can be used to hoist and unload materials from trucks. The weight an excavator can lift depends on the distance of the load from the machine's center of gravity. It is essential to consult the current specification sheets before attempting any lift. Always position the excavator as close to the load as possible. Another crucial factor to consider is the swing and positioning of the machine. The lifting capacity is 65 to 70 percent greater when lifting over the front of the machine compared to over the side. These machines are designed to handle loads of up to 15,000 pounds at a swing radius of 15 feet from the side.

PRODUCTION ESTIMATES

8-24. Factors that affect hoe production are the—

- Width of the excavation.
- Depth of the cut.
- Material type.

- Working radius for digging and dumping.
- Required bucket dumping height.

8-25. EXAMPLE:
Use a hoe equipped with a 0.25 cubic yard bucket to excavate hard clay. The depth of cut will average about 50 percent of the machine's maximum digging depth and the swing angle should be less than 60°. What is the expected production, in BCY per hour, assuming 50 working minutes per hour?

- ***Step 1.*** Determine the bucket fill factor based on the material type (table 8-1, page 100)

$$\boldsymbol{Fill\ factor\ for\ hard\ clay} = \mathbf{80\ to\ 90}\ \boldsymbol{percent}$$

  Lacking any other information, use an average of 85percent.
- ***Step 2.*** Use a hoe cycle time based on past performance data if available or use the average cycle time given in paragraph 8-12.

  Average cycle time = 14 seconds
- ***Step 3.*** Determine the ideal production rate (LCY per hour).

$$\boldsymbol{Ideal\ production\ rate\ (LCY\ per\ hour)} =$$

$$\frac{3{,}600\ second\ per\ hour}{backhoe\ cycle\ time\ (seconds)} x bucket\ size\ (cubic\ yards)$$

$$\boldsymbol{x\ fill\ factor\ (from\ step\ 1)}$$

$$Ideal\ production\ rate\ = \frac{3{,}600}{14}\ x\ 0.25\ x\ 0.85 = 55\ LCY\ per\ hour$$

- ***Step 4.*** Determine the production rate (LCY per hour) by adjusting for efficiency.

$$Production\ rate = ideal\ production\ rate\ (LCY\ per\ hour)\ x\ efficiency\ factor$$

$$Production\ rate\ (LCY\ per\ hour) = 55\ x\ \frac{50\ minutes}{60\ minutes} = 45\ LCY\ per\ hour$$

- ***Step 5.*** Convert the production rate from LCY per hour to BCY per hour. Determine the soil-volume correction factor from table 1-1, page 3 (LCY to BCY for hard clay).

$$Soil\ conversion\ factor\ for\ clay\ (loose\ to\ bank) = 0.7$$

$$Production\ rate = 45\ LCY\ per\ hour\ x\ 0.7 = 32\ BCY\ per\ hour$$

Chapter 9
Air Compressors and Pneumatic Tools

When air is compressed, it absorbs energy from the compression process. This energy is then transported through a pipe or hose to the operating equipment, where part of it is converted into mechanical work. A compressed air system typically includes one or more compressors, along with a distribution system that carries the air to where it is needed. Engineers use compressed air for various applications, such as inflating rubber equipment, spraying materials, operating pneumatic tools, cleaning equipment, and performing specific tasks in maintenance shops. Pneumatic tools rely on the energy from compressed air to function.

AIR COMPRESSORS

9-1. Portable air compressors are widely used on construction sites to accommodate frequently changing job requirements. Figures 9-1 and 9-2 (page 106) illustrate two types of air compressors. The capacity of an air compressor is measured by the amount of free air it can compress to a specified pressure within one minute, under standard conditions (an absolute pressure of 14.7 pounds per square inch [psi] at 60°F). This volume of free air is typically expressed in cubic feet per minute (cfm). The number of pneumatic tools that can be operated by a single air compressor depends on the air requirements of those specific tools.

Figure 9-1. Trailer-mounted, 260-cfm air compressor

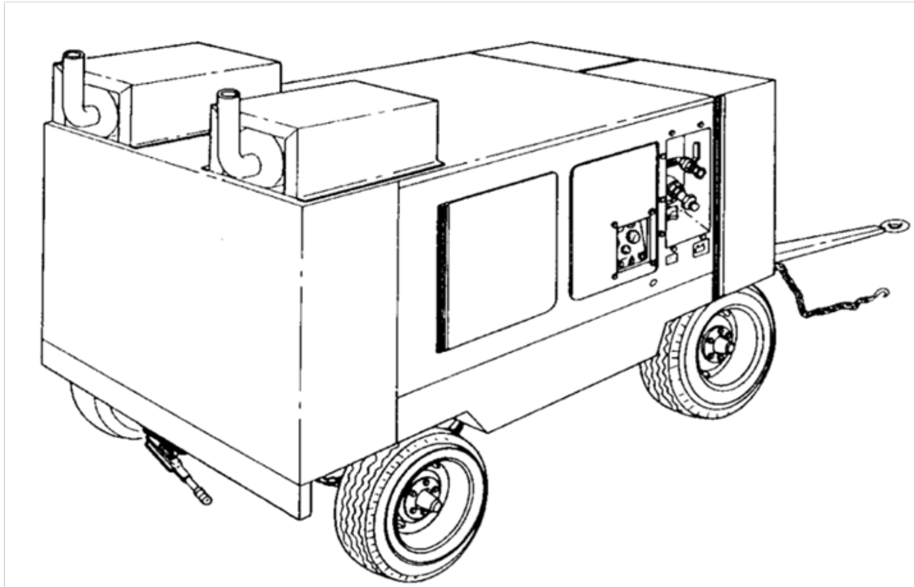

Figure 9-2. Wheel-mounted, 750-cfm air compressor

EFFECTS OF ALTITUDE

9-2. When a specific volume of free air is compressed, the original pressure is typically 14.7 psi (pounds per square inch) absolute pressure at sea level. However, if the same volume of free air is compressed to the same gauge pressure at a higher altitude, the resultant volume of the compressed air will be less than that at sea level. This means that while a compressor may achieve the same discharge pressure at higher altitudes, the volume of air supplied in a given time interval will be lower. Table 9-1 illustrates the percentage of volumetric efficiency at various altitudes based on a 100 psi gauge output pressure.

Table 9-1. Efficiency of air compressors at various altitudes (100-psi gauge output pressure)

Altitude (Feet)	*Single-Stage Reciprocating Compressor*	*Two-Stage Reciprocating Compressor*	*Rotary Compressor*
	Percent of Efficiency	*Percent of Efficiency*	*Percent of Efficiency*
2,000	98.7	99.4	100.0
5,000	92.5	98.5	100.0
7,000	—	—	100.0
8,000	87.3	97.6	99.9
10,000	84.0	97.0	—
12,000	—	—	98.6

CAPACITY OF COMPRESSORS

9-3. In a typical job, some tools are in constant operation while others are used less frequently. It is important to analyze the actual air requirements before determining the compressor needs. For example, when using ten rock drills, usually no more than five or six will be consuming air at the same time. Additionally, the air consumption can vary significantly depending on the application. Refer to Table 9-2 for data on the air requirements of specific tools. After assessing the number of active tools and their air usage, it is advisable to increase the total air demand by 10 percent to account for potential leaks.

Table 9-2. Description and operating data for pneumatic tools

Tool	Air Requirements		Hourly Work Output	Air-Line Hose Diameter
	psi	cfm		
Paving breaker (jackhammer) (80-lb) Attachments: chisel point, moil point, 8" diameter tamper, sheeting driver	80-100	65	15 sq ft of 6" asphalt paving with chisel point; 12 to 50 sq ft of 6" to 8" nonreinforced concrete with moil point depending upon width of cut (12 sq ft for narrow cut, 50 sq ft for wide cut); maximum lift of 8" with tamper; driving wood or up to 2" thick steel sheeting with sheeting driver	3/4"
Paving breaker (clay digger) (25-lb) Attachments: moil point, pick, spade, drum opening tool	80-90	35	Loosen 1.2 cubic yards of tough clay with spade; open 20 to 30, 55-gallon drums with a drum-ripping tool	1/2"
Nail driver Attachments: 1/2" and 3/4" head driving sets, rivet buster	90	30	250, 80d nails (after the nails have been started with a hammer or a sledge)	1/2"
Circular saw Attachments: woodworking, 12" blade (Special abrasive disks available for cutting other materials.)	80-100	75	Cuts 4" x 4" lumber in 30 seconds	1/2"
Chain saw Attachments: 24" blade, Type I, Size 1	80-100	90	Cuts 12" diameter hardwood log in 50 seconds. (Under 25': 5/8", 25' to 100': 3/4", over 100': 1")	5/8" to 1/2"
Wood drill Attachments: 2" diameter capacity. Ship augers range from 7/16" to 2" in 1' and 3' lengths.	80-100	60	Using largest size auger, 125 holes 36" deep	3/4"
Sump pump (3" discharge, 175-GPM capacity)	80-90	100	175 GPM at 25' head 150 GPM at 150' head	3/4"
Steel drill (Number 3 Morse taper chuck, 1 1/4" capacity)	90-100	27	30 each 1" diameter holes in 1" thick steel plate (lead holes of 1/4" diameter drilled previously)	1/2"
Handheld rock drill (dry-type, 55-lb) Attachments: 2', 4', 6', and 8' hollow-steel drill rods and 1 5/8", 1 3/4", 1 7/8", and 2" drill bits	80-100	95	1 3/4" Hole Soft rock: 15-20' Medium rock: 10-15' Hard rock: 5-10'	3/4"

NUMBER OF COMPRESSORS

9-4. The number of compressors needed depends on the available sizes. Typically, if 1,400 cfm of free air is required for a specific job, two 750-cfm units would be sufficient. Air compressors are robust machines but, like all mechanical equipment, they need regular maintenance. As a result, having a standby unit may sometimes be necessary.

LOCATION OF COMPRESSORS

9-5. To the extent possible, locate all compressors in a central position on the job site. This setup offers the benefits of unified operation and improved supervision. However, if a central location is not feasible due to insufficient piping, excessive friction loss, or obstructions, it will be necessary to position the compressors at suitable points instead. Ensure that all air compressors are leveled and positioned as close to the air-operated devices as conditions allow.

OPERATION OF COMPRESSORS

9-6. Air compressors should always be positioned upwind from the work area to prevent foreign materials from entering the air intake. When operating in extremely dusty conditions, it's important to take precautions to protect the units from excessive dust. Other factors to consider include:

- Open all drain cocks to drain condensation after each 8 hours of operation, thus eliminating the possibility of rusting or freezing.
- Close the side panels of the compressor housing when it is being operated in cold weather.
- Block the wheels and engage the hand brake of the trailer mount before operation.
- Ensure that the receiver tank is drained of air when operations are complete.

COMPRESSED-AIR USES

9-7. Compressed air is used extensively on construction projects. In many instances, compressed air is the most convenient method of operating equipment and tools.

ASPHALT PLANTS

9-8. Air compressors are frequently used in asphalt plants for fuel atomization of the dryer burner. Compressors are also used to clean up the plant, to power various tools at the paving site, and to dedrum.

CONCRETE OPERATIONS

9-9. At the batch plant, vibrators may be used on the aggregate hopper to prevent bridging. Air-driven pin drivers and cleaning devices for cleaning sawed joints are used at the paving site.

PNEUMATIC TOOLS

9-10. The military uses pneumatic paving breakers, nail drivers, saws, drills, pumps, and a variety of other pneumatic tools. Pneumatic tools can be powered by either a reciprocating-percussion or a rotary-vane air motor.

- **Reciprocating-percussion air motor.** The reciprocating-percussion air motor is designed for applications where a hammering action is needed. It utilizes a free-floating piston that moves within a cylinder. When the throttle is opened, a set of valves alternately introduces air to either end of the cylinder, causing the piston to move back and forth. This motion is then transmitted to the tool, which performs the work.
- **Rotary-vane air motor.** The rotary-vane air motor is used when rotary motion is required. It consists of a cylinder with an eccentrically mounted, slotted rotor, where each slot contains a spring-loaded vane. When the throttle opens, compressed air enters a small compartment, creating pressure on the vanes. This pressure causes the rotor to turn toward a larger compartment. A gear train then transmits this rotation to an attachment that performs the intended work.

9-11. Two important factors that affect the condition of a pneumatic tool are lubrication and air pressure.

- **Lubrication.** To ensure proper lubrication of a pneumatic tool, hold a piece of paper in front of the exhaust port of the tool. If a thin film of oil collects on the paper, the tool is adequately lubricated. However, if drops of oil form on the paper or if oil foams around the exhaust port, the tool is over-lubricated. If no oil is visible, check the lubrication device immediately.
- **Air pressure.** Each tool requires a specific volume of air at a designated pressure. If the air volume or pressure drops excessively, it can cause significant damage. Check for air leaks in the hose and around the air connections. Pay attention to the sound and behavior of the tool while it is operating. If a tool seems to be working sluggishly or exhibits surging (erratic operation), it may have too much or too little pressure. Tools should never be operated with less than 70 psi or more than 100 psi at

the tool. If the air pressure gauge on the compressor consistently reads below 70 psi, the unit is overloaded, leading to insufficient pressure at the tool.

9-12. Many pneumatic tools tend to be heavy and produce significant vibration, which can lead to operator fatigue. This issue is especially pronounced for inexperienced users. It is important to select operators carefully, ensuring they are physically fit and strong enough to handle the equipment effectively.

AIR MANIFOLDS

9-13. Many construction jobs require more compressed air per minute than any single compressor can produce. An air manifold is a large-diameter pipe used to transport compressed air from one or more air compressors without causing significant friction loss.

CONSTRUCTION

9-14. Manifolds can be constructed from any durable pipe. Compressors are connected to the manifold using flexible hoses. A one-way check valve must be installed between the compressor and the manifold to prevent back pressure from forcing air back into the compressor’s receiver tank. While compressors grouped to supply an air manifold may differ in capacity, they should all have a final discharge pressure of 100 psi. It is important not to use different types of compressors on the same air manifold; the differing pressure control systems of rotary and reciprocating compressors could lead to one compressor being overloaded while the other remains idle. The Army typically constructs air manifolds using 6-inch-diameter invasion piping. To use air at any point along the manifold, outlet valves can be installed for connecting air lines and pneumatic tools.

COMPRESSED-AIR DISTRIBUTION SYSTEM

9-15. The purpose of installing a compressed air distribution system is to deliver an adequate volume of air to the work site at sufficient pressures for efficient tool operation. Any drop in pressure between the compressor and the point of use results in a loss that cannot be recovered. Therefore, the distribution system is one of the most critical components of the entire system. When planning a compressed air distribution system, keep the following general rules in mind:

- Pipe sizes should be large enough so that the pressure drop between the compressor and point of use does not exceed 10 percent of the initial pressure.
- Each header or main line should be provided with outlets as close as possible to the point of use. This permits shorter hose lengths and avoids large pressure drops through the hose.
- Condensate drains should be located at appropriate places along the headers or main lines.

FRICTION LOSSES

9-16. The hose or pipe that connects the tool to the air compressor can impede the flow of air. As a result, the pressure at the tool end of the line is lower than at the compressor end. Air-line friction increases when the diameter of the hose or pipe decreases or when the length increases. Through practical experience, it has been determined that a hose measuring 200 feet in length and 3/4 inch in diameter is the maximum size for efficient operation of a handheld tool. Standard tables (specifically tables 9-3 and 9-4) are available to help calculate friction loss in a pipe or hose.

AIR-LINE HOSE

9-17. The air-line hose is a rubber-covered, pressure-type hose designed for transmitting compressed air. For hand-operated tools, a hose with a 3/4-inch inside diameter is typically used, while a 2-inch inside diameter hose is employed with crawler-mounted drills. These hoses are usually available in 50-foot lengths and come equipped with quick-acting fittings for connecting to tools, compressors, or other hoses. Leader hoses, made from oil-resistant neoprene rubber, have end attachments and are used between the air-line oiler and an air tool. Sections of leader hose typically measure either 12 or 25 feet in length and have diameters of 1/2 or 3/4 inch.

AIR-LINE OILER

9-18. An air-line oiler is a reservoir installed directly in front of an air tool within the air line. Its purpose is to lubricate the tool by mixing oil with the air as it passes through. An adjustable needle allows users to control the amount of oil that enters the air stream. There are two types of oilers: directional and nondirectional. When connecting the oiler to the air line, ensure that the arrow points in the direction of the airflow.

PNEUMATIC TOOLS

9-19. Pneumatic tools are simpler in design than similar gasoline or electric-powered tools and require less maintenance. A pneumatic tool with nonsparking attachments can be operated around petroleum products or explosive materials without presenting a fire hazard.

Table 9-3. Loss of air pressure due to friction in a pipe[1]
(in psi per 1,000 feet of pipe with 100-pound-gauge initial pressure)

Cubic Feet of Free Air Per Minute	*Nominal Pipe Diameter (Inches)*								
	1	*1 1/4*	*1 1/2*	*2*	*2 1/2*	*3*	*3 1/2*	*4*	*4 1/2*
100	27.9	6.47	2.86	0.77	0.30	—	—	—	—
125	48.6	10.20	4.49	1.19	0.46	—	—	—	—
150	62.8	14.60	6.43	1.72	0.66	0.21	—	—	—
175	—	19.80	8.72	2.36	0.91	0.28	—	—	—
200	—	25.90	11.40	3.06	1.19	0.37	0.17	—	—
250	—	40.40	17.90	4.78	1.85	0.58	0.27	—	—
300	—	58.20	25.80	6.85	2.67	0.84	0.39	0.20	—
350	—	—	35.10	9.36	3.64	1.14	0.53	0.27	—
400	—	—	45.80	12.10	4.75	1.50	0.69	0.35	0.19
450	—	—	58.00	15.40	5.98	1.89	0.88	0.46	0.25
500	—	—	71.60	19.20	7.42	2.34	1.09	0.55	0.30
600	—	—	—	27.60	10.70	3.36	1.56	0.79	0.44
700	—	—	—	37.70	14.50	4.55	2.13	1.09	0.59
800	—	—	—	49.00	19.00	5.89	2.77	1.42	0.78
900	—	—	—	62.30	24.10	7.60	3.51	1.80	0.99
1,000	—	—	—	76.90	29.80	9.30	4.35	2.21	1.22
1,500	—	—	—	—	67.00	21.00	9.80	4.90	2.73
[1]Compressed Air Handbook, Compressed Air and Gas Institute, 1947.									

Table 9-4. Loss of air pressure due to friction in a hose[1]
(in psi per 50 feet of hose with 100-pound-gauge initial pressure)

Cubic Feet of Free Air Per Minute	*Nominal Hose Diameter (Inches)*				
	1/2	*3/4*	*1*	*1 1/4*	*1 1/2*
20	0.6	0.2	—	—	—
30	2.0	0.4	0.1	—	—
40	4.3	0.6	0.2	—	—

Table 9-4. Loss of air pressure due to friction in a hose[1]
(in psi per 50 feet of hose with 100-pound-gauge initial pressure)[continued]

Cubic Feet of Free Air Per Minute	Nominal Hose Diameter (Inches)				
	1/2	3/4	1	1 1/4	1 1/2
50	7.6	1.0	0.2	—	—
60	12.0	1.4	0.4	—	—
70	17.6	2.0	0.5	0.1	—
80	24.6	2.7	0.6	0.2	—
90	33.3	3.5	0.8	0.2	—
100	44.5	4.4	1.0	0.3	—
110	—	5.4	1.2	0.4	—
120	—	6.6	1.5	0.4	0.1
130	—	7.9	1.8	0.5	0.2
140	—	9.4	2.1	0.6	0.2
150	—	11.1	2.4	0.7	0.2

[1]Compressed Air Handbook, Compressed Air and Gas Institute, 1947.

PAVING BREAKER (JACKHAMMER) (80-POUND)

9-20. The pneumatic paving breaker, classified in the 80-pound weight category, is designed for heavy-duty demolition tasks such as breaking concrete, brick, asphalt, and macadam. It is also effective for demolishing walls, columns, piers, foundations, and for general rock breaking. Various attachments can be used with this tool depending on the specific job requirements. This breaker is part of the reciprocating percussion family of air tools. It weighs 87.5 pounds, uses a 3/4-inch diameter hose, and requires 65 cfm of air at a pressure range of 80 to 100 psi. The tool is constructed in three main components: the back head, the cylinder, and the front head. The back-head group includes the air controls, oil reservoir, and handle. The cylinder group consists of the cylinder, piston, and automatic valve assembly. Lastly, the front-head group serves to hold the tool steel or any attachment securely in place.

