3

Excavating and Lifting

3–1 INTRODUCTION

Excavating and Lifting Equipment

An *excavator* is defined as a power-driven digging machine. The major types of excavators used in earthmoving operations include hydraulic excavators and the members of the cable-operated crane-shovel family (shovels, draglines, hoes, and clamshells). Dozers, loaders, and scrapers can also serve as excavators. In this chapter we focus on hydraulic excavators and the members of the crane-shovel family used for excavating and lifting operations. Operations involving the dozer, loader, and scraper are described in Chapter 4. Special considerations involved in rock excavation are discussed in Chapter 8.

Excavators and Crane-Shovels

In 1836, William S. Otis developed a machine that mechanically duplicated the motion of a worker digging with a hand shovel. From this machine evolved a family of cable-operated construction machines known as the *crane-shovel.* Members of this family include the shovel, backhoe, dragline, clamshell, mobile crane, and pile driver.

While *hydraulic excavators* (Figure 3–1) have largely replaced the cable-operated crane-shovel family, functionally similar hydraulic machines are available including the front shovel and backhoe. The advantages of hydraulic excavators over cable-operated machines are faster cycle time, higher bucket penetrating force, more precise digging, and easier operator control. Hydraulic telescoping-boom mobile cranes are also available. The major remaining cable-operated machines based on the original crane-shovel are the dragline and the mobile lattice-boom crane.

Some of many attachments for the hydraulic excavator and their uses include:

Arms, extendible: Replaces the standard stick to provide extra reach.

Auger: Drills holes for poles, posts, soil sampling, and ground improvement.

Booms: Extended booms used for long-reach applications.

Figure 3–1 Hydraulic excavator. (Courtesy of Volvo Construction Equipment North America, Inc.)

Breaker/hammer: Vibratory hammer used to break up concrete and rock.

Bucket, 4-in-1: Also called a multipurpose bucket or multisegment bucket. Similar to the loader bucket shown in Figure 4–16. Such buckets are capable of performing as a clamshell, dozer, or scraper, as well as a conventional excavator bucket.

Bucket, articulating clam: A hydraulic clamshell bucket with full rotation.

Bucket, cemetery: Used for digging straight wall trenches.

Bucket, clamshell: Performs like the clamshell described in Section 3–5.

Bucket, ditch cleaning: Wide, shallow, and smooth-edged bucket; may be perforated for drainage.

Bucket, drop center: Used for trenching. The drop center excavates for pipe bedding while the sides excavate to the required trench width.

Bucket, general purpose: Standard excavator bucket.

Bucket, muck: Used for excavating mud and muck; usually perforated for drainage.

Bucket, pavement removal: A forked bucket used for removing and loading pavement slabs.

Bucket, ripper: The bucket sides and bottom are lined with ripper teeth to break up hard soil or soft rock.

Bucket, rock: A heavy-duty bucket designed for loading rock.

Bucket, sand: Has a flat bottom and tapered sides to reduce the chance of soil cave-in.

Bucket, side tilting: Can be tilted for grading slopes and for ditching.

Compaction plate/tamper: See Section 5–2 and Figure 5–9.

Compaction wheel: See Section 5–2 and Figure 5–8.

Coupler, quick: Permits rapid exchange of attachments.

Cutter/processor: Power jaws primarily used for crushing concrete.

Drill, rock: Mounted on the end of the stick to drill blast holes.

Grapple: Equipped with tong-type arms for handling rock, logs, and other materials.

Pile driver/extractor: Used for driving and extracting piles; see Section 10–3.

Shear: Primarily used for processing scrap metal but also used for demolition.

Thumb, bucket: Attached to bucket to provide a hook capability. It can be retracted when not needed.

Excavators and crane-shovels consist of three major assemblies: a carrier or mounting, a revolving superstructure containing the power and control units (also called the revolving deck or turntable), and a front-end assembly. Carriers available include crawler, truck, and wheel mountings, as shown in Figure 3–2. The crawler mounting provides excellent on-site mobility, and its low ground pressure enables it to operate in areas of low trafficability. Crawler mountings are widely used for drainage and trenching work as well as for rock excavation. Truck and wheel mountings provide greater mobility between job sites but are less stable than crawler mountings and require better surfaces over which to operate. Truck mountings use a modified truck chassis as a carrier and thus have separate stations for operating the carrier and the revolving superstructure. Wheel mountings, on the other hand, use a single operator's station to control both the carrier and the excavating mechanism. Truck mountings are capable of highway travel of 50 mi/h (80 km/h) or more, whereas wheel mountings are usually limited to 30 mi/h (48 km/h) or less.

In this chapter, we discuss the principles of operation, methods of employment, and techniques for estimating the production of shovels, backhoes, clamshells, and draglines. Cranes and their employment are also discussed. Pile drivers and their employment are covered in Chapter 10.

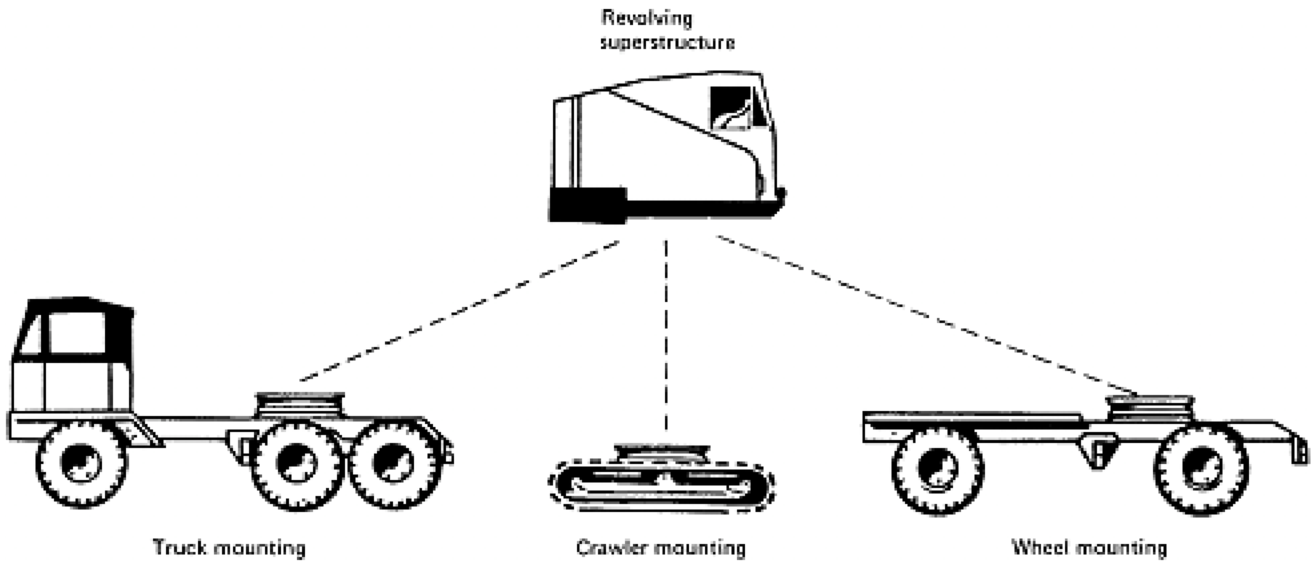


Figure 3–2 Crane-shovel mounting and revolving superstructure. (U.S. Department of the Army)

Table 3–1 Bucket-capacity rating methods

Machine	Rated Bucket Capacity
Backhoe and shovel	
Cable	Struck volume
Hydraulic	Heaped volume at 1:1 angle of repose
Clamshell	Plate line or water line volume
Dragline	90% of struck volume
Loader	Heaped volume at 2:1 angle of repose

Excavator Production

To utilize Equation 2–1 for estimating the production of an excavator, it is necessary to know the volume of material actually contained in one bucket load. The methods by which excavator bucket and dozer blade capacity are rated are given in Table 3–1. *Plate line capacity* is the bucket volume contained within the bucket when following the outline of the bucket sides. *Struck capacity* is the bucket capacity when the load is struck off flush with the bucket sides. *Water line capacity* assumes a level of material flush with the lowest edge of the bucket (i.e., the material level corresponds to the water level that would result if the bucket were filled with water). *Heaped volume* is the maximum volume that can be placed in the bucket without spillage based on a specified angle of repose for the material in the bucket.

Since bucket ratings for the cable shovel, dragline, and cable backhoe are based on struck volume, it is often assumed that the heaping of the buckets will compensate for the swell of the soil. That is, a 5-cu-yd bucket would be assumed to actually hold 5 bank cu yd of material. A better estimate of the volume of material in one bucket load will be obtained if the nominal bucket volume is multiplied by a *bucket fill factor* or bucket efficiency factor. Suggested values of bucket fill factor for common soils are given in Table 3–2. The most accurate estimate of bucket load is obtained by multiplying the heaped bucket volume (loose measure) by the bucket fill factor. If desired, the bucket load may be converted to bank volume by multiplying its loose volume by the soil's load factor. This procedure is illustrated in Example 3–1.

Table 3–2 Bucket fill factors for excavators

Material	Bucket Fill Factor
Common earth, loam	0.80–1.10
Sand and gravel	0.90–1.00
Hard clay	0.65–0.95
Wet clay	0.50–0.90
Rock, well-blasted	0.70–0.90
Rock, poorly blasted	0.40–0.70

EXAMPLE 3–1

Estimate the actual bucket load in bank cubic yards for a loader bucket whose heaped capacity is 5 cu yd (3.82 m^3). The soil's bucket fill factor is 0.90 and its load factor is 0.80.

SOLUTION

$$\text{Bucket load} = \times 0.90 = 4.5 \text{ LCY} \times 0.80 = 3.6 \text{ BCY}$$

$$[= 3.82 \times 0.90 = 3.44 \text{ LCM} \times 0.80 = 2.75 \text{ BCM}]$$

3–2 HYDRAULIC EXCAVATORS

Operation and Employment

The original and most common form of hydraulically powered excavator is the *hydraulic excavator* equipped with a hoe front end. This machine is also called a *hydraulic hoe* or *hydraulic excavator-backhoe.* A *backhoe* (or simply *hoe*) is an excavator designed primarily for excavation below grade. As the name implies, it digs by pulling the dipper back toward the machine. The backhoe shares the characteristics of positive digging action and precise lateral control with the shovel. Cable-operated backhoes exist but are largely being replaced by hydraulic models because of their superior speed of operation and ease of control. Backhoe attachments are also available for loaders and tractors.

The components of a hydraulic excavator are illustrated in Figure 3–3. In this machine, the boom and dipper arms are raised and lowered by hydraulic cylinders. In addition, the dipper is pivoted at the end of the dipper arm so that a wrist-like action is provided.

