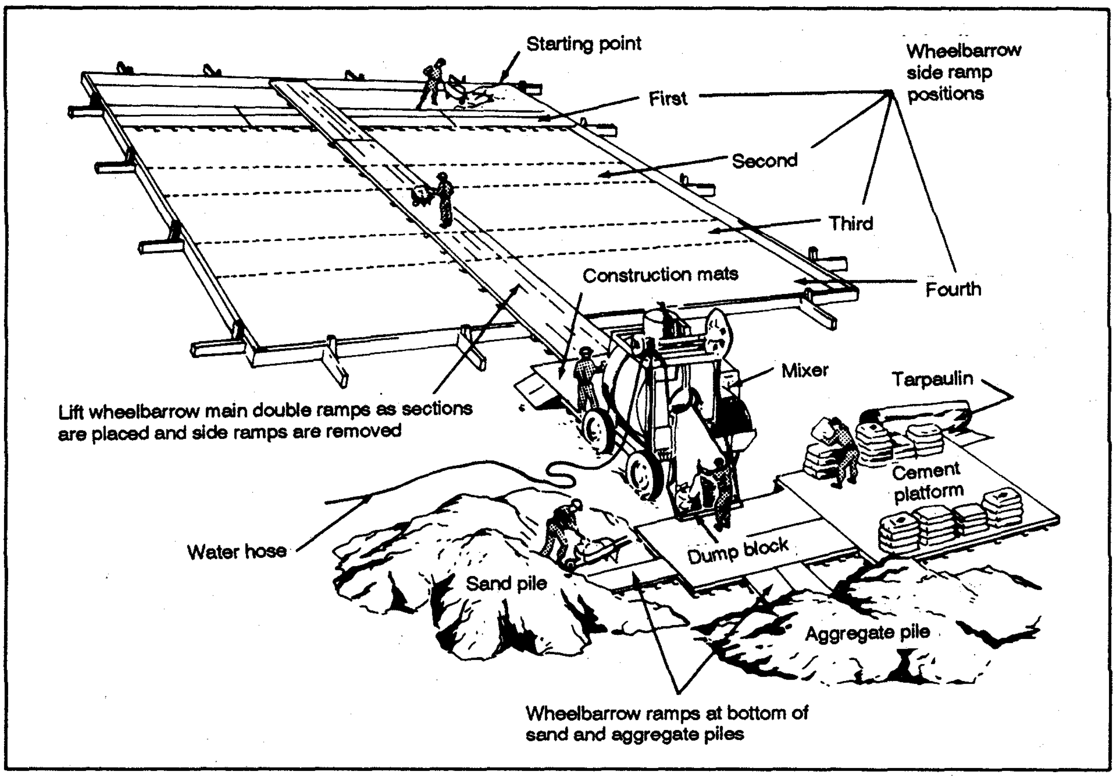
SUBCOURSE
EN 5466

EDITION
A

US ARMY ENGINEER CENTER AND SCHOOL

CONCRETE ENGINEERING



THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT
ARMY CORRESPONDENCE COURSE PROGRAM

AIPD

READINESS/PROFESSIONALISM THRU GROWTH

CONCRETE ENGINEERING

Subcourse Number EN 5466

EDITION A

United States Army Engineer School
Fort Leonard Wood, MO 65473

9 Credit Hours

Edition Date: September 1992

SUBCOURSE OVERVIEW

This subcourse is designed to teach you how to identify, plan, and supervise in general and specific terms for the following items: characteristic and properties of the components of concrete; ways to design concrete mixes; determination of quantities of concrete needed for specific construction projects; formwork design; mixing, placing and curing of concrete; and physical plants employed in the production of concrete.

There are no prerequisites for this subcourse.

This subcourse reflects current doctrine when this subcourse was prepared. In your own work, always refer to the latest publications.

Unless otherwise stated, the masculine gender of singular pronouns is used to refer to both men and women.

TERMINAL LEARNING OBJECTIVE

ACTION: You will identify concrete and concrete components; identify, plan, and use methods for proportioning concrete mixtures; identify and plan the design of forms and their construction. You will also identify and plan construction procedures for concreting operations.

CONDITION: Given this subcourse, a number (No) 2 pencil, paper, and an Army Correspondence Course Program (ACCP) examination response sheet. A calculator is recommended.

STANDARD: To demonstrate competency of this task, you must achieve a minimum of 70 percent on this subcourse examination.

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FM 5-742 Concrete and Masonry, 14 March 1985.

Use the above publication extracts to take this subcourse. At the time we wrote this subcourse, these were the current publications. In your own work situation, always refer to the latest publications.

LESSON 1

CONCRETE COMPONENTS

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will learn to identify desirable concrete properties and components and the use of factors involved in producing concrete and the methods employed.

TERMINAL LEARNING OBJECTIVE:

ACTION: Identify desirable concrete properties and components. Have the ability to use the factors involved in producing a desirable concrete mix and the methods employed to overcome limitations involved in concrete production.

CONDITION: You are given the materials contained in this lesson.

STANDARD: Correctly answer all practice exercise questions at the end of each lesson.

REFERENCE: The material contained in this lesson was derived from the following publication: FM 5-742, with change 1.

INTRODUCTION

Concrete is one of the most versatile, economical, and universally used construction material. It is among the few building materials produced directly on the job by the user. To know proper mix, it is important for the user to identify desirable properties and components and to be able to use factors involved in producing concrete and the methods employed in concrete production. This lesson will help supervisors gain knowledge of the production and use of concrete materials.

PART A - DESIRABLE CONCRETE PROPERTIES

BASIC CONSIDERATION

Concrete Composition

Concrete is a mixture of aggregate and often controlled amounts of entrained air held together by a hardened paste made from cement and water. Although there are other kinds of cement, the word *cement*, in common usage, refers to portland cement. A chemical reaction between the portland cement and water, not drying of the mixture, causes concrete to harden to a stonelike condition. This reaction is called hydration. Hydration gives off heat, known as the *heat of hydration*. Because hydration, not air drying, hardens concrete, freshly placed concrete submerged underwater will harden. When correctly proportioned, concrete is at first a plastic mass that can be cast or molded into nearly any size or shape. Upon hydration of the cement by the water, concrete becomes stonelike in strength, durability, and hardness.

Portland Cement. This is the most commonly used of modern hydraulic cements. In this case, the word *hydraulic* means that the cement's characteristic of holding aggregate together is caused by water or other low-viscosity fluids. Portland cement is a carefully proportioned and specially processed chemical combination of lime, silica, iron oxide, and alumina.

Mixing Water. Unless tests or experience indicates that a particular water source is satisfactory, mixing water should be free from acids, alkalies, oils, and organic purities. The basic ratio of water to cement determines the strength of concrete. The less water in the mix, as long as it is workable and not too stiff, the stronger, more durable, and watertight the concrete. Too much water dilutes cement paste (binder), resulting in weak and porous concrete. Concrete quality varies widely, depending on the characteristics of its ingredients and the proportion of the mix.