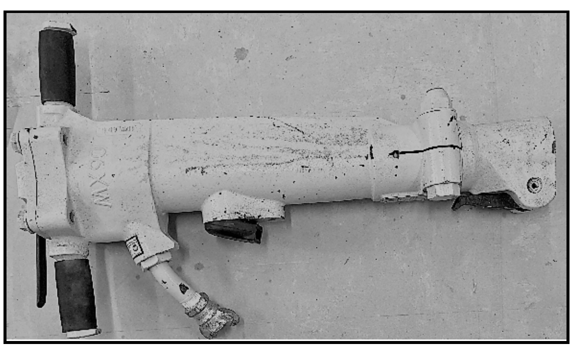

Figure 9-3. Paving breaker (80-pound)

Attachments

9-21. Four primary attachments are issued with this paving breaker. They are the moil point, the chisel point, the tamper, and the sheeting driver.

- The moil point is a 20-inch-long, 1 1/4-inch-diameter hexagonal tool made of steel. One end is pointed, while the other end features a retainer collar positioned 6 inches from the tip. This tool is designed for breaking through concrete, stone, or other materials that are high in abrasiveness and density.

- The chisel point resembles the moil point, but it features a 3-inch-wide working edge designed for cutting through macadam, frozen ground, or very hard earth. Additionally, it can be used to create a marking line that serves as a guide when cutting concrete.
- The tamper is a steel pad with a diameter of 5 to 7 inches, mounted on a 1 1/4-inch hexagonal tool steel handle. It is used for compacting loose material.
- The sheeting driver consists of two steel angles and an impact pad that transfers the force to the wood or metal sheeting being driven.

Production

9-22. Due to varying job-site conditions and the mechanical state of air compressors and pneumatic tools, it is impossible to predict the work output of these tools across all projects. In non-reinforced concrete that is 6 to 8 inches deep, using a moil point, the average work output ranges from 50 square feet per hour in large areas to 12 square feet per hour in narrow cuts. In the case of reinforced concrete, the production rate may decrease to 50 square feet over an 8-hour shift.

Operation

9-23. While operating the paving breaker, hold it down firmly, but apply only enough pressure to guide the tool and keep it stable. Leaning too heavily on the breaker can shorten the tool's stroke and reduce work output. It is most effective to operate breakers in tandem. When breaking hard materials, take only small bites, approximately 4 to 8 inches behind the working face. If a moil point becomes stuck, use a second breaker to free the material around it. If the point remains stuck while using a single breaker, remove the paving breaker and use another point to break it free. Here are some important operating precautions to keep in mind:

- Wear double hearing protection.
- Wear goggles to protect eyes from chips and dust.
- Ensure that the shank of each attachment is the correct size. Improper shank sizes will reduce the effectiveness of the blow and will cause damage to the paving breaker.
- Keep the points of the attachments sharp.
- Keep all nuts tight. The air hose to the paving-breaker connections should be checked frequently to ensure that no air is escaping.
- Provide a clear work area for efficient tool operation.

Maintenance

9-24. Maintenance issues with the paving breaker often arise from improper use of its attachments. Many users mistakenly attempt to drill holes with the moil point, which is actually designed as a breaking tool. Using it for drilling can lead to damage and breakage of the point. The chisel point, on the other hand, is intended for cutting asphalt and soft materials; if used for breaking concrete, it may become irreparably damaged. Another common problem is the breakage of the tool-latch retainer bolt. This typically occurs when the operator fails to turn off the tool after the moil point breaks through the material. The resulting bounce of the front head against the concrete can lead to the retainer bolt breaking.

PAVING BREAKER (CLAY DIGGER) (25-POUND)

9-25. The pneumatic paving breaker in the 25-pound weight class (see figure 9-4) is a medium-weight tool designed for tasks such as spading, trimming, cutting, or picking clay, hardpan, or frozen ground. It weighs 25.2 pounds and operates with a 1/2-inch diameter hose, requiring 35 cfm of air at a pressure of 80 to 90 psi. This tool is composed of three main parts: the back head, the cylinder, and the front head. The back head includes the handle, while the cylinder forms the main body of the tool, housing the hammer that is driven against the shank by air pressure. The front head functions as the tool retainer.

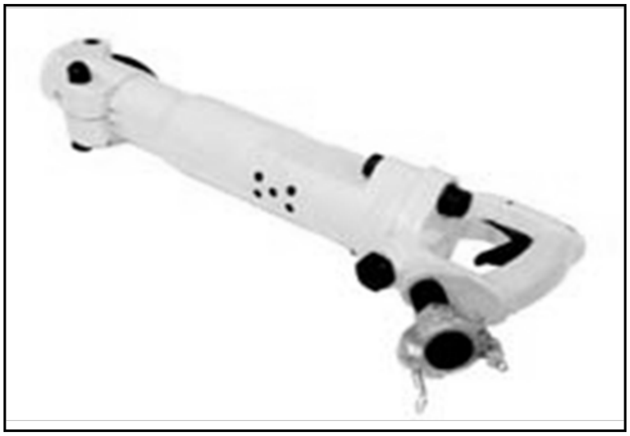

Figure 9-4. Paving breaker (25-pound)

Attachments

9-26. The three primary attachments normally issued with this breaker are the moil point, the pick, and the spade. A metal, drum-ripping tool may be issued for opening 55-gallon drums.

9-27. The moil point consists of a 15-inch straight length of 1-inch-diameter tool steel that is pointed on one end. It is used as a light demolition tool on masonry, concrete, or other dense material.

9-28. The pick's blade is 3 inches wide by 8 inches long with a pointed cutting end. It is used for digging into frozen ground, cemented gravel, or other materials too hard to be penetrated by the spade.

9-29. The spade, resembling a garden spade, measures 5 1/2 inches in width and 8 inches in length. It is designed for digging trenches, preparing footings or foundations, digging caissons, driving tunnels, or performing any general digging tasks that are too difficult and time-consuming for a standard hand spade.

9-30. The metal, drum-ripping tool has a 1-inch-wide cutting blade, topped by a 5/8-inch-thick, extended snubnose. The Army has the following two types—

- Type I is used to cut heads from metal drums. The nose of this ripping tool is curved to allow it to easily follow the curvature of the head on the drum.
- Type II is used to split metal drums lengthwise. It has a straight nose and is capable of opening 20 to 30, 55-gallon drums per hour.

Production

9-31. The attachment used most frequently with the 25-pound breaker is the clay spade. About 12 cubic yards of tough clay can be loosened per 10-hour shift.

Operation

9-32. Operators should merely guide the tool, never ride or lean on it. The tool is designed for trimming or digging, not for prying.

Maintenance

9-33. Pay special attention to the tool's retainer assembly. Dirt and other abrasive materials can enter the bottom of the retainer and cause excessive wear. To prevent this wear, ensure that the tool does not penetrate beyond the wider portion of the clay spade.

NAIL DRIVER

9-34. The pneumatic nail driver (see figure 9-5) is a long-stroke, piston-action riveting hammer, specifically designed for driving heavy drift pins and spikes. It weighs 24 pounds and uses a 1/2-inch-diameter hose, requiring 30 cfm of air at 90 psi. The handle is ergonomically designed to fit comfortably in the hand and features a thumb-operated throttle lever that controls the airflow. Inside the barrel of the driver, you'll find the valve mechanism, piston, and nail set. A protective sleeve on the end of the nail set prevents the tool from slipping off the head of the nail. Additionally, a safety set retainer screws onto the nozzle end of the barrel to keep the nail set securely in the tool at all times.

Figure 9-5. Nail driver

Attachments

9-35. The nail driver is issued with 1/2- and 3/4-inch nail sets and a rivet buster.

Production

9-36. Used as a nail driver, 250 60-penny nails can be driven per hour (after the nails have been started by hand).

Operation

9-37. Always begin driving nails or spikes with a handheld hammer. The nail driver should be aligned with the nail or spike being driven and struck squarely to minimize the risk of bending.

Maintenance

9-38. The retainer housing on a nail driver often breaks because the operator fails to keep the nail set pressed against the work. Any attempt to countersink a nail will result in a broken retainer spring.

CIRCULAR SAW

9-39. The pneumatic circular saw (see figure 9-6) is designed for both ripping and crosscutting tasks. It weighs 32.5 pounds and requires a 1/2-inch-diameter hose, providing 75 cfm of air at 80 to 100 psi. The handle assembly features a D-shaped handle with a trigger-type throttle and a thumb-operated plunger lock. Inside, the saw contains a rotary-vane air motor equipped with a flyball governor that limits the motor speed to 2,400 rpm. A fixed blade guard is attached to the left side of the body to protect the operator. The top handle, positioned above the body, is used to control and guide the saw. The foot is hinged at the front of the upper blade guard through a sector. By loosening a wing nut on this sector, the foot can be tilted for bevel cuts of up to 45 degrees. At the back of the foot, a second sector, secured by a wing nut, allows for adjustment of the cutting depth, ranging from 2 3/8 inches to 6 inches. Two V-shaped notches on the front of the foot aid in cutting along a line. The deeper V-notch aligns with the blade for right-angle cuts, while the smaller V-notch is positioned for 45-degree bevel cuts. A rip fence, which attaches to the front of the foot with a wing screw, should be used for long ripping cuts. Additionally, a telescopic blade guard covers the lower part of the blade when the saw is not in use. This spring-loaded guard automatically closes when the blade is lifted from the cut and folds into the fixed blade guard when the saw is in operation.

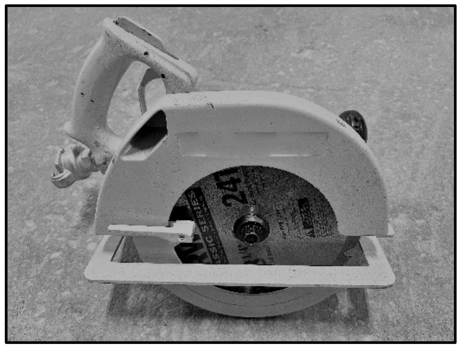

Figure 9-6. Circular saw

Attachments

9-40. This saw comes with a 12-inch combination blade that is designed for ripping and crosscutting wood only. When fitted with the appropriate abrasive disc, the pneumatic saw can also cut through materials such as brick, stone, concrete, tile, asbestos cement sheets, steel, or cast iron. It is important to note that no single type of abrasive disc or saw blade is suitable for all materials, so be sure to order the correct items for each specific job.

Production

9-41. Using the combination blade for crosscutting, the saw will cut a 4- by 4-inch board in 30 seconds. The maximum depth of cut at 90° is 4 3/8 inches.

Operation

9-42. Always use the appropriate blade for the material you are cutting. Ensure that the material is free from nails, spikes, or any similar objects. Never force the saw into a cut. If the saw is used upside down for extended periods, be cautious to prevent the exhaust port from becoming clogged. Keep your hands away from the blades, and turn off the air supply when the tool is not in use.

Maintenance

9-43. In many instances, the pneumatic circular saw is used upside down as a table saw. When this occurs, the exhaust port becomes exposed to the wood shavings. If these shavings accumulate, they can clog the air motor, rendering the saw ineffective.

CHAIN SAW

9-44. The pneumatic chain saw (see figure 9-7) is a heavy-duty tool designed primarily for cutting trees or timbers with a diameter of up to 24 inches. It weighs 45 pounds and requires 90 cfm of air at a pressure of 80 to 100 psi. The diameter of the hose depends on the distance from the air source: for distances of 25 feet or less, use a 5/8 inch hose; for distances between 26 to 100 feet, use a 3/4 inch hose; and for distances over 100 feet, use a 1 inch hose. The head assembly includes a drive housing, two handles, a guide bracket, a bumper, and an air connection. Within the drive housing is a four-vane rotary motor. A guard bar, made of heavy steel, extends from the head assembly to the idler assembly and is slightly arched so that it sits about 3/4 inch away from the upper part of the chain. This guard bar is crucial for protecting the operator from injury in the event of a chain break, and the saw should never be operated without it. The guard bar included with the chain saw is designed for the 24-inch model; however, guard bars are also available through supply channels for the 36-inch and 48-inch models. Please note that operating the 48-inch saw requires two operators.

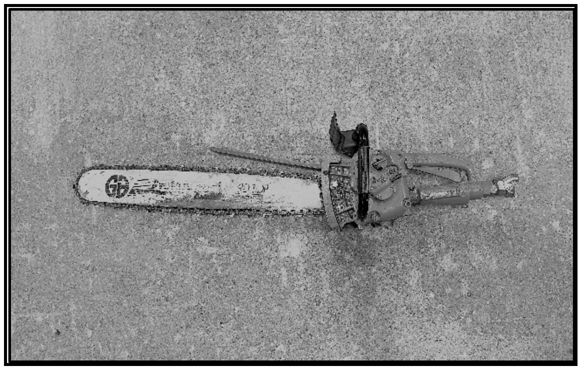

Figure 9-7. Chain saw

Chains

9-45. The standard chain features a 3/4-inch pitch and a 3/8-inch cut, making it suitable for general-purpose use on any capacity saw. It is effective for felling and cutting both hardwood and softwood. The chain is easy to sharpen and maintains its cutting edge for a relatively long time. This chain is made up of three-link sets. The center link in each set contains a raker tooth, which is alternately set to the right and left. The first and third links in each set include a cutter tooth. These cutter teeth alternate along the chain and are also set to the right and left, controlling the width of the cut. A 76-inch chain is standard with the 24-inch chain saw; however, chains measuring 100 and 124 inches are available through supply channels for use with 36-inch and 48-inch chain saws, respectively.

Production

9-46. A chainsaw can cut through a 12-inch hardwood log in 50 seconds. Avoid forcing the saw into the wood; instead, let it cut at its natural speed. It is important to ensure that the saw does not twist while you are cutting.

Maintenance

9-47. Keep the chain properly tensioned and sharpened. The blade should be adjusted to maintain a 1/2-inch slack in the chain when pulled up at the center. Having too much slack can cause the chain to jump out of the saw guide, leading to potential bending or breaking of the blade. Conversely, if the chain is too tight, it can bend and damage the sprocket.

Wood Drill

9-48. The pneumatic wood drill is a heavy-duty, low-speed tool specifically designed to drive auger-type drill bits. It weighs 27.5 pounds and requires a 3/4-inch-diameter hose, using 60 cfm of air at a pressure range of 80 to 100 psi. This drill is commonly used in trestle bridge construction and other timber projects where drilling holes for bolts and pins is necessary. The drill features a rotary-vane air motor housed within its body, along with a gear train that reduces the motor's speed to approximately 800 rpm at the chuck. It includes a chuck that accommodates 1/2-inch-diameter drill-bit shanks, secured in place by a large Allen-type setscrew. There are two types of chucks available: the Morse taper and the two-screw. The chuck is mounted on a shaft designed for the shank to extend into the base of the grip handle. Additionally, a slot in the handle's base allows for the insertion of a wedge to assist in loosening the bit if it becomes jammed in the chuck. The airline connects at the end of the throttle handle.

Attachments

9-49. Auger-type drill bits are available in lengths of 1 and 3 feet, with diameters of 7/16, 3/4, 1, and 2 inches.

Production

9-50. The drill will create 125 holes, each 36 inches deep, in one hour using a 2-inch diameter auger bit.

Operation

9-51. The wood drill can be rotated in reverse. Always begin drilling slowly until the screw is securely set. Hold the drill firmly but avoid applying excessive force. Use enough pressure to counterbalance the drill's tendency to rotate and be ready to resist the torque if the bit gets stuck. When boring and withdrawing the auger, ensure it remains aligned with the hole.

Maintenance

9-52. The auger bit often gets stuck in the chuck. Use the auger ejector to remove it. Attempting to knock it out with a hammer can damage both the chuck and the auger.

SUMP PUMP

9-53. The pneumatic sump pump (see figure 9-8) is a small-capacity device that weighs 50 pounds. It uses a 3/4-inch diameter hose and requires 100 cfm of air at a pressure of 80 to 90 psi. Thanks to its simple and robust construction, it requires minimal maintenance. The pump can operate while fully submerged when an exhaust line is installed. The assembly includes an open-impeller centrifugal pump, with a combination bottom plate and inlet strainer that cover the pump’s intake opening. Additionally, there is a 3-inch exhaust connection mounted on the side of the pump housing.

Figure 9-8. Sump pump

Production

9-54. The pneumatic sump pump can be classified into two categories: Class 1, which is designed for transferring sewage and sludge, and Class 2, intended for transferring petroleum products. This pump has a capacity of 175 GPM against a 25-foot head or 150 GPM against a 150-foot head.

Operation

9-55. To maximize efficiency, make sure the inlet strainer is clean and free of debris. Keep the pump away from mud and clean the strainer as often as needed. Ensure that the exhaust-line outlet remains above the water level. Only use water-pump grease for the fittings on the pump. Drain the pump of water when it is not in use.

Maintenance

9-56. If silt and dirt remain in the pump after use, it can cause the impeller to stick, requiring disassembly and cleaning before the pump can be used again. Additionally, allowing water to enter the pump through the exhaust port can lead to the failure of the grease seals.

Steel Drill

9-57. The pneumatic steel drill is a portable tool designed for drilling, reaming, and tapping in metal. It weighs 27.5 pounds and requires a 1/2-inch-diameter hose, using 27 cubic feet per minute of air at a pressure of 90 to 100 psi. The chuck speed is 425 rpm. This tool is suitable for drilling up to 1 1/4 inches and can handle reaming or tapping up to 1 inch.

Attachments

9-58. Bits for use with this drill are 1/2-inch in diameter with a Number 3 Morse-taper shank.

Production

9-59. Used as a drill, thirty 1-inch holes can be drilled per hour if the steel plate has been prepared beforehand with 1/4-inch lead holes.

Operation

9-60. The rotation of the steel drill cannot be reversed. It is important to ensure that the bits have clean, sharp edges, and that they are not chipped or damaged in any way.

- Use cutting oil to cool and lubricate the drill bit.
- Use a center punch to mark the center and to hold the tip of the drill in place when starting a hole.
- Do not use worn chucks.
- Wear goggles to protect eyes from steel chips or shavings.
- Clamp all material that is being drilled to a bench. This will prevent injuries to personnel if the drill should bind in the material.

Maintenance

9-61. Failing to use cutting oil can damage the bit from heat. Excessive pressure on the bit will stall the drill and cause unnecessary wear on the gear assembly, potentially damaging the feed-screw system.

Handheld Rock Drill

9-62. The pneumatic handheld rock drill is a piston-action tool featuring independent air-motor rotation. Although it is primarily designed for hard rock, it also performs well in soft and medium formations. Weighing 57 pounds, it utilizes a 3/4-inch-diameter hose and requires 95 cfm of air at pressures ranging from 80 to 100 psi. The drill is comprised of three main components: a back-head group, a cylinder unit, and a front-head group. It is engineered to direct air through the drill, down the drill steel, and into the bottom of the hole, effectively blowing out rock cuttings.

Attachments

9-63. This drill comes with drill rods in lengths of 2, 4, 6, and 8 feet, and drill-bit sizes of 1 5/8, 1 3/4, 1 7/8, and 2 inches.

Production

9-64. The drill is specifically designed for vertical drilling. If a large number of horizontal holes need to be created, a mechanical method must be implemented to secure the drill in place. It can efficiently drill holes to a depth of 10 feet. For production rates, please refer to table 9-2, page 107.

Operation

9-65. Bent drill steels should not be used. They cause damage to the drill and usually result in a stuck bit and lost production.

SAFETY

9-66. Exercise caution when using compressed air. At close range, it can cause serious injuries such as eye damage, ruptured eardrums, severe skin blisters, or even death.

AIR COMPRESSORS

- Ensure the intake air is cool and free from flammable gases or vapors.
- Do not permit wood or other flammable materials to remain in contact with the air-discharge pipe.
- Shut down the compressor immediately if the air discharged from any stage rises unduly or exceeds 400°F.
- Ensure that all the pressure gauges are in good working order.
- Do not kink a hose to stop the airflow.
- Check the safety valves, pressure valves, and regulators to determine if they are working correctly before starting the air compressor.
- Do not leave the compressor after starting it unless you know the control, unloading, and governing devices are working correctly.
- Do not run an air compressor faster than the manufacturer’s recommended speed.
- Use only the proper grade of oil as recommended by the manufacturer.
- Use only oils that have high flash points to lubricate the air cylinders.
- Avoid the application of too much oil.
- Keep the compressor, tanks, and piping clean to guard against oil-vapor explosion.
- Clean the intake air filters periodically.
- Use only soapy water or a nontoxic, nonflammable solution for cleaning compressor intake filters, cylinders, or air passages. Never use benzene, kerosene, or other light oils to clean these portions of a system. These oils vaporize easily, and the vapor explodes when compressed.
- Turn off the motor before making adjustments and repairs.
- Make sure that the compressor is secured and cannot be started automatically or by accident, that the air pressure in the compressor is completely relieved, and that all the valves between the compressor and the receivers are closed before working on or removing any part of the compressor.