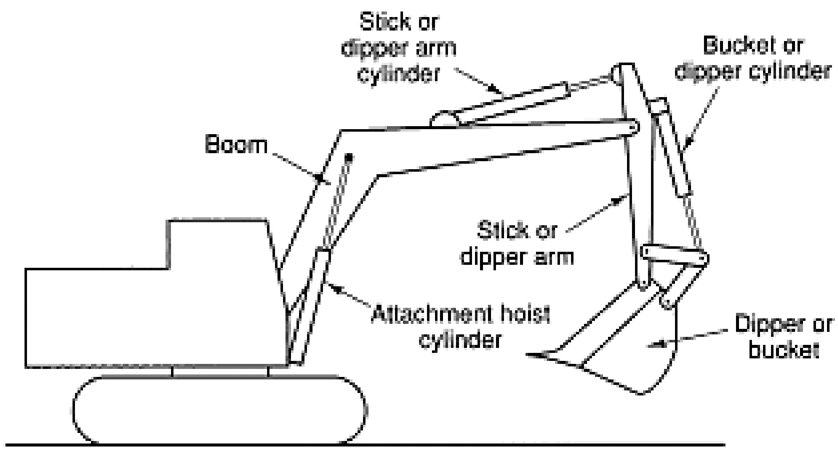


Figure 3–3 Components of a hydraulic excavator-backhoe.

When the dipper is filled, the dipper is curled up to reduce spillage, and the boom is raised and swung to the unloading position. The load is then dumped by swinging the dipper up and away from the machine.

The backhoe is widely utilized for trenching work. In addition to excavating the trench, it can perform many other trenching functions, such as laying pipe bedding, placing pipe, pulling trench shields, and backfilling the trench. In trench excavation the best measure of production is the length of trench excavated per unit of time. Therefore, a dipper width should be chosen which matches the required trench width as closely as possible. For this reason, dippers are available in a wide range of sizes and widths. Side cutters are also available to increase the cutting width of dippers. Other suitable backhoe applications include excavating basements, cleaning roadside ditches, and grading embankments.

A special form of hydraulic excavator which utilizes a rigid telescoping boom in place of the boom and dipper arm of a conventional hydraulic backhoe is shown in Figure 3–4. Because of their telescoping boom and pivoting bucket, these machines are very versatile and capable of ditching, sloping, finishing, cleaning ditches, ripping, and demolishing as well as trenching.

The use of compact or “mini” excavating equipment is a growing trend in the construction equipment industry. Such equipment includes the skid steer loader and the compact loader described in Section 4–3 as well as hydraulically powered *mini-excavators*. The advantages of such equipment include compact size, hydraulic power, light weight, maneuverability, and versatility. A typical mini-excavator is illustrated in Figure 3–5. These machines are available in sizes from about 10 to 60 hp (7.5–45 kW) with digging depths

Figure 3–4 Telescoping-boom hydraulic excavator. (Courtesy of JLG Industries, Inc.)

Figure 3–5 Mini-excavator. (Courtesy of JCB Inc.)

from about 7 to 15 ft (2.1–4.6 m). Some machines are as narrow as 29 in. (0.74 m) making them very useful for excavating in confined spaces. The mini-excavator's ability to operate with a full 360-degree swing, their hydraulic power, and their low ground pressure have resulted in their replacing backhoe/loaders in some applications. When equipped with dozer blade, they may also be employed in leveling, grading, backfilling, and general job cleanup.

Production Estimating

No production tables have been prepared for the hydraulic excavator. However, production may be estimated by using Equation 3–1 together with Tables 3–3 and 3–4, which have been prepared from manufacturers' data.

$$\text{Production (LCY/h)} = C \times S \times V \times B \times E \qquad \textbf{(3–1)}$$

where C = cycles/h (Table 3–3)
S = swing-depth factor (Table 3–4)
V = heaped bucket volume (LCY or LCM)
B = bucket fill factor (Table 3–2)
E = job efficiency

In trenching work a fall-in factor should be applied to excavator production to account for the work required to clean out material that falls back into the trench from the trench walls. Normal excavator production should be multiplied by the appropriate value from Table 3–5 to obtain the effective trench production.

Table 3–3 Standard cycles per hour for hydraulic excavators

	Machine Size			
Type of Material	***Wheel Tractor***	***Small Excavator: 1 yd (0.76 m^3) or Less***	***Medium Excavator: 1¼–2¼ yd (0.94–1.72 m^3)***	***Large Excavator: Over 2½ yd (1.72 m^3)***
Soft (sand, gravel, loam)	170	250	200	150
Average (common earth, soft clay)	135	200	160	120
Hard (tough clay, rock)	110	160	130	100

Table 3–4 Swing-depth factor for backhoes

Depth of Cut (% of Maximum)	Angle of Swing (deg)					
	45	***60***	***75***	***90***	***120***	***180***
30	1.33	1.26	1.21	1.15	1.08	0.95
50	1.28	1.21	1.16	1.10	1.03	0.91
70	1.16	1.10	1.05	1.00	0.94	0.83
90	1.04	1.00	0.95	0.90	0.85	0.75

EXAMPLE 3–2

Find the expected production in loose cubic yards (LCM) per hour of a small hydraulic excavator. Heaped bucket capacity is ¾ cu yd (0.57 m^3). The material is sand and gravel with a bucket fill factor of 0.95. Job efficiency is 50 min/h. Average depth of cut is 14 ft (4.3 m). Maximum depth of cut is 20 ft (6.1 m) and average swing is 90.

SOLUTION

$$\text{Cycle output} = 250 \text{ cycles/60 min (Table 3–3)}$$
$$\text{Swing-depth factor} = 1.00 \text{ (Table 3–4)}$$
$$\text{Bucket volume} = 0.75 \text{ LCY (0.57 LCM)}$$
$$\text{Bucket fill factor} = 0.95$$
$$\text{Job efficiency} = 50/60 = 0.833$$
$$\text{Production} = 250 \times 1.00 \times 0.75 \times 0.95 \times 0.833 = 148 \text{ LCY/h}$$
$$[= 250 \times 1.00 \times 0.57 \times 0.95 \times 0.833 = 113 \text{ LCM/h}]$$

Table 3–5 Adjustment factor for trench production

Type of Material	Adjustment Factor
Loose (sand, gravel, loam)	0.60–0.70
Average (common earth)	0.90–0.95
Firm (firm plastic soils)	0.95–1.00

Job Management

In selecting the proper excavator for a project, consideration must be given to the maximum depth, working radius, and dumping height required. Check also for adequate clearance for the carrier, superstructure, and boom during operation.

Although the excavator will excavate fairly hard material, do not use the bucket as a sledge in attempting to fracture rock. Light blasting, ripping, or use of a power hammer may be necessary to loosen rock sufficiently for excavation. When lifting pipe into place do not exceed load given in the manufacturer's safe capacity chart for the situation.

3–3 SHOVELS

Operation and Employment

The *hydraulic shovel* illustrated in Figure 3–6 is also called a *front shovel* or *hydraulic excavator-front shovel.* Its major components are identified in Figure 3–7. The hydraulic shovel digs with a combination of crowding force and breakout (or prying) force as illustrated in Figure 3–8. Crowding force is generated by the stick cylinder and acts at the bucket edge on a tangent to the arc of the radius from point *A*. Breakout force is generated by the bucket cylinder and acts at the bucket edge on a tangent to the arc of the radius through point *B*. After the bucket has penetrated and filled with material, it is rolled up to reduce spillage during the swing cycle.

Both front-dump and bottom-dump buckets are available for hydraulic shovels. Bottom-dump buckets are more versatile, provide greater reach and dump clearance, and produce less spillage. However, they are heavier than front-dump buckets of equal capacity, resulting in a lower bucket capacity for equal bucket weight. Hence front-dump buckets usually have a slight production advantage. In addition, front-dump buckets cost less and require less maintenance.

Although the shovel has a limited ability to dig below track level, it is most efficient when digging above track level. Other excavators (such as the hydraulic excavator and dragline) are better suited than the shovel for excavating below ground level. Since the shovel starts its most efficient digging cycle at ground level, it can form its own roadway as it advances—an important advantage. The shovel is also able to shape the sides of its cut

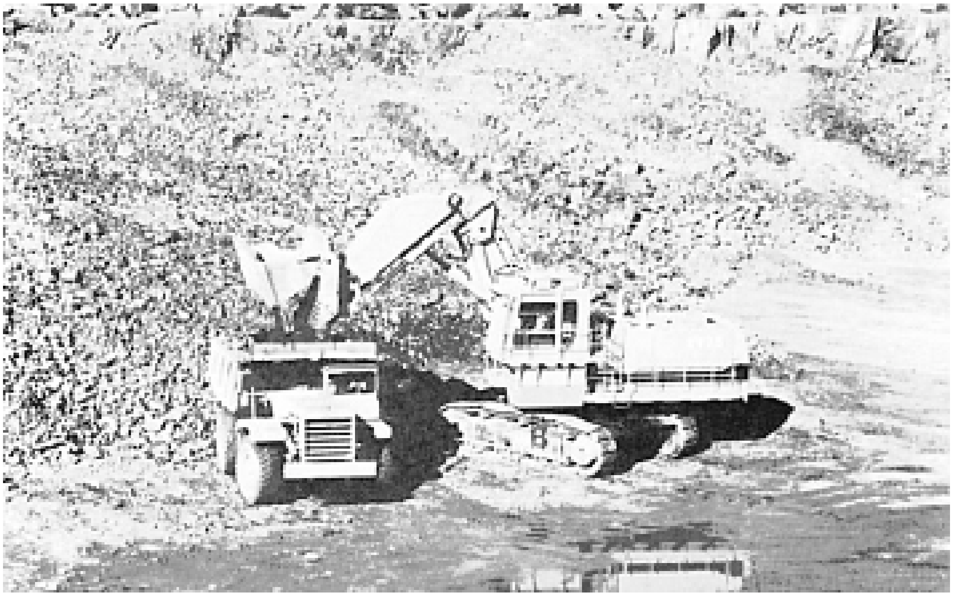


Figure 3–6 Hydraulic shovel. (Courtesy of Kobelco Construction Machinery America LLC)

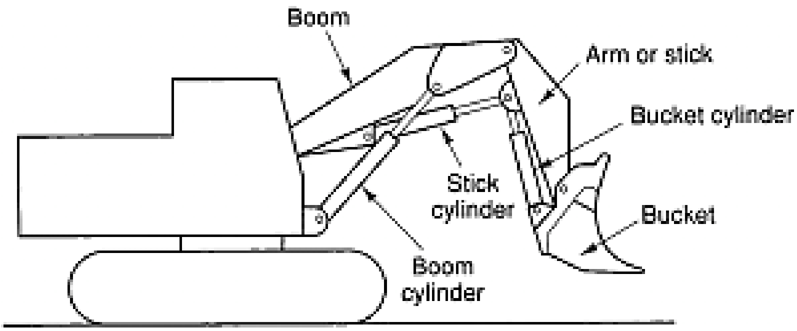


Figure 3–7 Components of a hydraulic shovel.

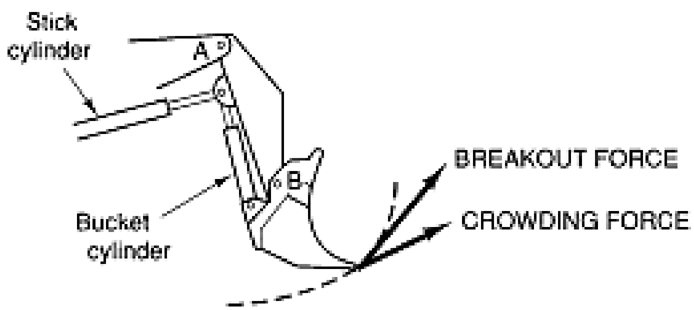


Figure 3–8 Digging action of a hydraulic shovel.