Aggregates. Inert filler material (usually sand and stone or gravel) make up between 60 to 80 percent of the volume of normal concrete. Aggregate is often washed when impurities or excess fines that can retard cement hydration or otherwise deteriorate concrete quality are found. All aggregate is screened to ensure proper size gradation because concrete differs from other cement-water-aggregate mixtures in the size of its aggregate. For example, when cement is mixed with water and an aggregate passing the No 4 sieve, it is called *mortar*, *stucco*, or *cement plaster*. When cement is mixed with coarse aggregate of more than 1/4-inch, plus fine aggregate and water, the product is *concrete*. The physical and chemical properties of the aggregate also affect concrete properties. Aggregate size, shape, and grade influence the amount of water required. Aggregate surface texture influences the bond between the aggregate and the cement paste. In properly mixed concrete, the paste completely surrounds each aggregate particle and fills all spaces between the particles. The elastic properties of the aggregate influence the elastic properties of the concrete and the pastes resistance to shrinkage. Reactions between the cement paste and the aggregate can either improve or harm the bond between the two and, consequently, the concrete quality.

Air. All concrete contains some air. If air is chemically induced into the mix, it is called *entrained air*. Entrained air adds beneficial qualities to the concrete such as increased freeze-thaw capabilities, durability, and watertightness. Entrained air can range from 1.5 to 7.5 percent. Air that is added to the mix as a result of the mixing process is called *entrapped air*. Entrapped air adds nothing to the mix; however, this air can range from 0.5 to 3 percent.

Admixtures. When mixing concrete, these substances are added to accelerate or retard the initial set, improve workability, reduce mixing water requirements, increase strength, or otherwise alter concrete properties. They usually cause a chemical reaction within the concrete. Admixtures are normally classified into accelerators, retarders, air-entraining agents, water reducers, and pozzolans. Many admixtures fall into more than one classification.

Concrete as a Building Material

Concrete has a great variety of applications because it not only meets structural demands but also lends itself readily to architectural treatment. In buildings, concrete is used for footings, foundations, columns, beams, girders, wall slabs, and roof units--in short, all important building elements. Other important concrete applications are in road pavements, airport runways, bridges, dams, irrigation canals, water-diversion structures, sewage-treatment plants, and water-distribution pipelines. A great deal of concrete is used in manufacturing masonry units, such as concrete blocks and concrete bricks.

Advantages. Concrete and cement are among the most important construction materials. Concrete is fireproof, watertight, comparatively economical, and easy to make. It offers surface continuity (absence of joints) and solidity and bond with other materials.

Limitations. Certain limitations of concrete cause cracking and other structural weaknesses that detract from the appearance, serviceability, and useful life of concrete structures. Listed below are some principal limitations and disadvantages of concrete:

- *Low tensile strength.* Concrete members subject to tensile stress must be reinforced with steel (rebar) to prevent excess cracking and failure.

- *Thermal movements.* During setting and hardening, the heat of hydration raises the concrete temperature, and then gradually cools. These temperature changes can cause severe thermal strains and early cracking. In addition, hardened concrete expands and contracts with changes in temperature (at roughly the same rate as steel); therefore, expansion and contraction joints must be provided in many types of concrete structures to prevent failures.

- *Drying shrinkage and moisture movements.* Concrete shrinks as it dries out and, even when hardened, expands and contracts with wetting and drying. These movements require that control joints be provided at intervals to avoid unsightly cracks. To prevent drying shrinkage in newly placed concrete, its surface is kept moist continuously during the curing process. Moisture is applied as soon as the concrete is hard enough to prevent damage to the concrete's surface.

- *Creep.* Concrete deforms creeps gradually under load, and this deformation does recover completely when the load is removed.

- *Permeability.* Even the best quality concrete is not entirely impervious to moisture. It contains soluble compounds that are leached out in varying amounts by water. Unless properly constructed, joints allow water to enter the mass. Permeability is particularly important in reinforced concrete because the concrete must prevent water from reaching the steel reinforcement.

Describing and Measuring Ingredients. The unit of measure for cement is the cubic foot (cf). Thus, a standard sack of portland cement weighs 94 pounds and equals one loose cubic foot. Fine and coarse aggregate is measured by loose volume, whereas water is measured by the gallon. Concrete is usually referred to by cubic yards (cy).

CONCRETE PROPERTIES

Plastic Concrete

Plastic concrete in a relatively fluid state can be readily molded by hand like a clump of modeling clay. A plastic mix keeps all grains of sand and pieces of gravel or stones encased and held in place (homogeneous). The degree of plasicity influences the quality and character of the finished product Significant changes in the mix proportions affect plasticity. Desirable properties of plastic concrete are listed below.

Workability. This property describes the relative ease or difficulty of placing and consolidating concrete in the form. Workability is largely determined by the proportions of fine and coarse aggregate added to a given quantity of paste. One characteristic of workability is consistency, which is measured by the slump test (see Part C on page 1-20). A specific amount of slump is necessary to obtain the workability required by the intended conditions and method of placement. A very stiff mix has a low slump and, although difficult to place in heavily reinforced sections, is desirable for many uses. A more fluid mix is necessary when placing concrete around reinforcing steel.

Nonsegregation. Plastic concrete must be homogeneous and carefully handled to keep segregation to a minimum. For example, plastic concrete should not drop (free-fall) more than 3 to 5 feet nor be transported over long distances without proper agitation.

Uniformity. The uniformity of plastic concrete affects both its economy and strength. Uniformity is determined by how accurately the ingredients are proportioned and mixed according to specifications. Each separate batch of concrete must be proportioned and mixed exactly the same to ensure that the total structural mass has uniform structural properties.

Hardened Concrete

This is the end product of any concrete design. The essential properties it must have are strength, durability, and watertightness.

Strength. The ability of concrete to resist a load in compression, flexure, or shear is a measure of its strength. Concrete strength is largely determined by the ratio of water to cement in the mixture (pounds of water and pounds of cement). A sack of cement requires about 2 1/2 gallons of water for hydration. More water is added to allow for workability, but too much water (a high water and cement (w/c) ratio) reduces concrete strength. The amount of water in economical concrete mixes ranges from 4 gallons minimum to 7 gallons maximum per sack.

Durability. Climate and weather exposure affect durability. Concrete's ability to resist the effects of wind, frost, snow, ice, abrasion, and the chemical reaction of soils or salts is a measure of its durability. As the w/c ratio increases, durability decreases correspondingly. Durability should be a strong consideration for concrete structures expected to last longer than five years. Air-entrained concrete has improved freeze-thaw durability.

Watertightness. Tests show that the watertightness of a cement paste depends on the w/c ratio and the extent of the chemical reaction progress between the cement and water. Corps of Engineers specifications for watertightness limit the maximum amount of water in concrete mixtures to 5.5 gallons per sack of cement (w/c = 0.48) for concrete exposed to fresh water and 5.0 gallons per sack (w/c = 0.44) for concrete exposed to salt water. The watertightness of air-entrained concrete is superior to that of non-air-entrained concrete. (See Lesson 2, Table 2-1 on page 2-3.)

PART B - DESIRABLE CONCRETE COMPONENTS

PORTLAND CEMENTS

Composition

Portland cements contain lime and day minerals (such as limestone, oyster shells, coquina shells, marl, clay, and shale), silica, sand, iron ore, and aluminum.