PNEUMATIC TOOLS

- Wear protective clothing and equipment (such as goggles, gloves, and respirators) appropriate for the particular pneumatic tool.
- Maintain a firm grip on the tool at all times.
- Maintain a sound footing and proper balance while operating pneumatic tools.
- Release the throttle of the tool at the first indication that the tool is out of control. Release the tool and let it fall if it cannot be controlled.
- Turn off the air and disconnect the tool when repairs or adjustments are being made or the tool is not used. When disconnecting the tool, all pressurized air should be discharged from the line before the connection is broken.
- Inspect the hose to ensure it is in good condition and free from obstructions before connecting a pneumatic tool. When blowing out the line, ensure the hose’s end is pointed into the air and secured against whipping. Make sure all connections are tight before the line is pressurized.
- Lay down pneumatic tools so that no harm can be done if the switch is accidentally tripped. Do not leave an idle tool in a standing position.
- Keep pneumatic tools in good operating condition and thoroughly inspect them regularly. Give particular attention to the control and exhaust valves, the hose connections, the guide clips on hammers, and the chucks of reamers and drills.
- Shut off the tool and relieve the pressure from the line before disconnecting the tool from the line.
- Remove leaking or defective hoses from service. The air hose must be suitable to withstand the pressure required for the tool.
- Do not lay the hose over ladders, steps, or walkways in such a manner as to create a tripping hazard.
- Where a hose runs through a doorway, protect it against damage from the door’s edge.

- Do not lay the hose between the operator's legs while the tool is being operated.
- Never point an air hose at other personnel. Do not use compressed air to clean clothing being worn or to blow dust off the body.

HANDHELD ROCK DRILLS

- Do not (under any circumstances) wear loose or torn clothing.
- Examine the drill for defects. Pay particular attention to bit flutes, which must be ground to uniform size, sharpness, and length.
- Hold the machine in a straight line with the hole being bored.
- Do not feed the machine too fast.
- Establish a firm footing before starting the operation.
- Do not modify or bypass the handgrip switch. (All drills have a handgrip switch that will shut off the air supply when the grip is released.)

PAVING BREAKERS

- Wear suitable goggles when operating pneumatic breakers.
- Roughen hard materials or slick surfaces with a sledgehammer to improve breaker control.

Chapter 10
Hauling Equipment

The most common hauling equipment used for Army construction work includes 5-ton and 20-ton dump trucks, which are typically part of most engineer units. Equipment trailers are utilized to transport heavy construction equipment that is not designed for cross-country travel. These trailers are also used to haul long, oversized items and packaged goods.

DUMP TRUCKS

USE

10-1. The 5-ton family of Medium Tactical Vehicles (FMTV) (see figure 10-1) and the 20-ton dump trucks (refer to figure 10-2, page 122) serve various purposes. However, this manual specifically focuses on the use of dump trucks for hauling, dumping, and spreading earth, rock, or processed aggregates.

Figure 10-1. Dump truck (5-ton) FMTV

CAPACITY

10-2. The capacity of hauling equipment is measured in one of three ways: gravimetrically, by the weight of the load it can carry (in tons); by its struck rear-dump body volume (in cubic yards); or by its heaped rear-dump body capacity (also in cubic yards). For Army dump trucks, the hauling capacity is typically expressed gravimetrically, such as 5-ton and 20-ton capacities. On the other hand, the capacity of loading equipment is usually indicated in cubic yards. The unit weight of the materials being transported can vary significantly, ranging from as low as 1,700 pounds per loose cubic yard (LCY) for dry clay to as high as 3,500 pounds per LCY for trap rock (refer to table 1-2, page 3, for weights of common materials). Always ensure that the volumetric load does not exceed the gravimetric capacity of the truck.

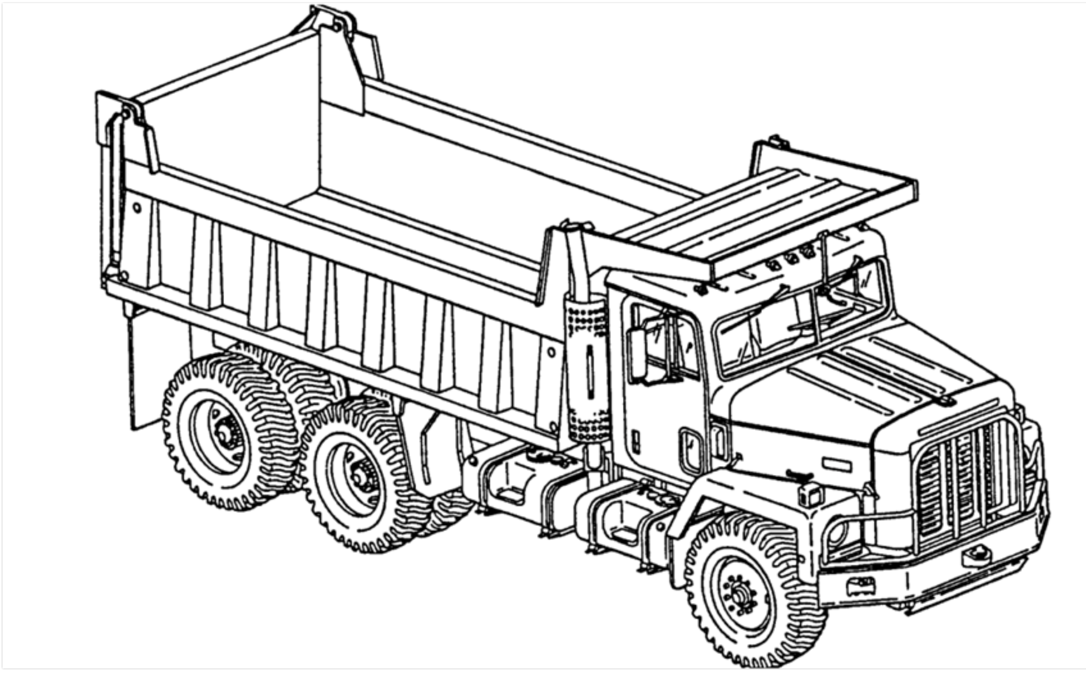

Figure 10-2. Dump truck (20-ton)

Operation

Loading

10-3. To optimize efficiency, load trucks as close to their rated hauling capacity as possible. However, adjust the load size if the haul roads are in poor condition or if the trucks need to navigate steep grades. Overloading can lead to higher fuel consumption, decreased tire life, and increased mechanical failures.

10-4. When trucks are loading from a hopper, a grizzly ramp, or a stockpile, it is important to use spotting markers. These markers are also helpful when excavators—such as draglines, clamshells, loaders, backhoes, or hoes—are used to load hauling equipment. Spotting markers improve the speed and accuracy of vehicle positioning, which enhances loading efficiency.

10-5. When loading with an excavator, position the trucks as close to the bank as possible. Make sure that the trucks are within the working radius of the dragline, clamshell, or hoe bucket. When using a loader, arrange the truck and loader to form a V shape. This configuration will help reduce the loader's cycle time (see figure 10-3).

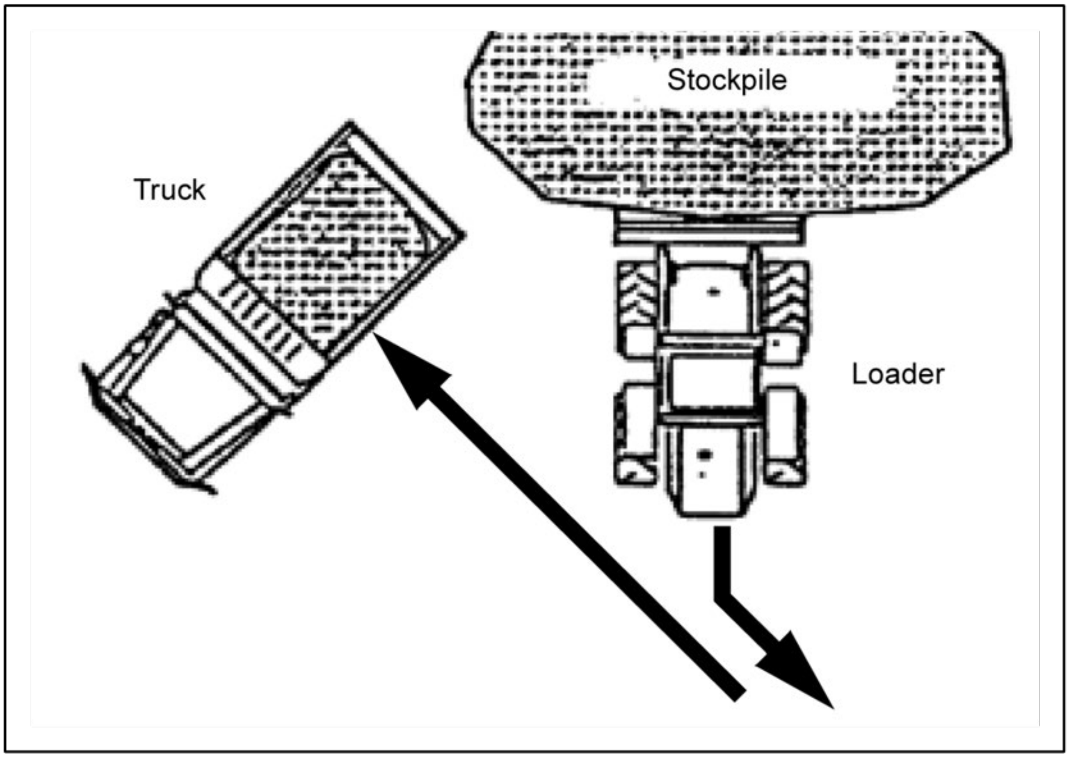

Figure 10-3. Truck and loader V-positioning for loading

Maintaining Proper Speed

10-6. Transport materials at the highest safe speed while ensuring you are in the appropriate gear. Avoid speeding, as it is unsafe and places unnecessary strain on equipment. When multiple trucks are in operation, it is crucial to maintain a consistent speed to prevent delays or bottlenecks at loading and dumping locations. If possible, use separate haul roads to and from the dump site. Additionally, keep haul roads well maintained and minimize the grade. Implement one-way traffic patterns to enhance efficiency.

Dumping (Unloading)

10-7. Always use spotters to oversee dumping operations. When unloading materials that need to be spread out, slowly move the truck forward while dumping the load to facilitate easier spreading. Additionally, establish alternative dumping locations to maintain proper truck spacing, especially when poor footing or difficult spotting slows down the dumping process.

Preventive Maintenance

10-8. Keep truck bodies clean and well-maintained. Accumulations of rust, dirt, dried concrete, or bituminous materials can hinder production. Consider the time spent cleaning and oiling dump bodies, especially for asphalt or concrete hauling, when calculating transportation requirements.

- Clean truck bodies thoroughly at the end of the day. When used to haul wet concrete mix, spray the dump beds with water before loading and clean them thoroughly as soon as practical after dumping.
- Coat the walls and sides of truck bodies with diesel fuel or oil to prevent bituminous materials (plant-mix asphalt) from sticking.

PRODUCTION ESTIMATES

10-9. The production capacity of loading equipment usually determines the hauling operation's efficiency. Always ensure loading equipment is not kept waiting. If there are not enough trucks available, production will be negatively affected.

Number of Trucks Required

10-10. Use the following formula to estimate the number of trucks required to keep loading equipment operating at maximum capacity:

$$Number\ of\ trucks\ required = 1 + \frac{truck\ cycle\ time\ (minutes)}{loader\ cycle\ time\ (minutes)}$$

- The numeral 1 in the formula is a safety factor against the necessity for closing down loading equipment due to a lack of hauling equipment. If all operations are on schedule, one truck will always stand by at the loader, ready for spotting.
- The truck cycle time is the time required for a truck to complete one cycle of operation. One complete cycle is when a loaded truck travels to the dump site, unloads, returns to the loading unit, and is reloaded.
- The loader cycle time is when it takes the loading equipment to load the truck, plus any time lost by the loading equipment while waiting for the truck to be spotted.

Note. After the job starts, the number of required trucks may vary due to changes in haul road conditions, adjustments in haul length, or modifications in the circumstances at the loading or unloading areas.

Number of Standby Trucks Required

10-11. To determine the number of standby trucks needed to replace those that experience mechanical issues, it's essential to consider the normal cycle time. The required number of standby trucks largely depends on the mechanical condition of the active trucks, as well as the size and importance of the job. For smaller fleets with a single loading unit, the ratio of standby trucks to active trucks could be as high as 1:4. In contrast, for larger jobs, this ratio tends to be smaller. It's important to note that standby trucks do not have to remain idle; they can be utilized for lower-priority tasks from which they can be easily redirected if needed.

10-12. Example:
How many 5-ton FMTV trucks (hauling 3 LCY per load) will it take to support a wheel loader having a 2-cubic-yard heaped-bucket capacity? The haul-unit cycle time is 20 minutes excluding loading time. The loader cycle time per bucket load is 0.5 minute. Consider a 60-minute working hour.

- **Step 1.** Determine the number of bucket loads required to fill a truck.

$$Bucket\ loads = \frac{haul - unit\ capacity}{bucket\ capacity} = \frac{3\ LCY}{2\ LCY} = 1.5\ bucket\ loads$$

  - Using only one bucket load would mean that the truck would only haul 2 LCY per trip. Using two bucket loads would mean that the truck would haul 4 LCY per trip and the extra material would spill out during the loading process.
- **Step 2**. Determine the loading time per haul unit.
  - Loading time per haul unit = bucket cycle time x number of bucket loads Considering one bucket load per truck—

$$\boldsymbol{Loading\ time\ per\ haul\ unit = 0.5\ minute\ x\ 1 = 0.5\ minute}$$

  - Considering two bucket loads per truck—

$$\boldsymbol{Loading\ time\ per\ haul\ unit = 0.5\ minute\ x\ 2 = 1\ minute}$$

- **Step 3**. Determine the number of hauling units needed to support the loading unit.
  - Considering one bucket load per truck—

$$\boldsymbol{Truck\ cycle\ time = 20\ minutes + 0.5\ minute = 20.5\ minutes}$$

$$Number\ of\ trucks\ required = 1 + \frac{truck\ cycle\ time\ (minutes)}{loader\ cycle\ time\ (minutes)}$$

$$= 1 + \frac{20.5\ minutes}{0.5\ minute} = 42\ trucks$$

- Considering two bucket loads per truck—

$$\boldsymbol{Truck\ cycle\ time} = \mathbf{20}\ \boldsymbol{minutes} + \mathbf{1}\ \boldsymbol{minute} = \mathbf{21}\ \boldsymbol{minutes}$$

$$Number\ of\ trucks\ required = 1 + \frac{truck\ cycle\ time\ (minutes)}{loader\ cycle\ time\ (minutes)}$$

$$= 1 + \frac{21\ minutes}{1\ minute} = 22\ trucks$$

- **Step 4**. Determine the production based on the number of hauling units used. The loader will control the production because of the one extra truck added to the formula. Therefore, there is always a truck waiting at the loader.

$$Production = haul\ unit\ load\ x\ \frac{minutes\ per\ working\ hour}{loader\ cycle\ time\ in\ minutes}$$

Using one bucket load per truck will require 42, 5-ton FMTV dump trucks.

$$Production = 2\ LCY\ x\ \frac{60}{0.5} = 240\ LCY\ per\ hour$$

Using two bucket loads per truck will require 22, 5-ton FMTV dump trucks.

$$Production = 3\ LCY\ x\ \frac{60}{1} = 180\ LCY\ per\ hour$$

With an understanding of the effect of the different choices, determine the number of trucks to use on the haul and how many bucket loads to place on each truck. This illustrates that the capacity of both the loader and the trucks are set numbers. Therefore, there is a relationship between bucket loads and haul-unit capacity, which in practice must be an integer number.

EQUIPMENT TRAILERS

USE

10-13. Use equipment trailers (see figure 10-4) to transport heavy construction equipment, such as cranes and dozers, or any machinery not designed for long-distance travel under its own power. A semi-truck is required when using these trailers. Additionally, these trailers can be used to haul long items like pipes or lumber, as well as packaged materials such as landing mats or bagged cement.

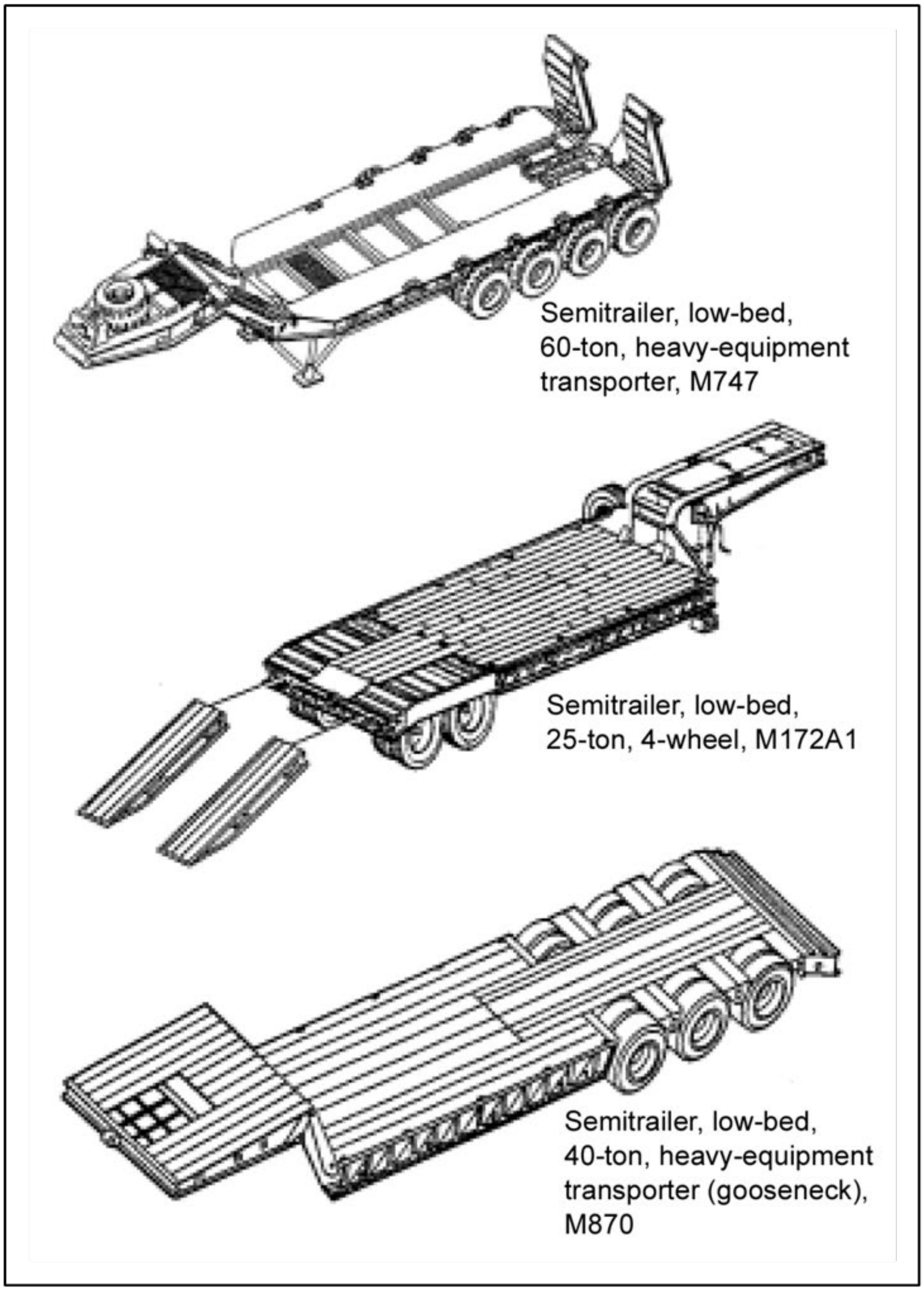

Figure 10-4. Equipment trailers

OPERATION

Loading

10-14. To maximize efficiency, load trailers as close to their rated capacity as possible. Always position a spotter on the trailer to guide the equipment operator and ensure the machine remains centered on the ramps and trailer.

10-15. When using rear-loading trailers, it is best to utilize low banks or built-up earth ramps whenever possible. Some trailers are equipped with loading ramps for easy access from level ground. When loading a dozer with these ramps, proceed slowly up the ramp with the blade raised. As you approach the balance point, reduce your speed or come to a stop. Then, lower the blade to allow the front of the tracks to settle gently onto the trailer bed. After that, slowly move the dozer forward onto the trailer. Additionally, some low-bed trailers are specifically designed for front-end loading.

10-16. In areas that restrict rear loading, load the trailer from the side. Take care not to damage the trailer bed.

> ***Note.*** Refer to the unit's SOP or to the appropriate technical manual for proper techniques for loading and securing equipment.

Positioning and Securing

10-17. After positioning the equipment on the trailer bed, block and chock it, and chain it to the trailer. Properly distribute the weight of large equipment on the trailer, as trailers have their load-weight centering positions marked.

Unloading

10-18. Unload heavy equipment slowly to prevent damage to the trailer or the equipment. Always use ramps to load and unload.

