PEARSON NEW INTERNATIONAL EDITION

Construction Methods and Management

Stephens W. Nunnally

Eighth Edition

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INTRODUCTION

1 THE CONSTRUCTION INDUSTRY

The construction industry (including design, new and renovation construction, and the manufacture and supply of building materials and equipment) is one of the largest industries in the United States, historically accounting for about 10% of the nation's gross national product and employing some 10 million workers (references 2 and 3). Annual U.S. new construction volume has exceeded $800 billion in recent years. Because construction is an exciting, dynamic process which often provides high income for workers and contractors, it is an appealing career opportunity. However, the seasonal and sporadic nature of construction work often serves to significantly reduce the annual income of many workers. In addition, construction contracting is a very competitive business with a high rate of bankruptcy.

It is widely recognized that construction as a discipline is a combination of art and science. While understanding the technical aspects of construction is extremely important, it is also essential that construction professionals have knowledge of the business and management aspects of the profession. Close observation and participation in actual construction projects are very valuable in obtaining an understanding of the construction process as well. Thus, the author encourages those who are studying construction in an academic environment to take every opportunity to observe and participate in actual construction activities. An understanding of the topics presented in the following chapters will provide a foundation in the methods and management of construction.

While construction has traditionally been a very conservative industry, the increasing rate of technological development and growing international competition in the industry are serving to accelerate the development of new construction methods, equipment, materials, and management techniques. As a result, coming years will see an increasing need for innovative and professionally competent construction professionals.

Construction Contractors

Companies and individuals engaged in the business of construction are commonly referred to as *construction contractors* (or simply *contractors*) because they operate under a contract arrangement with the owner. Construction contractors may be classified as general contractors or specialty contractors. *General contractors* engage in a wide range of construction activities and execute most major construction projects. When they enter into a contract with an owner to provide complete construction services, they are called *prime contractors. Specialty contractors* limit their activities to one or more construction specialties, such as electrical work, plumbing, heating and ventilating, or earthmoving. Specialty contractors are often employed by a prime contractor to accomplish some specific phase of a construction project. Since the specialty contractors are operating under subcontracts between themselves and the prime contractor, the specialty contractors are referred to as *subcontractors*. Thus, the terms *subcontractor* and *prime contractor* are defined by the contract arrangement involved, not by the work classification of the contractors themselves. Thus, a specialty contractor employed by an owner to carry out a particular project might employ a general contractor to execute some phase of the project. In this situation, the specialty contractor becomes the prime contractor for the project and the general contractor becomes a subcontractor.

While the number of construction contractors in the United States has been estimated to exceed 800,000, some 60% of these firms employ three or fewer workers. Contractors employing 100 or more workers make up less than 1% of the nation's construction firms but account for about 30% of the value of work performed. The trend in recent years has been for the large construction firms to capture an increasing share of the total U.S. construction market.

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FIGURE 1. Construction of St. Louis Gateway Arch. (Copyright© American Institute of Steel Construction, Inc. Reprinted with permission. All rights reserved.)

Construction Industry Divisions

The major divisions of the construction industry consist of building construction (also called "vertical construction") and heavy construction (also called "horizontal construction"). The distribution of total U.S. construction volume for a representative year is illustrated in Figure 2. *Building construction* (Figure 3), as the name implies, involves the construction of buildings. This category may be subdivided into public and private, residential and nonresidential building construction. While building construction accounts for a majority of the total U.S. new construction market (see Figure 2), many of the largest and most spectacular projects fall in the heavy construction area. *Heavy construction* (Figure 4) includes highways, airports, railroads, bridges, canals, harbors, dams, and other major public works. Other specialty divisions of the construction industry sometimes used include industrial construction, process plant construction, marine construction, and utility construction.

FIGURE 2. Distribution of U.S. new construction volume. (Source: Bureau of the Census)

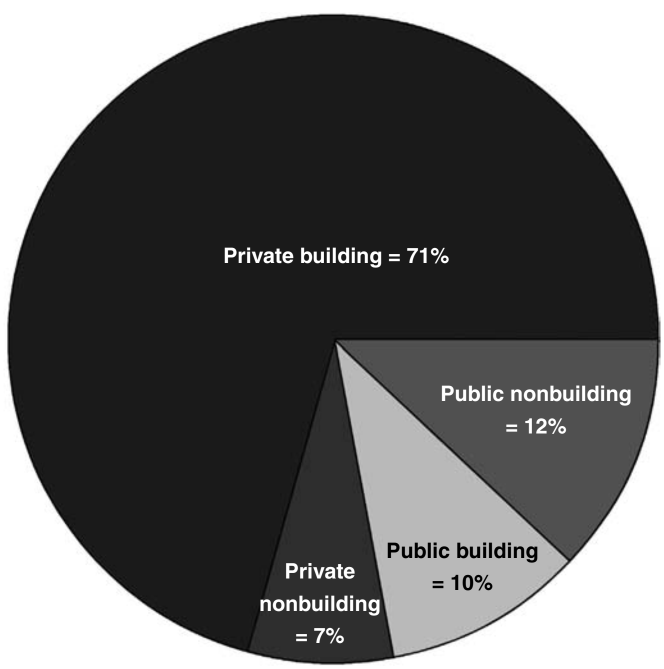

FIGURE 3. Modern building construction project.

FIGURE 4. Heavy construction project—Kennedy Space Center launch complex. (U.S. Air Force photograph)

2 THE CONSTRUCTION PROCESS

Project Development and Contract Procedures

The major steps in the construction contracting process include bid solicitation, bid preparation, bid submission, contract award, and contract administration. However, before the bidding process can take place, the owner must determine the requirements for the project and have the necessary plans, specifications, and other documents prepared. These activities make up the project development phase of construction. For major projects, steps in the project development process include the following:

- Recognizing the need for the project.
- Determining the technical and financial feasibility of the project.
- Preparing detailed plans, specifications, and cost estimates for the project.
- Obtaining approval from regulatory agencies. This involves ascertaining compliance with zoning regulations, building codes, and environmental and other regulations.

For small projects, many of these steps may be accomplished on a very informal basis. However, for large or complex projects this process may require years to complete.

How Construction Is Accomplished

The principal methods by which facilities are constructed are illustrated in Figures 5 to 9. These include the following:

- Construction employing an owner construction force.
- Owner management of construction.
- Construction by a general contractor.
- Construction using a design/build (turnkey) contract.
- Construction utilizing a construction management contract.

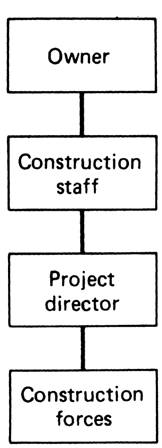

FIGURE 5. Construction employing owner construction forces.

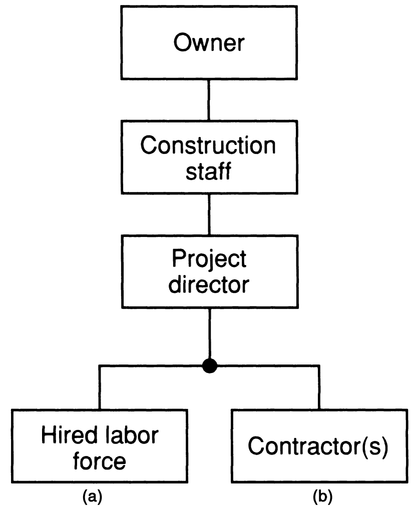

FIGURE 6. Owner-managed construction. [Either (a) or (b) or both may be employed.]

Many large industrial organizations, as well as a number of governmental agencies, possess their own construction forces. Although these forces are utilized primarily for performing repair, maintenance, and alteration work, they are often capable of undertaking new construction projects (Figure 5). More frequently, owners utilize their construction staffs to manage their new construction (Figure 6). The work may be carried out by workers hired directly by the owner (force account), by specialty contractors, or by a combination of these two methods.

Construction by a general contractor operating under a prime contract is probably the most common method of having a facility constructed (Figure 7). However, two newer methods of obtaining construction services are finding increasing use: design/build (or turnkey) construction and construction utilizing a construction management contract. Under the *design/build* or *turnkey* construction concept (Figure 8), an owner contracts with a firm to both design and build a facility meeting certain specified (usually, performance-oriented) requirements. Such contracts are frequently utilized by construction firms that specialize in a

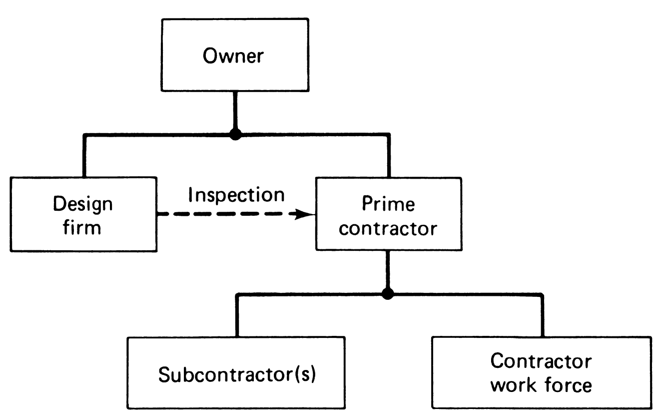

FIGURE 7. Construction by a general contractor.

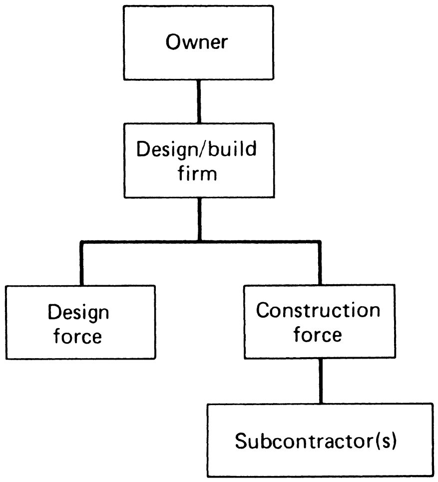

FIGURE 8. Construction employing a design/build firm.

particular type of construction and possess standard designs which they modify to suit the owner's needs. Since the same organization is both designing and building the facility, coordination problems are minimized and construction can begin before completion of final design. (Under conventional construction procedures, it is also possible to begin construction before design has been completed. In this case, the construction contract is normally on a cost reimbursement basis. This type of construction is referred to as *fast-track* construction.) The major disadvantages of the design/build concept are the difficulty of obtaining competition between suppliers and the complexity of evaluating their proposals.

Construction of a facility utilizing a *construction management contract* (Figure 9) is also somewhat different from the conventional construction procedure. Under the usual arrangement, also known as Agency Construction Management, a professional *construction manager* (CM) acts as the owner's agent to direct both the design and construction of a facility. Three separate contracts are awarded by the owner for design, construction, and construction management of the project. This arrangement offers potential savings in both time and cost compared with conventional procedures, as a result of the close coordination between design and construction. However, opponents of the method point out that the CM typically assumes little or no financial responsibility for the project and that the cost of his/her services may outweigh any savings resulting from improved coordination between design and construction. There is another, less common form of construction management contract known as Guaranteed Maximum Price Construction Management. Under this arrangement, the CM guarantees that the project cost will not exceed a specified amount. Under this procedure, which entails a certain amount of contractor risk, the construction contract is also normally held by the CM.