Manufacture

The raw materials are finely ground carefully proportioned, and then heated (calcined) to the fusion temperature (2,600° to 3,000° Fahrenheit (F)) to form hard pellets called clinkers. The clinkers are ground to a fine powder. The cement powder is so fine that nearly all of it will pass through a No 200 sieve (200 meshes to the linear inch, or 40,000 openings per square inch). Regardless of the manufacturer, portland cement is the standard for the trade.

American Society for Testing and Materials (ASTM) Types

ASTM specifications cover five types of portland cements in ASTM CI50, "Standard Specifications for Portland Cement."

- *Type I.* This is a general-purpose cement of concrete that does not require any special properties of the other types. In general, it is intended for concrete that is not subjected to sulfate attack or when the heat of hydration will not cause too much of a temperature rise. Type I portland cement is used in pavement and sidewalk construction, reinforced-concrete buildings and bridges, railways, tanks, reservoirs, sewers, culverts, water pipes, masonry units, and soil and cement mixtures. It is more available than the other types. Type I cement will reach its design strength in 28 days.

- *Type II.* This is modified to resist a moderate sulfate attack. It usually generates less heat of hydration and at a slower rate than Type I. Typical applications are drainage structures, where the sulfate concentrations in either the soil or groundwater are higher than normal but are not severe, and large structures in which its moderate heat of hydration produces only a slight temperature rise in the concrete. However, temperature rise can be a problem when concrete is placed in warm weather. Type I cement will reach its design strength in 45 days.

- *Type III.* This is a high, early strength cement that produces strengths at an early age, usually seven days or less. It has a higher heat of hydration and is more finely ground than Type I. Type III permits fast form removal and, in cold weather construction, reduces the period of protection against low temperatures. Although richer mixtures of Type I can obtain high early strength, Type III produces it more satisfactorily and more economically. Use it cautiously in concrete structures having a minimum dimension of 2 1/2 feet or more because the high heat of hydration can cause shrinkage cracking.

- *Type IV.* This cement is a very special cement. It has a low heat of hydration intended for applications requiring a minimal rate and amount of heat of hydration. Its strength also develops at a slower rate than the other types. Type IV is used primarily in large concrete structures, such as gravity dams, where the temperature rise from the heat of hydration could damage the structure. Type IV cement will reach its design strength in 90 days.

- *Type V.* This concrete is sulfate-resistant and is used mainly where the concrete is subject to severe sulfate action, such as when the soil or groundwater contacting the concrete has a high sulfate content. Type V cement will reach its design strength in 60 days.

Other ASTM Cements

Separate ASTM specifications cover the following types of portland cements:

- *Air-entrained portland cement.* Types IA, IIA, and IIIA correspond in composition to Types I, II, and III, with the addition of small quantities of air-entrained materials interground with the clinker during manufacturing. Air-entrained portland cements produce concrete that have improved resistance to freeze-thaw action and to scaling caused by snow and ice removal chemicals. Such concrete contains extremely small (as many as 300 billion per cubic yard), well-distributed, and completely separate air bubbles.

- *Masonry cements.* Sometimes called mortar cements, these are, typically, mixtures of portland cement and hydrated lime and other materials that improve workability, plasticity, and water retention.

Packaging and Shipping

Cement is shipped by railroad, truck, or barge either in standard sacks weighing 94 pounds or in bulk. Cement quantities for large projects maybe stated in tons.

Storage

Portland cement that is kept dry retains its quality indefinitely. Store sacked cement in a warehouse or shed that is as airtight as possible. If no shed is available, place the sacks on raised wooden platforms. Place the sacks close together (to reduce air circulation) and away from exterior walls. Cover sacks to be stored outside for long periods with tarpaulins or other waterproof coverings so that rain cannot reach either the cement or the platforms. Rain-soaked platforms can damage the bottom layers of sacks.

Cement should be free-flowing and free from lumps at the time of use. Sometimes sacked cement that is stored develops what is called warehouse pack. This is a slightly hardened condition caused by packing sacks too tightly or too high. Such cement still retains its quality and is usually restored to free-flowing by rolling the sacks on the floor. However, if the cement contains lumps that are difficult to break up, test the cement to determine its quality. Hard lumps indicate partial hydration that reduces both the strength and durability of the finished concrete. Partially hydrated cement must not be used in structures where strength is a critical factor. Store bulk cement in weatherproof bins.

WATER

Purpose

Water has two functions in the concrete mix, to effect hydration and to improve workability.

Impurities

Mixing water should be clean and free from organic materials, alkalies, acids, and oil. As a general rule, potable water is usually suitable for mixing with cement. However, water containing many sulfates may be drinkable, but it makes a weak paste that leads to concrete deterioration or failure. Water of unknown quality can be used if mortar cubes made with it have 7- and 28-day strengths, equaling at least 90 percent of the control cubes made with potable water. Test batches can also determine whether or not the cement's setting time is unfavorably affected by water impurities. Too many impurities in mixing water can affect not only setting time but can cause surface efflorescence and corrosion of the steel reinforcement. In some cases you can increase the concrete's cement content to offset the impurities.

AGGREGATES

Characteristics

Aggregates make up from 60 to 80 percent of concrete volume. Their characteristics influence the mix proportions and economy of the concrete considerably. For example, very rough-textured or flat and elongated particles require more water to produce workable concrete than do rounded or cubed particles. Angular particles require more cement paste to coat them, making the concrete more expensive. For most purposes, aggregates should be clean, hard, strong, durable, and free from chemicals or coatings of clay or other fine materials that affect the bond of the cement paste. The most common contaminating materials are dirt, silt, clay, mica, salts, and humus or other organic matter that appears as a coating or as loose, fine material. You can remove many contaminants simply by washing the aggregate. However, test coarse aggregate containing easily crumbled or laminated particles. The most commonly used aggregates are sand, gravel, crushed stone, and blast-furnace slag. They produce normal weight concrete (concrete that weighs 135 to 160 pounds per cubic foot). Normal weight aggregates should meet "Specifications for Concrete Aggregates," which restricts contaminating substances and provide standards for gradation, abrasion resistance, and soundness. Aggregate characteristics, significance, and standard tests for evaluating these characteristics are given in Table 1-1 and discussed below.

Table 1-1. Aggregate characteristics and standards tests.

Characteristic	Significance or Importance	ASTM Test or Practice Designation	Specification Requirement
Resistance to abrasion	Index of aggregate quality. Warehouse floors, loading platforms, and pavements.	C131	Maximum percent loss.*
Resistance to freezing and thawing	Structures subjected to weathering.	C666	Maximum number of cycles.
Chemical stability	Strength and durability of all types of structures.	C227 (mortar bar) C289 (chemical) C586 (aggregate prism) C295 (petrographic)	Maximum expansion of mortar bar. *Aggregates must not be reactive with cement alkalies.
Particle shape and surface texture	Workability of fresh concrete.		Maximum percent flat and elongated pieces.
Grading	Workability of fresh concrete. Economy.	C136	Maximum and minimum percent passing standard sieves.
Bulk unit weight	Mix design calculations. Classification.	C29	Maximum and minimum unit weight (special concrete).
Specific gravity	Mix design calculations.	C127 (coarse aggregate) C128 (fine aggregate)	
Absorption and surface moisture	Control of concrete quality.	C70, C127, and C128	

*Aggregates not conforming to specification requirements can be used if either service records or performance tests indicate that they produce concrete having the desired properties.