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Chapter 11

Soil Processing and Compaction

Horizontal construction projects, such as roads and airfields, utilize various types of soil. The suitability of these soil materials for construction depends on factors like gradation, physical characteristics, and load-bearing capacity. While some soil types are appropriate for structural use in their natural state, others require processing, such as adjusting moisture content through mixing and blending. There is a direct relationship between increased density and enhanced strength and bearing capacity, meaning that the engineering properties of most soils can be improved through compaction. For more detailed information on soil properties and compaction requirements, refer to TM 3-34.64/MCRP 3-17.7G.

SOIL PROCESSING

11-1. The amount of water in a soil mass significantly influences the ease of compaction and the achievable soil density. The water-content ratio is the standard measure used to assess the water present in a soil mass. This ratio compares the weight of the water in the soil to the weight of the soil solids in the same mass. Each type of soil has a specific optimum moisture content (OMC) at which it can reach maximum density for a given amount of compactive energy. Compacting soil with a water content that is either above or below the optimum can be very challenging. The OMC typically ranges from about 12 to 25 percent for fine-grained soils and from 7 to 12 percent for well-graded granular soils. Since achieving and maintaining the exact OMC is difficult, the usual practice is to operate within an acceptable moisture range, typically ±2 percent of the optimum. This range is intended to achieve maximum density with minimal compactive effort. Determining the OMC requires a laboratory test procedure. For detailed information on the moisture-density relationships of various soils, please refer to TM 3-34.64/MCRP 3-17.7G.

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.

11-3. To improve the soil at the borrow pit or construction site, add water to it. When working with granular materials, adding water directly to the site typically yields the best results. After adding the water, mix it thoroughly and uniformly with the soil.

Amount of Water Required

11-4. To determine the amount of water needed to achieve an acceptable soil moisture level, it is crucial to calculate how much water to add or remove for each station, which measures 100 feet in length. Use the formula provided, which is based on the compacted volume of the soil, to compute the required amount of water for a single station. This calculation relies on the dry weight of the soil.

$$Gallons\ per\ station\ for\ one\ lift = desired\ dry\ density\ of\ soil\ in\ pounds\ per\ cubic\ foot\ (pcf)$$

$$x\ \frac{desired\ moisture\ content\ (percent) -\ moisture\ content\ of\ borrow\ (percent)}{100}$$

$$x \frac{compacted\ volume\ of\ soil\ (cubic\ foot)}{8.33\ pounds\ per\ gallon}$$

where—

8.33 = the weight of a gallon of water

Note. It is advisable to adjust the desired moisture content to the OMC plus 2 percent. However, this may vary based on environmental conditions such as temperature and wind, as well as the type of soil. If the answer is negative, it means that water must be removed from the borrow material before compacting it in the fill.

11-5. Example:

Prepare to place soil in 6-inch (compacted) lifts. The target dry unit weight of the embankment is 120 pounds per cubic foot. The OMC for the soil is 12 percent; however, the soils technician has determined that the moisture content of the borrow material is only 5 percent. The roadway section to be constructed is 40 feet wide. Calculate the amount of water (in gallons) to be added per station for each lift of material.

$$Gallons\ per\ station\ for\ one\ lift = 120\ pcf\ x\ \frac{12\ percent\ (OMC) -\ 5\ percent\ (borrow)}{100}$$

$$x\ \frac{40\ feet\ x\ 100\ feet\ x\ 0.5\ foot}{8.33\ pounds\ per\ gallon}$$

$$= 120\ pcf\ x\ 0.07\ x\ \frac{2{,}000\ cubic\ feet}{8.33\ pounds\ per\ gallon}$$

*

$$= 2{,}017\ gallons$$

Note. If the road width remains consistent, calculate the total water required by multiplying the gallons needed per lift by the number of lifts, and then by the road length (in stations).

Rate of Water Application

11-6. 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.

$$Gallons\ per\ square\ yard = desired\ dry\ density\ of\ soil\ (pcf)$$

$$x\ \frac{percent\ of\ moisture\ added\ or\ removed}{100}\ x\ lift\ thickness\ (feet)$$

$$x\ \frac{9\ square\ feet\ per\ square\ yard}{8.33\ pounds\ per\ gallon}$$

where—

9 = factor used to convert square feet to square yards

8.33 = the weight of a gallon of water

11-7. Example:

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

Gallons per square yard

$$= 120\ pcf\ x\ 0.07\ x\ 0.5\ foot\ x \frac{9\ square\ feet\ per\ square\ yard}{8.33\ pounds\ per\ gallon}$$

$$= 4.5\ gallons\ per\ square\ yard$$

Method of Application

11-8. 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.

11-9. **Water Distributor.** The most common method for adding water is by using a water distributor. These distributors are designed to evenly distribute the correct amount of water over the fill area. A typical truck-mounted water distributor has a capacity of 1,000 gallons and can deliver water either under varying pressures or via gravity feed. It features a 12-foot folding spray bar that is mounted at the rear of the truck. The spray bar is adjustable, allowing for lengths between 4 to 24 feet in one-foot increments. To maintain the desired water application rate, the operator can control the vehicle's forward speed and the water distribution pressure. A cab-mounted odometer indicates the vehicle's speed in feet per minute (fpm). The project officer should provide the water distributor operator with the required application rate in gallons per square yard. With this information, the operator can determine the appropriate spray-bar length, pumping pressure, and vehicle speed needed to achieve the specified application rate. For specific details about application rates, refer to the vehicle's technical manual.

Figure 11-1. Truck-mounted, 1,000-gallon water distributor

11-10. **Ponding**. If time permits, add water by ponding the area until the desired moisture penetration depth is achieved. Controlling the application rate with this method can be challenging, and ponding typically requires several days for a uniform moisture distribution.

Effects of the Weather

11-11. Weather has a significant impact on the moisture content of soil. Cold, rainy, cloudy, or calm conditions tend to help soil retain water or even increase its moisture levels. In contrast, hot, dry, sunny, or windy weather promotes evaporation, which dries out the soil by reducing its moisture. In desert climates, significant evaporation can deplete the water available for soil moisture. Consequently, for projects in such areas, engineers may add up to 6 percent above the OMC in their calculations for water application. This approach ensures that the actual moisture content closely aligns with the desired levels when the material is placed and compacted.

REDUCING THE MOISTURE CONTENT

11-12. Soil that contains more water than desired (exceeding the optimum moisture range) can be challenging to compact effectively. Excess moisture makes it difficult to achieve the desired density. To address this issue, it is necessary to reduce the moisture content within the required range. Drying methods can be as simple as aerating the soil, or they may involve more complex solutions, such as adding a soil stabilization agent to change the soil's physical properties. Common stabilization agents for fine-grained soils include lime and fly ash. If excess moisture is caused by a high water table, some form of subsurface drainage will be necessary to lower the soil's moisture content. One effective method to reduce moisture is to scarify the soil before compaction. This can be done using the scarifying teeth of a grader or a stabilizer mixer, or by disking the soil. Another approach is to use the grader's blade to turn the soil into furrows, exposing more surface area for drying.

MIXING AND BLENDING

11-13. To improve soil moisture content, you can either add water to increase it or use a drying agent to reduce it. In both cases, it is crucial to mix the water or drying agent thoroughly and evenly with the soil. Even if no additional water is needed, mixing can still be important for achieving uniform moisture distribution. You can accomplish this mixing using graders, stabilizer mixers, or farm disks.

Grader

11-14. Use conventional graders to mix or blend a soil additive, such as water or a stabilizing agent, by moving the material from one side of the working lane to the other. For detailed instructions on grader operation, refer to chapter 4.

Stabilizer Mixer

11-15. The stabilizer mixer is a highly versatile piece of equipment designed for mixing, blending, and aerating various materials (see figure 11-2). It features a rear-mounted, removable-tine rotating tiller blade, which is covered by a removable hood. When the hood is in place, it forms an enclosed mixing chamber that enhances the thorough blending of soil (see figure 11-3). The tiller blade lifts the material as the mixer moves forward, throwing it against the leading edge of the hood. The material that deflects off the hood falls back onto the tiller blades, ensuring thorough mixing. As the stabilizer advances, it ejects the blended material from the rear of the mixing chamber. The trailing edge of the hood strikes the ejected material, resulting in a relatively level working surface. With the trailing edge of the hood fully opened, the churned soil achieves a high void content, which exposes it to the drying effects of the sun and wind. Models equipped with a spray bar can add water or stabilizing agents to the soil during the blending process. The stabilizer mixer is designed for use with materials less than 4 inches in diameter. The tines on the Army's mixer are capable of penetrating up to 12 inches below the existing surface. This unit is effective for scarifying and blending in-place (in situ) material as well as fill material.

Figure 11-2. Stabilizer mixer

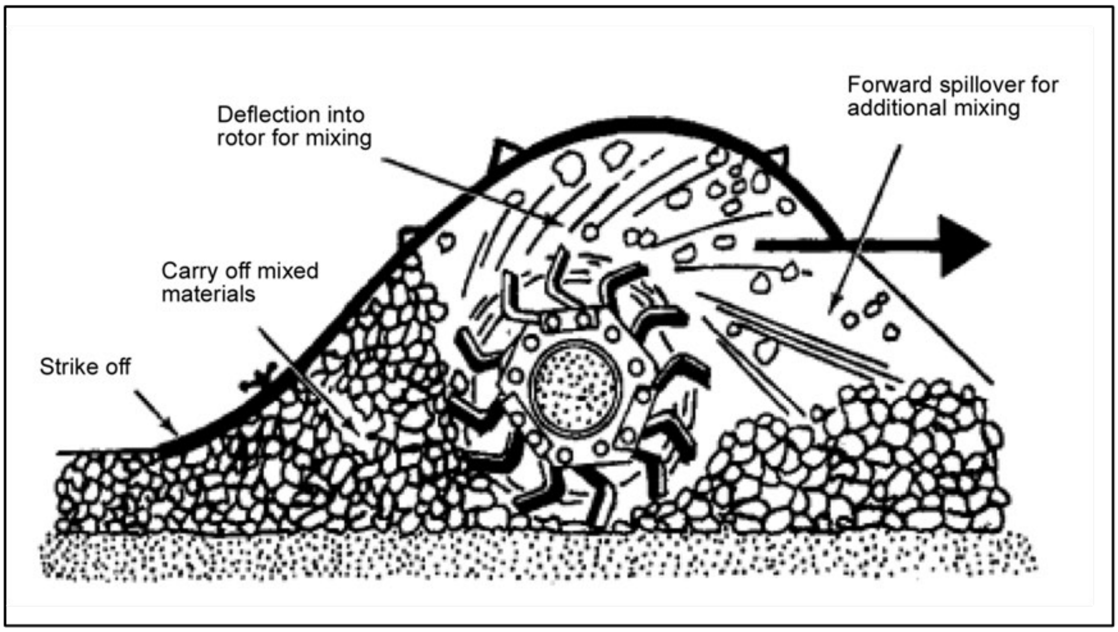


Figure 11-3. Mixing action in a stabilizer mixer

SOIL COMPACTION

11-16. Compaction is the process of mechanically densifying soil, typically by applying a dynamic load. This differs from consolidation, which involves the gradual densification of soil under a static load. When done correctly, compaction enhances a soil's load-bearing capacity (shear resistance), minimizes settlement (consolidation), alters the soil's volume, and reduces the rate at which water flows through the soil (permeability). It is important to note that not all soils respond equally to compaction. Nevertheless, the advantages gained from compaction make it a crucial element in the horizontal construction process.

COMPACTIVE EFFORT

11-17. Compactive effort refers to the amount of energy utilized to compact a soil mass. The appropriate level of compactive effort should be based on the soil's physical properties, including its gradation (whether it is well-graded or poorly graded), the Atterberg limits (whether the soil is cohesive or cohesionless), and the required final density. Compaction equipment employs one or more of the following methods to achieve soil densification:

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

EQUIPMENT SELECTION

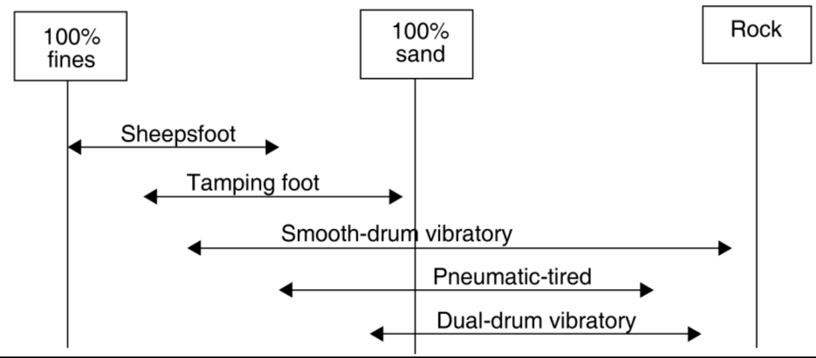
11-18. Compaction equipment varies from handheld vibratory tampers, which are suitable for small or confined areas, to large self-propelled rollers and high-speed compactors, which are better for extensive horizontal construction projects. When selecting compaction equipment, consider the following factors:

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

11-19. Soil-compacting equipment typically used by military engineers includes tamping-foot rollers, pneumatic-tired (rubber-tired) rollers, dual-drum vibratory rollers, and smooth-drum vibratory rollers. To choose the most suitable type of compaction equipment, a project officer must understand the characteristics, capabilities, and limitations of each type of roller. In general, tamping-foot compactors, which generate high unit pressures, are most effective for predominantly fine-grained cohesive materials, such as clays and sandy clays. Conversely, large steel-drum rollers are more suitable for larger particle materials like gravel or cobble. Vibratory rollers are ideal for well-graded or gap-graded materials since their shaking action helps smaller particles fill the voids around larger grains. Table 11-1, page 135, illustrates the capabilities of each type of roller and the compactive effort associated with them. Additionally, tables 11-2 (pages 136 and 137) and 11-3 (pages 138 and 139) outline the major soil classification categories, compaction requirements, and compatible compaction methods for 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

11-20. The self-propelled tamping-foot roller (see figure 11-4, page 140) features square or angular feet that taper down away from the drum. This design enhances penetration on the initial pass, resulting in thorough and uniform compaction throughout the lift. The roller compacts material from the bottom to the top of the lift and can walk out once the desired density is achieved. It is suitable for compacting all fine-grained materials but is generally not effective for cohesionless granular materials. The maximum lift thickness for the tamping-foot roller is limited to 8 inches of compacted depth. If the material is loose and reasonably workable, allowing the roller's feet to penetrate during the initial pass, uniform density can be attained throughout the entire depth of the lift. Before compaction, thoroughly loosen any material that has become compacted by the wheels of equipment during spreading or wetting. The tamping-foot roller does not effectively compact the upper 2 to 3 inches of a lift. Therefore, it is advisable to follow up with a pneumatic-tired or smooth-drum roller to complete the compaction or to seal the surface if a succeeding lift is not being placed. The self-propelled tamping-foot roller can achieve working speeds of up to 8 mph. This roller compacts material from the bottom up and is particularly suitable for plastic materials, making it ideal for working with soils that have moisture contents above the acceptable range, as it tends to aerate the soil while compacting.

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

Table 11-2. Soil classification (continued)

Major Soil Categories		Symbol and Description		Value as a Base, Subbase, or Subgrade	Potential Frost Action
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

Table 11-3. Average compaction requirements (continued)

		Soil Classification Symbol													
		GW	***GP***	***GM***	***GC***	***SW***	***SP***	***SM***	***SC***	***ML***	***CL***	***OL***	***MH***	***CH***	***OH***
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

11-21. Pneumatic-tired rollers, which can either be towed or self-propelled, are effective for compacting most granular materials; however, they are unsuitable for compacting fine-grained clays. These rollers employ two types of compactive efforts: static load and kneading. The Army currently operates a towed model with 13 wheels and a variable-pressure, self-propelled model with nine wheels. The nine-wheeled roller (see figure 11-6, page 141) can adjust its contact pressure to achieve the desired level of compaction by changing the tire pressure and wheel load. The towed 13-wheel model exerts approximately 210 pounds of contact pressure per inch of rolling width. It's important to note that the contact pressure is influenced by both tire pressure and wheel load.

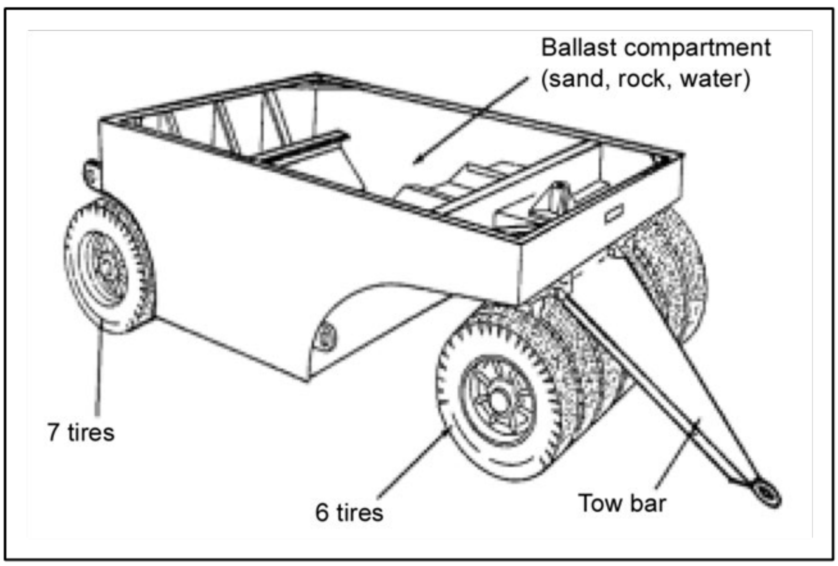


Figure 11-5. Towed, 13-wheel, pneumatic-tired roller

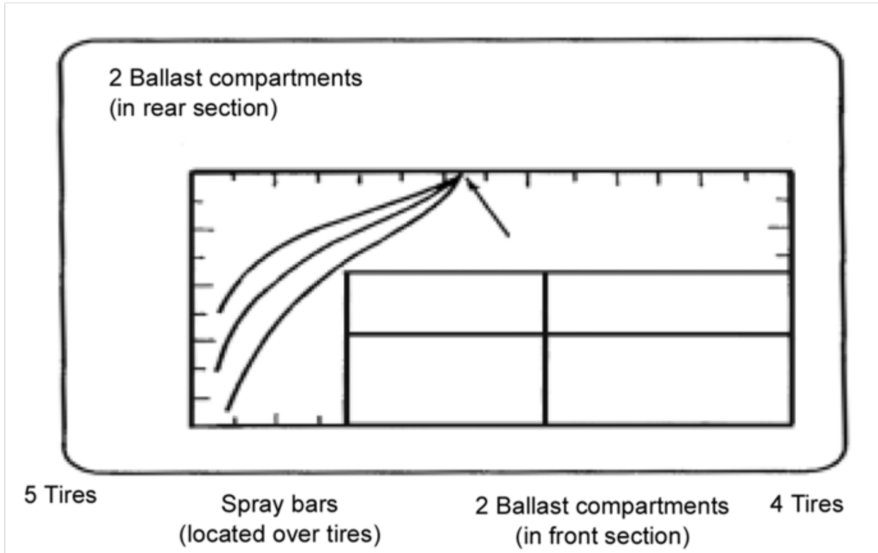


Figure 11-6. Self-propelled, nine-wheel, pneumatic-tired roller

- **Contact pressure.** The contact pressure of rollers is primarily determined by tire pressure. Within the rated load limits, the same load and tire pressure produce a similar contact area for any tire. Typically, the tire sidewalls support about 10 percent of the load, while the trapped air in the tire supports approximately 90 percent. As a result, the tire will deform until the contact area is sufficient, ensuring that the ground pressure on the tire matches the tire pressure. For instance, consider a tire with an internal pressure of 50 psi and a wheel load of 5,000 pounds; the contact area in this case would be 100 square inches. If the wheel load is increased to 10,000 pounds, the tire will deflect until it achieves a contact area of 200 square inches. Because the sidewalls bear 10 percent of the load, the effective contact area is—

$$contact\ area = \frac{0.9\ x\ wheel\ base}{tire\ pressure}$$

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.

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

- **Wheel load.** The wheel load is crucial for achieving optimal compaction at the required depth and for conducting test rolling to identify subsurface defects. Researchers have constructed test sections using 6-inch compacted layers with wheel loads of 10,000, 20,000, and 40,000 pounds to investigate whether higher wheel loads contribute to increased density. During the tests, the tire's inflation pressure was consistently maintained at 65 psi. Figure 11-7 illustrates the vertical pressure distribution for each tire loading. As shown, the effective pressure varies with depth; however, at shallow depths, the difference in pressure among the three loads was insufficient to achieve additional density. These findings, along with others, suggest that increasing wheel load is beneficial in compacting thicker lifts.