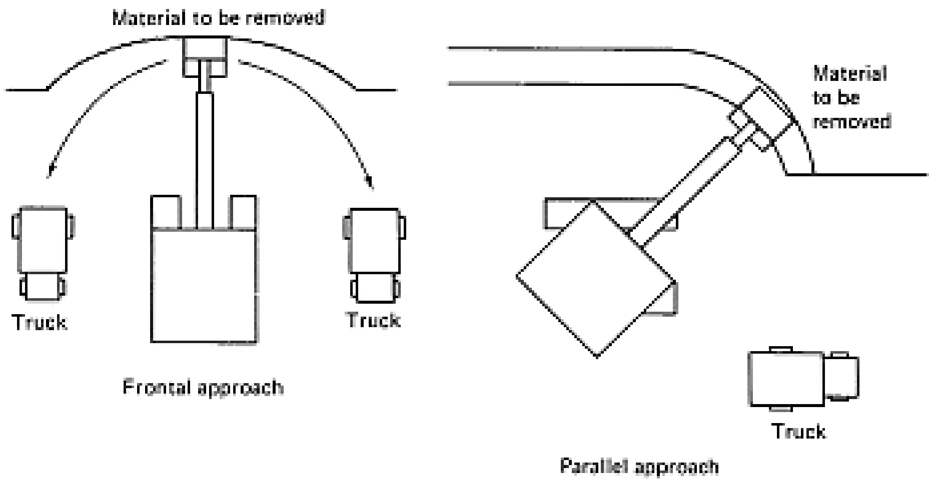


Figure 3–9 Shovel approach methods.

and to dress slopes when required. Material dug by the shovel can be loaded into haul units, dumped onto spoil banks, or sidecast into low areas.

The shovel should have a vertical face to dig against for most effective digging. This surface, known as the *digging face,* is easily formed when excavating a bank or hillside. When the material to be excavated is located below ground level, the shovel must dig a ramp down into the material until a digging face of suitable height is created. This process is known as *ramping down.* Once a suitable digging face has been obtained, the cut is typically developed by using one of the two basic methods of attack (or a variation of these) illustrated in Figure 3–9. The frontal approach allows the most effective digging position of the shovel to be used, since the shovel can exert the greatest digging force in this position. This is an important consideration in digging hard materials. Trucks can be located on either or both sides of the shovel with a minimum swing, usually no greater than 90°. The parallel approach permits fast move-up of the shovel as the digging face advances, and it permits a good traffic flow for hauling units. This approach is often used for highway cuts and whenever space is limited.

Production Estimating

Production for hydraulic shovels may be estimated using Equation 3–2 together with Table 3–6, which has been prepared from manufacturers' data.

$$\text{Production (LCY/h) or (LCM/h)} = C \times S \times V \times B \times E \qquad \textbf{(3–2)}$$

where C = cycles/h (Table 3–6)
S = swing factor (Table 3–6)
V = heaped bucket volume (LCY or LCM)
B = bucket fill factor (Table 3–2)
E = job efficiency

Table 3–6 Standard cycles per hour for hydraulic shovels

	Machine Size					
	Small Under 5 yd (3.8 m^3)		*Medium 5–10 yd (3.8–7.6 m^3)*		*Large Over 10 yd (7.6 m^3)*	
Material	**Bottom Dump**	**Front Dump**	**Bottom Dump**	**Front Dump**	**Bottom Dump**	**Front Dump**
Soft (sand, gravel, coal)	190	170	180	160	150	135
Average (common earth, soft clay, well-blasted rock)	170	150	160	145	145	130
Hard (tough clay, poorly blasted rock)	150	135	140	130	135	125

Adjustment for Swing Angle

	Angle of Swing (deg)					
	45	**60**	**75**	**90**	**120**	**180**
Adjustment factor	1.16	1.10	1.05	1.00	0.94	0.83

EXAMPLE 3–3

Find the expected production in loose cubic yards (LCM) per hour of a 3-yd (2.3-m^3) hydraulic shovel equipped with a front-dump bucket. The material is common earth with a bucket fill factor of 1.0. The average angle of swing is 75° and job efficiency is 0.80.

SOLUTION

$$\text{Standard cycles} = 150/60 \text{ min (Table 3–6)}$$
$$\text{Swing factor} = 1.05 \text{ (Table 3–6)}$$
$$\text{Bucket volume} = 3.0 \text{ LCY } (2.3 \text{ LCM}^3)$$
$$\text{Bucket fill factor} = 1.0$$
$$\text{Job efficiency} = 0.80$$
$$\text{Production} = 150 \times 1.05 \times 3.0 \times 1.0 \times 0.80 = 378 \text{ LCY/h}$$
$$[= 150 \times 1.05 \times 2.3 \quad 1.0 \times 0.80 = 290 \text{ LCM/h}]$$

For cable-operated shovels, the PCSA Bureau of CIMA has developed production tables that are widely used by the construction industry.

Job Management

The two major factors controlling shovel production are the swing angle and lost time during the production cycle. Therefore, the angle of swing between digging and dumping positions should always be kept to a minimum. Haul units must be positioned to minimize the time lost as units enter and leave the loading position. When only a single loading position is available, the shovel operator should utilize the time between the departure of one haul unit and the arrival of the next to move up to the digging face and to smooth the excavation area. The floor of the cut should be kept smooth to provide an even footing for the shovel and to facilitate movement in the cut area. The shovel should be moved up frequently to keep it at an optimum distance from the working face. Keeping dipper teeth sharp will also increase production.

3–4 DRAGLINES

Operation and Employment

The *dragline* is a very versatile machine that has the longest reach for digging and dumping of any member of the crane-shovel family. It can dig from above machine level to significant depths in soft to medium-hard material. The components of a dragline are shown in Figure 3–10.

Bucket teeth and weight produce digging action as the drag cable pulls the bucket across the ground surface. Digging is also controlled by the position at which the drag chain is attached to the bucket (Figure 3–11). The higher the point of attachment, the greater the angle at which the bucket enters the soil. During hoisting and swinging, material is retained

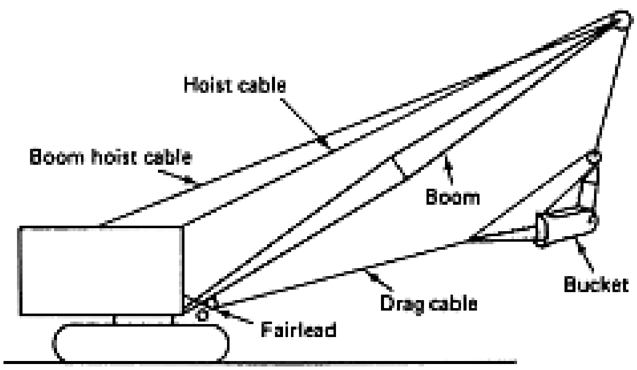


Figure 3–10 Components of a dragline.

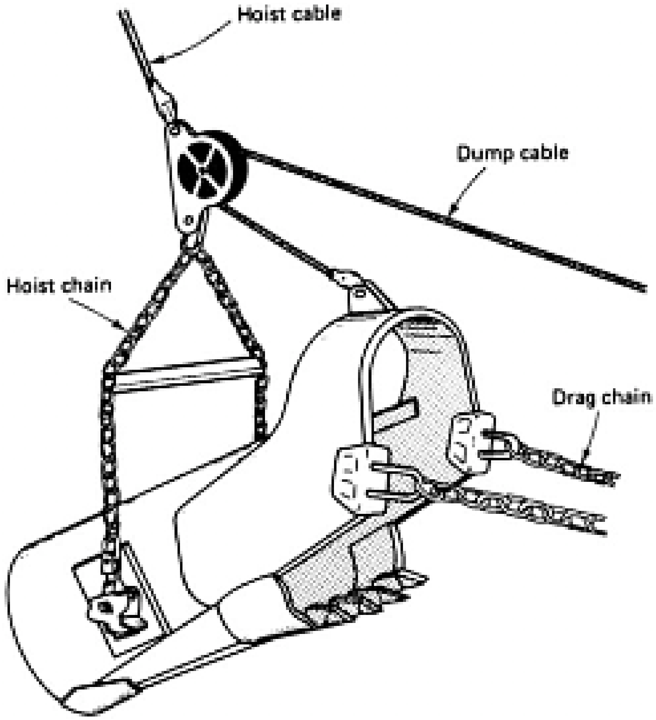


Figure 3–11 Dragline bucket.

in the bucket by tension on the dump cable. When tension on the drag cable is released, tension is removed from the dump cable, allowing the bucket to dump. Buckets are available in a wide range of sizes and weights, solid and perforated. Also available are archless buckets which eliminate the front cross-member connecting the bucket sides to provide easier flow of material into and out of the bucket.

While the dragline is a very versatile excavator, it does not have the positive digging action or lateral control of the shovel. Hence the bucket may bounce or move sideways during hard digging. Also, more spillage must be expected in loading operations than would occur with a shovel. While a skilled dragline operator can overcome many of these limitations, the size of haul units used for dragline loading should be greater than that of those used with a similar-size shovel. The maximum bucket size to be used on a dragline depends on machine power, boom length, and material weight. Therefore, use the dragline capacity chart provided by the manufacturer instead of the machine's lifting capacity chart to determine maximum allowable bucket size.

Production Estimating

The Association of Equipment Manufacturers [formerly the Construction Industry Manufacturers Association (CIMA)], through its PCSA Bureau, has made studies of cable-operated dragline operations and has developed production tables that are widely used by the construction industry. Tables 3–7 to 3–9 are based on PCSA data. Note, however, that these tables are applicable only to diesel-powered, cable-operated draglines.

To estimate dragline production using the tables, determine the ideal output of the dragline for the machine size and material (Table 3–7), then adjust this figure by multiplying it by a swing-depth factor (Table 3–9) and a job efficiency factor, as shown in Equation 3–3. Notice the conditions applicable to Table 3–7 given in the table footnote.

$$\text{Expected production} = \text{Ideal output} \times \text{Swing-depth factor} \times \text{Efficiency} \quad \textbf{(3–3)}$$

To use Table 3–9 it is first necessary to determine the optimum depth of cut for the machine and material involved from Table 3–8. Next, divide the actual depth of cut by the optimum depth and express the result as a percentage. The appropriate swing-depth factor is then obtained from Table 3–9, interpolating as necessary. The method of calculating expected hourly production is illustrated in Example 3–4.

EXAMPLE 3–4

Determine the expected dragline production in loose cubic yards (LCM) per hour based on the following information.