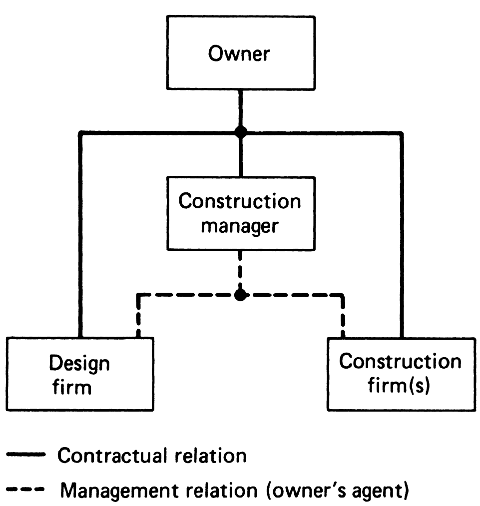

FIGURE 9. Construction utilizing a construction management contract.

3 CODES AND REGULATIONS

Projects constructed in most areas of the United States must comply with a number of governmental regulations. These include building codes, zoning regulations, environmental regulations, and contractor licensing laws, among others.

Building Codes

Building codes, which are concerned primarily with public safety, provide minimum design and construction standards for structural and fire safety. As the name implies, such codes apply only to the construction of buildings. In the United States, the Board of Fire Underwriters in 1905 published a *Recommended National Building Code,* which provided minimum standards for fire protection and structural safety. This code, later known as the *Basic/National Building Code*, published by the Building Officials and Code Administrators International, was the only nationally recognized building code for a number of years. Other major building codes later published include the *Uniform Building Code,* published by the International Conference of Building Officials, and the *Standard Building Code,* published by the Southern Building Code Congress International. In 1994 these three model code groups jointly formed the International Code Council (ICC) to publish a single set of model construction codes. Some of the International Codes since published include the *International Building Code* and the *International Residential Code* (which governs the construction of one- and two-family dwellings). A majority of the U.S. states and the District of Columbia have adopted these two building codes. The International Code Council has also published a number of other International Codes, including a plumbing code, a mechanical code, and an electrical code. However, most U.S. electrical construction is commonly governed by *NFPA 70: National Electrical Code,* published by the National Fire Protection Association under the auspices of the American National Standards Institute (ANSI).

Since the national model codes are purely advisory, a building code must be put into effect by local ordinance. While local building codes are usually based on the model codes, they often contain local modifications, which may be unnecessarily restrictive. Such restrictions, along with delays in updating local codes, result in increased building costs. Another problem associated with building codes at the local level is the quality of code administration. The lack of an adequate number of technically qualified building officials often leads to cursory inspections using a checklist approach and discourages contractors from utilizing new materials and procedures.

In most cases, a *building permit* must be obtained before construction of a building can begin. After a permit is issued, the local building department will inspect the project at designated points during construction. The scheduling of these inspections may pose problems for the contractor and often results in construction delays. When utilities are not available at the construction site, additional permits may be required for power plants, water wells, water treatment plants, sewage treatment plants or septic tanks, and similar facilities.

Zoning, Environmental, and Other Regulations

Although building codes apply only to building construction, many other regulations impact both building and heavy construction. Such regulations include zoning regulations, environmental regulations, safety regulations, labor laws, and others. Transportation construction (highways, bridges, airports, and ports) falls primarily under the jurisdiction of state transportation departments. These agencies are responsible for the design, construction, maintenance, and operation of transportation facilities. While much of the design and most construction is accomplished by private firms under contract to the state, the state transportation agency establishes design specifications, monitors design and construction, and operates and maintains the completed facilities.

Zoning regulations, which control land use, limit the size, type, and density of structures that may be erected at a particular location. Some typical zoning classifications include commercial, residential (with specified density), industrial, office, recreational, and agricultural. Zoning classifications are normally designated by a combination of letters and numbers. As an example, the R-4 zoning classification might represent residential housing with a maximum density of 4 units per acre. In order to construct a facility not conforming to the current zoning, it would be necessary to obtain a change in zoning or an administrative exception.

Environmental regulations protect the public and environment by controlling such factors as water usage, vehicular traffic, precipitation runoff, waste disposal, and preservation of beaches and wetlands. Large projects, such as new highways and airports, waste disposal facilities, major shopping centers, large industrial plants, large housing developments, and athletic centers, may require preparation and approval of an *Environmental Impact Statement* (EIS) describing and quantifying the effect the project will have on the environment. The preparation of an EIS is a complex, time-consuming, and expensive task which should be undertaken only with the assistance of a professional experienced in such matters. If municipal utility services are not available at the project site, additional permits may be required for water treatment plants, wells, sewage treatment, and similar facilities.

Safety regulations are designed to protect both construction workers and the public. In the United States, almost all industries, including construction, are governed by the Occupational Safety and Health Act of 1970 administered by the Occupational Safety and Health Administration (OSHA). However, states are permitted to adopt more stringent safety regulations if desired. Construction safety is discussed in more detail in Section 5.

The construction profession is also regulated by a number of governmental licensing and certification procedures. Communities having building departments usually require construction contractors to have their professional qualifications verified by licensing or certification. This may be done at the local level or by the state. State certification or licensing often requires satisfactory completion of a comprehensive written examination plus proof of financial capacity and verification of character. A business or occupational license is also normally required of all contractors. In addition, bonding is often required of construction contractors to further protect the public against financial loss.

4 STATE OF THE INDUSTRY

Construction Productivity

U.S. construction productivity (output per labor hour), which had shown an average annual increase of about 2% during the period after World War II until the mid-1960s, actually declined between 1965 and 1980. During the same period, inflation in construction costs rose even faster than inflation in the rest of the economy. However, indications are that construction productivity again increased substantially in the 1980s and 1990s (reference 1).

Concerned about the effects of declining construction industry productivity in the 1970s on the U.S. economy, the Business Roundtable (an organization made up of the chief executive officers of some 200 major U.S. corporations) sponsored a detailed study of the U.S. construction industry. Completed in 1982, the resulting Construction Industry Cost Effectiveness (CICE) study is probably the most comprehensive ever made of the U.S. construction industry. The study identified a number of construction industry problems and suggested improvements in the areas of project management, labor training and utilization, and governmental regulation (see references 5 and 8). It concluded that while much of the blame for industry problems should be shared by owners, contractors, labor, and government, many of the problems could be overcome by improved management of the construction effort by owners and contractors with the cooperation of the other parties. Conflicting productivity data for the period 1979 through 1998 makes it difficult to determine whether construction productivity has actually declined, remained constant, or increased since 1979 (reference 9).

Some techniques for improving construction productivity and performance are discussed in the following sections.

Reducing Construction Costs

Some of the best opportunities for construction cost savings occur in the design process even before construction begins. Some design factors that can reduce construction costs include the use of modular dimensions, grouping plumbing and other equipment to minimize piping and conduit runs, incorporating prefabricated components and assemblies, utilizing economical materials (eliminating "gold plating"), and employing new technology. Injecting constructability considerations into the design process is one of the advantages claimed for the use of the construction management contract arrangement.

Some ways in which productivity can be increased and costs minimized during construction include the following:

- Good work planning.
- Carefully selecting and training workers and managers.
- Efficiently scheduling labor, materials, and equipment.
- Properly organizing work.
- Using laborsaving techniques, such as prefabrication and preassembly.
- Minimizing rework through timely quality control.
- Preventing accidents through good safety procedures.

5 CONSTRUCTION MANAGEMENT

Elements of Construction Management

The term *construction management* may be confusing since it has several meanings. As explained earlier, it may refer to the contractual arrangement under which a firm supplies construction management services to an owner. However, in its more common use, it refers to the act of managing the construction process. The construction manager (CM), who may be a contractor, project manager, superintendent, or one of their representatives, manages the basic resources of construction. These resources include workers and subcontractors, equipment and construction plant, material, money (income, expenditure, and cash flow), and time. Skillful construction management results in project completion on time and within budget. Poor construction management practices, on the other hand, often result in one or more of the following:

- Project delays that increase labor and equipment cost and the cost of borrowed funds.
- High material costs caused by poor purchasing procedures, inefficient handling, and/or loss.
- Increased subcontractor cost and poor contractor–subcontractor relations.
- High insurance costs resulting from material and equipment loss or damage or a poor safety record.
- Low profit margin or a loss on construction volume.

Such poor management practices, if long continued, will inevitably lead to contractor failure.

While the principal objectives of every construction manager should be to complete the project on time and within budget, he or she has a number of other important responsibilities. These include safety, worker morale, public and professional relations, productivity improvement, innovation, and improvement of technology.

The scope of construction management is broad and includes such topics as construction contracts, construction methods and materials, production and cost estimating, progress and cost control, quality control, and safety. These are the problems to which the following portions of this book are addressed.

Quality Management

It has long been recognized that in all construction projects steps must be taken to ensure that the constructed project meets the requirements established by the designer in the project plans and specifications. More recently, the terms *quality management* (QM) and *quality assurance* (QA) have been adopted to include all aspects of producing and accepting a construction project which meets all required quality standards. Quality management includes such activities as specification development, process control, product acceptance, laboratory and technician certification, training, and communication. *Quality control* (QC), which is a part of the quality management process, is primarily concerned with the process control function. Since the contractor has the greatest control over the construction process, it has been found that quality control is most effective when performed by the contractor.

Regardless of the procedures established, the construction contractor is primarily responsible for construction quality. Quality assurance inspections and tests performed by an owner's representative or government agency provide little more than spot checks to verify that some particular aspect of the project meets minimum standards. Contractors should realize that the extra costs associated with rework are ultimately borne by the contractor, even on cost-type contracts. Poor quality control will result in the contractor gaining a reputation for poor work. The combined effect of increased cost and poor reputation often leads to construction company failure.

In recent years, there has been an increasing use of statistics-based methods for quality assurance, particularly in asphalt and concrete pavement construction (see reference 3). While the details of such procedures are beyond the scope of this book, the following is a brief explanation of some of the concepts involved.

Since the results of virtually all construction processes are products which vary over some statistical distribution, statistical methods can be used for the following purposes:

- Ensuring that all elements of the work have an equal chance of being included in test samples.
- Verifying that test samples taken by the contractor and by other parties come from the same population.
- Analyzing the variations in the test results of material and processes sampled.
- Establishing acceptable levels of variation in sample results.
- Developing a payment schedule which rewards or penalizes the contractor depending on the level of quality attained in the constructed product.

Safety and Health

Construction is inherently a dangerous process. Historically, the construction industry has had one of the highest accident rates among all industries. In the United States, concern over the frequency and extent of industrial accidents and health hazards led to the passage of the Occupational Safety and Health Act of 1970, which established specific safety and health requirements for virtually all industries, including construction. This act is administered by the Occupational Safety and Health Administration (OSHA). As a result, management concern has tended to focus on OSHA regulations and penalties. However, the financial impact of a poor safety record is often more serious than are OSHA penalties.