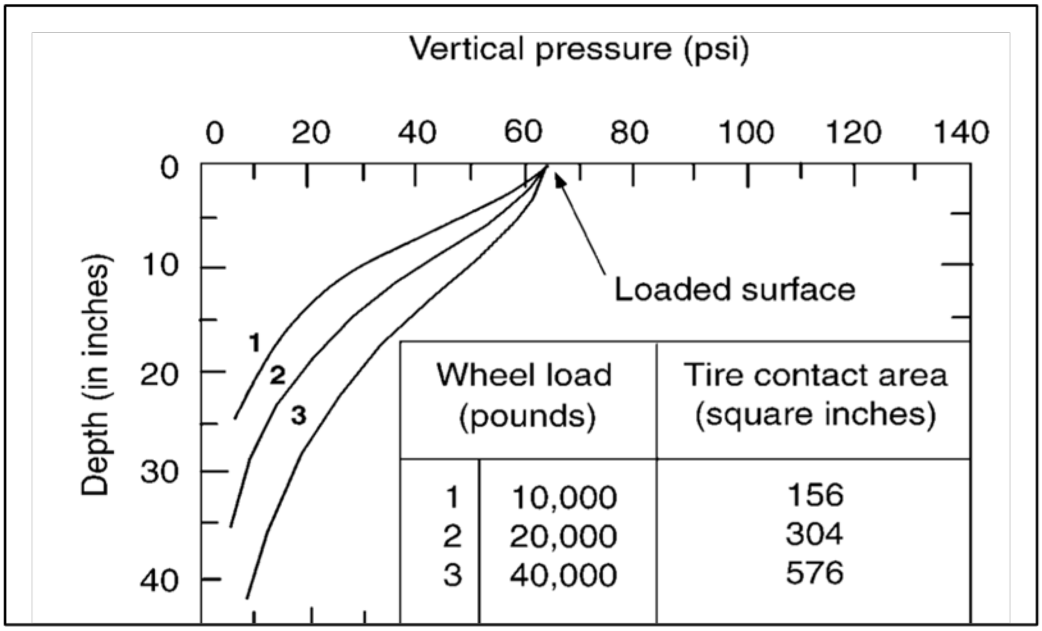


Figure 11-7. Vertical pressure distribution beneath a wheel load

- **Surface coverage.** The arrangement of the wheels and the deflection of the tires play a crucial role in determining surface coverage. Figure 11-8 illustrates the effects of varying wheel loads and tire pressures on the single-pass coverage of a heavy pneumatic-tired roller. Most pneumatic-tired rollers feature two rows of tires. The tires in one row are positioned to offset the gaps between the tires in the second row, ensuring complete coverage in just one pass. In contrast, heavier rollers typically have a single row of tires and require two passes to achieve full surface coverage. The pressure exerted by the wheels of heavier rollers influences the depth of coverage and the rolling pattern. As shown in figure 11-9, page 143, achieving adequate depth coverage necessitates significant overlap with each pass to ensure that the entire area has received uniform compactive effort.

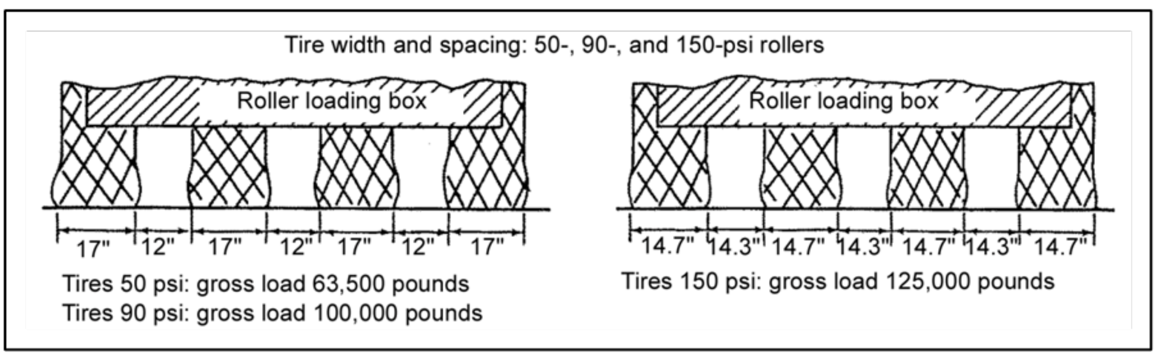
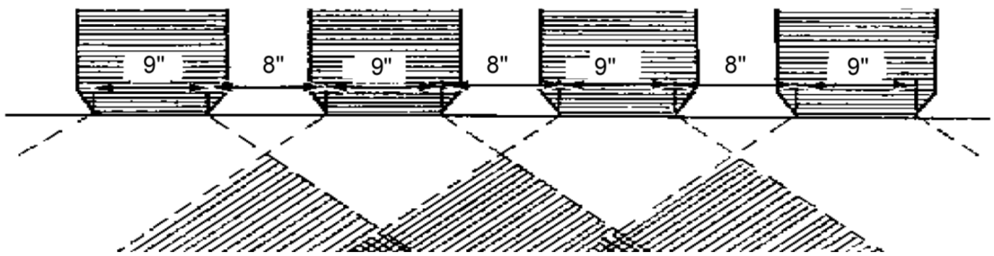


Figure 11-8. Varying wheel loads and tire pressures



Tire dimensions: 10.00 x 20 tire x 14-ply

Depth (Inches)	90-psi Tires (6,000-Pound Wheel Load)			120-psi Tires (8,000-Pound Wheel Load)		
	Equivalent Circle Diameter (Inches)	Area of Stress (Square Inches)	Pressure (psi)	Equivalent Circle Diameter (Inches)	Area of Stress (Square Inches)	Pressure (psi)
Surface	9.16	66.00	90.90	9.16	66.00	121.21
1	11.16	97.82	61.34	11.16	97.82	81.78
2	13.16	136.02	44.11	13.16	136.02	58.81
3	15.16	176.71	33.95	15.16	176.71	45.27
4	17.16	231.28	25.94	17.16	231.28	34.59
5	19.16	288.33	20.81	19.16	288.33	27.75
6	21.16	351.66	17.06	21.16	351.66	22.75
7	23.16	421.28	18.24	23.16	421.28	18.99
8	25.16	497.18	12.07	25.16	497.18	16.09
9	27.16	579.37	10.36	27.16	579.37	13.81
10	29.16	667.83	8.98	29.16	667.83	11.98
Pressure in Single-Hatch Areas						
5			41.62			55.50
6			34.12			45.50
7			28.48			37.98
8			24.14			32.18
9			20.72			27.62
10			17.96			23.96
Pressure in Double-Hatch Areas						
13			30.90			41.20
14			27.65			36.90
15			24.90			33.20
16			22.55			30.05
17			20.50			27.35
18			18.75			24.95
19			17.15			22.90
20			15.80			21.05

Figure 11-9. Tire pressures at various depths

Dual-Drum Vibratory Roller

11-22. The dual-drum vibratory roller, featuring a smooth steel drum (see figure 11-10), is capable of compacting a wide range of materials, from sand to cobble. This roller is ideal for compacting asphalt paving, cohesionless subgrades, base courses, and wearing surfaces. It is particularly effective when used immediately behind a blade, resulting in a smooth, dense, and watertight subgrade finish. Due to its relatively low unit pressure and its method of compaction from the top down, it is typically used for shallow layers (less than 4 inches). The smooth steel drum is especially suited for finishing base or wearing courses. It is important to exercise caution to avoid excessive crushing of the base-course material. Overall, this roller is the preferred choice for asphalt paving.

Figure 11-10. Dual-drum vibratory roller

Smooth-Drum Vibratory Roller

11-23. The smooth-drum vibratory roller (see figure 11-11, page 145) utilizes vibratory action combined with the drum's ballast weight to rearrange soil particles into a dense mass. When properly controlled, vibratory compaction can be one of the most effective and economical methods for achieving the desired density in cohesionless materials. This roller is particularly effective for compacting noncohesive and nonplastic sands and gravels, which are commonly used in subbase and base-course applications. Due to its relatively light weight, the recommended maximum depth of loose lift (the fill material measured before compaction) is 9 inches.

Note. Vibration is measured in two ways: amplitude and frequency. Amplitude refers to the extent of movement or throw, while frequency indicates how many repetitions occur within a specific period of time. The amplitude affects how deep the vibration penetrates the soil, whereas frequency determines the number of blows or oscillations transmitted over time.

Jay Tamper

11-24. The jay tamper is a small, self-contained, hand-operated vibratory compactor. It resembles a power lawn mower (see figure 11-12 on page 145). The jay tamper is particularly suitable for compacting materials in confined spaces, such as trenches around pipes or inside existing structures. Powered by a gasoline engine, this unit operates without the need for supply lines or auxiliary equipment, allowing for greater mobility and convenience.

Figure 11-11. Smooth-drum vibratory roller

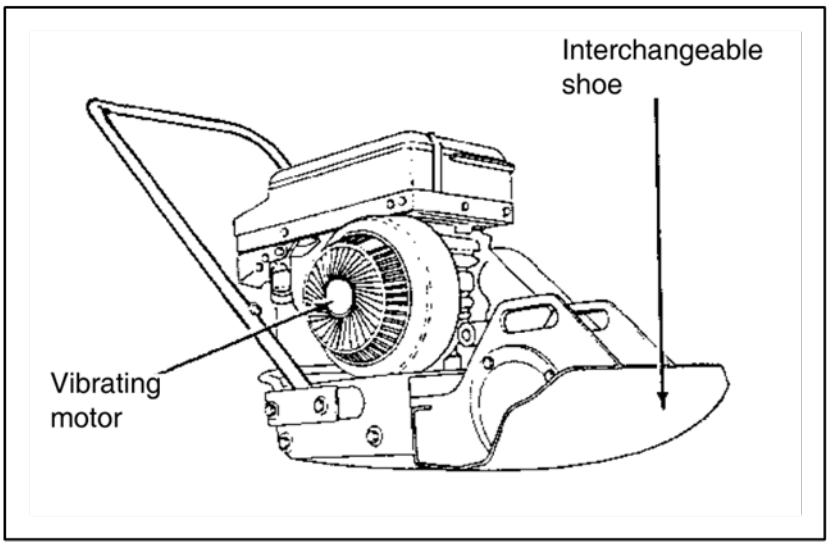


Figure 11-12. Jay tamper

EQUIPMENT TESTING

11-25. Because different types of compaction equipment can overlap in their functions, it is beneficial to create a test strip to determine the most efficient compactor and compaction procedures. Locate the test strip next to the project site. This test strip will help evaluate and validate the proposed construction methods. The information gathered from the test strip includes the following:

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

11-26. To select the appropriate compaction equipment, start by placing a 6-inch (uncompacted depth) lift of the material. Then, run each piece of equipment over a designated length of the strip for a predetermined number of passes, typically three. After compacting all the sections, conduct a density test to identify which roller produces the best results. Once you have determined the most effective type of equipment, use additional test strips to find the optimal lift thickness, the required number of passes, the ideal compactor speed, and, if using a vibratory roller, the resonant frequency.

PRODUCTION ESTIMATES

11-27. Use the following formula to determine compactor production in CCY per hour.

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

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

11-28. The accuracy of the compaction estimate relies heavily on the project officer's ability to judge the speed of the compactor, the thickness of the lift, and the number of passes needed to achieve the required density. This information is typically gathered from on-site test strips. For daytime compaction, the efficiency rate is generally 50 minutes of effective work per hour. For nighttime compaction, this efficiency should be adjusted to 45 minutes per hour. Typical compactor speeds can be found in table 11-4. These speeds should be cross-referenced with the data in table 11-2 (pages 136 and 137) and table 11-3 (pages 138 and 139). When calculating production estimates, be sure to use the average speed of the compactor based on the individual speeds 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 Walking out	 3-5 8-10
Heavy pneumatic	3-5
Multi-tiered pneumatic	5-15
Dual-drum vibratory	2-4
Smooth-drum vibratory	2-4
Vibratory: Plate Roller	 0.6-1.2 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.

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

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

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

11-29. Determine the total number of compactors required on the project, using the following formula.

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

Note. Refer to table 1-1, page 3, for soil conversion factors.

EXAMPLE

How many compactors are required on the project (previous example) if 1500 LCY of blasted rock is delivered per hour?

$$Compactors\ required = \frac{1500\ LCY\ per\ hour\ x\ 0.87\ (soil\ conversion\ factor)}{487\ CCY\ per\ hour}$$

$$= 2.7\ compactors, round\ up\ to\ 3$$

HORIZONTAL CONSTRUCTION PHASES

11-30. To meet the project's density requirement, it is important to understand the different phases of a horizontal construction project. These phases include preparing the subgrade, placing and spreading fill material, compacting the fill material for the subgrade and base courses, and carrying out finishing and surfacing operations.

Preparing Subgrade

11-31. The term subgrade refers to the in-place soil upon which a road, airfield, or heliport is constructed. Subgrade encompasses the soil to the depth that impacts the structural design of the project or to the depth at which the climate affects the soil. For pavements that support heavy loads, depths of up to 10 feet may be considered as subgrade. The quality and natural density of the subgrade material determine the necessary preparations. For instance, if the subgrade material is highly organic, it may need to be completely removed and replaced with a higher quality, select material. However, in many cases, the existing material is suitable and only requires some compaction effort to achieve the required density.

11-32. Heavy pneumatic-tired rollers are preferred for subgrade compaction due to their ability to compact soil to depths of up to 18 inches. It is often necessary to scarify the top 6 inches of the material to adjust its moisture content. After scarifying, the material can be recompacted to a higher density than what is achievable at the soil's natural moisture content. This process is known as scarify and compact in place (SCIP). The tamping-foot roller is particularly effective for this operation as it both loosens the material and compacts it as it moves through the area. Additionally, the tamping-foot roller helps break up oversized material or rock present in the soil. When using a tamping-foot roller to prepare the subgrade, it is also important to utilize 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, especially if rain is expected.

11-33. Shaping and sealing the surface protect the subgrade from the damaging effects of water infiltration. If a lift has already been sealed, scarify the top 1 to 2 inches before placing the next lift. This process ensures a strong bond between the layers. If the subgrade material is sand, using a vibratory compactor will provide the most effective compaction.

Placing And Spreading Fill Material

11-34. After preparing the subgrade, bring in fill material to create the subbase and base courses for the project. When placing the fill, it is essential to spread the material in uniform layers and maintain a relatively even surface. The thickness of these layers depends on the desired compacted lift thickness. Typically, the thickness of the uncompacted lift is 1.5 to 2 times the final compacted lift. For example, you should place fill in 9- to 12-inch layers to achieve a compacted lift thickness of 6 inches. To place the fill material, you can use a scraper or a dump truck, and then spread it using a dozer or grader. When spreading material on a prepared subgrade, start from the farthest point from the source and move toward the nearest point, or vice versa. The benefits of spreading fill from the farthest point to the nearest include:

- 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.

11-35. Spreading from the nearest point to the farthest point allows haul equipment to travel over the newly spread material. This compacts the material and significantly reduces the overall compaction effort required.

Compacting Fill Material

11-36. Before starting compaction operations, the project officer must assess 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, water should be added to the fill. Conversely, if the moisture content exceeds the acceptable range, one of the previously discussed methods should be employed to dry the soil. Once the appropriate moisture content is achieved, compaction operations can commence. The base course serves as the primary load-bearing layer of the road, ultimately providing strength to the pavement or other surface. Therefore, the base course material is of higher quality than the subgrade or the subbase fill. Typically, the base course consists of well-graded granular materials that have a liquid limit of less than 25 percent and a plastic limit of less than 6 percent. The thickness of the base course is determined by the strength of the subgrade. Smooth-drum vibratory rollers are ideal for compaction of the base course, although a dual-drum roller can also be used effectively.

OPERATING HINTS

Compacting Against Structures

11-37. Jay tampers and pneumatic backfill tampers are specifically designed for use in confined spaces, such as alongside existing structures. If these tampers are unavailable, a roller can be used to achieve satisfactory results. When space allows, run the roller parallel to the structure. If you need to work perpendicular to the structure, place the fill material (sloped to the height of the roller axle) against the structure. Apply compactive effort to this excess fill material, taking care to avoid damaging the existing structure.

Aerating Materials

11-38. 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

11-39. To eliminate noncompacted strips, each pass with the roller should overlap the preceding pass by at least 1 foot.

Turning

11-40. 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.

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Chapter 12
Road Surfacing

This chapter covers surface treatments and the equipment used for road surfacing. The types of surface treatments discussed include seal coats, sprayed bituminous materials with cover aggregate (both single and multiple treatments), and asphalt emulsions or slurry seals. For more information on paving and surfacing operations, please refer to TM 3-34.63.

SURFACE TREATMENT

12-1. The term surface treatment covers a wide range of applications and materials, with or without aggregate, applied to the top of a road or pavement. Surface treatments with aggregates can be—

- **Single surface**. A single surface treatment consists of applying a sprayed bituminous material, followed by a one-stone-thick aggregate cover. This process serves as both a wearing surface and waterproofing. Such surfacing requires minimal equipment, materials, and time to complete.
- **Multiple surface**. Repeating a single surface treatment process results in multiple surface treatments. This approach creates a denser layer for wear and waterproofing, while the added layers also enhance the road's structural integrity.

12-2. An initial single or double surface treatment may, when time and materials are available, be supplemented by additional surface treatments or thicker pavement structures. This process is known as stage construction.

SURFACING EQUIPMENT

SWEEPER

12-3. A sweeper is a tractor-type machine equipped with one or more brooms designed to remove dust from the surfaces of existing roadways before new asphalt is applied. Its main purpose is to eliminate dust and dirt to ensure proper bonding between the new asphalt, the base course, and the old pavement. When preparing a base course for surfacing, you can remove the dust layer either by using the sweeper or by wetting the base and recompacting it. Before operating a sweeper, always inspect it for excessive bristle wear and ensure that the power drive for all brooms is functioning properly.

ASPHALT DISTRIBUTOR

12-4. The Army asphalt distributor (see figure 12-1) is a truck-mounted unit designed for efficient asphalt application. It features a 1,500-gallon insulated storage tank equipped with a low-pressure heating system, a hydraulic-powered pumping unit mounted at the rear, and an adjustable spray bar for distributing bituminous material. To ensure a uniform application, the asphalt distributor requires constant attention. Proper maintenance of the asphalt heater and pump is essential. All gauges and measuring devices, including the pump tachometer, measuring stick, thermometers, and bitumeter, should be accurately calibrated. Additionally, make sure that the spray bars and nozzles are clean and positioned at the correct height above the surface being treated.

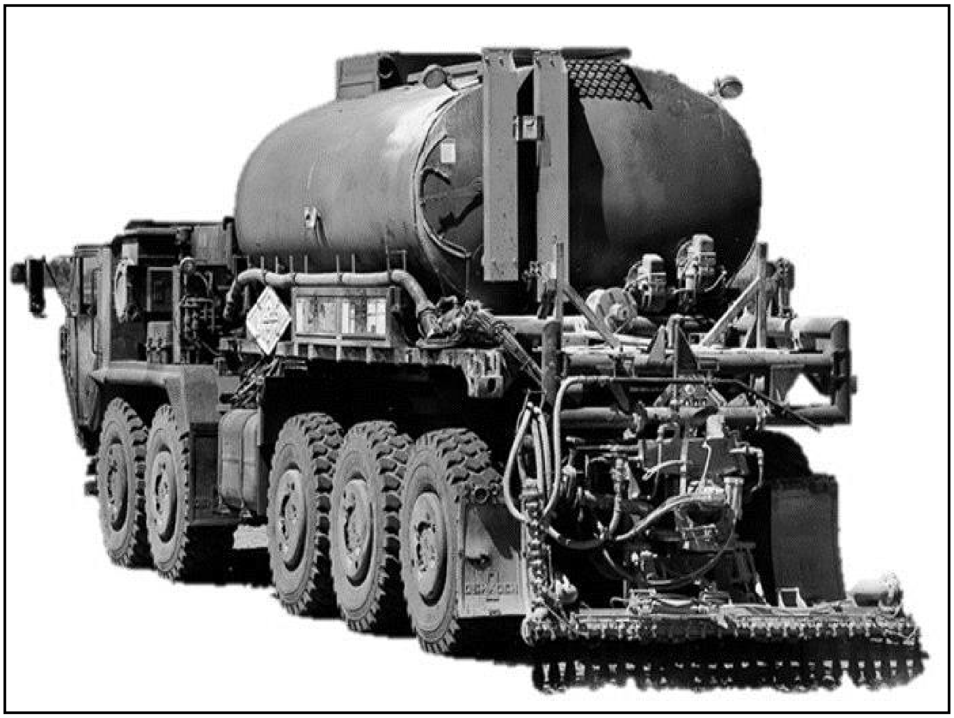

Figure 12-1. Army asphalt distributor

Heating System

12-5. Each of the system's two diesel burners is equipped with an air blower that supplies low-pressure air to atomize the burner fuel. The burners generate a flame directed into two U-shaped fire tubes located at the bottom of the asphalt storage tank. To prevent overheating and reduce the risk of fire or explosion, it is crucial to maintain at least 3 inches of asphalt cover over these fire tubes. Heating should only occur in a well-ventilated area, with the distributor truck leveled and completely stopped. Please refer to table 12-1, page 153, for guidelines on asphalt spraying temperatures.