Dragline size = 2 cu yd (1.53 m^3)
Swing angle = 120°
Average depth of cut = 7.9 ft (2.4 m)
Material = common earth
Job efficiency = 50 min/h
Soil swell = 25%

SOLUTION

Ideal output = 230 BCY/h (176 BCM/h) (Table 3–7)
Optimum depth of cut = 9.9 ft (3.0 m) (Table 3–8)
Actual depth/optimum depth = 7.9/9.9 × 100 = 80%
[= 2.4/3.0 × 100 = 80%]
Swing-depth factor = 0.90 (Table 3–9)
Efficiency factor = 50/60 = 0.833
Volume change factor = 1 + 0.25 = 1.25
Estimated production = 230 × 0.90 × 0.833 × 1.25 = 216 LCY/h
[= 176 × 0.90 × 0.833 × 1.25 = 165 LCM/h]

Table 3–7 Ideal dragline output—short boom [BCY/h (BCM/h)]*. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)

	Bucket Size [cu yd (m^3)]										
Type of Material	***$\frac{3}{4}$ (0.57)***	***1 (0.75)***	***$1\frac{1}{4}$ (0.94)***	***$1\frac{1}{2}$ (1.13)***	***$1\frac{3}{4}$ (1.32)***	***2 (1.53)***	***$2\frac{1}{2}$ (1.87)***	***3 (2.29)***	***$3\frac{1}{2}$ (2.62)***	***4 (3.06)***	***5 (3.82)***
Light moist clay	130	160	195	220	245	265	305	350	390	465	540
or loam	(99)	(122)	(149)	(168)	(187)	(203)	(233)	(268)	(298)	(356)	(413)
Sand and gravel	125	155	185	210	235	255	295	340	380	455	530
	(96)	(119)	(141)	(161)	(180)	(195)	(226)	(260)	(291)	(348)	(405)
Common earth	105	135	165	190	210	230	265	305	340	375	445
	(80)	(103)	(126)	(145)	(161)	(176)	(203)	(233)	(260)	(287)	(340)
Tough clay	90	110	135	160	180	195	230	270	305	340	410
	(69)	(84)	(103)	(122)	(138)	(149)	(176)	(206)	(233)	(260)	(313)
Wet, sticky clay	55	75	95	110	130	145	175	210	240	270	330
	(42)	(57)	(73)	(84)	(99)	(111)	(134)	(161)	(183)	(206)	(252)

*Based on 100% efficiency, 90° swing, optimum depth of cut, material loaded into haul units at grade level.

Table 3–8 Optimum depth of cut for short boom. (This is a modification of data published in *Technical Bulletin No. 4,* Power Crane and Shovel Association, Bureau of CIMA, 1968.)

	Bucket Size [cu yd (m^3)]										
Type of Material	***$\frac{3}{4}$ (0.57)***	***1 (0.75)***	***$1\frac{1}{4}$ (0.94)***	***$1\frac{1}{2}$ (1.13)***	***$1\frac{3}{4}$ (1.32)***	***2 (1.53)***	***$2\frac{1}{2}$ (1.87)***	***3 (2.29)***	***$3\frac{1}{2}$ (2.62)***	***4 (3.06)***	***5 (3.82)***
Light moist clay, loam, sand, and gravel	6.0 (1.8)	6.6 (2.0)	7.0 (2.1)	7.4 (2.2)	7.7 (2.3)	8.0 (2.4)	8.5 (2.6)	9.0 (2.7)	9.5 (2.9)	10.0 (3.0)	11.0 (3.3)
Common earth	7.4 (2.3)	8.0 (2.4)	8.5 (2.6)	9.0 (2.7)	9.5 (2.9)	9.9 (3.0)	10.5 (3.2)	11.0 (3.3)	11.5 (3.5)	12.0 (3.7)	13.0 (4.0)
Wet, sticky clay	8.7 (2.7)	9.3 (2.8)	10.0 (3.0)	10.7 (3.2)	11.3 (3.4)	11.8 (3.6)	12.3 (3.7)	12.8 (3.9)	13.3 (4.1)	13.8 (4.2)	14.3 (4.4)

Table 3–9 Swing-depth factor for draglines. (This is a modification of data published in *Technical Bulletin No. 4,* Power Crane and Shovel Association, Bureau of CIMA, 1968.)

Depth of Cut (% of Optimum)	Angle of Swing (deg)							
	30	*45*	*60*	*75*	*90*	*120*	*150*	*180*
20	1.06	0.99	0.94	0.90	0.87	0.81	0.75	0.70
40	1.17	1.08	1.02	0.97	0.93	0.85	0.78	0.72
60	1.25	1.13	1.06	1.01	0.97	0.88	0.80	0.74
80	1.29	1.17	1.09	1.04	0.99	0.90	0.82	0.76
100	1.32	1.19	1.11	1.05	1.00	0.91	0.83	0.77
120	1.29	1.17	1.09	1.03	0.98	0.90	0.82	0.76
140	1.25	1.14	1.06	1.00	0.96	0.88	0.81	0.75
160	1.20	1.10	1.02	0.97	0.93	0.85	0.79	0.73
180	1.15	1.05	0.98	0.94	0.90	0.82	0.76	0.71
200	1.10	1.00	0.94	0.90	0.87	0.79	0.73	0.69

Job Management

Trial operations may be necessary to select the boom length, boom angle, bucket size and weight, and the attachment position of the drag chain that yield maximum production. As in shovel operation, maximum production is obtained with a minimum swing angle. In general, the lightest bucket capable of satisfactory digging should be used, since this increases the allowable bucket size and reduces cycle time. It has been found that the most efficient digging area is located within 15° forward and back of a vertical line through the boom point, as illustrated in Figure 3–12. Special bucket hitches are available which shorten the drag distance necessary to obtain a full bucket load. Deep cuts should be excavated in layers whose thickness is as close to the optimum depth of cut as possible.

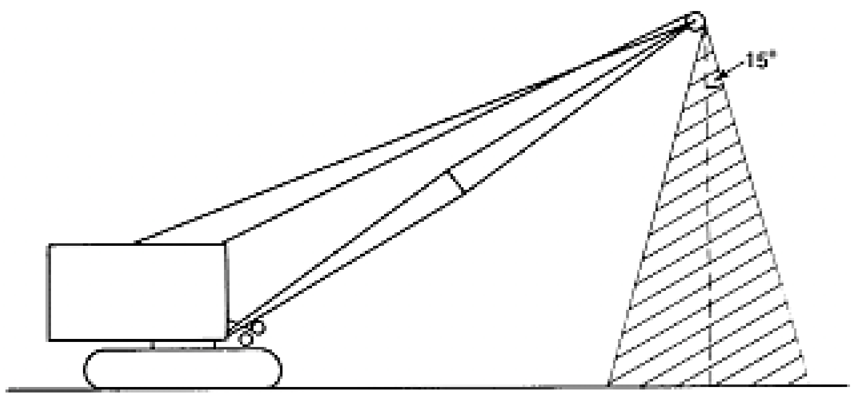


Figure 3–12 Most efficient digging area for a dragline.

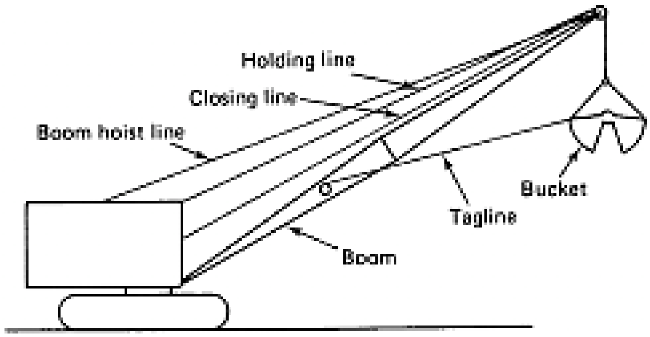


Figure 3–13 Components of a clamshell.

3–5 CLAMSHELLS

When the crane-shovel is equipped with a crane boom and clamshell bucket, it becomes an excavator known as a *clamshell.* The clamshell is capable of excavating to great depths but lacks the positive digging action and precise lateral control of the shovel and backhoe. Clamshells are commonly used for excavating vertical shafts and footings, unloading bulk materials from rail cars and ships, and moving bulk material from stockpiles to bins, hoppers, or haul units. The components of a cable-operated clamshell are identified in Figure 3–13. Clamshell attachments are also available for the hydraulic excavator.

A clamshell bucket is illustrated in Figure 3–14. Notice that the bucket halves are forced together by the action of the closing line against the sheaves. When the closing line is released, the counterweights cause the bucket halves to open as the bucket is held by the holding line. Bucket penetration depends on bucket weight assisted by the bucket teeth. Therefore, buckets are available in light, medium, and heavy weights, with and without teeth. Heavy buckets are suitable for digging medium soils. Medium buckets are used for general-purpose work, including the excavation of loose soils. Light buckets are used for handling bulk materials such as sand and gravel.

The orange peel bucket illustrated in Figure 3–15 is principally utilized for underwater excavation and for rock placement. Because of its circular shape, it is also well suited to excavating piers and shafts. It operates on the same principle as does the clamshell.

Production Estimating

No standard production tables are available for the clamshell. Thus production estimation should be based on the use of Equation 2–1. The procedure is illustrated in Example 3–5.

EXAMPLE 3–5

Estimate the production in loose cubic yards per hour for a medium-weight clamshell excavating loose earth. Heaped bucket capacity is 1 cu yd (0.75 m^3). The soil is common earth

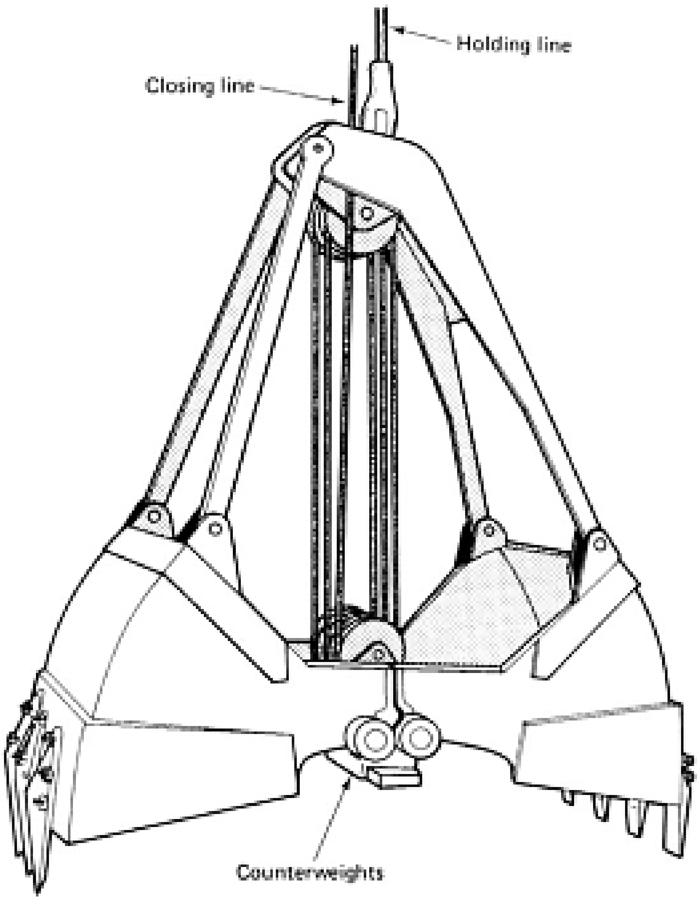


Figure 3–14 Clamshell bucket.

with a bucket fill factor of 0.95. Estimated cycle time is 40 s. Job efficiency is estimated at 50 min/h.