Aggregate Size, Distribution, and Grading

These affect the concrete's workability, economy, porosity, and shrinkage. For example, experience shows that very fine sands are uneconomical, whereas very coarse sands produce harsh, unworkable mixes. The proportioning of the different particle sizes is called grading an aggregate. Grading is controlled by the aggregate producer. The particle size distribution of aggregate is determined by separation with a series of standard sieves. The six standard sieves for fine-aggregate are Nos 4, 8, 16, 30, 50, and 100. Sieves for coarse aggregate are 3, 1 1/2, 3/4, and 3/8 inch, and No 4. The number of a fine-aggregate sieve corresponds to the number of meshes (square openings) to the linear inch that the sieve contains. The higher the number, the finer the sieve. Any material retained in the No 4 sieve is considered coarse aggregate, and any material that passes the No 200 sieve is too fine for concrete. The finest coarse-aggregate sieve is the same No 4 used as the coarsest fine-aggregate sieve. With this exception, a coarse-aggregate sieve is designated by the size of one of its mesh openings. The size of the mesh openings in consecutive sieves is related by a constant ratio. Size distribution graphs show the percent of material passing each sieve (see Figure 1-1). Figure 1-1 also gives the grade limits for fine-aggregates and for one designated size of coarse aggregate. Normal coarse aggregate consists of gravel or crushed stone, whereas normal fine aggregate is sand.

Figure 1-1. Limits specified in ASTM C33 for fine-aggregates and for one size of coarse-aggregate.

- *Fineness modulus (FM).* This is a number that indicates the fineness of a fine aggregate but is not the same as its grade. Many fine-aggregate gradings can have an identical FM. To obtain the FM of a fine aggregate (see Figure 1-2), quarter a sample of at least 500 grams of sand and sieve it through the Nos 4, 8, 16, 30, 50, and 100 sieves. Record the individual weights of the materials retained on each sieve and the cumulative retained weights. Add the cumulative percents and divide by 100. The result is the FM of the sample. A sand with an FM falling between 2.3 and 3.1 is suitable for concrete (see Table 1-2). In general, fine aggregate having either a very high or a very low FM is not as good a concrete aggregate as medium sand. Coarse sand is not as workable, and fine sands are uneconomical. Take care to obtain representative samples. The FM of the aggregate taken from one source should not vary more than 0.20 from all test samples taken at that source.

Screen Size	Weight Retained (Grams) Individual	Cumulative	Cumulative Percent Retained
No 4	40	40	4
No 8	130	170	17
No 16	130	300	30
No 30	250	550	55
No 50	270	820	82
No 100	100	920	92
Pan	80	—	—
Total Weight	1,000	—	280
	$FM = \frac{280}{100} = 2.80$		

Figure 1-2. Typical FM calculation.

Table 1-2. FM ranges for fine aggregate.

FM	Designation
2.3 to 2.59	Fine sand
2.6 to 2.89	Medium sand
2.9 to 3.1	Coarse sand

- *Fine-aggregate grading.* The selection of the best fine-aggregate grading depends on the application, richness of the mix, and the maximum size of coarse aggregate used. In leaner mixes, or when small coarse aggregate is used, a fine-aggregate grading near the maximum recommended percentage passing each sieve is desirable for workability. In richer mixes, coarser fine-aggregate gradings are desirable for economy. In general, if the water and cement ratio is kept constant and the ratio of fine-to-coarse aggregate is chosen correctly, you can use a wide range of fine-aggregate gradings without much effect on strength. Grading is expressed as the percentages by weight passing through the various standard sieves. The amount of fine aggregate passing the No 50 and 100 sieves affects workability, finished surface texture, and water gain or bleeding. For thin walls, hard-finished concrete floors, and smooth concrete surfaces cast against forms, the fine aggregate should contain not less than 15 percent passing the No 50 sieve and at least 3 or 4 percent, but not more than 10 percent, passing the No 100 sieve. These minimum amounts of fines give the concrete better workability, make it more cohesive, and produce less water gain or bleeding than lower percentages of fines. In no case should the percent passing a No 200 sieve exceed 5 percent and only 3 percent if the structure is exposed to abrasive wear. Aggregate gradings falling within the limits are generally satisfactory for most concretes.

- *Coarse-aggregate grading.* The grading of coarse aggregate of a given maximum size can vary over a wide range without much effect on cement and water requirements if the proportion of fine aggregate produces concrete having good workability. Table 1-3 gives the grading requirements for coarse aggregate. If coarse-aggregate grading varies too much, you may need to vary the mix proportions to produce workable concrete or, more economically, request the producer to adjust his operation to meet the grading requirements.

Table 1-3. Grading requirements for coarse aggregate.

Amount Finer Than Each Laboratory Sieve (Square Openings), Percent by Weight								
Size Number	Nominal Size (Sieves) with Square Openings	4 inches	3 1/3 inches	3 inches	2 1/2 inches	2 inches	1 1/2 inches	1 inch
1	3 1/2 to 1 1/2 inches	100	90 to 100		25 to 60		0 to 15	
2	2 1/2 to 1 1/2 inches			100	90 to 100	35 to 70	0 to 15	
357	2 inches to No 4				100	95 to 100		35 to 70
467	1 1/2 inches to No 4					100	95 to 100	
57	1 inch to No 4						100	95 to 100
67	3/4 inch to No 4							100
7	1/2 inch to No 4							
8	3/8 inch to No 8							
3	2 to 1 inch				100	90 to 100	35 to 70	0 to 15
4	1 1/2 to 3/4 inch					100	90 to 100	20 to 55

Amount Finer Than Each Laboratory Sieve (Square Openings), Percent by Weight							
Size Number	Nominal Size (Sieves) with Square Openings	3/4 inch	1/2 inch	3/4 inch	No 4	No 8	No 16
1	3 1/2 to 1 1/2 inches	0 to 5					
2	2 1/2 to 1 1/2 inches	0 to 5					
357	2 inches to No 4		10 to 30		0 to 5		
467	1 1/2 inches to No 4	35 to 70		10 to 30	0 to 5		
57	1 inch to No 4		25 to 100		0 to 10	0 to 5	
67	3/4 inch to No 4	90 to 100		20 to 55	0 to 10	0 to 5	
7	1/2 inch to No 4	100	90 to 100	40 to 70	0 to 15	0 to 5	
8	3/8 inch to No 8		100	85 to 100	10 to 30	0 to 10	0 to 5
3	2 to 1 inch		0 to 5				
4	1/2 to 3/4 inch	0 to 15		0 to 5			

*From specifications for concrete aggregate (ASTM-C33).