WARNING

Exercise extreme caution while heating the asphalt to prevent damage to the heating system and possible fires and explosions.

Spraying System

12-6. The spraying system comprises piping, an adjustable spray bar, a bitumen pump tachometer, and a bitumeter. To determine the correct settings for the desired application rate, refer to table 12-2 on page 154. The application rate is regulated by—

- The length of the spray bar.
- The bitumen pump output. The pump tachometer dial in the cab of the truck (figure 12-1) registers the pump output in GPM from the tachometer mounted on the rear of the storage tank.
- The forward speed of the distributor truck. The bitumeter mounted inside the truck cab monitors the forward speed in fpm.

12-7. **Spray Bar**. The spray bar can be either full-circulating or non-circulating, depending on the model of the distributor. It is adjustable to cover widths ranging from 8 to 24 feet. Along the spray bar, several nozzles are equipped with hand-operated valves that control the flow of asphalt. The nozzles may be sized at either 1/8 inch or 3/16 inch, with the 1/8-inch nozzle being suitable for most applications. To ensure a uniform application, it is important to position the spray bar at the correct height and ensure that all nozzles are the same size and free of obstructions.

- **Spray-bar height.** To ensure a uniform double or triple overlap in a single-layer application, it is essential to properly adjust the height of the spray bar above the pavement. Maintaining the correct height throughout the entire application is crucial. If the spray bar is positioned too low or too high, it can lead to streaking.
- **Nozzle spacing.** Spray bars are typically designed with either a 4-inch or a 6-inch nozzle spacing. For 4-inch nozzle spacing, optimal application results are achieved using a triple overlap of the spray fans (see figure 12-2, page 155). To determine the appropriate spray-bar height for triple overlap coverage, open every third nozzle on the spray bar. Then, raise the bar until there is single-layer coverage along its entire length. A visual inspection will help confirm this. When all the nozzles are opened, this height will provide the desired triple overlap of the spray fans. For double overlap coverage, follow the same procedure, but open every other nozzle instead. With 6-inch nozzle spacing, the height of the spray bar needed to achieve triple overlap coverage may often cause wind distortion of the spray fans, leading to uneven application. Consequently, with 6-inch nozzle spacing, only double overlap coverage can be effectively achieved.

Table 12-1. Typical pug mill and spraying temperatures for asphalts (degrees Fahrenheit)

Type and Grade of Asphalt		*Pug Mill Mixture Temperatures[1]*		*Spraying Temperatures[5]*		*Notes*
		Dense-Graded Mixes	*Open-Graded Mixes*	*Road Mixes*	*Surface Treatments*	
Asphalt cements	AC-2.5	235-280	180-250	æ	270+	Temperatures for asphalt cements and cutback asphalts are guides only. [1]Temperature of mixture immediately after discharge from the pug mill rather than temperature of asphalt cement or cutback asphalt. [2]Application temperatures may, in some cases, be above the flash point of the material. Exercise caution to prevent fire or explosion. [3]Rapid curing grades are not recommended for hot pug mill mixtures. [4]Temperature of the emulsified asphalt in the pug mill mixture. [5]The maximum temperature (asphalt cement and cutback asphalt) must be below the temperature at which fogging occurs.
	AC-5	250-295	180-250	æ	280+	
	AC-10	250-315	180-250	æ	280+	
	AC-20	265-330	180-250	æ	295+	
	AC-40	270-340	180-250	æ	300+	
	AR-1,000	225-275	180-250	—	275+	
	AR-2,000	275-325	180-250	—	285+	
	AR-4,000	275-325	180-250	—	290+	
	AR-8,000	275-325	180-250	—	295+	
	AR-16,000	300-350	180-250	—	¾	
	200-300 pen	325-305	180-250	—	265+	
	120-150 pen	245-310	180-250	—	270+	
	85-100 pen	250-325	180-250	—	280+	
	60-70 pen	265-335	180-250	—	295+	
	40-50 pen	270-350	180-250	—	300+	
Cutback asphalts (RC, MC, SC)[2]	30 (MC only)	—	—	—	85+	
	70	—	—	65+	120+	
	250	135-175[3]	—	105+	165+	
	800	165-210[3]	—	135+	200+	
	3,000	180-240[3]	—	—	230+	

Table 12-1. Typical pug mill and spraying temperatures for asphalts (degrees Fahrenheit)[continued]

Emulsified asphalts	RS-1 RS-2	— —	— —	70-140 125-185
	MS-1	50-160[4]	70-160	—
	MS-2	50-160[4]	70-160	—
	MS-2h	50-160[4]	70-160	—
	SS-1	50-160[4]	70-160	—
	SS-1h	50-160[4]	70-160	—
	CRS-1 CRS-2	— —	— —	125-185 125-185
	CMS-2	50-160[4]	70-160	—
	CMS-2h	50-160[4]	70-160	—
	CSS-1	50-160[4]	70-160	—
	CSS-1h	50-160[4]	70-160	

Legend:

AC	viscosity-graded asphalt cement
AR	viscosity-graded, aged-residue asphalt cement
CMS	cationic-medium cement
CRS	cationic rapid-setting
CSS	cationic slow-setting
MC	medium curing
MS	medium setting
pen	penetration-graded asphalt
RC	rapid curing
RS	rapid setting
SS	slow setting

Table 12-2. Asphalt-Distributor Application Rates

Gallons Per Sq Yd	***Nozzle Size (Inch)***	***Bitu-meter Reading***	***Pump Tachometer Readings (GPM) — Spray-Bar Length (Feet)***															
			8	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***	***21***	***22***	***24***
0.10	1/8 3/16	900 1350	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.20	1/8 3/16	450 675	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.25	1/8 3/16	360 540	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.30	1/8 3/16	300 450	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240

Table 12-2. Asphalt-Distributor Application Rates (continued)

0.40	1/8 3/16	225 340	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.50	1/8 3/16	180 270	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.60	1/8 3/16	150 225	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.70	1/8 3/16	130 195	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.75	1/8 3/16	120 180	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.80	1/8 3/16	110 170	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
0.90	1/8 3/16	100 150	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
1.00	1/8 3/16	90 135	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
1.10	1/8 3/16	80 120	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
1.20	1/8 3/16	75 110	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
1.25	1/8 3/16	70 105	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
1.50	1/8 3/16	60 90	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
1.75	1/8 3/16	50 80	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
2.00	1/8 3/16	45 70	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
2.50	1/8 3/16	35 55	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240
3.00	1/8 3/16	30 45	80 120	90 135	100 150	110 165	120 180	130 195	140 210	150 225	160 240	170 255	180 270	190 285	200 300	210	220	240

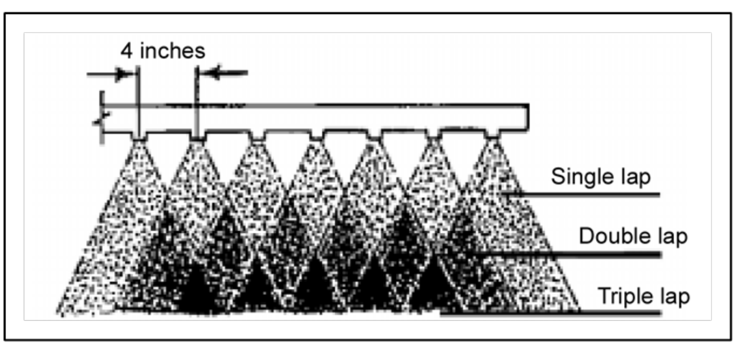

Figure 12-2. Perfect triple lap

12-8. **Nozzle angle setting.** To achieve a clean edge, it is common practice to position the end nozzles at a different angle (60° relative to the spray bar) compared to the other nozzles. However, this practice should be avoided, as it can create a thick streak at the edge and prevent the adjacent spray fan from receiving the necessary overlap from this nozzle. Instead, using a curtain at the end of the spray bar or employing a special end nozzle with all nozzles set at the same angle will provide more uniform coverage and result in a better edge.

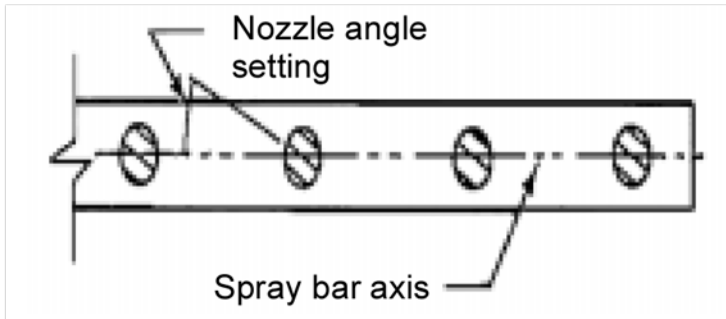

Figure 12-3. Proper nozzle angle setting

12-9. **Bitumeter.** The bitumeter (see figure 12-1, page 152) consists of a small rubber-tired wheel mounted on a retractable frame located beneath the distributor. A cable connects this wheel to a dial in the truck cab, which indicates the distributor's rate of travel in feet per minute (fpm) and the total travel distance in feet. In some models, the bitumeter can also measure the application rate in gallons per square yard. To ensure that speed readings are accurate, it is essential to check the bitumeter at regular intervals. The following procedure outlines how to check the bitumeter:

- ***Step 1.*** Mark off a distance of 500 to 1,000 feet on a straight, level surface.
- ***Step 2***. Drive the distributor at a constant speed over this length while timing the trip with a stopwatch.
- ***Step 3***. Determine the distributor speed in fpm and compare this calculation with the bitumeter reading recorded during the run.
- ***Step 4***. Repeat this procedure for a number of different speeds, bracketing the speed to be used for spraying.
- ***Step 5***. Tabulate or plot on a graph errors found at various speeds so a correction can be readily applied when using the distributor.

Note. Keep the bitumeter wheel clean to ensure accurate registering of the truck's speed. Asphalt buildup on the wheel causes errors.

AGGREGATE SPREADER

12-10. To apply aggregate to freshly sprayed asphalt surfaces, use a towed aggregate spreader (see figure 12-4). The spreader is equipped with a charging hopper that has a capacity of 2.5 cubic yards, an aggregate feed roller, an adjustable strike-off gate, traction tires, a towing tongue, and a travel axle. During the spreading operations, the spreader connects to the dump truck using a two-point, quick-coupling hitch but remains supported by its traction tires. It can apply aggregate while being towed or pushed by the dump truck that supplies aggregate to the charging hopper. For surface treatment operations, it is recommended to push the spreader with the dump truck, allowing both the aggregate spreader and the dump truck to ride on the freshly laid aggregate. As the spreader moves along the project site, the rotation of its traction tires drives the aggregate feed roller. You can control the application rate (in pounds per square yard) of the aggregate using the adjustable gate setting. The application width can be adjusted from 4 to 8 feet in 1-foot increments. To regulate the width of application, install blocking plates inside the charging hopper to block off a segment of the gate opening.

Note. It is important to spread the aggregate immediately after application of the asphalt, before the asphalt cools.

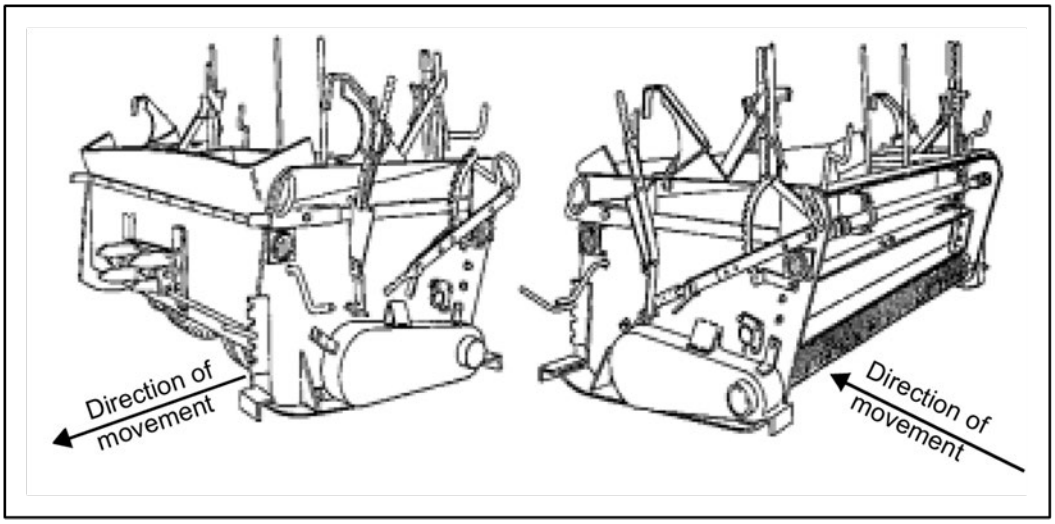

Figure 12-4. Towed aggregate spreader

ROLLER

12-11. All rollers must be in good mechanical condition and should be capable of starting, stopping, and reversing smoothly. They must also be equipped with a water-sprinkling system to keep the drums or tires wet. This prevents the asphalt from sticking to the drum surface and damaging the new pavement. When operating the rollers on the asphalt, position the drive wheel toward the spreader or asphalt paver. This orientation pulls the mix under the roller, resulting in a smooth surface. If the rollers are positioned with the guide roller facing the spreader, they will push the hot asphalt forward, creating a mound of material in front of the roller (see figure 12-5). As the roller passes over this mound, it leaves a bump in the finished pavement, which is often irreparable with subsequent rolling.

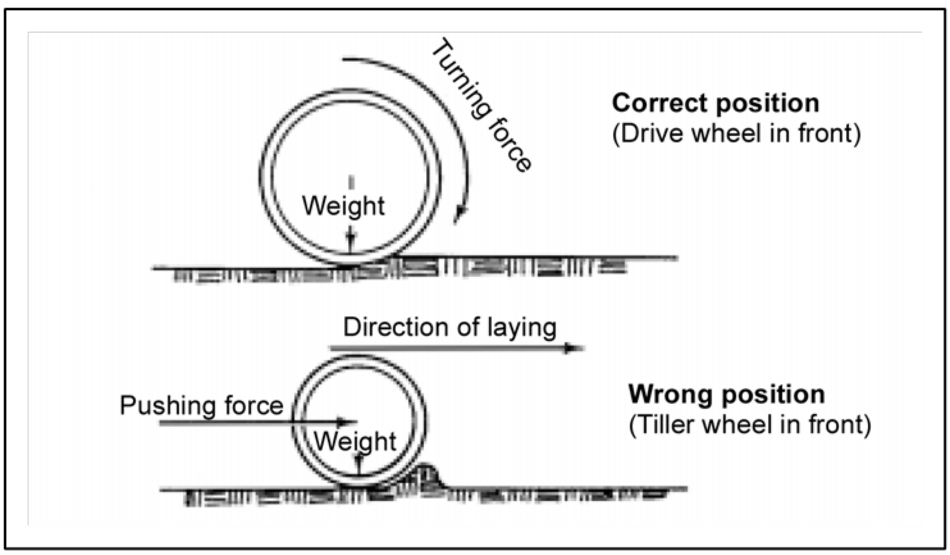

Figure 12-5. Correct roller drive-wheel position

Dual-Drum Vibratory Roller

12-12. A dual-drum vibratory roller weighing between 7 and 14 tons is ideal for compacting surface treatments, particularly after the application of the second layer of aggregate. However, it is crucial that the roller is not excessively heavy and that the vibration amplitude is not set too high, as doing so could damage the aggregate particles.

Pneumatic-Tired Roller

12-13. A pneumatic-tired roller is the preferred equipment for compacting bituminous surface treatments. Refer to chapter 11 for details on pneumatic-tired rollers.

IN-PLACE MIXING EQUIPMENT

12-14. The Army has two pieces of equipment for in-place mixing of asphalt or other stabilizing agents—grader and stabilizer-mixer.

GRADER

12-15. To spread the aggregate, use a grader, whether you are working from piles or scarifying the existing material. After applying the liquid asphalt with the distributor, use the grader to mix the asphalt and aggregate thoroughly. For effective mixing, position the grader's blade fully forward and angle it to side-cast the windrow. Typically, it takes five or six passes with the grader to ensure the materials are mixed thoroughly after each application of asphalt. For more detailed information on mixing asphalt with a grader, refer to chapter 4.

STABILIZER MIXER

12-16. The stabilizer mixer is preferred over a grader for road mixing materials because it is faster and provides better control over the asphalt-to-aggregate ratio. This results in a thoroughly mixed material. First, use the mixer to loosen the in-place materials and blend in selected aggregates. The asphalt distributor delivers asphalt directly to the mixer pump through a flexible metal hose. When using this hose, it is important to connect the two units with a safety chain to prevent any damage to the hose. Asphalt is sprayed onto the aggregate using a spray bar mounted under the mixer hood. This spraying happens while the mixer is in motion and the tines are rotating, ensuring a complete blend of asphalt and aggregate. For more information on stabilizer mixers, please refer to chapter 11.

BITUMEN HANDLING AND DEDRUMMING EQUIPMENT

ASPHALT MELTER

12-17. The asphalt melter (see figure 12-6, page 159) is designed to melt asphalt from 55-gallon drums and heat it to the required pumping temperature. The upper section of the melter features dual dedrumming tunnels, while the lower section contains an asphalt melting and storage tank. To begin the dedrumming process, first cut away one end of each 55-gallon drum. Then, place the drum upside down in the dedrumming tunnel. An oil heater should be used alongside the asphalt melter. Hot-oil coils run along the sides and bottom of the tunnel, providing the necessary heat to melt the asphalt inside the drums. Additional hot-oil coils located throughout the storage tank ensure that the asphalt reaches the appropriate mixing temperature. For guidance on suitable asphalt mixing temperatures for pug mills, refer to table 12-1, page 153.

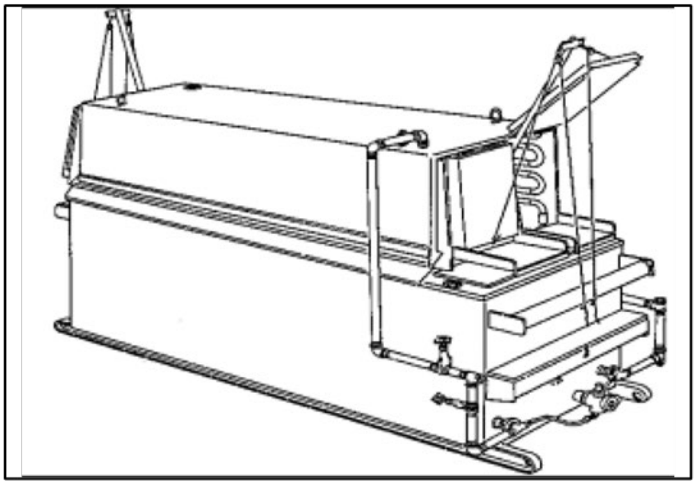

Figure 12-6. Asphalt melter

OIL HEATER

12-18. An oil heater is designed to heat and circulate hot oil to systems such as asphalt melters or storage tanks. It uses a diesel burner to generate the heat necessary to raise the oil's temperature. A pump then circulates this hot oil to the connected systems. You can set the desired heating requirements using the heater's temperature controller. Once set, a programmed circuit automatically manages the operation, incorporating a safety check-and-balance procedure. In the event of a malfunction, safety devices will shut down the unit to prevent any potential issues. Oil heaters are typically mounted on trailers for the transport and use of liquid asphalt storage tanks.

ASPHALT KETTLE

12-19. The 165-gallon asphalt kettle (see figure 12-7) is primarily designed for surface patching and maintenance operations. This trailer-mounted tank consists of an outer shell that encases a storage and heating tank with a capacity of 165 gallons. Inside the outer shell, there is a removable distillate burner that provides heat to the kettle, while a flue vents exhaust gases. A small two-cylinder gasoline engine supplies power to the asphalt pump. Asphalt is applied to small patching projects through a flexible hose connected to a handheld spray assembly.