SOLUTION

$$\text{Production} = \frac{3600}{40} \times 1 \times 0.95 \times \frac{50}{60} = 71 \text{ LCY/h}$$

$$B = \frac{3600}{40} \times 0.75 \times 0.95 \times \frac{50}{60} = 53 \text{ LCM/h}R$$

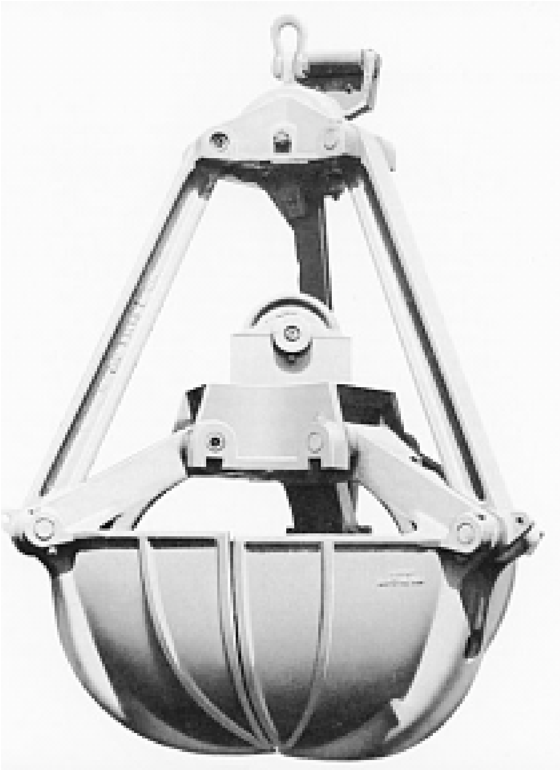


Figure 3–15 Orange peel bucket. (Courtesy of ESCO Corporation)

Job Management

The maximum allowable load (bucket weight plus soil weight) on a clamshell should be obtained from the manufacturer's clamshell loading chart for continuous operation. If a clamshell loading chart is not available, limit the load to 80% of the safe lifting capacity given by the crane capacity chart for rubber-tired equipment or 90% for crawler-mounted equipment. Since the machine load includes the weight of the bucket as well as its load, use of the lightest bucket capable of digging the material will enable a larger bucket to be used and will usually increase production. Tests may be necessary to determine the size of bucket that yields maximum production in a particular situation. Cycle time is reduced by organizing the job so that the dumping radius is the same as the digging radius. Keep the machine level to avoid swinging uphill or downhill. Nonlevel swinging is hard on the machine and usually increases cycle time.

3–6 TRENCHING AND TRENCHLESS TECHNOLOGY

The use of backhoes and other excavators for digging trenches was discussed earlier in this chapter. In addition, there is a growing demand for methods of installing utility systems below the ground with minimum open excavation. Some methods available for achieving this goal include specialized trenching machines and plows as well as trenchless technology (also called trenchless excavation). Safety considerations in trenching operations are discussed in Section 10–6.

Figure 3–16 Chain trencher. (© Vermeer Manufacturing Company, All Rights Reserved)

Trenching Machines and Plows

Some of the types of trenching machines available include chain trenchers, ladder trenchers, and bucket wheel trenchers. Figure 3–16 shows a large chain trencher capable of digging 14- to 36-in.-(356–914-mm-) wide vertical-sided trenches to a depth of 10 ft (3.1 m). Ladder trenchers are similar to chain trenchers but are larger. They are capable of digging trenches up to 10 ft (3.1 m) wide and 25 ft (7.6 m) deep. Bucket wheel trenchers use a revolving bucket wheel to cut a trench up to 5 ft (1.5 m) wide and 9 ft (2.7 m) deep.

Plows can be used to cut a narrow trench and simultaneously insert a small diameter cable or pipeline in most soils. Vibratory plows such as those shown in Figure 3–17 deliver a more powerful cutting action than static plows and can be used to insert utility lines in hard soil or soft rock.

Figure 3–17 Hydrostatic vibratory plow. (Courtesy of Vermeer Manufacturing Company, All Rights Reserved)

Trenchless Technology

While a number of different techniques are used in trenchless technology, the principal categories include pipe jacking, horizontal earth boring, and microtunneling.

The process of *pipe jacking* (Figure 3–18) involves forcing pipe horizontally through the soil. Working from a vertical shaft, a section of pipe is carefully aligned and advanced through the soil by hydraulic jacks braced against the shaft sides. As the pipe advances, spoil is removed through the inside of the pipe. After the pipe section has advanced far enough, the hydraulic rams are retracted and another section of pipe is placed into position for installation. The process often requires workers to enter the pipe during the pipe jacking operation.

In *horizontal earth boring* a horizontal hole is created mechanically or hydraulically with the pipe to be installed serving as the casing for the hole. Some of the many installation methods used include auger boring, rod pushing (thrust boring), rotational compaction boring, impact piercing, horizontal directional drilling, and fluid boring. A track-mounted thrust boring machine with percussive hammer action is shown in Figure 3–19. Many of these technologies utilize lasers and television cameras for hole alignment and boring control. A number of types of detectors are available to locate the drill head and ensure that the desired alignment and depth are being maintained. The use of a pneumatic piercing tool to create a borehole for a utility line is illustrated in Figure 3–20. After the bore has been completed, several methods are available to place pipe into the borehole. In one method, pipe

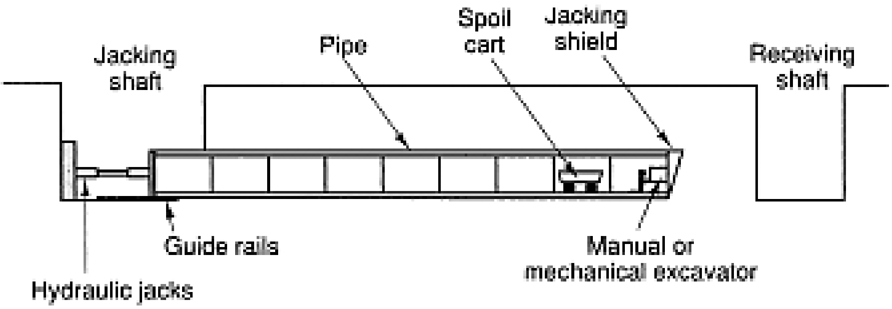


Figure 3–18 Installing a utility line by pipe jacking.

Figure 3–19 Grundodrill & Thrust boring machine with percussive action. (Courtesy of TT Technologies, Inc.)

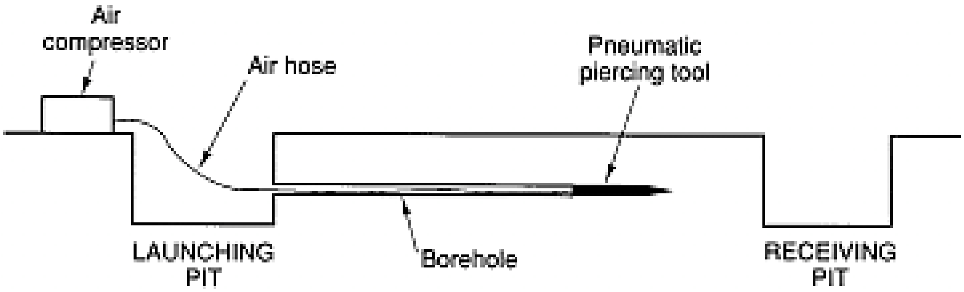


Figure 3–20 Installing a utility line by horizontal earth boring.

is pulled through the bore using the tool's air hose or a steel cable pulled by the air hose. Another method uses the piercing tool to push the pipe through the borehole. A third method uses a pipe pulling adapter attached to the piercing tool to advance the pipe at the same time as the piercing tool advances the bore.

Microtunneling or *utility tunneling* is similar to the conventional tunneling described in Section 8–1 except for the tunnel size and use. Since the tunnels are used for utility systems rather than for vehicle passage, they are normally smaller than road or rail tunnels. They differ from other trenchless methods in their use of a conventional tunnel liner instead of using the pipe itself as a liner. Small moles (see Section 8–1) are frequently used in creating such tunnels.

Repair and Rehabilitation of Pipelines

The repair and rehabilitation of existing pipelines without excavation is another form of trenchless technology. While a number of methods exist, most involve the relining of the existing pipeline or the bursting of the existing pipe while inserting a new pipe.

The relining of a pipeline is accomplished by pulling a new plastic pipe into the existing pipe or by inserting a liner into the existing pipe. When a new pipe is used to reline the pipe, the resulting pipe must be slightly smaller than the original pipe. Another relining technique involves pulling a folded liner into the existing pipe, expanding the liner, treating the liner with an epoxy, and curing it in place.

Pipe bursting (Figure 3–21) uses a high-powered hydraulic or pneumatic piercing tool equipped with a special bursting head to shatter the existing pipe and enlarge the opening. A new, often larger, pipe is then pulled into the opening by the piercing head.

3–7 CRANES

Cranes are primarily used for lifting, lowering, and transporting loads. They move loads horizontally by swinging or traveling. Most mobile cranes consist of a carrier and superstructure equipped with a boom and hook as illustrated in Figure 3–22. The current trend

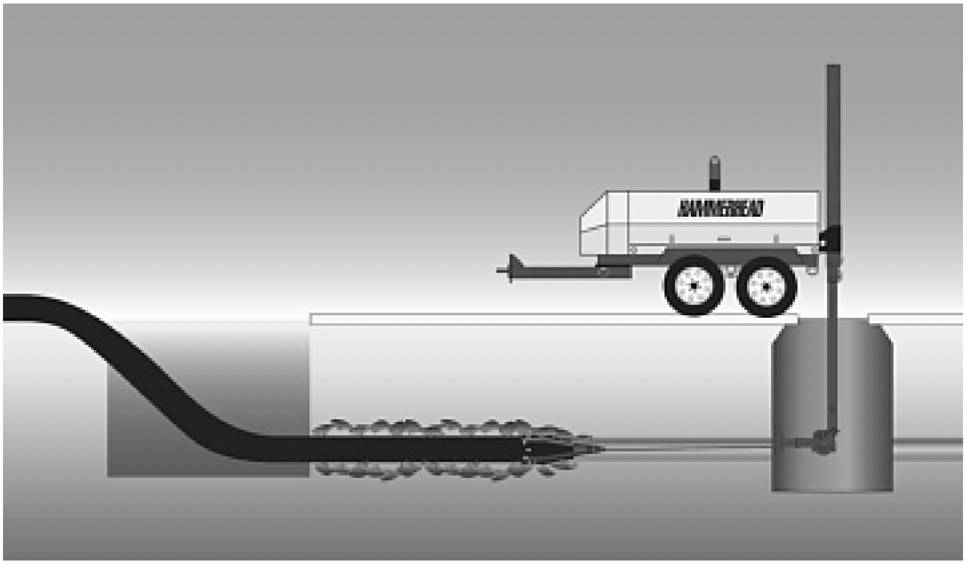
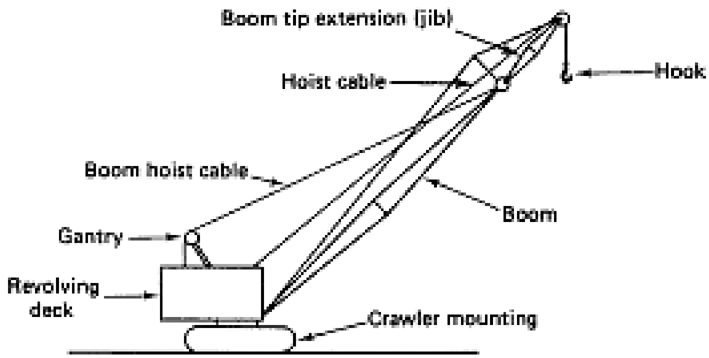


Figure 3–21 Schematic of pneumatic pipe bursting method. (Courtesy of Earth Tool Company LLC)

Figure 3–22 Components of a crane.



toward the use of hydraulically operated equipment includes hydraulically powered telescoping boom cranes. The mobile telescoping boom crane shown in Figure 3–23 is capable of lifting loads to the top of a 24-story building. Some specialized types of lifting equipment used in steel construction are described in Chapter 14.