Coarse aggregate should be graded up to the largest practicable size for the job conditions. According to the American Concrete Institute (ACI) 318-83, nominal maximum size of coarse aggregate cannot be larger than one-fifth the narrowest dimension between the sides of forms, nor one-third the depth of slabs, nor three-fourth the minimum clear spacing between individual reinforcing bars or wires, bundles of bars, or prestressing tendons or ducts. The type of equipment also limits the aggregate size. The 16S mixer can handle up to 3 inches of aggregate, while the maximum size aggregate for the M919 concrete mobile is 1.5 inches. These limitations may be waived if, in the judgment of the engineer, workability and methods of consolidation are such that concrete can be placed without honeycomb or voids. The larger the maximum size of the coarse aggregate, the less paste (water and cement) required to produce a given quality. Field experience shows that the amount of water required per unit volume of concrete for a given consistency and given aggregates is nearly constant, regardless of the cement content or relative proportions of water to cement. Further, the amount of water required decreases with increases in the maximum size of the aggregate. The water required per cubic yard of concrete with a slump of 3 to 4 inches is shown in Figure 1-3 for a wide range of coarse-aggregate sizes. The figure demonstrates that for a given w/c ratio, the amount of cement required decreases as the maximum size of coarse aggregate increases. However, in some instances, especially in higher strength ranges, concrete containing smaller maximum-size aggregate has a higher compressive strength than concrete with larger maximum-size aggregate at the same w/c ratio.

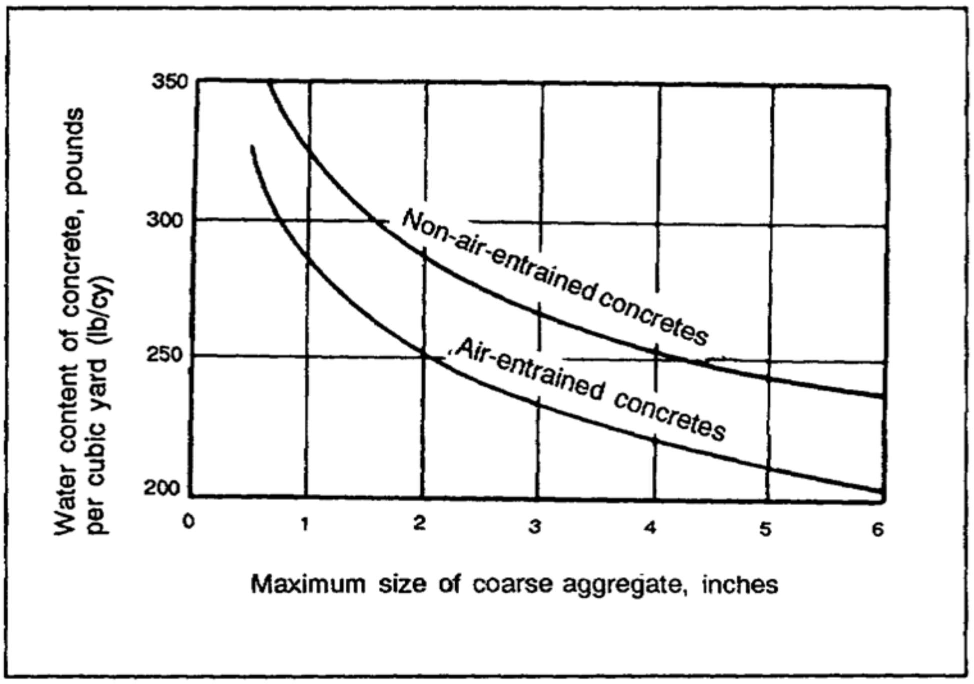

Figure 1-3. Water requirement for concrete of a given consistency as a function of coarse-aggregate size.

Bulk Unit Weight

The weight of the aggregate that fills a 1-cubic-foot container. This term is used because the volume contains both aggregate and voids air spaces.

Specific Gravity

The ratio of the density of an aggregate to the density of water. Normal weight aggregates have specific gravities ranging from 2.4 to 2.9. The internal structure of an aggregate particle is made up of both solid matter and pores or voids that may or may not contain water. The specific gravities used in concrete calculations are generally for saturated, surface-dry aggregates, that is, when all pores are filled with water but no excess moisture is present on the surface.

Absorption and Surface Moisture

Both must be known to control the net water content of the concrete and determine correct batch weights. The four moisture conditions of aggregates are illustrated in Figure 1-4.

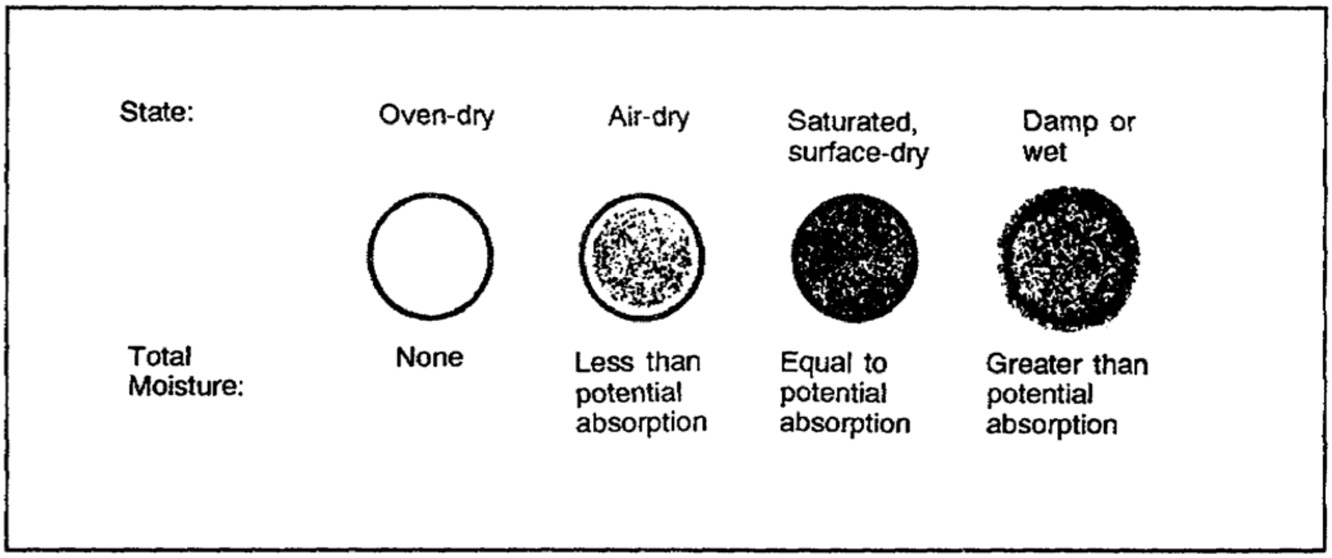

Figure 1-4. Moisture conditions of aggregates.

- *Oven-dry.* Surface and pores are bone-dry and fully absorbent.
- *Air-dry.* Surface is dry but contains some interior moisture and is therefore somewhat absorbent.
- *Saturate surface-dry (SSD).* Surface is dry but pores are saturated--neither absorbing water from nor contributing water to the concrete mix. The design is based on aggregate in the SSD condition.
- *Damp or wet.* Surface contains an excess of moisture (free surface moisture (FSM)).