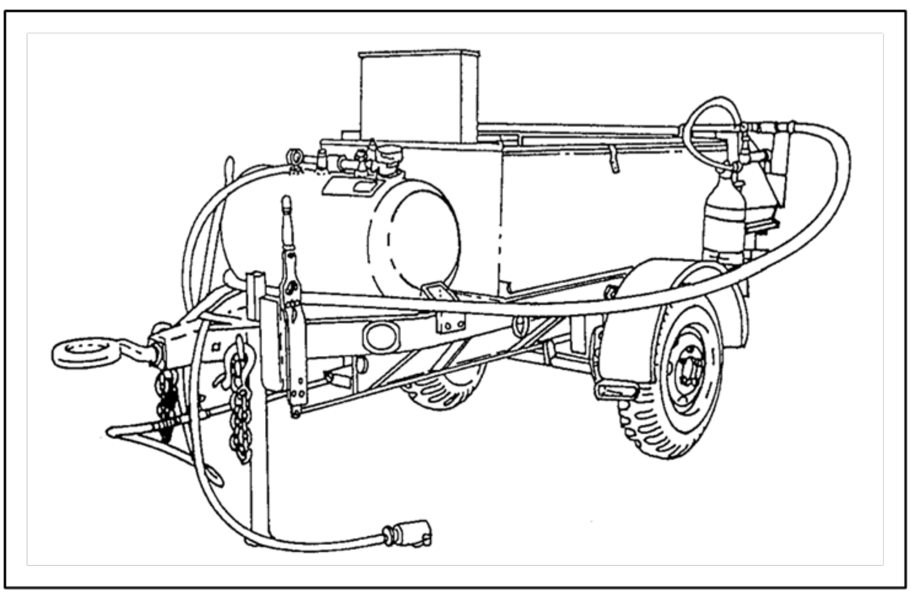

Figure 12-7. Asphalt kettle

SUPPORT EQUIPMENT

12-20. Use a rough-terrain forklift to move and lift asphalt drums and mineral filler. For more information on operating forklifts, refer to chapter 6. Additionally, utilize a loader to manage aggregate stockpiles and handle other material tasks. See chapter 5 for details on loaders.

Chapter 13
Safety

Supervisors are responsible for ensuring that personnel adhere to safety standards. Time is often a critical factor in construction operations in the theater of operations. The need to maintain efficiency, along with the temporary nature of much of the work, can lead to safety precautions that are significantly less stringent than those typically followed in civilian practices. However, this does not mean that safety should be overlooked. It is important to note that construction equipment, aside from dump trucks, is designed to accommodate only the operator.

SAFETY PROGRAM

13-1. Do not interpret the absence of documented hazards as a sign that they do not exist or are unimportant. When safety precautions are necessary but not documented, or if existing precautions are deemed insufficient, the commanding officer must issue new or additional warnings. Every job has its own specific safety hazards. It is crucial to identify these dangers and create a safety program aimed at reducing or eliminating all hazards. Supervisors must ensure that all operations are conducted in accordance with the guidelines outlined in the safety program. For assistance in making safety-related decisions, refer to the safety information in the United States Army Corps of Engineers Manual (EM) 385-1-1. Additionally, operators' manuals provide important do's and don'ts, cautions, and safety warnings.

GENERAL SAFETY RULES

13-2. The appropriate chapters of this manual identify safety rules for specific equipment. Also, check applicable technical and operator manuals prior to operating all equipment. Some general safety rules are as follows:

- Inspect equipment before use, and periodically on a regular basis.
- Ensure that mechanized equipment is operated by qualified and authorized personnel only.
- Use seat belts when they are available.
- Provide barriers to prevent personnel from walking under loading equipment that has a hoist or lift capability.
- Operate equipment in a manner that will not endanger persons or property.
- Observe safe operating speeds.
- Shut down and turn off the engine when equipment is unattended.
- Stop the equipment completely (apply the parking brake if available) before mounting or dismounting.
- Do not operate any machinery or equipment for more than 10 consecutive hours without an 8-hour rest interval.
- Post the safe load capacities at the operator's position on all equipment not rigged to prevent overloading.
- Post the safe operating speeds at the operator’s position on all equipment not having a speed governor.
- Mount a ROPS on equipment whenever it is available. Do not make any modifications to the ROPS.
- Ensure that only the operator is on the equipment while it is running. Supervisors can authorize exceptions in emergency situations, some training situations, and when required for maintenance.
- Shut down and turn off the engine when refueling motor vehicles and mechanized equipment.

OPERATOR INDOCTRINATION

13-3. During machine operation training, it is essential to teach operators about safety practices. Operators should be made aware of job hazards and the methods to reduce or avoid them. They must also be instructed to watch their fellow workers and alert them when they are in dangerous situations. Ongoing training should be provided throughout the project to ensure that personnel understand the job hazards and the objectives of the safety program. Additionally, horseplay and practical jokes can lead to extremely hazardous situations on the work site.

OPERATOR QUALIFICATIONS AND REQUIREMENTS

13-4. Operators of construction and material-handling equipment must be tested and licensed in accordance with Army Regulation (AR) 600-55 and the Marine Corps' Technical Manual 11275-15/4. An apprentice or applicant is only allowed to operate equipment under the direct supervision of a licensed operator. It is important not to allow anyone who is not physically or mentally capable to operate any equipment. Operators are responsible for the safe operation of their equipment as well as the safety of their passengers and cargo.

EQUIPMENT INSPECTION

13-5. Before operating a machine, a qualified and licensed operator should inspect and test the equipment to confirm that it is in safe working condition. Regular maintenance checks, service logs, and sound judgment are essential for ensuring safe operation and proper upkeep. If any machinery or equipment is deemed unsafe, it should be tagged as "Out of Service, Do Not Use" at the operator's station to prevent its use until it has been repaired. Additionally, verify that all safety features, such as backup alarms and lights, are functioning properly.

REPAIRS AND MAINTENANCE

13-6. Besides the following items, check the unit's SOP for special repair and maintenance procedures.

- Shut down or lock out equipment controls while a machine is being repaired, adjusted, or serviced.
- Position the equipment in a place, away from the project area, that is safe for the mechanic to work.
- Crib or block suspended machinery, equipment, or parts, and machines held apart by slings, hoists, or jacks. Do not work underneath or between items not properly blocked.
- Lower blades, bowls, hooks, buckets, and forks to the ground or onto suitable blocking material when equipment is undergoing maintenance or repairs.

GUARDS AND SAFETY DEVICES

13-7. Equipment guards, appliances, and similar safety devices are essential for protecting personnel. These devices should never be removed or disabled. If it becomes necessary to remove guards temporarily during repairs, lubrication, or adjustments, ensure that the power is turned off first. Once the work is completed, promptly replace all guards and safety devices. Additionally, all equipment must be equipped with functioning warning devices, such as backup alarms and turn signals.

SIGNALS

13-8. Provide a warning device or a signal person in areas where moving equipment may pose danger to fellow workers or others. If the situation allows, the signal person should wear a reflective orange vest.

ROPES, CABLES, AND CHAINS

13-9. Tables 13-1, page 163, and 13-2, page 163, and 13-3, page 164, provide information on load limitations and safety factors for ropes, cables, and chains. These materials, when used in construction operations, pose significant safety risks. To mitigate these hazards—

- Perform periodic inspections of their physical condition.
- Use only according to manufacturers' recommended procedures or within the safe limits recommended by the manufacturers of the equipment.
- Wear leather gloves when handling wire rope.

Table 13-1. Breaking strengths of 6 x 19 standard wire hoisting rope

Diameter (Inches)	Approximate Weight Per 100 Feet (Pounds)	Breaking Strength in Tons (2,000-Pound Ton)		
		Mild Plow Steel	Plow Steel	Improved Plow Steel
1/4	10	2.07	2.39	2.74
3/8	23	5.00	5.50	6.30
1/2	40	8.50	9.40	10.80
5/8	63	13.10	14.40	16.60
3/4	90	18.70	20.60	23.70
7/8	123	25.40	28.00	32.20
1	160	33.00	36.50	42.00
1 1/8	203	41.50	46.00	53.00
1 1/4	250	57.00	56.50	65.00
1 1/2	360	72.50	80.50	92.50

Notes:
1. A 6 x 19 rope is composed of 6 strands of 19 wires each. The strength of wire rope varies slightly with the strand construction and the number of strands.
2. The maximum allowable load is the breaking strength divided by the appropriate safety factor. The safety factors are shown in table 13-3, page 164.

Table 13-2. Breaking strengths and safe loads for manila and sisal rope

Nominal Diameter (Inches)	Circumference (Inches)	Weight Per 100 Feet (Pounds)	Number 1 Manila		Sisal	
			Breaking Strength (Pounds)	Safe Load (Pounds) (Safety Factor = 4)	Breaking Strength (Pounds)	Safe Load (Pounds) (Safety Factor = 4)
1/4	3/4	2.00	540	140	440	120
3/8	1 1/8	4.10	1,260	320	1,020	260
1/2	1 1/2	7.50	2,640	660	2,120	530
5/8	2	13.30	4,400	1,100	3,520	880
3/4	2 1/4	16.70	5,400	1,350	4,320	1,080
7/8	2 3/4	18.60	7,700	1,920	6,160	1,540
1	3	27.00	9,000	2,250	7,200	1,800
1 1/8	3 1/2	36.00	12,000	3,000	9,600	2,400
1 1/4	3 3/4	41.80	13,440	3,360	10,800	2,700
1 1/2	4 1/2	60.00	18,500	4,620	14,800	3,700
1 3/4	5 1/2	89.50	26,500	6,620	21,200	5,300
2	6	108.00	31,000	7,750	24,800	6,200
2 1/2	7 1/2	135.00	46,500	11,620	37,200	9,300
3	9	242.00	64,000	16,000	51,200	12,800

Note. The above figures are for new rope used under favorable conditions. As rope ages or deteriorates, progressively reduce safe load values to one-half the values given. See safety factors shown in table 13-3.

Table 13-3. Safety factors for ropes, cables, and chains

Type of Service	*Wire Rope (Cable)*	*Manila or Sisal Rope*	*Chain*
Guy lines	3.5	3.5	3.5
Miscellaneous hoisting equipment	5.0	7.0	5.0
Haulage lines	6.0	8.0	6.0
Overhead and gantry cranes	6.0	—	—
Jib and pillar cranes	6.0	—	—
Derricks	6.0	—	—
Small, electric or air hoists	7.0	—	7.0
Slings	8.0	10.0	8.0
Note. To determine the safe load for a single line, divide the breaking strength of the line by the applicable safety factor and multiply the result by an assumed efficiency factor of 80 percent for fittings.			

INSPECTION

13-10. Inspect wire ropes or cables during installation and as part of daily maintenance by operators. Remove the wire rope or cable from hoisting service if it is kinked or has multiple broken wires in any strand. Additionally, remove the wire rope or cable when—

- Three broken wires are found in one strand of 6 × 7 wire rope.
- Six broken wires are found in one strand of 6 × 19 wire rope.
- Eight broken wires are found in one strand of 8 × 19 wire rope.
- Nine broken wires are found in one strand of 6 × 37 wire rope.

Note. Plainly mark defective wire rope as unsuitable for further use and dispose of properly.

SLINGS

13-11. Only qualified rigging personnel should attach slings to a load. When using slings, their fasteners, and other rigging attachments:

- Inspect daily for evidence of overloading, excessive wear, or damage. Replace defective slings or accessories.
- Make all eye splices (figure 13-1) using the proper size of wire-rope thimbles.
- Place the U-bolt of the U-bolt clips on the dead (short) end of the wire rope (see figure 13-1). Tighten the U-bolts immediately after initial load application and at frequent intervals thereafter. Table 13-4, page 165, shows the number and spacing of clips and the proper torque to apply to the nuts of the clips (do not over torque). The minimum number of clips is three.

Figure 13-1. Eye splice

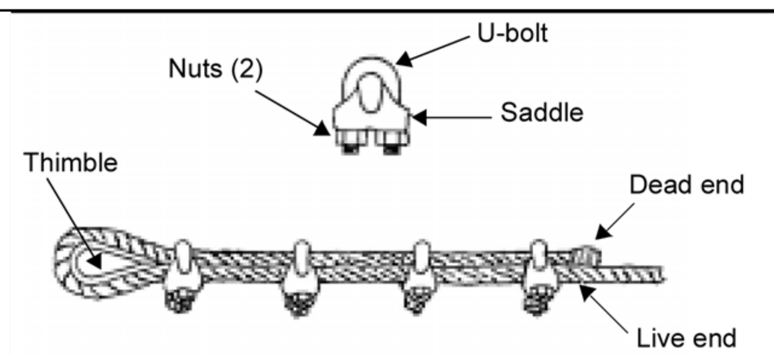

Table 13-4. Number and spacing of u-bolt clips for wire-rope eye connections

Wire-Rope Diameter		*Nominal Clip Size (Inches)*	*Number of Clips*	*Spacing of Clips*		*Torque to be Applied to Nuts of Clips*	
Inches	*Millimeters*			*Inches*	*Millimeters*	*Foot-Pounds*	*(M-Kg) (0.1383)*
5/16	7.95	3/8	3	2	50	25	3.5
3/8	9.52	3/8	3	2 1/4	57	25	3.5
7/16	11.11	1/2	4	2 3/4	70	40	5.5
1/2	12.70	1/2	4	3	76	40	5.5
5/8	15.85	5/8	4	3 3/4	95	65	9.0
3/4	19.05	3/4	4	4 1/2	114	100	14.0
7/8	22.22	1	5	5 1/4	133	165	23.0
1	25.40	1	5	6	152	165	23.0
1 1/4	31.75	1 1/4	5	7 1/2	190	250	35.0
1 3/8	34.92	1 1/2	6	8 1/4	210	375	52.0
1 1/2	38.10	1 1/2	6	9	230	375	52.0
1 3/4	44.45	1 3/4	6	10 1/2	267	560	78.0

Note. The spacing of clips should be six times the diameter of the wire rope. For end-to-end connections, increase the number of clips listed above by two, and apply the proper torque listed above on all clips. Reverse U-bolts at the center of the connection, so that they are on the dead (reduced load) end of each wire rope.

HOOKS AND SHACKLES

13-12. When using hooks and shackles—

- Replace bent, twisted, or otherwise damaged hooks, shackles, rings, and pad eyes and other fittings that show excessive wear.
- Close all hooks used to support human loads or loads that pass over workers. Where there is danger of relieving the tension on the cable due to the load or hook catching or fouling (such as lowering a load in a confined space), do not use open hooks.
- Extend the dead end of the wire rope a distance of six to nine times the wire rope's diameter beyond the socket when using a wedge-socket fastener (figure 13-2). Clamp the dead end of the wire rope to an extra piece of short wire rope. Place the clamp as close to the wedge as possible. Never clamp the dead end of wire to the live end. The U-bolt should bear against the tail, and the saddle of the clip should bear against the short extra piece.

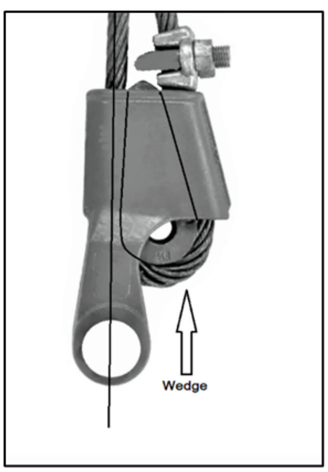

Figure 13-2. Wedge-socket fastener

EQUIPMENT LOADING

13-13. When loading equipment using suspended or overhead loading devices, the operator of the truck to be loaded must leave the cab. When loading equipment for transporting—

- Distribute, chock, and tie down the load.
- Make sure that the forward and side vision are clear, and that the load does not interfere in any way with the safe operation of the vehicle.
- Keep the load within the sides of the hauling equipment. When working with oversize loads that extend beyond the sides or end of hauling equipment, give adequate warnings and precautions to prevent endangering passing or opposing traffic, or damaging the vehicle.

EQUIPMENT TRANSPORTING

13-14. Give special consideration to equipment that is wider than standard vehicles or that protrudes past the sides or end of the hauling trailer. When oversize equipment is traveling or being transported from one job site to another—

- Travel or transport during daylight hours.
- Use warning flags and/or lights.
- Accompany the equipment with a lead and/or follow vehicle with warning signs whenever possible, especially in congested or heavy traffic areas.

NIGHT OPERATIONS

13-15. When operating equipment at night—

- Equip all mobile equipment with adequate headlights and taillights.
- Keep construction roads and working areas well illuminated until all workers have left the area.
- Ensure that signalers, spotters, inspectors, maintenance personnel, and others who work in dark areas exposed to vehicular traffic wear reflectorized vests or other such apparel if the tactical situation permits.

EXCAVATIONS

13-16. When excavating—

- Shore, brace, or slope excavations that are more than 4 feet deep, unless working in solid rock, hard shale, hardpan, cemented sand and gravel, or other similar materials.
- Design shoring and bracing to be effective all the way to the bottom of the excavation.
- Use sheet piling, bracing, shoring, trench boxes, or other methods of protection, including sloping, based upon calculation of the pressures exerted by and the condition and nature of the materials being retained.
- Provide additional shoring and bracing to prevent slides or cave-ins when excavating or trenching in locations adjacent to backfilled excavations or when subjected to vibrations from traffic, vehicles, or machinery.

Chapter 14
Environmental Protection

US military forces operate under increasingly diverse environmental requirements, both domestically and abroad, especially during stability and support operations. Growing environmental concerns have prompted all federal agencies, including the armed services, to consider the environmental impacts of their proposed actions. Compliance with environmental laws and regulations has become an essential aspect of operations. The military must adhere to all applicable environmental laws and regulations for its installations and areas of operation. For more information on military environmental protection, see TC 20-401.

PREOPERATIONS CHECKLIST

14-1. Unit leaders must consider the environmental impact of unit actions and plan to eliminate or minimize negative effects. An example of a preoperations checklist is shown below.

- Has coordination occurred with the installation and operational staffs concerning applicable environmental laws, regulations, and considerations?
- Has the operation plan /operation order and or constructive directives been reviewed for environmental requirements or considerations?
- Has the environmental-protection portion of the unit's SOP been reviewed, especially the areas concerning spill response and reporting?
- Have land-use permits and range clearances been obtained? Have all other unique, environmental-related requirements been completed?
- Has a recent risk assessment been performed to identify environmental-related risks?
- Have areas of environmental concern been verified during site reconnaissance?
- Are rehearsals conducted to ensure that all safety and environmental considerations are satisfied?
- Are hazardous material (HM) and petroleum, oils, and lubricants checked to ensure that they are properly labeled and that a material safety data sheet is on hand for each substance before transporting?
- Are personnel designated for the spill-response team(s) properly trained and aware of their assignment?
- Are tools, equipment, and materials (spill kits) available for environmental emergencies?
- Have previous after action reviews been evaluated for environmental lessons learned concerning the area(s) of operation and the mission type, and have preventive measures been taken?

PERSONNEL-PREPARATION CHECKLIST

14-2. An example of a personnel-preparation checklist is shown below.

- Do soldiers understand their responsibilities in reducing the generation of hazardous waste (HW) and minimizing damage to the environment?
- Have all soldiers been briefed on range or maneuver restrictions and endangered species, vegetation, archeological, cultural, and historic resource preservation?
- Are identified environmental risks discussed during planning?

SPILL-RESPONSE PLAN

14-3. A spill is defined as any release of petroleum products exceeding 5 gallons, or any amount of hazardous waste, depending on local regulations, as some states have stricter limits than 5 gallons. If a spill occurs, take the following actions immediately (see figure 14-1).

14-4. Protect yourself by—

- Evacuating the area in a manner appropriate to the type of spill.
- Taking personal precautions as detailed in the material safety data sheet for the type of material spilled.
- Using the proper personal protective equipment.
- Extinguishing smoking materials and all sources of ignition.
- Turning off power if there is the possibility of fire.
- Ventilating the area.
- Showering and changing clothes (as soon as possible) if hazardous waste contamination occurs.

14-5. Stop the flow if it is possible, without taking unnecessary chances or causing injury or contamination, by shutting off valves and turning drums upright.

14-6. Contain the spill by—

- Using an absorbent.
- Making dams to keep the spill from spreading farther. Do not let it enter storm or sewer drains or other waterways.
- Diverting the flow to prevent the spill from entering any water source (including drains) if containment is not possible.