The following construction operations have been found to account for the majority of serious construction injuries:

- Concrete construction, especially construction of formwork, placing concrete into formwork, and failure of formwork during construction.
- The erection of prefabricated trusses, precast concrete elements, and structural steel.
- The construction and operation of temporary facilities including scaffolding, construction plants, lifts, and storage facilities.
- Working from elevated positions resulting in falls.
- Construction equipment operations.

Construction managers should give special attention to the control of the safety hazards described above.

In the area of worker health, the major environmental hazards likely to be encountered by construction workers consist of noise, dust, radiation, toxic materials, and extreme temperatures.

Organization for Construction

There are probably as many different forms of construction company organization as there are construction firms. However, Figure 10 presents an organization chart that reasonably represents a medium- to large-size general construction company.

Reasons for Construction Company Failure

Dun & Bradstreet and others have investigated the reasons for the high rate of bankruptcy in the construction industry. Some of the major factors they have identified include lack of capital, poor cost estimating, inadequate cost accounting, and lack of general management ability. All of these factors can be categorized as elements of poor management. Such studies indicate that at least 90% of all construction company failures can be attributed to inadequate management.

Use of Computers

The wide availability and low cost of personal computers have placed these powerful tools at the disposal of every construction professional. Construction applications of computers are almost unlimited. Examples of construction applications of personal computers are presented in the end-of-chapter problems.

Perhaps the most exciting development in the construction application of computers is the wide availability of the Internet (World Wide Web) with its almost unlimited resources, along with electronic mail (e-mail) services. Equipment manufacturers are increasingly engaging in electronic communications with dealers and dealers with contractors. Contractors exchange information and data among projects and between project sites and the home office. Manufacturers are also providing online parts catalogs, as well as service and repair bulletins to dealers. Equipment warranty service requests are also being electronically processed. While some manufacturers' information is available only to dealers and not to contractors,

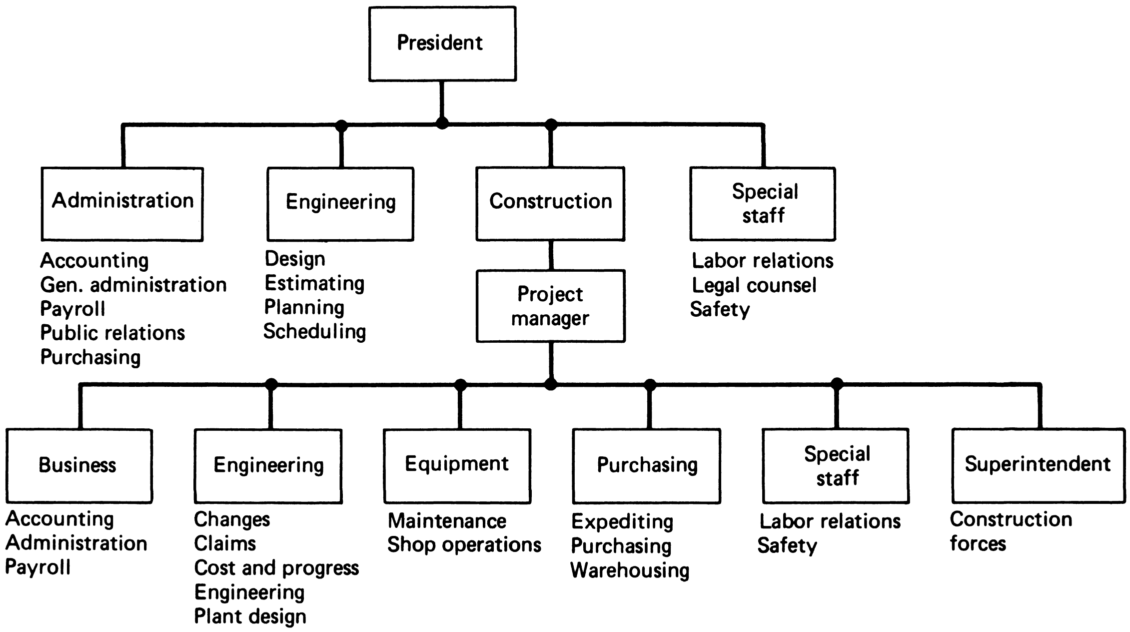

FIGURE 10. Representative construction company organization chart.

increasingly such data and services will become available to contractors. Electronic sales of new and used equipment and parts are also growing rapidly. In addition, much information of value to contractors is available on the Internet.

More traditional construction applications of computers include word processing, cost and time estimating, financial planning, planning and scheduling, project management, and equipment management, among others. With the increasing power and declining cost of computers, more powerful user-friendly construction software is becoming available almost daily.

6 CONSTRUCTION TRENDS AND PROSPECTS

Construction Trends

Some of the major trends noted in the construction industry in recent years include increasing international competition, rapid changes in technology, the wide availability of information via the Internet, increasing speed and ease of communication, and increasing governmental regulation of the industry, particularly in the areas of safety and environmental protection. As a result of these developments, the larger well-managed construction firms are capturing an increasing share of the total construction market.

These trends, along with the increasing use of computers for design and management, have created a growing demand for technically competent and innovative construction managers. With the increasing automation of construction equipment has come an increasing demand for highly skilled equipment operators and technicians.

Problems and Prospects

In recent years, industry problems of low productivity and high cost have served to reduce construction's share of the U.S. gross national product. This problem has been particularly acute in the building construction industry because the use of larger and more productive earthmoving equipment has served to keep earthmoving costs relatively stable.

Studies of international competition in design and construction have found that the U.S. share of the world's market has declined significantly since 1975. During this period, foreign construction firms greatly increased their share of the U.S. domestic construction market. Despite these trends, many observers are confident that the U.S. construction industry will, over time, regain its predominant position in the world construction market.

Although high costs have often served to limit the demand for construction, during times of high demand the U.S. construction industry has actually approached its maximum capacity. When the demand for construction again peaks, it is probable that new forms of construction organization and management as well as new construction methods will have to be developed to meet these demands. In any event, the U.S. construction industry will continue to provide many opportunities and rewards to the innovative, professionally competent, and conscientious construction professional.

In summary, the future of construction appears as dynamic as does its past. An abundance of problems, challenges, opportunities, and rewards wait for those who choose to enter the construction industry.

Problems

1. Describe the size of the U.S. construction industry and the distribution of contract value within the industry.
2. List and briefly explain three major characteristics of the U.S. construction industry.
3. Briefly explain the purpose of a building code.
4. Describe the principal methods by which construction of a facility may be accomplished.
5. Briefly explain the effect of construction productivity on the U.S. economy.
6. Are heavy (horizontal) construction projects more likely to be private or public projects? Explain.
7. What is construction quality control and whose responsibility is it?
8. Identify those construction operations which account for a majority of serious construction injuries.
9. What is an Environmental Impact Statement (EIS) and how is it prepared?
10. Describe three specific construction applications of a personal computer which you believe would be valuable to a construction professional.

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EARTHMOVING MATERIALS AND OPERATIONS

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EARTHMOVING MATERIALS AND OPERATIONS

1 INTRODUCTION TO EARTHMOVING

The Earthmoving Process

Earthmoving is the process of moving soil or rock from one location to another and processing it so that it meets construction requirements of location, elevation, density, moisture content, and so on. Activities involved in this process include excavating, loading, hauling, placing (dumping and spreading), compacting, grading, and finishing. Efficient management of the earthmoving process requires accurate estimating of work quantities and job conditions, proper selection of equipment, and competent job management.

Equipment Selection

The choice of equipment to be used on a construction project has a major influence on the efficiency and profitability of the construction operation. Although there are a number of factors that should be considered in selecting equipment for a project, the most important criterion is the ability of the equipment to perform the required work. Among those items of equipment capable of performing the job, the principal criterion for selection should be maximizing the profit or return on the investment produced by the equipment. Usually, but not always, profit is maximized when the lowest cost per unit of production is achieved. Other factors that should be considered when selecting equipment for a project include possible future use of the equipment, its availability, the availability of parts and service, and the effect of equipment downtime on other construction equipment and operations.

After the equipment has been selected for a project, a plan must be developed to efficiently utilize the equipment. The final phase of the process is, of course, competent job management to assure compliance with the operating plan and to make adjustments for unexpected conditions.

Production of Earthmoving Equipment

The basic relationship for estimating the production of all earthmoving equipment is as follows:

$$\text{Production} = \text{Volume per cycle} \times \text{Cycles per hour} \tag{1}$$

The term *volume per cycle* should represent the average volume of material moved per equipment cycle. Thus the nominal capacity of the excavator or haul unit must be modified by an appropriate fill factor based on the type of material and equipment involved. The term *cycles per hour* must include any appropriate efficiency factors, so that it represents the number of cycles actually achieved (or expected to be achieved) per hour. In addition to this basic production relationship, specific procedures for estimating the production of major types of earthmoving equipment are presented in the chapters that follow.

The cost per unit of production may be calculated as follows:

$$\begin{array}{c}\text{Cost per unit}\\ \text{of production}\end{array} = \frac{\text{Equipment cost per hour}}{\text{Equipment production per hour}} \tag{2}$$

There are two principal approaches to estimating job efficiency in determining the number of cycles per hour to be used in Equation 1. One method is to use the number of effective working minutes per hour to calculate the number of cycles achieved per hour. This is equivalent to using an efficiency factor equal to the number of working minutes per hour divided by 60. The other approach is to multiply the number of theoretical cycles per 60-min hour by a numerical efficiency factor. A table of efficiency factors based on a

Table 1. Job efficiency factors for earthmoving operations (From TM 5-331B, U.S. Department of the Army)

	Management Conditions*			
Job Conditions**	Excellent	Good	Fair	Poor
Excellent	0.84	0.81	0.76	0.70
Good	0.78	0.75	0.71	0.65
Fair	0.72	0.69	0.65	0.60
Poor	0.63	0.61	0.57	0.52

*Management conditions include the following:
Skill, training, and motivation of workers.
Selection, operation, and maintenance of equipment.
Planning, job layout, supervision, and coordination of work.

**Job conditions are the physical conditions of a job that affect the production rate (not including the type of material involved). They include the following:
Topography and work dimensions.
Surface and weather conditions.
Specification requirements for work methods or sequence.

combination of job conditions and management conditions is presented in Table 1. Both methods are illustrated in the example problems.

2 EARTHMOVING MATERIALS

Soil and Rock

Soil and rock are the materials that make up the crust of the earth and are, therefore, the materials of interest to the constructor. In the remainder of this chapter, we will consider those characteristics of soil and rock that affect their construction use, including their volume-change characteristics, methods of classification, and field identification.