Bulking

Bulking is the increase in volume caused by surface moisture holding the particles apart. This occurs when damp fine aggregate is handled. Figure 1-5 shows the variation in the amount of bulking with moisture content and grading. Sand is usually delivered in batch quantities in a damp condition. Due to bulking actual sand content can vary widely in a batch volume, often not in proportion to the moisture content of the sand. Therefore, be very careful when proportioning by volume. Too much moisture on the aggregate surfaces also adds to the concrete mixing water. The amount can be considerable, especially the excess water in fine aggregate.

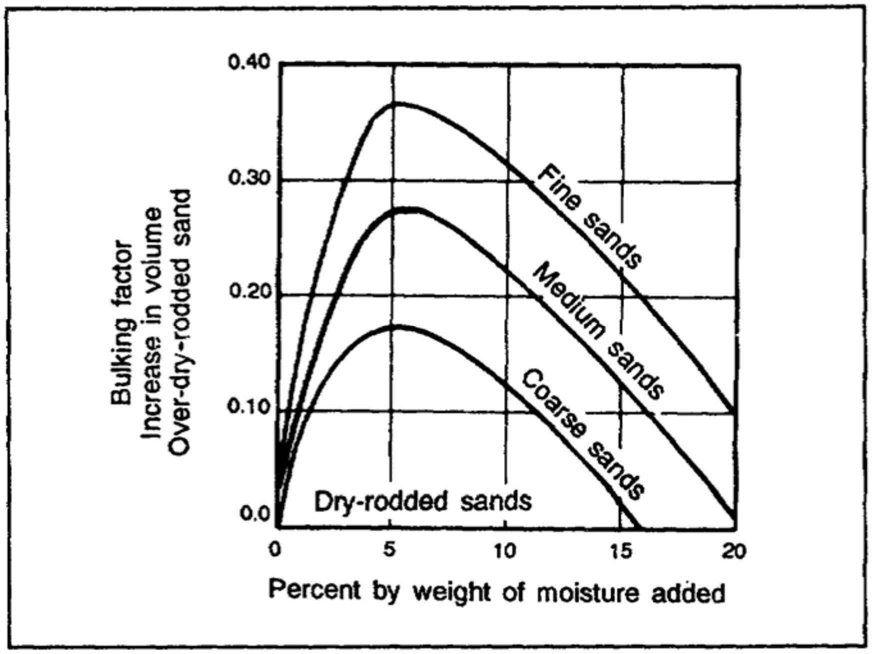

Figure 1-5. Variation in fine-aggregate bulking with moisture and aggregate grading.

Impurities

Aggregates can contain such impure substances as organic matter, silt, clay, coal, lignite, and certain lightweight and soft particles. Table 1-4 summarizes the effects of these substances on concrete.

Table 1-4. Impurities in aggregates.

Impure Substances	Effect on Concrete	ASTM Test Designation
Organic impurities	Setting and hardening, may cause deterioration	C40 C87
Materials finer than No 200 sieve	Bonding increase in water requirement	C117
Coal, lignite, or other lightweight materials	Durability, may cause stains and popouts	C123
Soft particles	Durability	C235
Friable particles	Workability and durability, may cause popouts	C142

Handling and Storing

Figure 1-6 on pages 1-14 and 1-15 shows both the correct and incorrect methods of handling and storing aggregate. You must handle and store aggregates to minimize segregation and prevent contamination by impure substances. Aggregate is normally stored in stockpiles built up in layers of uniform thickness. Do not build up the stockpiles in high cones or allow them to run down slopes because this causes segregation. Do not allow aggregate to fall freely from the end of a conveyor belt either. To minimize segregation, remove aggregates from stockpiles in horizontal layers. When you are using batching equipment and storing some aggregate in bins, load the bins by allowing the aggregate to fall vertically over the outlet. Chuting the materials at an angle against the side of the bin causes particle segregation.

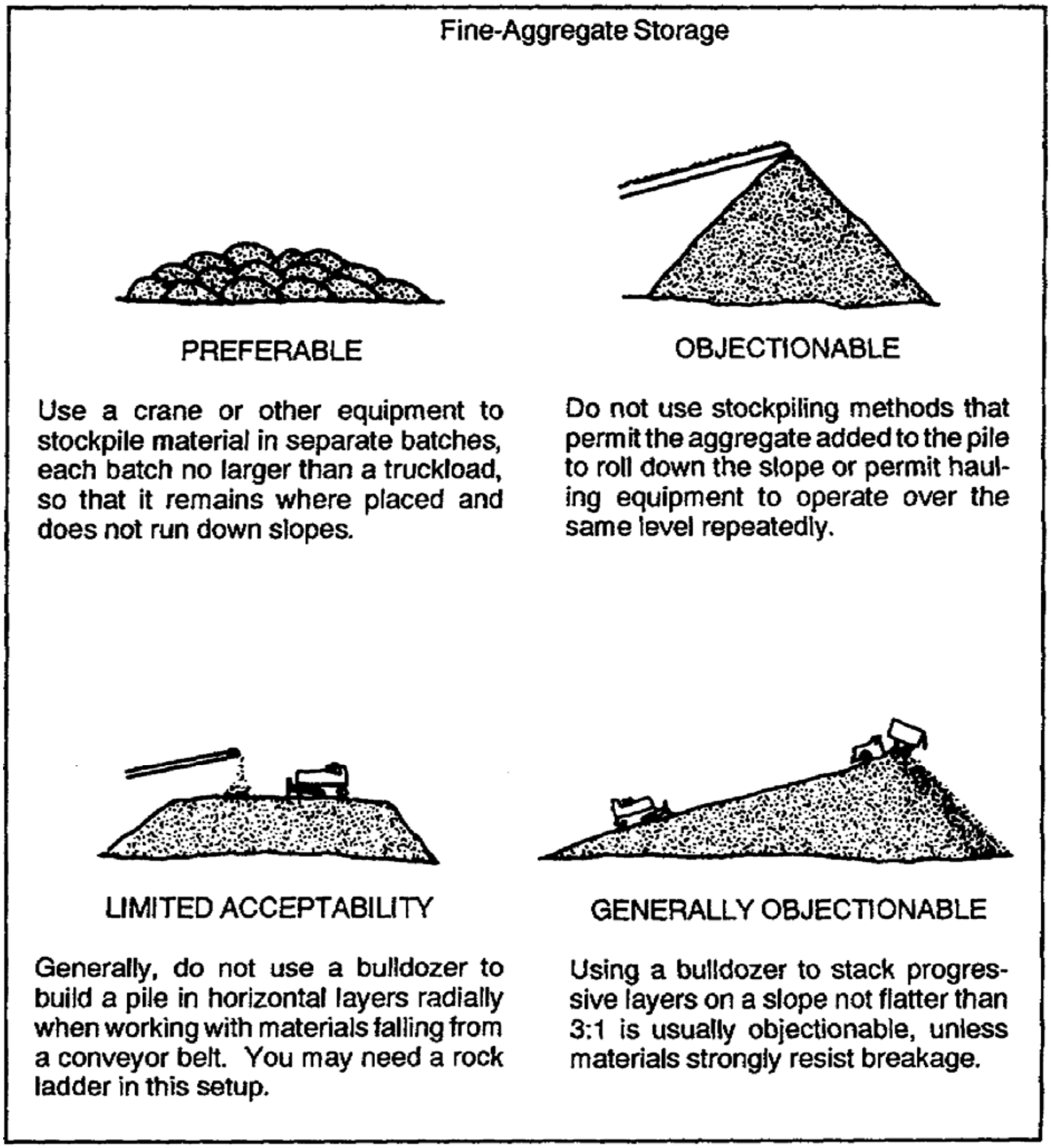

Figure 1-6. Correct and incorrect aggregate handling and storage.