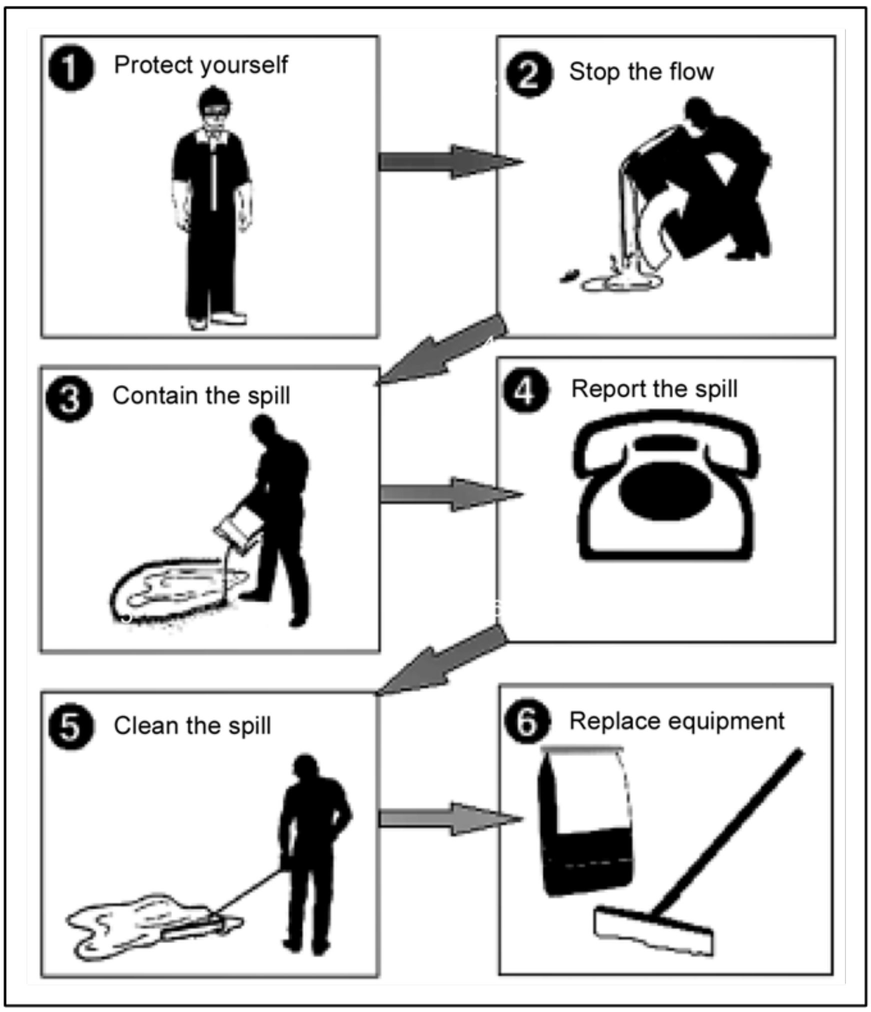

Figure 14-1. Spill-response actions

14-7. Report the spill to a superior and—

- Sound an alarm or give a verbal warning.
- Continue to assess the size and severity of the spill, while having another person call the installation fire department.
- Report the spill of any hazardous material other than a petroleum product (regardless of the quantity) to the unit environmental compliance officer or the installation's environmental office immediately.

15-8. Clean the spill by—

- Scooping up the contaminated material and put it in a container. Mark the container "Hazardous Waste, Contaminated Dirt" if the spill occurred on concrete or asphalt and the spill was cleaned up with dirt.
- * Checking with the unit supply sergeant or the Defense Reutilization Management Service for proper disposal procedures.

16-9. Replace the spill equipment through the following procedures—

- Immediately after a spill is cleaned, the spill-response team's noncommissioned officer in charge (NCOIC) will account for all tools and supplies. The NCOIC will order replacement consumables (sweeping compound and rags) from unit supply. The NCOIC will also identify missing property and initiate appropriate action (statement of charges or report of survey) to maintain accountability.
- Before resealing the drums, the spill-response team's NCOIC will complete a spill-kit inventory.

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Appendix A

METRIC CONVERSION CHART

This appendix complies with current Army directives, which state that the metric system will be incorporated into all new publications. The following table is an English-to-metric conversion chart.

Table A-1. Metric Conversion Chart

US Units	*Multiplied By*	*Equals Metric Units*	*Metric Units*	*Multiplied By*	*Equals US Units*
Length					
Inches	2.5400	Centimeters	Centimeters	0.3937	Inches
Feet	0.3048	Meters	Meters	3.2808	Feet
Yards	0.9144	Meters	Meters	1.0936	Yards
Miles	1.6093	Kilometers	Kilometers	0.6214	Miles
Area					
Square inches	6.4516	Square centimeters	Square centimeters	0.1550	Square inches
Square feet	0.0929	Square meters	Square meters	10.7640	Square feet
Square yards	0.8361	Square meters	Square meters	1.1960	Square yards
Acres	0.4047	Hectares	Hectares	2.4710	Acres
Volume					
Cubic feet	0.0283	Cubic meters	Cubic meters	35.3144	Cubic feet
Cubic yards	0.7646	Cubic meters	Cubic meters	1.3079	Cubic yards
Gallons	3.7854	Liters	Liters	0.2642	Gallons
Weight					
Foot-pounds	1.3830	Newton-meters	Newton-meters	0.7380	Foot-pounds
Pounds	0.4536	Kilograms	Kilograms	2.2046	Pounds
Foot-pounds	1.3830	Newton-meters	Newton-meters	0.7380	Foot-pounds

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Appendix B

Marine Corps Earthmoving Equipment

* This appendix offers a concise overview of the Marine Corps Engineer equipment used for earthmoving operations and general construction work. The following paragraphs include brief descriptions of the functions and operating characteristics for each type of equipment. For detailed information on any item listed, please refer to the appropriate technical manual 11275-15/3E or the Stock List (SL-3 or SL-4). Which can be located at https://marines.mil.

* MEDIUM CRAWLER TRACTOR

B-1. The Medium Crawler Tractor (MCT) is designed for land clearing, tree removal, and dozing operations. It is utilized by units within the Aviation Combat Element (ACE), the Ground Combat Element (GCE), and the Logistics Combat Element (LCE). The MCT is equipped with all the necessary components to operate effectively with attachments such as a 3-shank ripper or a rear-mounted winch and drawbar/towing coupler. See figure B-1.

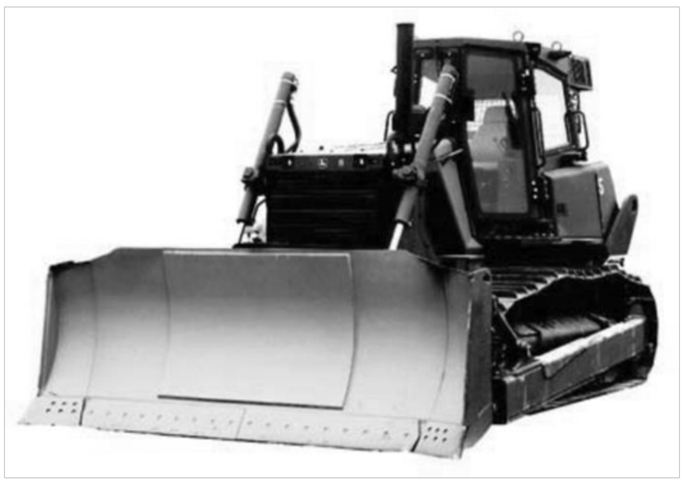

Figure B-1. Medium crawler dozer

D6K DOZER

B-2. The D6K dozer is a versatile, medium-sized, self-propelled, full-tracked crawler designed for cutting, moving, and dozing various types of materials. It features a 6-way angle blade, allowing for increased flexibility and performance. Due to its size and maneuverability, the D6K effectively bridges the gap between the Medium Crawler Tractor and the 120M grader. This machine is compatible with GCS 900 and is equipped for plug-and-play operations in grade control applications. The ACE, GCE, and LCE units all utilize the D6K dozer. See figure B-2.

Figure B-2. D6K dozer

621G SCRAPER

B-3. The ACE and LCE units utilize the 621G scraper. The 621G is an open-bowl, pneumatic-tired, 2-axle scraper with a capacity ranging from 15.7 to 22 cubic yards. It is powered by a single diesel engine and features an articulated frame-steer scraper. This scraper can be used for various tasks, including hauling, dumping, and spreading loose materials, as well as for medium-haul earthmoving operations. It is also effective for moving ripped materials and shot rock. The 621G can be transported by a C-5 aircraft. See figure B-3.

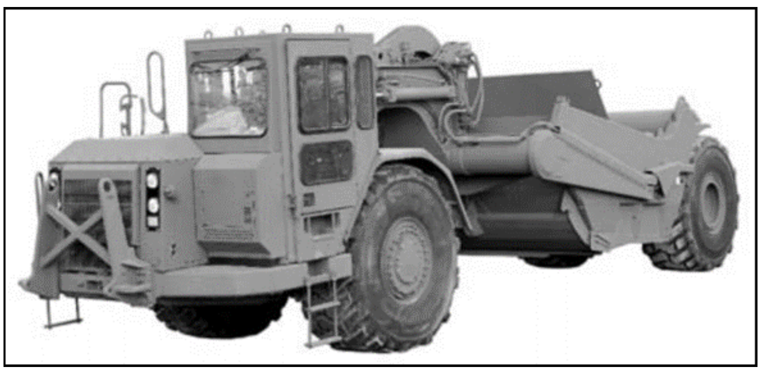

Figure B-3. 621G scraper

120M MOTORIZED ROAD GRADER

B-4. The 120M motorized road grader is a self-propelled grading machine powered by a diesel engine. The ACE, GCE, and LCE units utilize the 120M motorized road grader. This machine features rubber tires, six-wheel drive, and an articulated frame with a front-wheel steering design. It is equipped with a 12-foot blade that has a minimum shoulder reach of 6 feet beyond the wheels and can lift to a minimum height of 16 inches above the ground. Additionally, it can be reconfigured to accommodate an armored cab. The advanced joystick control system replaces the traditional array of levers and steering wheel, significantly simplifying the operation of the motor grader by allowing the operator to control the entire machine, drawbar, and moldboard with both hands. The applications of the 120M include grading both coarse and fine soil, creating low and high bank slopes, forming flat and V-ditches, scarifying surfaces, removing snow, and building and maintaining roads and airfields. See figure B-4.

Figure B-4. 120M motorized road grader

TRACTOR RUBBER-TIRE ARTICULATING, MOBILE

B-5. The 644-tractor rubber-tire articulating mobile (TRAM) is utilized by ACE, GCE, and LCE units. This diesel-powered, four-wheel drive tractor features articulated steering and rubber tires. The TRAM is versatile and is used for various tasks, including loading trucks, stockpiling materials, digging basements or gun emplacements, backfilling ditches, lifting and moving construction materials, and, when equipped with rock-type tread tires, operating in and around rock quarries. Additionally, it can perform a wide range of miscellaneous construction tasks, designed for shoveling, hoisting, and discharging bulk materials such as earth, aggregate, and snow. See figure B-5.

Figure B-5. 644 TRAM

ALL TERRAIN CRANE

B-6. The all-terrain crane is a rubber-tired, hydraulic boom crane capable of lifting and swinging a maximum load of 80,000 pounds. It is used to load and unload breakbulk cargo from fixed ports or piers, as well as on and off airfield runways and over unprepared, uneven surfaces. The crane can be driven on primary and secondary highways, including across sand, snow, and mud. It comes equipped with a set of lifting slings, each with a lifting capacity of 40 tons. Both the ACE and LCE units utilize the all-terrain crane. See figure B-6.

Figure B-6. All terrain crane

BACKHOE LOADERS 420D AND 420E

B-7. The ACE, GCE, and LCE units utilize the BHL. Both the BHL 420D and the BHL 420E are highly mobile, lightweight tractors with rubber tires, equipped with a front-end loader and an excavator. These vehicles can keep up with other wheeled vehicles in the maneuver force and can achieve road speeds exceeding 20 mph. The BHL is also capable of operating hydraulic power tools and can be externally transported by a CH-53 helicopter. See figure B-7.

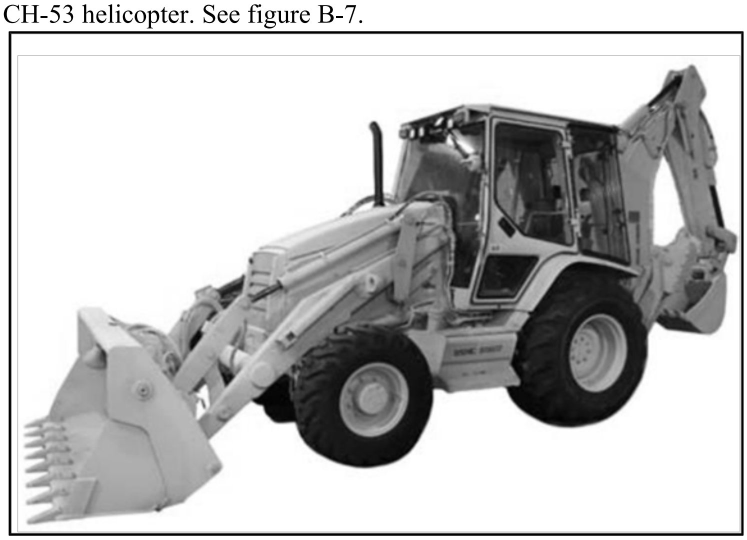

Figure B-7. 420D backhoe loader

HYDRAULIC EXCAVATOR

B-8. The hydraulic excavator (HYEX) is utilized by ACE and LCE units. It is outfitted with a hydraulic thumb clamp, a deep digging attachment, a heavy-duty bucket, and a utility bucket designed for general digging and trenching tasks. Additionally, the HYEX can be reconfigured to accommodate an armored plug-and-play cab. See figure B-8, Page 177.

Figure B-8. Hydraulic excavator

260 CFM COMPRESSOR

* B-9. The portable air compressor with pneumatic tools is a trailer-mounted unit that delivers compressed air at a rate of 260 cubic feet per minute, with a pressure of 100 pounds per square inch. It is designed to operate effectively under challenging conditions, including extreme heat, cold, rain, and dust. This compressor is capable of powering pneumatic tools and providing compressed air for bridging operations and bulk fuel handling. The compressor is utilized by combat engineer battalions, engineer support battalions, artillery regiments, and Marine Wing Support Squadrons. The pneumatic tools are components (SL-3 items) of the compressor unit. See figure B-9.

Figure B-9. 260 CFM compressor

7-TON DUMP TRUCK

B-10. The MK29/MK30 dump truck is used by the ACE, GCE, and LCE units. It features a steel-welded dump body that extends over the vehicle cab to prevent damage during loading. The MK30 model is equipped with a self-recovery winch that has a capacity of 20,000 pounds. This dump truck can navigate a 60 percent gradient and handle a 30 percent side slope at speeds of up to 15 mph, as well as a 40 percent side slope at 5 mph while carrying its maximum cross-country load. It has an on-road cruising range of 300 miles. Additionally, this model includes upgraded cab mounts, armored flooring, enhanced suspension, and air conditioning. An optional troop seat kit allows for up to 12 passengers in the cargo bed. See figure B-10, Page 178.

Figure B-10. 7-ton dump truck

ROLLER COMPACTOR VIBRATORY SELF-PROPELLED

B-11. The vibratory compactor is a diesel-powered, articulated steering machine designed for various types of horizontal construction. It is utilized by both the ACE and LCE units. The vibratory compactor has several key capabilities, including the construction of roads, airfield complexes, dams, open storage areas, and hardstands for vehicle and equipment parks. It is also used for repairing bomb damage on airfields and compacting building sites. See figure B-11.

Figure B-11. Roller compactor vibratory self-propelled

Glossary

The glossary lists acronyms and terms with Army or joint definitions. Terms for which TM 3-34.62/MCRP 3-40D.9 is the proponent are marked with an asterisk (*).

SECTION I – ACRONYMS AND ABBREVIATIONS

ACE	aviation combat element
AR	Army regulation
BCY	bank cubic yard(s)
BHL	backhoe loader
CCY	compacted cubic yard(s)
cfm	cubic feet per minute
DA	Department of the Army
DEUCE	deployable universal combat earthmover
EM	engineer manual
EVW	empty vehicle weight
F	Fahrenheit
FM	field manual
FMTV	family of medium tactical vehicles
fpm	foot, feet per minute
ft	foot, feet
GCE	ground combat element
GPM	gallons(s) per minute
GVW	gross vehicle weight
HYEX	hydraulic excavator
kph	kilometers(s) per hour
lb	pound(s)
LCE	logistics combat element
LCY	loose cubic yard(s)
MCT	medium crawler tractor
M-Kg	meters to kilograms
mph	mile(s) per hour
NAVFAC	naval facility
NCOIC	noncommissioned officer in charge
NSN	national stock number
OMC	optimum moisture content
PCSA	Power Crane and Shovel Association
psi	pound(s) per square inch
ROPS	rollover protective system

rpm	revolution(s) per minute
RPR	rimpull required
SOP	standing operating procedure
sq	square
STP	soldier training publication
TB	technical bulletin
TC	training circular
TM	technical manual
TRADOC	United States Army Training and Doctrine Command
TRAM	tractor rubber-tire articulating, mobile
U.S.	United States
yd	yard(s)

SECTION II – TERMS

aggregate

a clustered mass of individual soil particles varied in shape, ranging in size from a microscopic granule to a small crumb, and considered the basic structural unit of soil

atomize

to reduce to a fine spray

Atterberg limits

water contents at certain critical stages in soil behavior; they can be used to describe the plasticity of a soil and if the soil is cohesive or cohesionless

ballast

a heavy substance (such as wet sand) used to increase the weight of rollers

base course or base

important element in a road structure; it functions as the primary load-bearing component of the road, ultimately providing the pavement (or surface) strength; therefore, it is made of higher quality material than subbase material

binder

a material that produces cohesion in loosely assembled substances; for example, tar, cement, and cohesive soil material passing a Number 40 sieve

borrow pit

an area where material is excavated for use as fill at another location

chock

motionless; for blocking the movement of a wheel

clay

a cohesive soil that exhibits plasticity within a range of water contents and whose particles are less than 0.005 millimeters in size

coefficient

any of the factors of a product considered in relation to a specific factor, especially a constant factor of a term as distinguished from a variable

cohesion

the act or state of sticking together tightly

cycle time

cycle time is the time required for a machine to complete one cycle of operation

desired dry density

usually expressed as an acceptable density range but stated as a single value when used to determine soil stabilizing requirements

dredging

method of moving material from below a body of water

efficiency factor

a percentage factor (60-minute working hour = 100 percent) used to adjust production estimates for normal production delays

finishing

the final grading of an embankment or other earthwork or the smoothing of a wearing surface after it is placed

gantry

a triangular frame on top of a crane superstructure, which carries sheaves for the boom support lines; also, a platform (usually supported by towers) made to carry a traveling crane on parallel tracks

gap graded

see soil gradation

gradation

see soil gradation

granular

consisting of particles having a bulky shape

gravel

see soil

heaped

material piled above the sides of a restricting container (such as an excavator bucket, a scraper bowl, or a dump-truck carrying box)

hopper

usually, a funnel-shaped receptacle for holding and loading material (grain, sand, crushed rock, or coal); also, any of various other receptacles for the temporary storage of material

in situ

soil in its natural (undisturbed) state

in-place mixing

mixing done at the construction site

lift

the depth of material that may be placed or compacted at one time

load time

the time it takes the loading equipment to actually load the haul unit, plus any time lost by the loading equipment while waiting for the haul unit to be spotted

loam

a general agricultural term applied most frequently to sandy, silty topsoils that contain a trace of clay

optimum moisture content

the moisture content at which the soil's highest density can be obtained for a given amount of compactive input energy; soils compacted at moisture contents below optimum do not compact as completely as those at optimum moisture; those above optimum approach a plastic stage and begin to act like liquids, distributing an applied force equally in all directions and not moving particles into the voids

outriggers

stabilizers used on cranes and backhoes to prevent tipping while loading or digging

pintle

a pivot pin (usually upright) on which another part turns

plasticity

the ability of a soil to deform without cracking or breaking; see also optimum moisture content

push loading

loading a scraper with dozer (push tractor) assistance

push tractor or pusher assistance

a dozer pushing a scraper during earthmoving operations

rimpull

the usable force developed between the driving tires and the travel surface

ripping

digging or tearing hard material using shanks (teeth) mounted on a dozer, grader, or other machine; the number of shanks mounted on the back of a dozer can usually be changed to engage one, two, or three shanks

shore

(1) to give support to; brace; (2) a prop for preventing sinking or sagging; (3) a prop placed against or beneath equipment to restrict movement

shoulder

that part of the top surface of an approach embankment, causeway, or cut immediately adjoining the roadway that accommodates stopped vehicles in emergencies and laterally supports base and surface courses

side casting

to push or throw to the side, using with the blade or bucket

soil

soil is classified by particle size and type; gravel has large, coarse, blocky-shaped particles, while clay has small, fine, platy-shaped particles; sand and silt have particle sizes between these two extremes; (for earthmoving, soil is placed in three categories: rock, soil, and rock soil)

soil gradation

soil is either well-graded or poorly graded; well-graded soil is capable of being tightly compacted; it contains a variety of particle sizes; during compaction, smaller particles are worked between and around larger particles to reduce the percentage of voids, making the soil denser and stronger; poorly graded soil is difficult or impossible to compact; it contains a high percentage of similar-size particles (called uniformly gapped) or a poor relationship of the percentage of sizes (called gap -graded); such soil has a relatively high percentage of voids after compaction; therefore, it lacks density and strength

struck

a full load of material that is level with the top of its container, (such as a scraper bowl or a dump-truck body)

tandem

a group of two or more arranged one behind the other or used or acting in conjunction

tine

a slender, pointed projecting part; a prong

torque

a force that produces or tends to produce rotation or torsion (such as an auto engine delivers to the drive shaft)

windrows

a long, low ridge of material scraped to the side, using a blade, when moving earth

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29 July 2026

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