The major factor controlling the load that may be safely lifted by a crane is its *operating radius* (horizontal distance from the center of rotation to the hook). For other than the horizontal jib tower cranes to be described later in this section, this is a function of boom length and boom angle above the horizontal. Some of the other factors influencing a crane's

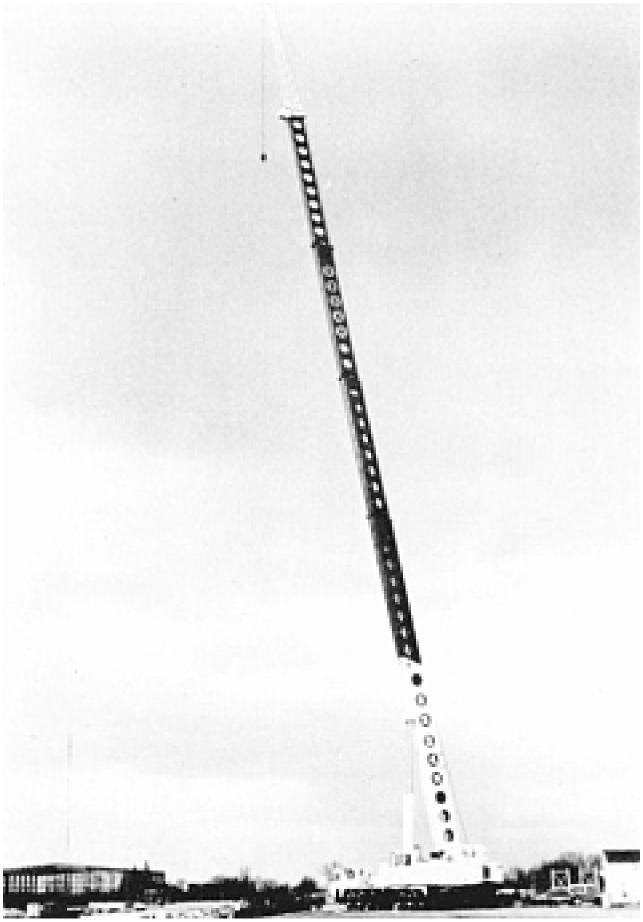


Figure 3–23 Large mobile hydraulic crane with telescoping boom. (Courtesy of Grove Worldwide)

safe lifting capacity include the position of the boom in relation to the carrier, whether or not *outriggers* (beams that widen the effective base of a crane) are used, the amount of counterweight, and the condition of the supporting surface. Safety regulations limit maximum crane load to a percentage of the *tipping load* (load that will cause the crane to actually begin to tip). Crane manufacturers provide charts, such as that shown in Figure 3–24, giving the safe load capacity of the machine under various conditions. Notice that hook blocks, slings, spreader bars, and other load-handling devices are considered part of the load and their weight must be included in the maximum safe load capacity calculation. Electronic load indicators are available that measure the actual load on the crane and provide a warning if the safe capacity is being exceeded.

A standard method of rating the capacity of mobile cranes has been adopted by the PCSA Bureau of the Association of Equipment Manufacturers [which incorporates the

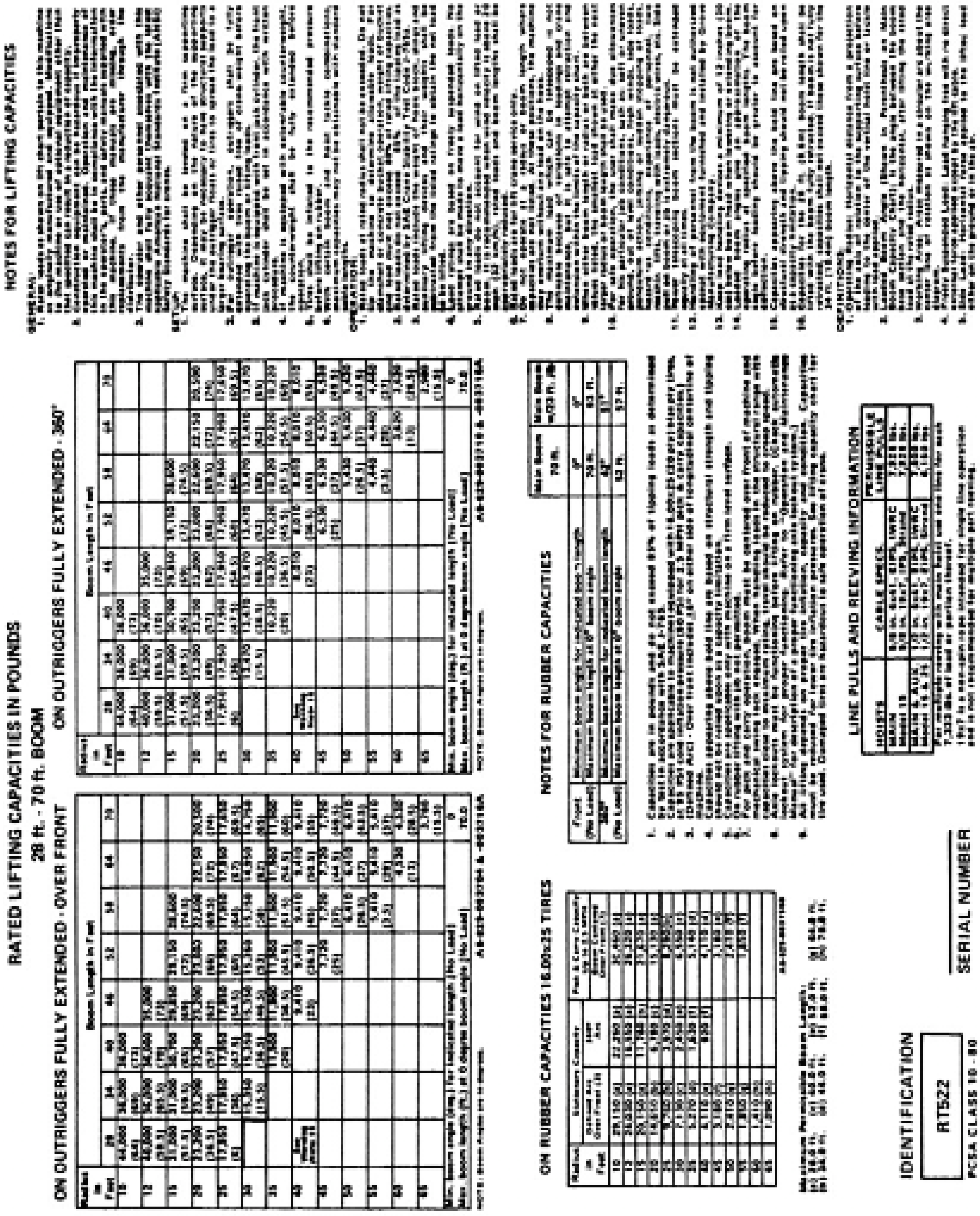


Figure 3–24 Crane load capacity chart. (Courtesy of Grove Worldwide)

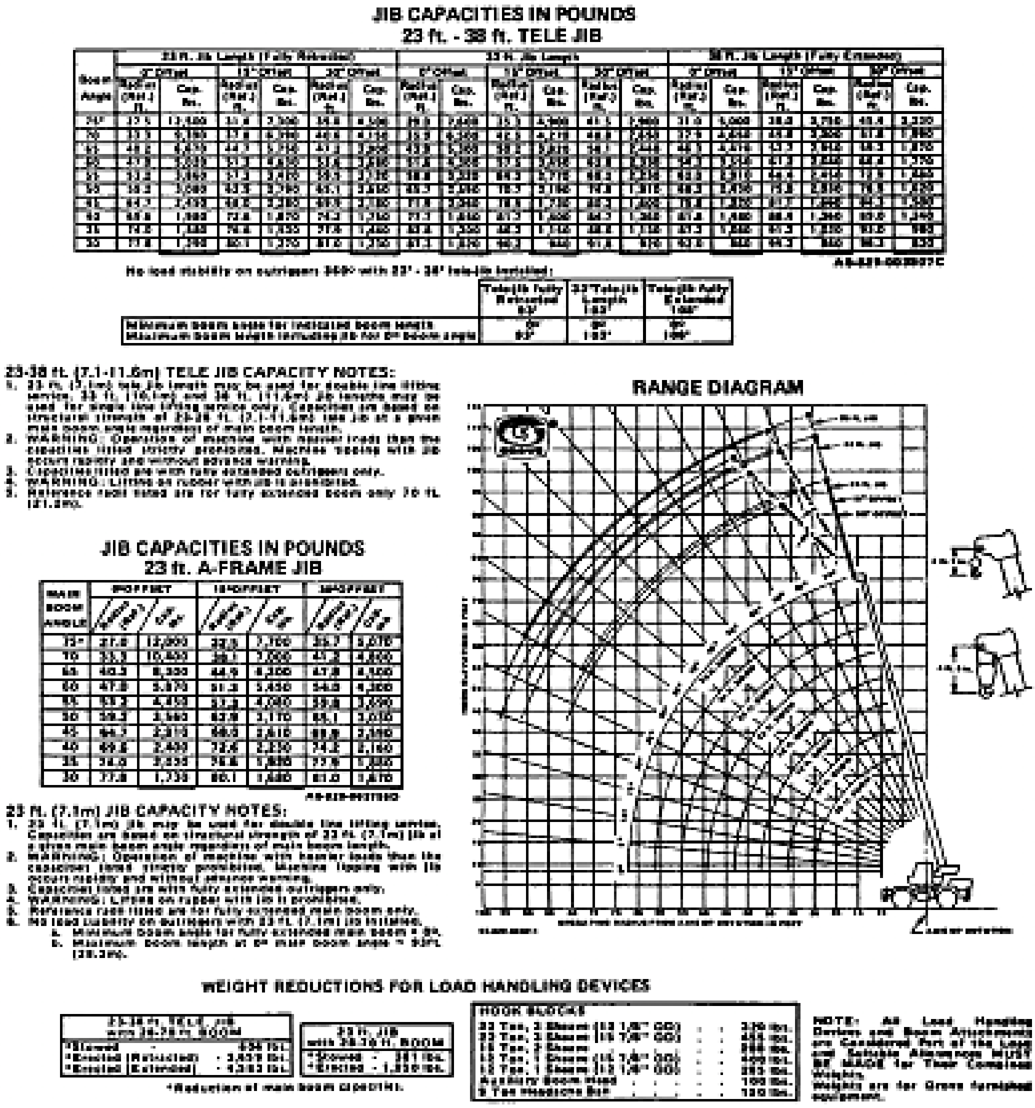


Figure 3–24 (continued)

former Construction Industry Manufacturers Association (CIMA)]. Under this system, a nominal capacity rating is assigned which indicates the safe load capacity (with outriggers set) for a specified operating radius [usually 12 ft (3.6 m) in the direction of least stability]. The PCSA class number following the nominal rating consists of two number symbols. The first number indicates the operating radius for the nominal capacity. The second number gives the rated load in hundreds of pounds at a 40-ft (12.2-m) operating radius using a 50-ft (15.2-m) boom. Thus the crane whose capacity chart is shown in Figure 3–24

Figure 3–25 Large crawler-mounted lattice-boom mobile crane. (Courtesy of Manitowoc Cranes, Inc.)

has a nominal capacity of 22 tons (19.9 t) at a 10-ft (3-m) operating radius. Therefore, this crane should be able to safely lift a load of 22 tons (19.9 t) at a radius of 10 ft (3 m) and a load of 8000 lb (3629 kg) at an operating radius of 40 ft (12.2 m) with a 50-ft (15.2-m) boom. Both capacities require outriggers to be set and apply regardless of the position of the boom relative to the carrier.