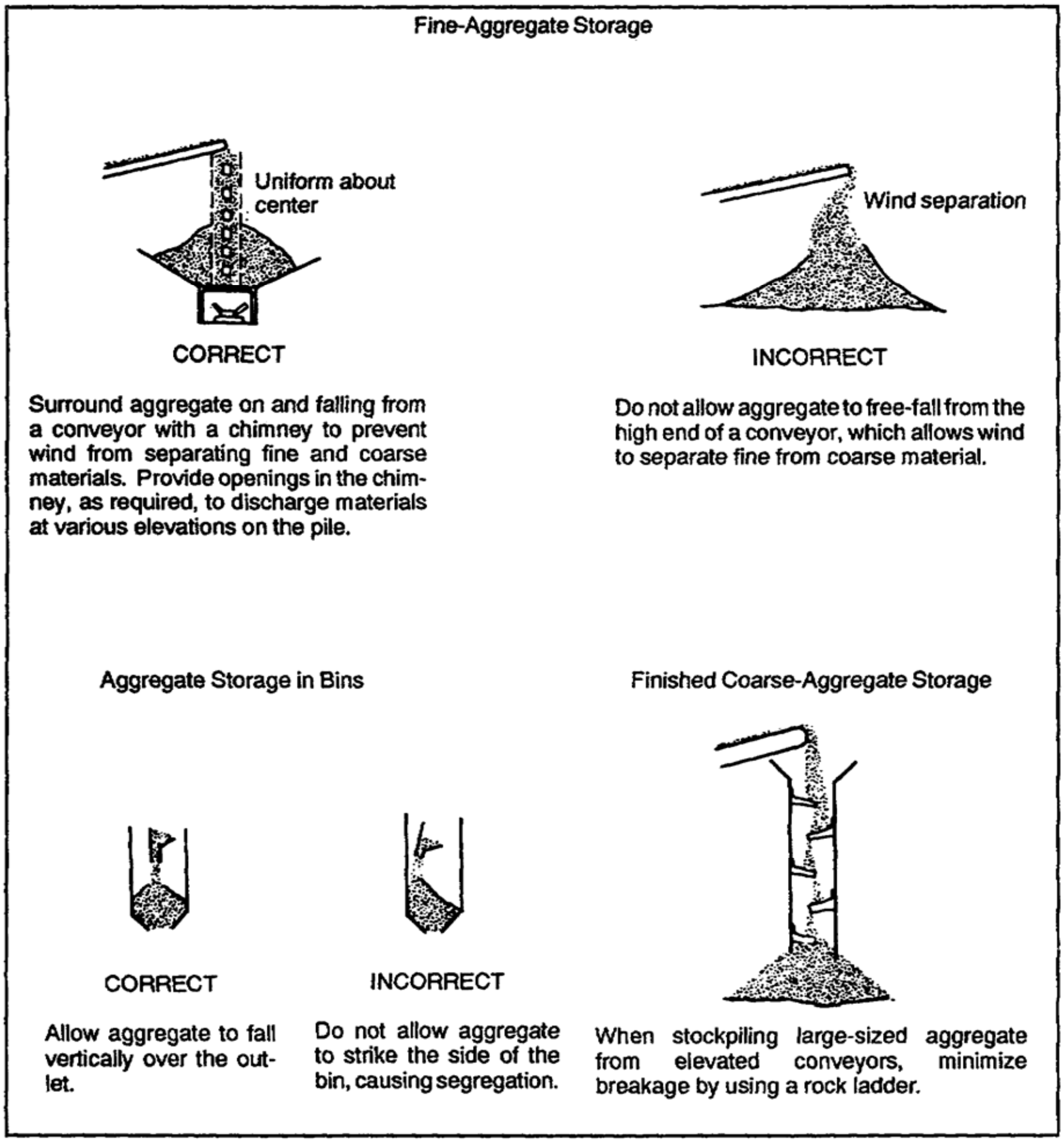

Figure 1-6. Correct and incorrect aggregates handling and storage. (continued)

ADMIXTURES

Definition and Purpose

An admixture is any material other than cement, water, or aggregate that is added to concrete in small quantities, either immediately before or during mixing, to modify such properties as workability, strength, durability, watertightness, or wear resistance. Admixtures can also reduce segregation and the heat of hydration and entrained air and either accelerate or retard setting and hardening. You can often obtain similar results by changing the concrete mix proportions instead of using admixtures (except air-entrained ones). When possible, examine all alternatives before using an admixture to determine which is more economical and convenient

Air-Entrained Concrete

A major advance in concrete technology in recent years is the introduction of tiny disconnected air bubbles into concrete called *air-entrainment*. Air-entrainment concrete results from using either an air-entrained cement or an air-entrained admixture during mixing. Adding entrained air to concrete is recommended for most purposes because it provides important benefits in both plastic and hardened concrete, such as resistance to freezing and thawing in a saturated environment. Air entrapped in non-air-entrained concrete fills relatively large voids that are not uniformly distributed throughout the mix. However, entrained air is well-distributed throughout the mass as shown in Figure 1-7. Note that the microphotograph is scaled in hundredths, not thousandths of an inch, although the bubble diameters actually have sizes of less than 0.004 of an inch. Air-entrained concrete improves its workability, watertightness, and resistance to deicers and sulfates.

Figure 1-7. Polished section of air-entrained concrete magnified many times.

Air-entrained materials. Air can be entrained in concrete by using air-entrained cement, by using an air-entrained admixture at the mixer, or by combining both methods. Use adequate controls to ensure the proper air content at all times.

Factors Affecting Air Content

- *Slump and vibration.* This affects the air content of air-entrained concrete because the greater the slump, the larger the percent reduction in air content during vibration. At all slumps, even 15-second vibration causes reduced air content. However, properly applied vibration mainly eliminates large air bubbles and little of the intentionally entrained air bubbles.

- *Concrete temperature.* The effects of concrete temperature becomes more pronounced as the slump increases. Less air is entrained as concrete temperature increases.

- *Mixing action.* This is the most important factor in producing air-entrained concrete. The amount of entrained air varies with the mixer type and condition, the amount of concrete mixed, and the mixing rate. Stationary and transit mixers may produce concrete having very different amounts of entrained air. Mixers not loaded to capacity can increase air content, whereas overloading can decrease air content. Generally, more air is entrained as the mixing speed increases.

- *Premature finishing operations.* This can cause excess water to work to the concrete surface. If this occurs, the surface zone may not contain enough entrained air and be susceptible to scaling.