General Soil Characteristics

Several terms relating to a soil's behavior in the construction environment should be understood. *Trafficability* is the ability of a soil to support the weight of vehicles under repeated traffic. In construction, trafficability controls the amount and type of traffic that can use unimproved access roads, as well as the operation of earthmoving equipment within the construction area. Trafficability is usually expressed qualitatively, although devices are available for quantitative measurement. Trafficability is primarily a function of soil type and moisture conditions. Drainage, stabilization of haul routes, or the use of low-ground-pressure construction equipment may be required when poor trafficability conditions exist. Soil drainage characteristics are important to trafficability and affect the ease with which soils may be dried out. *Loadability* is a measure of the difficulty in excavating and loading a soil. Loose granular soils are highly loadable, whereas compacted cohesive soils and rock have low loadability.

Unit soil weight is normally expressed in pounds per cubic yard or kilograms per cubic meter. Unit weight depends on soil type, moisture content, and degree of compaction. For a specific soil, there is a relationship between the soil's unit weight and its bearing capacity. Thus soil unit weight is commonly used as a measure of compaction. Soil unit weight is also a factor in determining the capacity of a haul unit.

In their natural state, all soils contain some moisture. The moisture content of a soil is expressed as a percentage that represents the weight of water in the soil divided by the dry weight of the soil:

$$\text{Moisture content (\%)} = \frac{\text{Moist weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 \qquad \textbf{(3)}$$

If, for example, a soil sample weighed 120 lb (54.4 kg) in the natural state and 100 lb (45.3 kg) after drying, the weight of water in the sample would be 20 lb (9.1 kg) and the soil moisture content would be 20%. Using Equation 3, this is calculated as follows:

$$\text{Moisture content} = \frac{120 - 100}{100} \times 100 = 20\%$$

$$\left[= \frac{54.4 - 45.3}{45.3} \times 100 = 20\% \right]$$

3 SOIL IDENTIFICATION AND CLASSIFICATION

Soil is considered to consist of five fundamental material types: gravel, sand, silt, clay, and organic material. *Gravel* is composed of individual particles larger than about $\frac{1}{4}$ in. (6 mm) in diameter but smaller than 3 in. (76 mm) in diameter. Rock particles larger than 3 in. (76 mm) in diameter are called *cobbles* or *boulders*. *Sand* is material smaller than gravel but larger than the No. 200 sieve opening (0.7 mm). *Silt* particles pass the No. 200 sieve but are larger than 0.002 mm. *Clay* is composed of particles less than 0.002 mm in diameter. *Organic soils* contain partially decomposed vegetable matter. *Peat* is a highly organic soil having a fibrous texture. It is normally readily identified by its dark color, odor, and spongy feel. It is generally considered unsuitable for any construction use.

Because a soil's characteristics are largely determined by the amount and type of each of the five basic materials present, these factors are used for the identification and classification procedures described in the remainder of this section.

Soil Classification Systems

Two principal soil classification systems are used for design and construction in the United States. These are the *Unified System* and the *AASHTO* [American Association of State Highway and Transportation Officials, formerly known as the American Association of State Highway Officials

(AASHO)] *System.* In both systems, soil particles 3 in. or larger in diameter are removed before performing classification tests.

The *liquid limit* (LL) of a soil is the water content (expressed in percentage of dry weight) at which the soil will just start to flow when subjected to a standard shaking test. The *plastic limit* (PL) of a soil is the moisture content in percent at which the soil just begins to crumble when rolled into a thread $\frac{1}{8}$ in. (0.3 cm) in diameter. The *plasticity index* (PI) is the numerical difference between the liquid and plastic limits and represents the range in moisture content over which the soil remains plastic.

The Unified System assigns a two-letter symbol to identify each soil type. Field classification procedures are given in Table 2. Soils that have less than 50% by weight passing the No. 200 sieve are further classified as *coarse-grained soils,* whereas soils that have more than 50% by weight passing the No. 200 sieve are *fine-grained soils.* Gradation curves for well graded and poorly graded sand and gravel are illustrated in Figure 1.

Under the AASHTO System, soils are classified as types A-1 through A-7, corresponding to their relative value as subgrade material. Classification procedures for the AASHTO System are given in Table 3.

Field Identification of Soil (Unified System)

When identifying soil in connection with construction operations, adequate time and laboratory facilities are frequently not available for complete soil classification. The use of the procedures described here together with Table 2 should permit a reasonably accurate soil classification to be made in a minimum of time.

All particles over 3 in. (76 mm) in diameter are first removed. The soil particles are then separated visually at the No. 200 sieve size: This corresponds to the smallest particles that can be seen by the naked eye. If more than 50% of the soil by weight is larger than the No. 200 sieve, it is a coarse-grained soil. The coarse particles are then divided into particles larger and smaller than $\frac{1}{4}$ in. (6 mm) in diameter. If over 50% of the coarse fraction (by weight) is larger than $\frac{1}{4}$ in. (6 mm) in diameter, the soil is classified as gravel; otherwise, it is sand. If less than 10% by weight of the total sample is smaller than the No. 200 sieve, the second letter is assigned based on grain size distribution. That is, it is either well graded (W) or poorly graded (P). If more than 10% of the sample is smaller than the No. 200 sieve, the second classification letter is based on the plasticity of the fines (L or H), as shown in the table.

Table 2. Unified system of soil classification—field identification

Coarse-Grained Soils (Less Than 50% Pass No. 200 Sieve) Symbol	Name	Percent of Coarse Fraction Less Than $\frac{1}{4}$ in.	Percent of Sample Smaller Than No. 200 Sieve	Comments
GW	Well-graded gravel	50 max.	< 10	Wide range of grain sizes with all intermediate sizes
GP	Poorly graded gravel	50 max.	< 10	Predominantly one size or some sizes missing
SW	Well-graded sand	51 min.	< 10	Wide range of grain sizes with all intermediate sizes
SP	Poorly graded sand	51 min.	< 10	Predominantly one size or some sizes missing
GM	Silty gravel	50 max.	≥ 10	Low-plasticity fines (see ML below)
GC	Clayey gravel	50 max.	≥ 10	Plastic fines (see CL below)
SM	Silty sand	51 min.	≥ 10	Low-plasticity fines (see ML below)
SC	Clayey sand	51 min.	≥ 10	Plastic fines (see CL below)

Fine-Grained Soils (50% or More Pass No. 200 Sieve) Symbol	Name	Tests on Fraction Passing No. 40 Sieve (Approx. $\frac{1}{64}$ in. or 0.4 mm)* Dry Strength	Shaking	Other
ML	Low-plasticity silt	Low	Medium to quick	
CL	Low-plasticity clay	Low to medium	None to slow	
OL	Low-plasticity organic	Low to medium	Slow	Color and odor
MH	High-plasticity silt	Medium to high	None to slow	
CH	High-plasticity clay	High	None	
OH	High-plasticity organic	Medium to high	None to slow	Color and odor
Pt	Peat	Identified by dull brown to black color, odor, spongy feel, and fibrous texture		

*Laboratory classification based on liquid limit and plasticity index values.

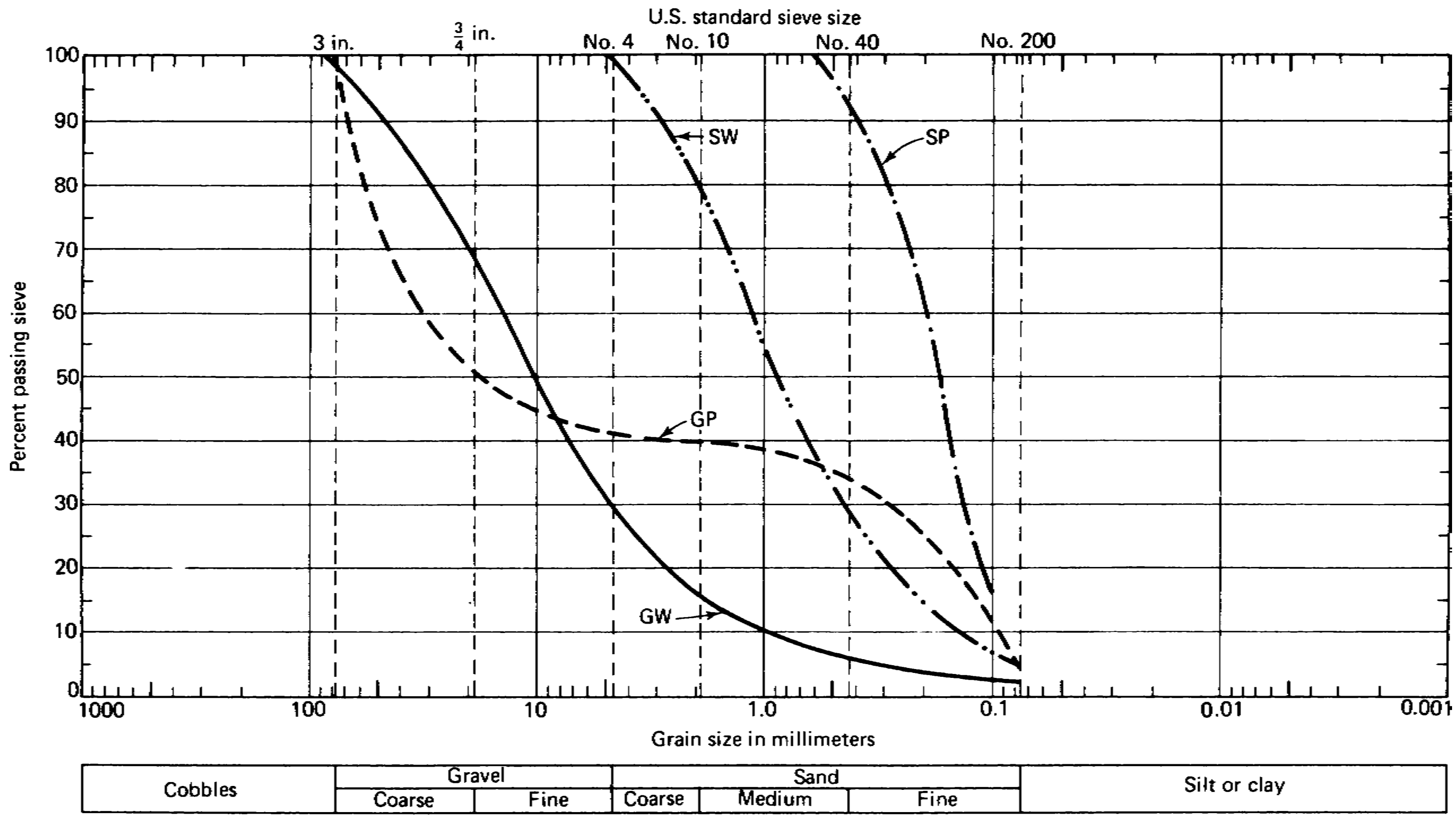

FIGURE 1. Typical gradation curves for coarse-grained soils. (U.S. Army Engineer School)

Table 3. AASHTO system of soil classification (Courtesy of BOMAG Americas)

	Group Number										
	A-1		A-2								
	A-1-a	A-1-b	A-2-4	A-2-5	A-2-6	A-2-7	A-3	A-4	A-5	A-6	A-7
Percent passing											
No. 10 sieve	50 max.										
No. 40 sieve	30 max.	50 max.					51 min.				
No. 200 sieve	15 max.	25 max.	35 max.	35 max.	35 max.	35 max.	10 max.	36 min.	36 min.	36 min.	36 min.
Fraction passing No. 40											
Liquid limit	6 max.	6 max.	40 max.	41 min.	40 max.	41 min.		40 max.	41 min.	40 max.	41 min.
Plasticity index			10 max.	10 max.	11 min.	11 min.		10 max.	10 max.	11 min.	11 min.
Typical material	Gravel and sand		Silty or clayey sand or gravel				Fine sand	Silt	Silt	Clay	Clay

If the sample is fine-grained (more than 50% by weight smaller than the No. 200 sieve), classification is based on dry strength and shaking tests of the material smaller than $\frac{1}{64}$ in. (0.4 mm) in diameter.