Heavy Lift Cranes

Cranes intended for lifting very heavy loads are usually crawler-mounted lattice-boom models such as that shown in Figure 3–25. The crane shown has a maximum lifting capacity of 230 tons (209 t) and a maximum lifting height of 371.5 ft (113.3 m).

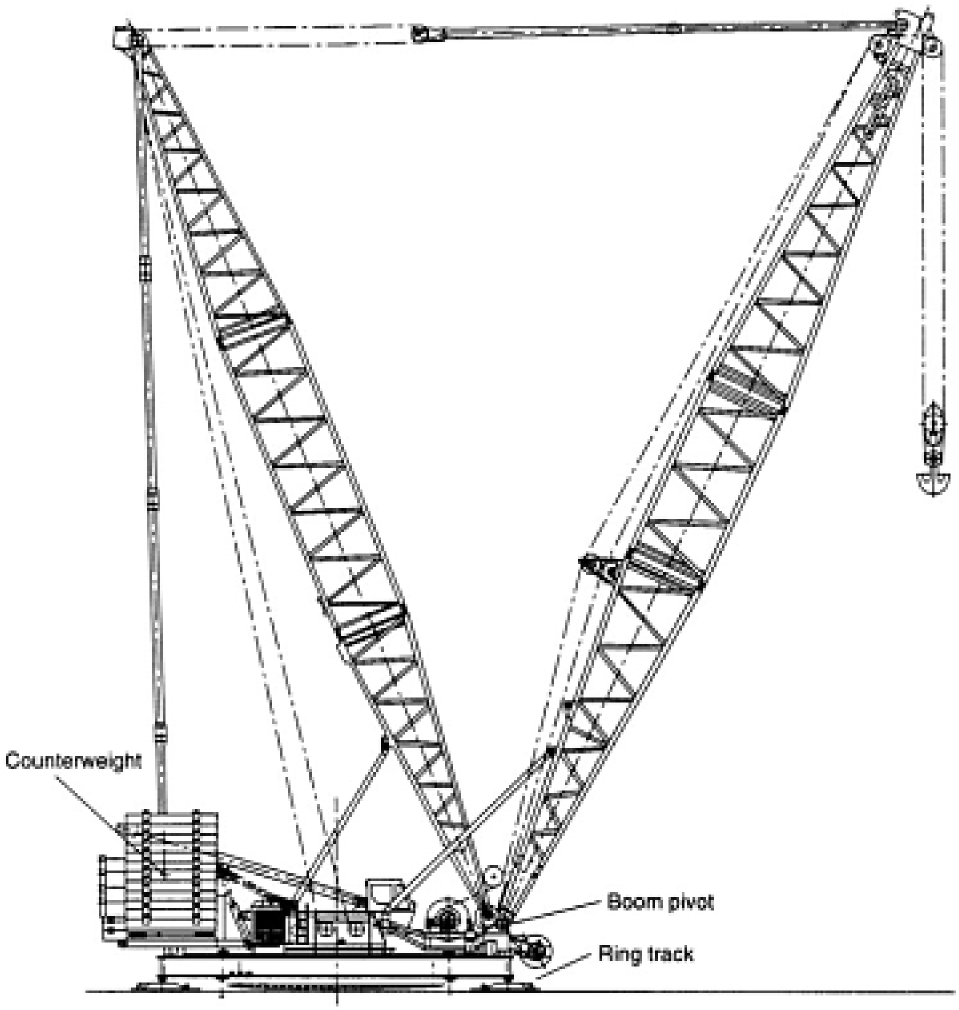


Figure 3–26 Crane with ring attachment. (Courtesy of Manitowoc Cranes Group)

To lift even heavier loads, several cranes can be used together or the crane can be modified to allow the use of extra counterweight. When a modified counterweight is used, some method must be provided to support the counterweight when there is no load on the hook. One method of accomplishing this is to remove the crane from its mounting and support the counterweight and boom butt on a circular track called a ring mount. Such an arrangement is illustrated in Figure 3–26. Such an attachment for the crane shown in Figure 3–23 can boost the maximum capacity to 600 tons (544 t).

Figure 3–27 Tower crane on a building site. (Courtesy of Potain Tower Cranes, Inc.)

Tower Cranes

Another special type of crane is the *tower crane,* illustrated in Figure 3–27. The tower crane is widely used on building construction projects because of its wide operating radius and almost unlimited height capability. Major types of tower cranes include *horizontal jib* (or *saddle jib*) cranes, *luffing boom* cranes, and *articulated jib* cranes as illustrated in Figure 3–28.

The majority of tower cranes are of the horizontal jib type shown in Figure 3–27. The terminology for this type of crane is illustrated in Figure 3–29. However, luffing boom (inclined boom) models (see Figure 14–8) have the ability to operate in areas of restricted horizontal clearance not suitable for horizontal jib cranes with their fixed jibs and counterweights. Articulated jib cranes are able to reposition their hinged jibs to convert excess hook reach into added hook height. Thus, such cranes can be operated in either the horizontal or luffed position.

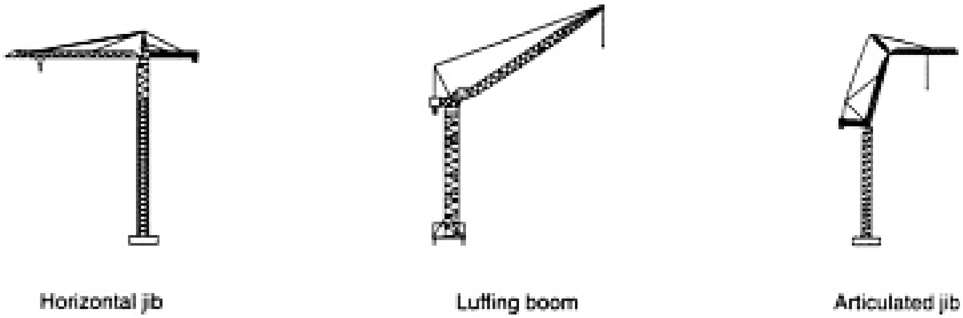


Figure 3–28 Major types of tower cranes.

Types of tower crane by method of mounting include static (fixed mount) tower cranes, rail-mounted tower cranes, mobile tower cranes, and climbing cranes. Climbing cranes are supported by completed building floors and are capable of raising themselves from floor to floor as the building is erected. Most tower cranes incorporate self-raising masts. That is, they can raise themselves section by section until the mast or tower reaches the desired height. A typical procedure is as follows (refer to Figure 3–30). The crane lifts an additional tower section together with a monorail beam and trolley (a). The monorail beam is fastened to the crane's turntable base and the new section is trolleyed close to the tower. The turntable base is unbolted from the tower. The climbing frame's hydraulic cylinders lift the climbing frame and the new section is inserted into the climbing frame using the monorail beam trolley (b). The climbing frame is then lowered and the new section is bolted to the tower and the turntable base (c).

As always, tower crane capacity depends on the operating radius, amount of counterweight, and the mounting used. The lifting capacity of a representative horizontal jib tower crane is shown in Table 3–10. The weight of the hook block has been incorporated into Table 3–10. However, the weight of all other load handling devices must be included in the calculated weight of the load.

Job Management

A number of attachments besides the basic hook are available to assist the crane in performing construction tasks. Several of these attachments are illustrated in Figure 3–31. Among these attachments, concrete buckets, slings, special hooks, and load dropping tools (weights) are most often used in construction applications. The skull cracker (wrecking ball) is a heavy weight that is hoisted by the crane and then swung or allowed to drop free to perform like a huge sledge hammer. It is used to break up pavement and for demolition work. The simplest form of pile driver, a *drop hammer,* uses a similar action to drive piles. The hammer is hoisted and then dropped onto the pile cap to hammer the pile into the soil. Pile drivers are discussed in more detail in Section 10–3.

High-voltage lines present a major safety hazard to crane operations. U.S. Occupational Safety and Health Act (OSHA) regulations prohibit a crane or its load from approaching closer

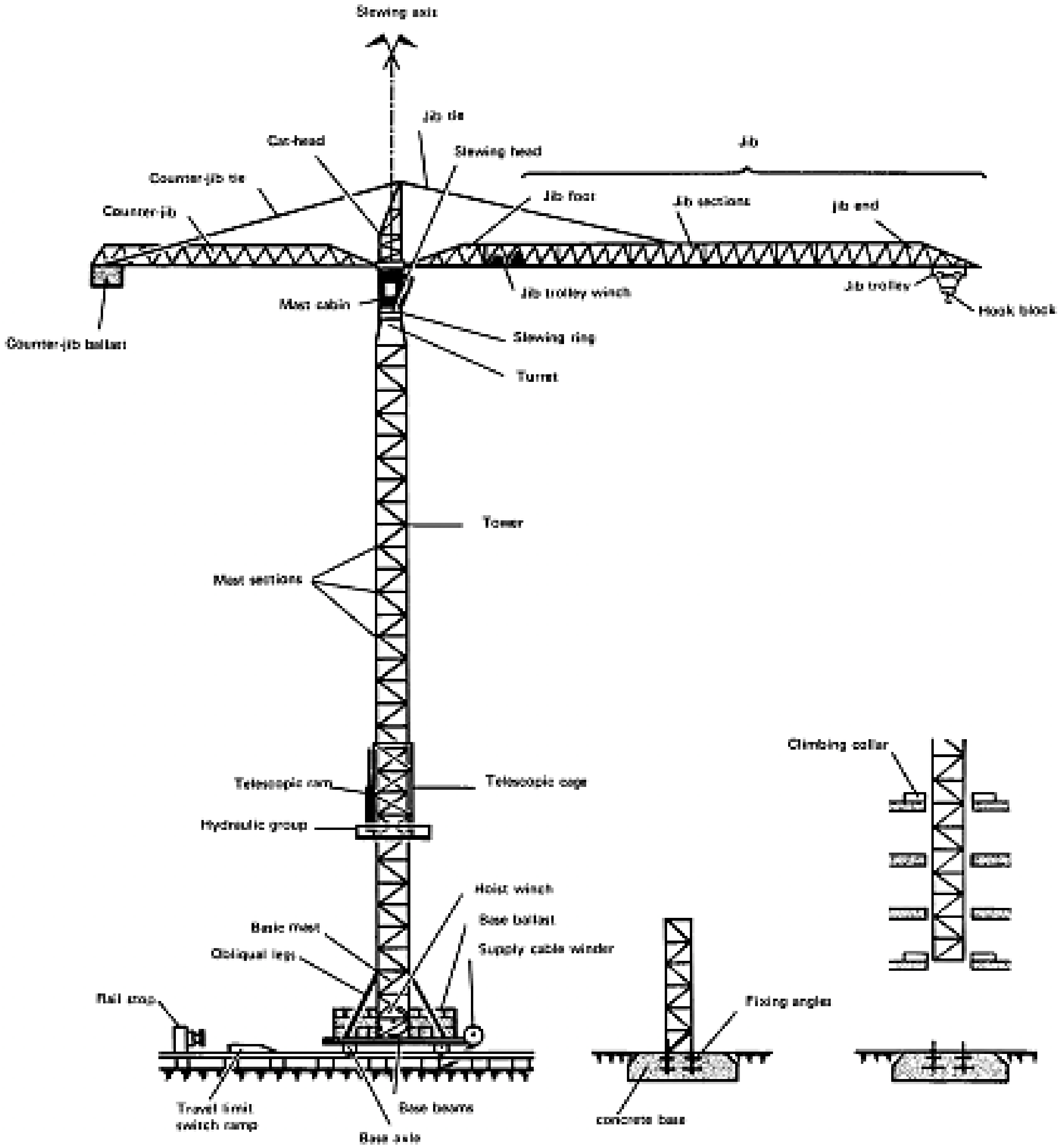


Figure 3–29 Terminology of a horizontal jib tower crane. (Courtesy of Potain Tower Cranes, Inc.)