Dry Strength Test Mold a sample into a ball about the size of a golf ball to the consistency of putty, adding water as needed. Allow the sample to dry completely. Attempt to break the sample using the thumb and forefinger of both hands. If the sample cannot be broken, the soil is highly plastic. If the sample breaks, attempt to powder it by rubbing it between the thumb and forefinger of one hand. If the sample is difficult to break and powder, it has medium plasticity. Samples of low plasticity will break and powder easily.

Shaking Test Form the material into a ball about $\frac{3}{4}$ in. (19 mm) in diameter, adding water until the sample does not stick to the fingers as it is molded. Put the sample in the palm of the hand and shake vigorously. Observe the speed with which water comes to the surface of the sample to produce a shiny surface. A rapid reaction indicates a nonplastic silt.

Construction Characteristics of Soils

Some important construction characteristics of soils as classified under the Unified System are summarized in Table 4.

Table 4. Construction characteristics of soils (Unified System)

Soil Type	Symbol	Drainage	Construction Workability	Suitability for Subgrade (No Frost Action)	Suitability for Surfacing
Well-graded gravel	GW	Excellent	Excellent	Good	Good
Poorly graded gravel	GP	Excellent	Good	Good to excellent	Poor
Silty gravel	GM	Poor to fair	Good	Good to excellent	Fair
Clayey gravel	GC	Poor	Good	Good	Excellent
Well-graded sand	SW	Excellent	Excellent	Good	Good
Poorly graded sand	SP	Excellent	Fair	Fair to good	Poor
Silty sand	SM	Poor to fair	Fair	Fair to good	Fair
Clayey sand	SC	Poor	Good	Poor to fair	Excellent
Low-plasticity silt	ML	Poor to fair	Fair	Poor to fair	Poor
Low-plasticity clay	CL	Poor	Fair to good	Poor to fair	Fair
Low-plasticity organic	OL	Poor	Fair	Poor	Poor
High-plasticity silt	MH	Poor to fair	Poor	Poor	Poor
High-plasticity clay	CH	Very poor	Poor	Poor to fair	Poor
High-plasticity organic	OH	Very poor	Poor	Very poor to poor	Poor
Peat	Pt	Poor to fair	Unsuitable	Unsuitable	Unsuitable

4 SOIL VOLUME-CHANGE CHARACTERISTICS

Soil Conditions

There are three principal conditions or states in which earthmoving material may exist: bank, loose, and compacted. The meanings of these terms are as follows:

- **Bank:** Material in its natural state before disturbance. Often referred to as "in-place" or "in situ." A unit volume is identified as a *bank cubic yard* (BCY) or a *bank cubic meter* (BCM).
- **Loose:** Material that has been excavated or loaded. A unit volume is identified as a *loose cubic yard* (LCY) or *loose cubic meter* (LCM).
- **Compacted:** Material after compaction. A unit volume is identified as a *compacted cubic yard* (CCY) or *compacted cubic meter* (CCM).

Swell

A soil increases in volume when it is excavated because the soil grains are loosened during excavation and air fills the void spaces created. As a result, a unit volume of soil in the bank condition will occupy more than one unit volume after excavation. This phenomenon is called *swell.* Swell may be calculated as follows:

$$\text{Swell}\ (\%) = \left(\frac{\text{Weight/bank volume}}{\text{Weight/loose volume}} - 1\right) \times 100 \qquad \textbf{(4)}$$

Example 1 Find the swell of a soil that weighs 2800 lb/cu yd (1661 kg/m^3) in its natural state and 2000 lb/cu yd (1186 kg/m^3) after excavation.

Solution

$$\text{Swell} = \left(\frac{2800}{2000} - 1\right) \times 100 = 40\% \quad \text{(Eq 4)}$$

$$\left[= \left(\frac{1661}{1186} - 1\right) \times 100 = 40\% \right]$$

That is, 1 bank cubic yard (meter) of material will expand to 1.4 loose cubic yards (meters) after excavation.

Shrinkage

When a soil is compacted, some of the air is forced out of the soil's void spaces. As a result, the soil will occupy less volume than it did under either the bank or loose conditions. This phenomenon, which is the reverse of the swell phenomenon, is called *shrinkage.* The value of shrinkage may be determined as follows:

$$\text{Shrinkage}\ (\%) = \left(1 - \frac{\text{Weight/bank volume}}{\text{Weight/compacted volume}}\right) \times 100 \qquad \textbf{(5)}$$

Soil volume change caused by excavation and compaction is illustrated in Figure 2. Note that both swell and shrinkage are calculated from the bank (or natural) condition.

Example 2 Find the shrinkage of a soil that weighs 2800 lb/cu yd (1661 kg/m^3) in its natural state and 3500 lb/cu yd (2077 kg/m^3) after compaction.

Solution

$$\text{Shrinkage} = \left(1 - \frac{2800}{3500}\right) \times 100 = 20\% \quad \text{(Eq 5)}$$

$$\left[= \left(1 - \frac{1661}{2077}\right) \times 100 = 20\% \right]$$

Hence 1 bank cubic yard (meter) of material will shrink to 0.8 compacted cubic yard (meter) as a result of compaction.

Load and Shrinkage Factors

In performing earthmoving calculations, it is important to convert all material volumes to a common unit of measure. Although the bank cubic yard (or meter) is most commonly used for this purpose, any of the three volume units may be used. A *pay yard* (or meter) is the volume unit specified as the basis for payment in an earthmoving contract. It may be any of the three volume units.

Because haul unit and spoil bank volume are commonly expressed in loose measure, it is convenient to have a conversion factor to simplify the conversion of loose volume to bank volume. The factor used for this purpose is called a *load factor.* A soil's load factor may be calculated by use of

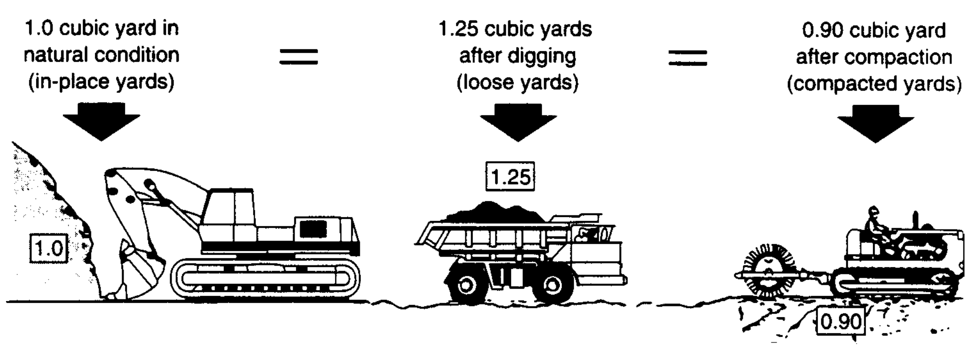

FIGURE 2. Typical soil volume change during earthmoving.

Table 5. Typical soil weight and volume change characteristics*

	Unit Weight [lb/cu yd (kg/m^3)]			Swell (%)	Shrinkage (%)	Load Factor	Shrinkage Factor
	Loose	Bank	Compacted				
Clay	2310 (1370)	3000 (1780)	3750 (2225)	30	20	0.77	0.80
Common earth	2480 (1471)	3100 (1839)	3450 (2047)	25	10	0.80	0.90
Rock (blasted)	3060 (1815)	4600 (2729)	3550 (2106)	50	–30**	0.67	1.30**
Sand and gravel	2860 (1697)	3200 (1899)	3650 (2166)	12	12	0.89	0.88

*Exact values vary with grain size distribution, moisture, compaction, and other factors. Tests are required to determine exact values for a specific soil.
**Compacted rock is less dense than is in-place rock.

Equation 6 or 7. Loose volume is multiplied by the load factor to obtain bank volume.

$$\text{Load factor} = \frac{\text{Weight/loose unit volume}}{\text{Weight/bank unit volume}} \quad (6)$$

or

$$\text{Load factor} = \frac{1}{1 + \text{swell}} \quad (7)$$

A factor used for the conversion of bank volume to compacted volume is sometimes referred to as a *shrinkage factor*. The shrinkage factor may be calculated by use of Equation 8 or 9. Bank volume may be multiplied by the shrinkage factor to obtain compacted volume or compacted volume may be divided by the shrinkage factor to obtain bank volume.

$$\text{Shrinkage factor} = \frac{\text{Weight/bank unit volume}}{\text{Weight/compacted unit volume}} \quad (8)$$

or

$$\text{Shrinkage factor} = 1 - \text{shrinkage} \quad (9)$$

Example 3 A soil weighs 1960 lb/LCY (1163 kg/LCM), 2800 lb/BCY (1661 kg/BCM), and 3500 lb/CCY (2077 kg/CCM). (a) Find the load factor and shrinkage factor for the soil. (b) How many bank cubic yards (BCY) or meters (BCM) and compacted cubic yards (CCY) or meters (CCM) are contained in 1 million loose cubic yards (593,300 LCM) of this soil?

Solution

$$\text{(a) Load factor} = \frac{1960}{2800} = 0.70 \quad \text{(Eq 6)}$$

$$\left[= \frac{1163}{1661} = 0.70 \right]$$

$$\text{Shrinkage factor} = \frac{2800}{3500} = 0.80 \quad \text{(Eq 8)}$$

$$\left[= \frac{1661}{2077} = 0.80 \right]$$

$$\text{(b) Bank volume} = 1{,}000{,}000 \times 0.70 = 700{,}000 \text{ BCY}$$

$$[= 593{,}300 \times 0.70 = 415{,}310 \text{ BCM}]$$

$$\text{Compacted volume} = 700{,}000 \times 0.80 = 560{,}000 \text{ CCY}$$

$$= [415{,}310 \times 0.80 = 332{,}248 \text{ CCM}]$$

Typical values of unit weight, swell, shrinkage, load factor, and shrinkage factor for some common earthmoving materials are given in Table 5.

5 SPOIL BANKS

When planning and estimating earthwork, it is frequently necessary to determine the size of the pile of material that will be created by the material removed from the excavation. If the pile of material is long in relation to its width, it is referred to as a *spoil bank*. Spoil banks are characterized by a triangular cross section. If the material is dumped from a fixed position, a *spoil pile* is created which has a conical shape. To determine the dimensions of spoil banks or piles, it is first necessary to convert the volume of excavation from in-place conditions (BCY or BCM) to loose conditions (LCY or LCM). Bank or pile dimensions may then be calculated using Equations 10 to 13 if the soil's angle of repose is known.