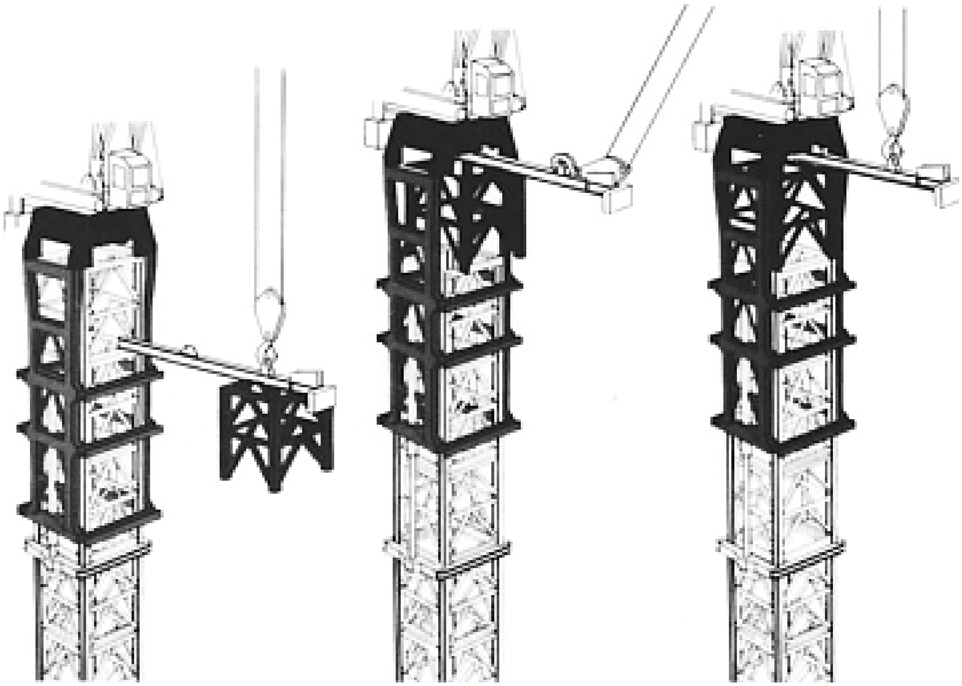


Figure 3–30 Self-raising tower crane mast. (Courtesy of FMC Construction Equipment Group)

than 10 ft (3 m) to a high-voltage line carrying 50 kV or less. An additional 0.4 in. (1 cm) must be added for each kilovolt over 50 kV. These safety clearances must be maintained unless the line is deenergized and visibly grounded at the work site or unless insulating barriers not attached to the crane are erected which physically prevent contact with the power line.

Crane accidents occur all too frequently in construction work, particularly when lifting near-capacity loads and when operating with long booms. In an effort to reduce U.S. crane accidents by ensuring that crane operators are fully qualified, a National Commission for the Certification of Crane Operators has been formed. The purpose of the commission is to establish and administer a nationwide program for the certification of crane operators. Some suggestions for safe crane operations include the following:

- Carefully set outriggers on firm supports.
- The crane base must be level. Safe crane capacity is reduced as much as 50% when the crane is out of level by only 3° and operating with a long boom at minimum radius.
- Use a communications system or hand signals when the crane operator cannot see the load at all times. Make sure that all workers involved in the operation know the hand signals to be used.

Table 3–10 Maximum capacity vs. lift radius for a tower crane [pounds (kilograms)]

Lift Radius ft (m)	Boom Length (maximum hook radius)—ft (m)					
	260 (79.2)	*230 (70.1)*	*200 (61.0)*	*170 (51.8)*	*140 (42.7)*	*110 (33.5)*
110 (33.5)	21564 (9781)	23607 (10708)	28458 (12908)	34857 (15811)	39680 (18000)	39680 (18000)
120 (36.6)	19584 (8883)	21465 (9737)	25938 (11765)	31842 (14444)	38097 (17281)	
130 (39.6)	17802 (8075)	19548 (8867)	23652 (10729)	29124 (13211)	34920 (15840)	
140 (42.7)	16380 (7430)	18018 (8173)	21861 (9916)	26982 (12239)		
150 (45.7)	15057 (6830)	16596 (7528)	20196 (9161)	24984 (11333)		
160 (48.8)	13699 (6214)	15143 (6869)	18534 (8407)	24705 (11206)		
170 (51.8)	12654 (5740)	14012 (6356)	17214 (7808)	23037 (10450)		
180 (54.9)	11818 (5361)	13119 (5951)	16160 (7330)			
190 (57.9)	10468 (4748)	11666 (5292)	14450 (6555)			
200 (61.0)	9700 (4400)	10811 (4904)	12440 (5643)			
210 (64.0)	9092 (4124)	10156 (4607)				
220 (67.1)	8208 (3723)	9215 (4180)				
260 (79.2)	7334 (3327)					

Minimum lift radius = 12.0 ft (3.6 m)

- Provide *tag lines* (restraining lines) when there is any danger caused by swinging loads.
- Ensure that crane operators are well trained and know the capability of their machines.
- Check safe-lifting-capacity charts for the entire range of planned swing before starting a lift. Use a load indicator if possible.

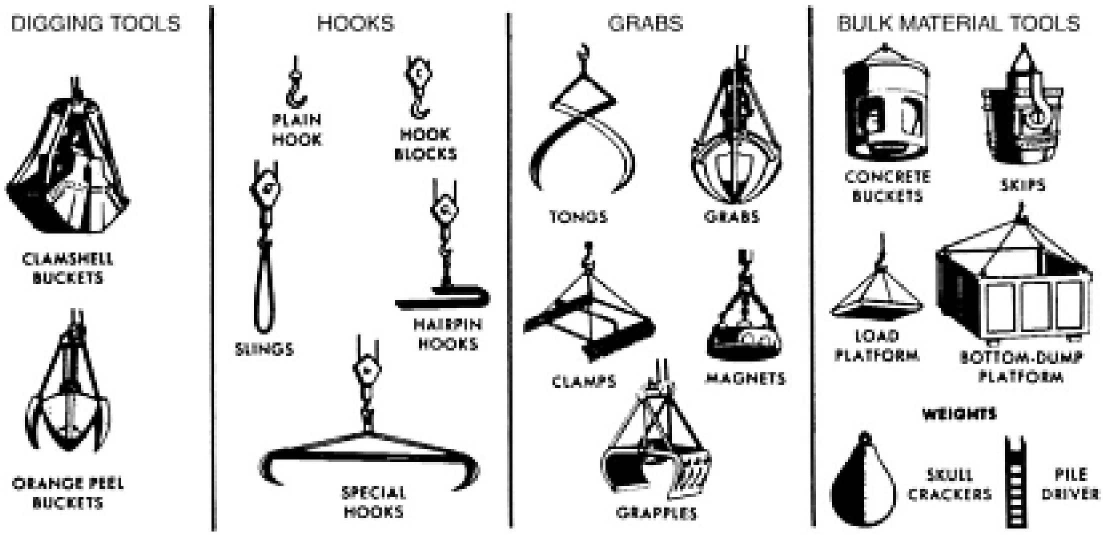


Figure 3–31 Crane boom attachments. [Permission to reproduce this material has been granted by the Power Crane & Shovel Assn. (PCSA), a bureau of the Construction Industry Manufacturers Assn. (CIMA). Neither PCSA nor CIMA can assume responsibility for the accuracy of the reproduction.]

PROBLEMS

1. A 2-yd (1.53-m^3) dragline is being used to excavate a canal in common earth. The average swing angle is 70°, the average depth of cut is 8.9 ft (2.7 m), and job efficiency is 50 min/h. Estimate the dragline's hourly production in loose measure.
2. A 3.5-yd (2.68 m^3, heaped) hydraulic shovel with a bottom dump bucket is excavating tough clay. The swing angle is 120°, and job efficiency is 75%. Estimate the shovel's hourly production in bank measure.
3. How can a contractor verify that the desired alignment and depth are being maintained while performing horizontal earth boring?
4. Estimate the time required to load 400 cu yd (306 m^3) of gravel into trucks using a clamshell having a heaped bucket capacity of 1 cu yd (0.75 m^3). Estimated cycle time is 25s. Job efficiency is estimated to be 80%.
5. What is the maximum net load that can be safely lifted over a 360˚ swing by the crane of Figure 3–24 under the following conditions? The crane is equipped with a 23- to 38-ft telescoping jib (stowed) with a 15-ton, two-sheave hook block, the boom length is 52 ft (15.9 m), and the operating radius is 25 ft (7.6 m). What restrictions must be observed in order to safely lift this load?
6. The tower crane whose capacity chart is shown in Table 3–10 is equipped with a 260-ft (79.2-m) boom. The crane is preparing to lift a load weighing 10,000 lb (4536 kg).

The weight of slings and the spreader bar to be used is 1200 lb (544 kg). What is the maximum safe lift radius for this load?

7. A small hydraulic excavator will be used to dig a trench in hard clay (bucket fill factor = 0.80). The minimum trench size is 26 in. (0.66 m) wide by 5 ft (1.53 m) deep. The excavator bucket available is 30 in. (0.76 m) wide and has a heaped capacity of ¾ cu yd (0.57 m^3). The maximum digging depth of the excavator is 16 ft (4.9 m). The average swing angle is expected to be 85°. Estimate the hourly trench production in linear feet (meters) if job efficiency is 70%.
8. A hydraulic excavator-backhoe is excavating the basement for a building. Heaped bucket capacity is 1.5 cu yd (1.15 m^3). The material is common earth with a bucket fill factor of 0.90. Job efficiency is estimated to be 50 min/h. The machine's maximum depth of cut is 24 ft (7.3 m) and the average digging depth is 13 ft (4.0 m). Average swing angle is 90°. Estimate the hourly production in bank measure.
9. Identify the two basic approach methods available for a shovel excavating a cut. Which of these methods permit the shovel to exert the greatest digging force?
10. Write a computer program to estimate the production of a hydraulic shovel based on Equation 3–2 and Table 3–6. Input should include rated shovel size, type of material, angle of swing, heaped bucket capacity, bucket fill factor, soil load factor, and job efficiency. Output should be in bank measure if the soil load factor is input; otherwise, it should be in loose measure.

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