A soil's *angle of repose* is the angle that the sides of a spoil bank or pile naturally form with the horizontal when the excavated soil is dumped onto the pile. The angle of repose (which represents the equilibrium position of the soil) varies with the soil's physical characteristics and its moisture content. Typical values of angle of repose for common soils are given in Table 6.

Table 6. Typical values of angle of repose of excavated soil

Material	Angle of Repose (deg)
Clay	35
Common earth, dry	32
Common earth, moist	37
Gravel	35
Sand, dry	25
Sand, moist	37

Triangular Spoil Bank

$$\text{Volume} = \text{Section area} \times \text{Length} \tag{10}$$

$$B = \left(\frac{4V}{L \times \tan R}\right)^{\frac{1}{2}}$$

$$H = \frac{B \times \tan R}{2} \tag{11}$$

where B = base width (ft or m)
H = pile height (ft or m)
L = pile length (ft or m)
R = angle of repose (deg)
V = pile volume (cu ft or m^3)

Conical Spoil Pile

$$\text{Volume} = \frac{1}{3} \times \text{Base area} \times \text{Height}$$

$$D = \left(\frac{7.64V}{\tan R}\right)^{\frac{1}{3}} \tag{12}$$

$$H = \frac{D}{2} \times \tan R \tag{13}$$

where D is the diameter of the pile base (ft or m).

Example 4 Find the base width and height of a triangular spoil bank containing 100 BCY (76.5 BCM) if the pile length is 30 ft (9.14 m), the soil's angle of repose is 37°, and its swell is 25%.

Solution

$$\text{Loose volume} = 27 \times 100 \times 1.25 = 3375 \text{ cu ft}$$
$$[= 76.5 \times 1.25 = 95.6 \text{ m}^3]$$

$$\text{Base width} = \left(\frac{4 \times 3375}{30 \times \tan 37°}\right)^{\frac{1}{2}} = 24.4 \text{ ft} \quad \text{(Eq 10)}$$

$$\left[= \left(\frac{4 \times 95.6}{9.14 \times \tan 37°}\right)^{\frac{1}{2}} = 7.45 \text{ m}\right]$$

$$\text{Height} = \frac{24.4}{2} \times \tan 37° = 9.2 \text{ ft} \quad \text{(Eq 11)}$$

$$\left[= \frac{7.45}{2} \times \tan 37° = 2.80 \text{ m}\right]$$

Example 5 Find the base diameter and height of a conical spoil pile that will contain 100 BCY (76.5 BCM) of excavation if the soil's angle of repose is 32° and its swell is 12%.

Solution

$$\text{Loose volume} = 27 \times 100 \times 1.12 = 3024 \text{ cu ft}$$
$$[= 76.5 \times 1.12 \times 85.7 \text{ m}^3]$$

$$\text{Base diameter} = \left(\frac{7.64 \times 3024}{\tan 32°}\right)^{\frac{1}{3}} = 33.3 \text{ ft} \quad \text{(Eq 12)}$$

$$\left[= \left(\frac{7.64 \times 85.7}{\tan 32°}\right)^{\frac{1}{3}} = 10.16 \text{ m}\right]$$

$$\text{Height} = \frac{33.3}{2} \times \tan 32° = 10.4 \text{ ft} \quad \text{(Eq 13)}$$

$$\left[= \frac{10.16}{2} \times \tan 32° = 3.17 \text{ m}\right]$$

6 ESTIMATING EARTHWORK VOLUME

When planning or estimating an earthmoving project, it is often necessary to estimate the volume of material to be excavated or placed as fill. The procedures to be followed can be divided into three principal categories: (1) pit excavations (small, relatively deep excavations such as those required for basements and foundations), (2) trench excavation for utility lines, and (3) excavating or grading relatively large areas. Procedures suggested for each of these three cases are described in the following sections.

The estimation of the earthwork volume involved in the construction of roads and airfields is customarily performed by the design engineer. The usual method is to calculate the cross-sectional area of cut or fill at regular intervals (such as *stations* [100 ft or 33 m]) along the centerline. The volume of cut or fill between stations is then calculated, accumulated, and plotted as a *mass diagram*. While the construction of a mass diagram is beyond the scope of this book, some construction uses of the mass diagram are described in Section 7.

When making earthwork volume calculations, keep in mind that cut volume is normally calculated in bank measure while the volume of compacted fill is calculated in compacted measure. Both cut and fill must be expressed in the same volume units before being added.

Pit Excavations

For these cases, simply multiply the horizontal area of excavation by the average depth of excavation (Equation 14).

$$\text{Volume} = \text{Horizontal area} \times \text{Average depth} \tag{14}$$

To perform these calculations, first divide the horizontal area into a convenient set of rectangles, triangles, or circular segments. After the area of each segment has been calculated, the total area is found as the sum of the segment areas. The average depth is then calculated. For simple rectangular excavations, the average depth can be taken as simply the average of the four corner depths. For more complex areas, measure the depth at additional points along the perimeter of the excavation and average all depths.

Example 6 Estimate the volume of excavation required (bank measure) for the basement shown in Figure 3. Values shown at each corner are depths of excavation. All values are in feet (m).

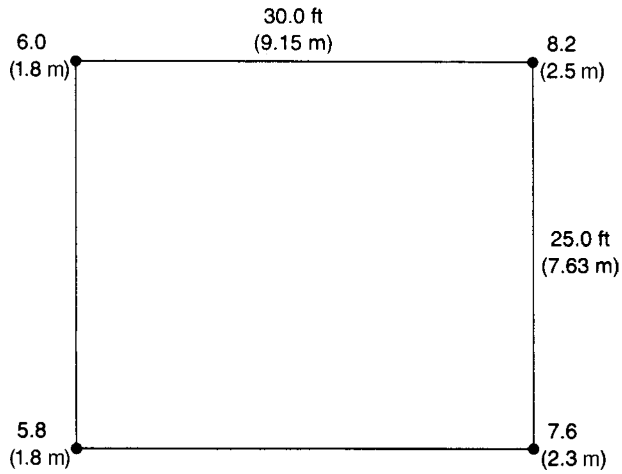

FIGURE 3. Figure for Example 6.

Solution

$$\text{Area} = 25 \times 30 = 750 \text{ sq ft}$$
$$[= 7.63 \times 9.15 = 69.8 \text{ m}^2]$$
$$\text{Average depth} = \frac{6.0 + 8.2 + 7.6 + 5.8}{4} = 6.9 \text{ ft}$$
$$\left[= \frac{1.8 + 2.5 + 2.3 + 1.8}{4} = 2.1 \text{ m} \right]$$
$$\text{Volume} = \frac{750 \times 6.9}{27} = 191.7 \text{ BCY}$$
$$[= 69.8 \times 2.1 = 146.6 \text{ BCM}]$$

Trench Excavations

The volume of excavation required for a trench can be calculated as the product of the trench cross-sectional area and the linear distance along the trench line (Equation 15). For rectangular trench sections where the trench depth and width are relatively constant, trench volume can be found as simply the product of trench width, depth, and length. When trench sides are sloped and vary in width and/or depth, cross sections should be taken at frequent linear intervals and the volumes between locations computed. These volumes are then added to find total trench volume.

$$\text{Volume} = \text{Cross-sectional area} \times \text{Length} \tag{15}$$

Example 7 Find the volume (bank measure) of excavation required for a trench 3 ft (0.92 m) wide, 6 ft (1.83 m) deep, and 500 ft (152 m) long. Assume that the trench sides will be approximately vertical.

Solution

$$\text{Cross-sectional area} = 3 \times 6 = 18 \text{ sq ft}$$
$$[= 0.92 \times 1.83 = 1.68 \text{ m}^2]$$
$$\text{Volume} = \frac{18 \times 500}{27} = 333 \text{ BCY}$$
$$[= 1.68 \times 152 = 255 \text{ BCM}]$$

Large Areas

To estimate the earthwork volume involved in large or complex areas, one method is to divide the area into a grid indicating the depth of excavation or fill at each grid intersection. Assign the depth at each corner or segment intersection a weight according to its location (number of segment lines intersecting at the point). Thus, interior points (intersection of four segments) are assigned a weight of four, exterior points at the intersection of two segments are assigned a weight of two, and corner points are assigned a weight of one. Average depth is then computed using Equation 16 and multiplied by the horizontal area to obtain the volume of excavation. Note, however, that this calculation yields the net volume of excavation for the area. Any balancing of cut and fill within the area is not identified in the result.

$$\text{Average depth} = \frac{\text{Sum of products of depth} \times \text{Weight}}{\text{Sum of weights}} \tag{16}$$

Example 8 Find the volume of excavation required for the area shown in Figure 4. The figure at each grid intersection represents the depth of cut at that location. Depths in parentheses represent meters.

Solution

$$\text{Corner points} = 6.0 + 3.4 + 2.0 + 4.0 = 15.4 \text{ ft}$$
$$[= 1.83 + 1.04 + 0.61 + 1.22 = 4.70 \text{ m}]$$
$$\text{Border points} = 5.8 + 5.2 + 4.6 + 3.0 + 2.8 + 3.0 + 3.5 + 4.8 + 4.8 + 5.5 = 43.0 \text{ ft}$$
$$[= 1.77 + 1.59 + 1.40 + 0.92 + 0.85 + 0.92 + 1.07 + 1.46 + 1.46 + 1.68 = 13.12 \text{ m}]$$
$$\text{Interior points} = 5.0 + 4.6 + 4.2 + 4.9 + 4.0 + 3.6 = 26.3 \text{ ft}$$
$$[= 1.52 + 1.40 + 1.28 + 1.49 + 1.22 + 1.10 = 8.01 \text{ m}]$$
$$\text{Average depth} = \frac{15.4 + 2(43.0) + 4(26.3)}{48} = 4.30 \text{ ft}$$
$$\left[= \frac{4.70 + 2(13.12) + 4(8.01)}{48} = 1.31 \text{ m} \right]$$
$$\text{Area} = 300 \times 400 = 120{,}000 \text{ sq ft}$$
$$[= 91.4 \times 121.9 = 11{,}142 \text{ m}^2]$$
$$\text{Volume} = \frac{120{,}000 \times 4.30}{27} = 19{,}111 \text{ BCY}$$
$$[= 11{,}142 \times 1.31 = 14{,}596 \text{ BCM}]$$

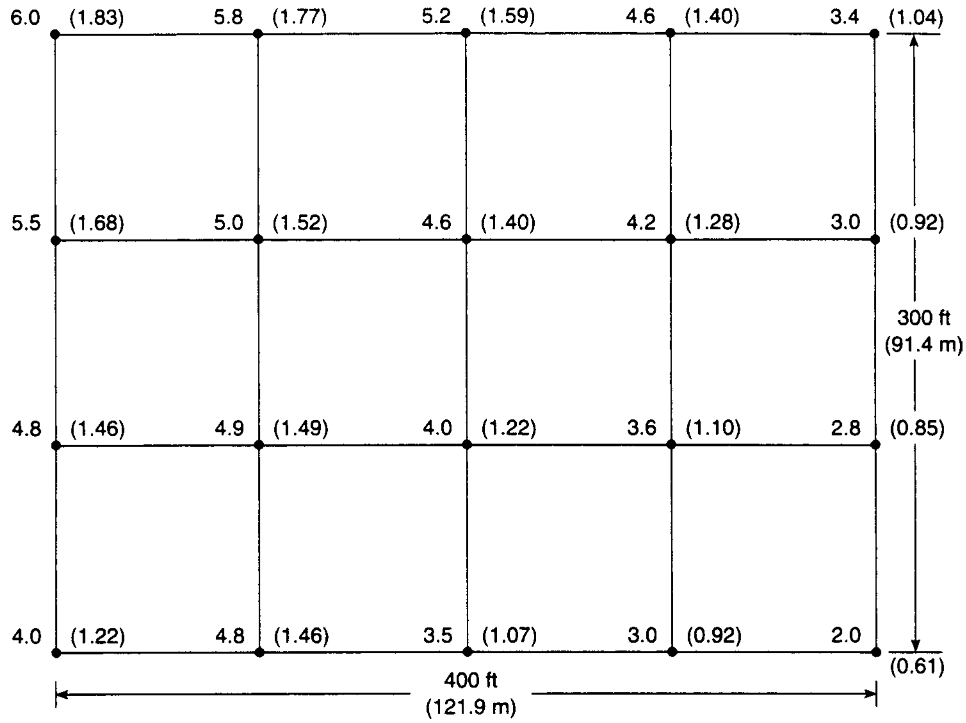

FIGURE 4. Figure for Example 8.

7 CONSTRUCTION USE OF THE MASS DIAGRAM

A *mass diagram* is a continuous curve representing the accumulated volume of earthwork plotted against the linear profile of a roadway or airfield. Mass diagrams are prepared by highway and airfield designers to assist in selecting an alignment which minimizes the earthwork required to construct the facility while meeting established limits of roadway grade and curvature. Since the mass diagram is intended as a design aid, it is not normally provided to contractors as part of a construction bid package. However, the mass diagram can provide very useful information to the construction manager, and it is usually available to the contractor upon request. A typical mass diagram and corresponding roadway profile are illustrated in Figure 5.

Characteristics of a Mass Diagram

Some of the principal characteristics of a mass diagram include the following:

- The vertical coordinate of the mass diagram corresponding to any location on the roadway profile represents the cumulative earthwork volume from the origin to that point.
- Within a cut, the curve rises from left to right.
- Within a fill, the curve falls from left to right.
- A peak on the curve represents a point where the earthwork changes from cut to fill.
- A valley (low point) on the curve represents a point where the earthwork changes from fill to cut.
- When a horizontal line intersects the curve at two or more points, the accumulated volumes at these points are equal. Thus, such a line represents a balance line on the diagram.

Using the Mass Diagram

Some of the information which a mass diagram can provide a construction manager includes the following:

- The length and direction of haul within a balanced section.
- The average length of haul for a balanced section.
- The location and amount of borrow (material hauled in from a borrow pit) and waste (material hauled away to a waste area) for the project.

The following explanation of methods for obtaining this information from a mass diagram will be illustrated using Figure 6.

1. For a balanced section (section 1 on the figure), project the end points of the section up to the profile (points A and B). These points identify the limits of the balanced section.
2. Locate point C on the profile corresponding to the lowest point of the mass diagram within section 1. This is the point at which the excavation changes from fill to cut. The areas of cut and fill can now be identified on the profile.
3. The direction of haul within a balanced section is always from cut to fill.

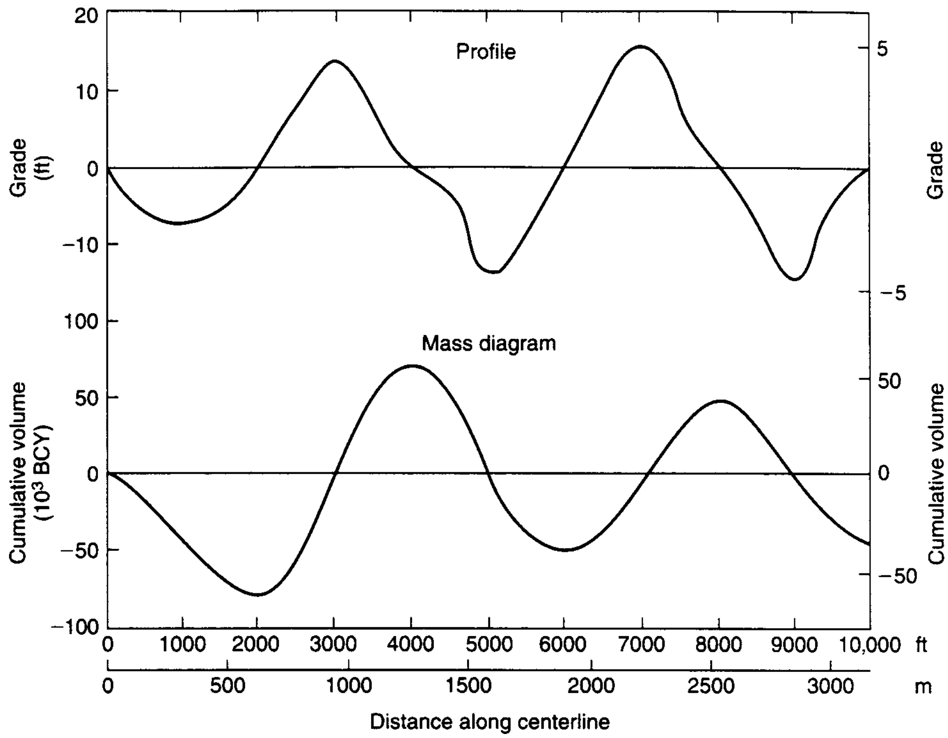

FIGURE 5. A mass diagram.

4. Repeat this process for sections 2, 3, and 4 as shown.
5. Since the mass diagram has a negative value from point D to the end, the ordinate at point E (−50,000 BCY or −38,230 BCM) represents the volume of material which must be brought in from a borrow pit to complete the roadway embankment.
6. The approximate average haul distance within a balanced section can be taken as the length of a horizontal line located midway between the balance line for the section and the peak or valley of the curve for the section. Thus, the length of the line F–G represents the average haul distance for section 1, which is 1800 ft or 549 m.

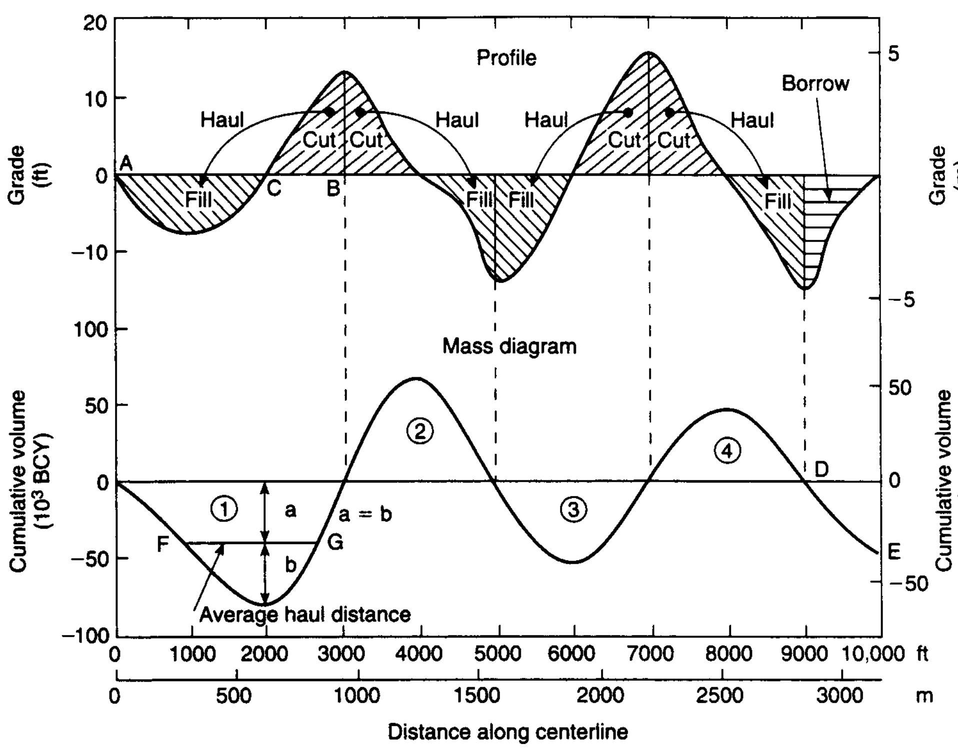

FIGURE 6. Construction use of a mass diagram.

Problems

1. Eliminating the four points on the right-hand side of Example 8 (depths of 3.4, 3.0, 2.8, and 2.0 ft), calculate the volume of excavation in bank measure.
2. A sample of gravel from a stockpile weighs 15 lb (6.80 kg). After oven drying, the sample weighs 14.2 lb (6.44 kg). Calculate the moisture content of the sample.
3. Find the size of a conical spoil bank created by the excavation of 500 BCY (382 BCM) of clay. The soil's swell is 30% and its angle of repose is 35°.
4. Use the profile and mass diagram of Figure 6 to find the following values:
   a. The total volume of (1) cut, (2) fill, (3) waste, and (4) borrow.
   b. The average length of haul for Section 2.
5. A soil weighs 2400 lb/cu yd (1089 kg/m^3) loose, 3050 lb/cu yd (1383 kg/m^3) in-place, and 3600 lb/cu yd (1633 kg/m^3) compacted. Find the swell and shrinkage of this soil.
6. Observations indicate that an excavator carries an average bucket load of 3.0 LCY (2.3 LCM) per cycle. The soil's load factor is 0.80. Cycle time averages 0.35 min. Job conditions are rated fair, and management conditions are rated as good. Estimate the hourly excavator production in bank measure.
7. A ditch having a cross-sectional area of 50 sq ft (4.6 m^2) is being excavated in common earth. The soil's angle of repose is 35° and its swell is 25%. Find the height and base width of the triangular spoil bank that will result from the excavation.
8. The hourly cost of a hydraulic shovel is $65 and of a truck is $35. If an equipment fleet consisting of one shovel and a fleet of six trucks achieve a production of 300 BCY (180 BCM), what is the unit cost of loading and hauling?
9. Using the AASHTO System, classify the soil whose test results are shown below:

   Passing No. 200 Sieve = 34%
   Liquid Limit = 30
   Plasticity Index = 8

10. Develop a computer program to determine the height and base width (ft or m) of the triangular spoil bank that will result from a rectangular trench excavation. Input should include the ditch width and average depth (or cross-sectional area) and length, or the bank volume of the excavation, as well as the soil's angle of repose (degrees) and swell (%). Solve Problem 7 using your program.

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EXCAVATING AND LIFTING

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EXCAVATING AND LIFTING

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.

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 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 the following:

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.

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

Bucket, 4-in-1: Also called a multipurpose bucket or multisegment bucket. 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 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.

FIGURE 1. Hydraulic excavator. (Courtesy of Volvo Construction Equipment North America, Inc.)

Compaction plate/tamper

Compaction wheel

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.

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 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.

Excavator Production

In order to estimate the production of an excavator using the Production = Volume per cycle × Cycles per hour equation, 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

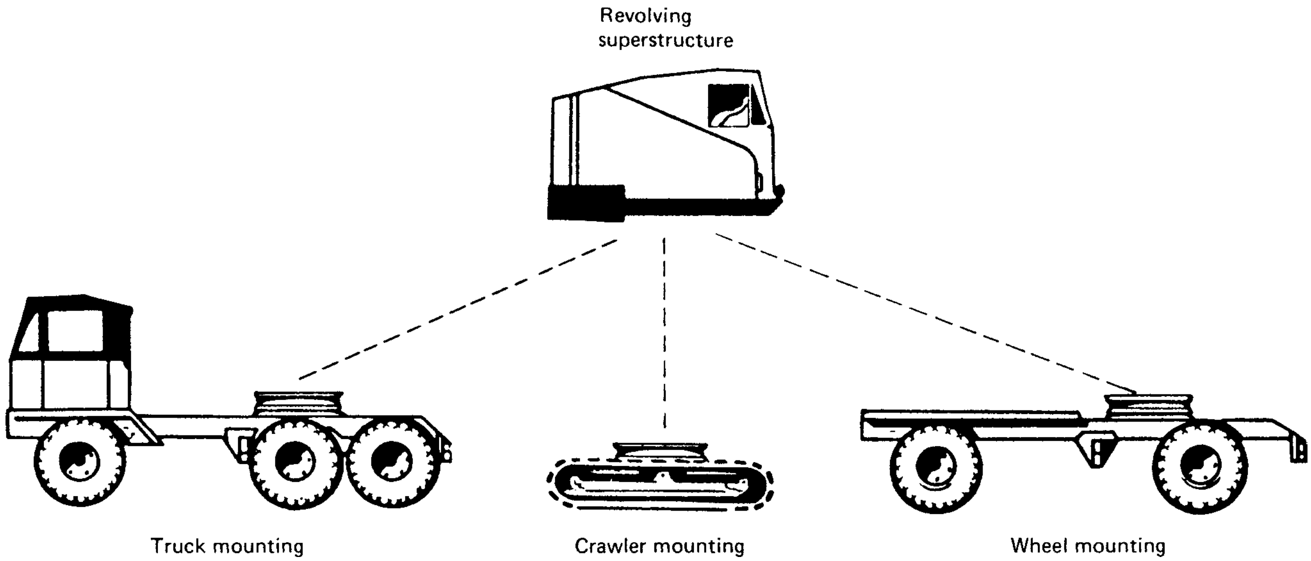


FIGURE 2. Crane-shovel mounting and revolving superstructure. (U.S. Department of the Army)

Table 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 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 1.

Table 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

Table 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 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

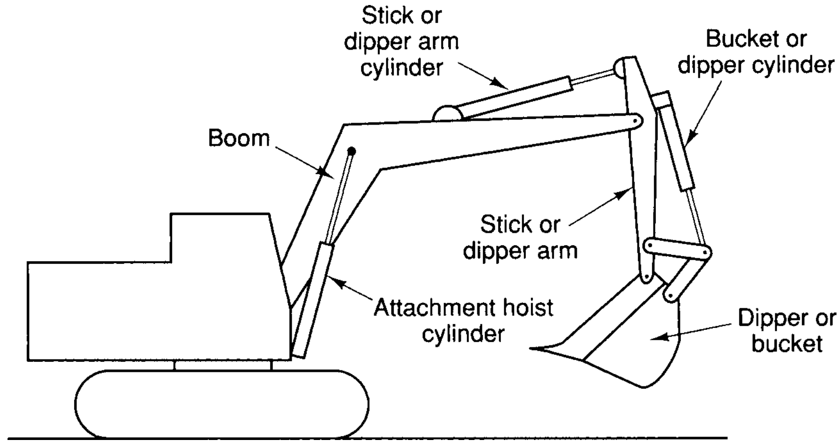
$$\text{Bucket load} = 5 \times 0.90 = 4.5 \text{ LCY} \times 0.80 = 3.6 \text{ BCY}$$
$$[= 3.82 \times 0.90 = 3.44 \text{ LCM} \times 0.80 = 2.75 \text{ BCM}]$$

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

FIGURE 3. Components of a hydraulic excavator backhoe.



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. 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. 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 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 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

FIGURE 4. Telescoping-boom hydraulic excavator. (Courtesy of JLG Industries, Inc.)

FIGURE 5. Mini-excavator. (Courtesy of JCB Inc.)

illustrated in Figure 5. These machines are available in sizes from about 10 to 60 hp (7.5–45 kW) with digging depths 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° swing, its hydraulic power, and its low ground pressure have resulted in its 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 1 together with Tables 3 and 4, which have been prepared from manufacturers' data.

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

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

Table 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

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 5 to obtain the effective trench production.

Example 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.

Table 3. Standard cycles per hour for hydraulic excavators

Type of Material	Machine Size: Wheel Tractor	Small Excavator: 1 yd (0.76 m^3) or Less	Medium Excavator: $1\frac{1}{4}$–$2\frac{1}{4}$ yd (0.94–1.72 m^3)	Large Excavator: Over $2\frac{1}{2}$ 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 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

Solution

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

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 SHOVELS

Operation and Employment

The *hydraulic shovel* illustrated in Figure 6 is also called a *front shovel* or *hydraulic excavator-front shovel*. Its major components are identified in Figure 7. The hydraulic shovel digs with a combination of crowding force and breakout (or prying) force, as illustrated in Figure 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 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.

FIGURE 6. Hydraulic shovel. (Courtesy of Kobelco Construction Machinery America LLC)

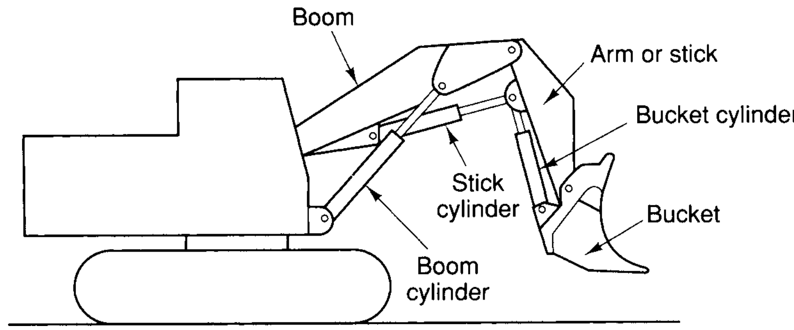


FIGURE 7. Components of a hydraulic shovel.

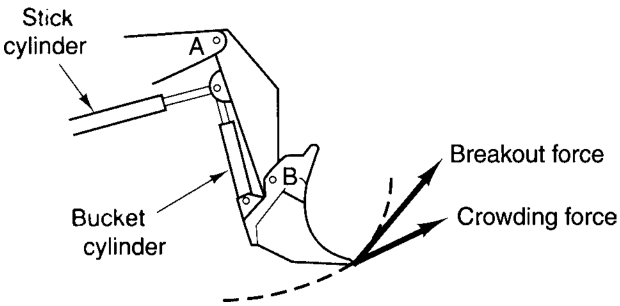


FIGURE 8. Digging action of a hydraulic shovel.

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 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 2 together with Table 6, which has been prepared from manufacturers' data.

$$\begin{matrix}\text{Production(LCY/h)} \\ \text{or (LCM/h)}\end{matrix} = C \times S \times V \times B \times E \qquad (2)$$

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

Example 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.

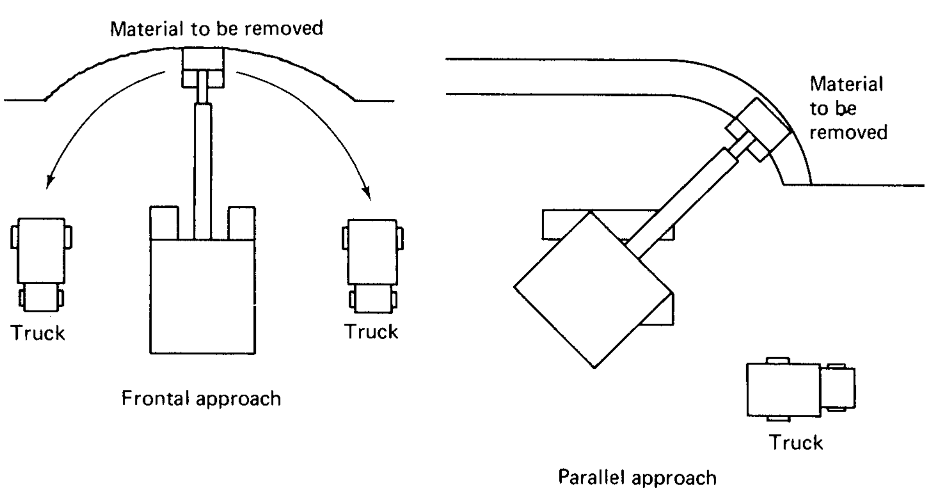


FIGURE 9. Shovel approach methods.

Table 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

Solution

Standard cycles = 150/60 min (Table 6)

Swing factor = 1.05 (Table 6)

Bucket volume = 3.0 LCY (2.3 LCM^3)

Bucket fill factor = 1.0

Job efficiency = 0.80

Production = $150 \times 1.05 \times 3.0 \times 1.0 \times 0.80$

= 378 LCY/h

[= $150 \times 1.05 \times 2.3 \times 1.0 \times 0.80$

= 290 LCM/h]

For cable-operated shovels, the Power Crane & Shovel Association (PCSA) Bureau of Construction Industry Manufacturers Association (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.

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 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 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 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.

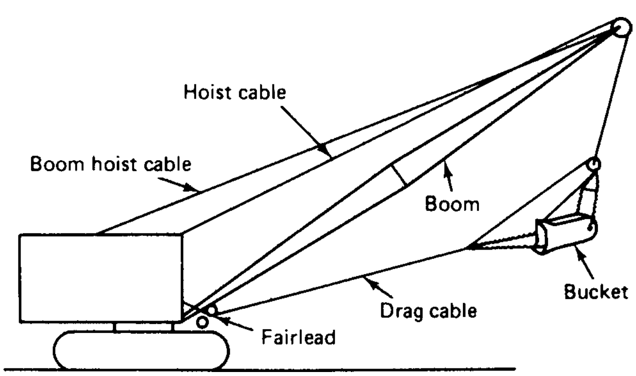


FIGURE 10. Components of a dragline.