Recommended Air Contents

Air contents for frost-resistant concrete are shown in Table 1-5. Such concrete must be used when there is a danger of concrete freezing while saturated or nearly saturated with water.

Table 1-5. Approximate mixing water and air content requirements for different slumps and maximum sizes of aggregates.

Water, Pounds per Cubic Yard of Concrete, for Indicated Maximum Sizes of Aggregate.*								
Slump, inches	3/8	1/2	3/4	1	1 1/2	2**	3**	6**
Non-air-Entrained Concrete								
1 to 2	350	335	315	300	275	260	240	210
3 to 4	385	365	340	325	300	285	265	230
6 to 7	410	385	360	340	315	300	285	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained Concrete								
1 to 2	305	295	280	270	250	240	225	200
3 to 4	340	325	305	295	275	265	250	220
6 to 7	365	345	325	310	290	280	270	—
Recommended average total air content, percent for level of exposure								
Mild exposure	4.5	4.0	3.5	3.0	5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

*These quantities of mixing water are for use in computing cement factors for trial batches. They are maximums for reasonably well-shaped angular coarse aggregates graded within limits of accepted specifications.

**The slump values for concrete containing aggregate larger than 1 1/2 inches are based on slump tests made after removal of particles larger than 1 1/2 inches by wet-screening.

Tests for Air Content

Tests that determine air-entrainment in freshly mixed concrete measure only air volume, not air void characteristics. Make tests regularly during construction, using plastic samples taken immediately after discharge from the mixer and also from already placed and consolidated concrete. Standard methods to determine the air content of plastic concrete include pressure (air-entrained meter), volumetric, and gravimetric method. Check with your battalion as to which method is normally used.

Water-Reducing Admixtures

These reduce the quantity of mixing water required to produce concrete of a given consistency. They increase the slump for a given water content.

Retarding Admixtures

These are sometime used to reduce the rate of hydration to permit placing and consolidating concrete before the initial set. They also offset the accelerating effect of hot weather on the set. These admixtures generally consist of fatty acids, sugars, and starches.

Accelerating Admixtures

These accelerate the set and strength development. Calcium chloride is the most common. Add it in solution form as part of the mixing water but not exceeding 2 percent by weight of cement. Do not use calcium chloride or other admixtures containing soluble chlorides in prestressed concrete, concrete containing embedded aluminum which has permanent contact with galvanized steel (subject to alkali-aggregate reaction), or exposed soils or water containing sulfates. Table 1-6 shows the limitations.

Table 1-6. Maximum chloride ion content for corrosion protection.

Type of Member	Maximum Water Soluble Chloride Ion ($C1^-$) in Concrete, Percent by Weight of Concrete
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

Pozzolans

These materials contain silica or silica and alumina. They combine with calcium hydroxide to form compounds having cementitious properties. Because the properties of pozzolans and their effects on concrete vary considerably, test them first to determine their suitability.

PART C - SLUMP TEST

METHOD AND EQUIPMENT

Method

This test method covers the procedure to use both in the laboratory and in the field to determine portland cement concrete consistency. Although not a precise method, it gives sufficiently accurate results. The slump test does not apply if the concrete contains aggregate much larger than 2 inches in size.

Apparatus

The metal mold and tamping rod are available in the mobile laboratory.

Metal Mold

This is a No 16-gauge galvanized, metal mold shaped like a 12-inch-high truncated (cut off) cone having an 8-inch-diameter base and a 4-inch-diameter top (see Figure 1-8). Both the base and top are open parallel to each other and perpendicular to the axis of the cone.

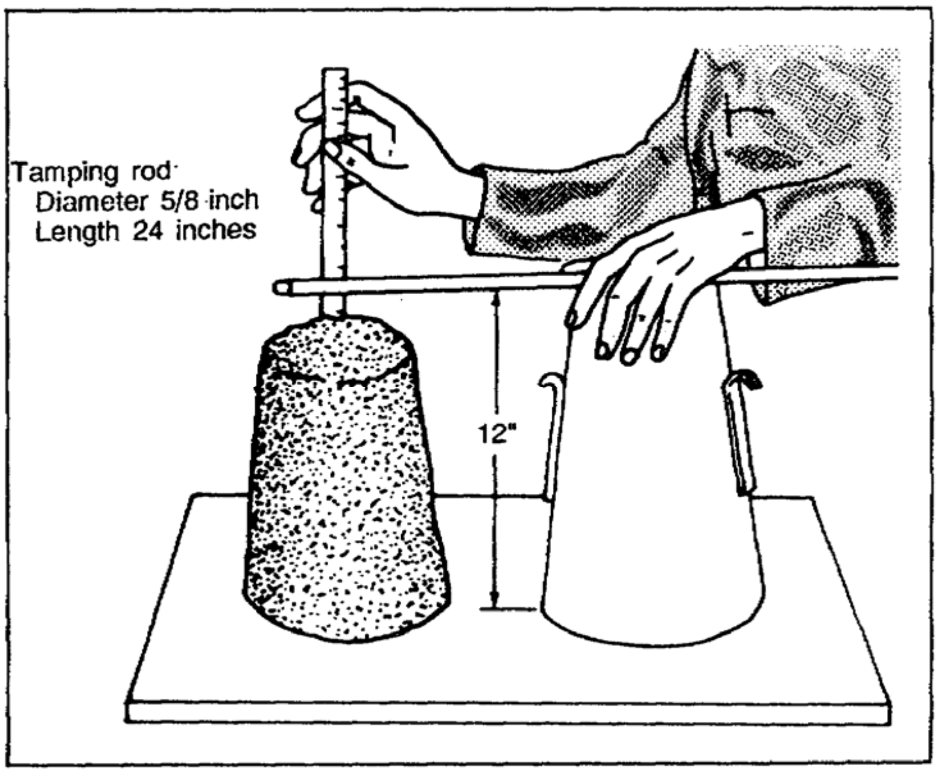

Figure 1-8. Measuring slump.

Tamping Rod

The tamping rod is 5/8 inch in diameter and 24 inches long and has a 1-inch taper at one end terminating in a rounded tip bullet nose having a radius of about 1/4 inch.

TESTING AND PROCEDURES

Procedure

The mold should be dampened and placed on a flat, moist, nonabsorbent, firm surface. Fill the mold immediately with three equal layers of a concrete specimen. As you fill the mold, rotate each scoopful of the concrete around the top edge of the mold as the concrete slides from it. This ensures a symmetrical concrete distribution within the mold. Tamp each layer 25 strokes with the tamping rod, distributing the strokes uniformly over the cross section of the mold and penetrating the underlaying layer. Tamp the bottom layer throughout its depth. After tamping the top layer, strike off the surface with a trowel so that the concrete fills the mold exactly. Without delay, carefully lift the mold straight up from the concrete and place it beside the specimen.

Slump Measurement

The tamping rod should be placed across the top of the mold. Measure the distance between the bottom of the rod and the displaced original center of the top surface of the specimen. If a decided falling away or shearing off of concrete from one side or portion of the mass occurs, disregard the test and make a new test on another portion of the sample.

NOTE: If two consecutive tests on a sample of concrete show a falling away or shearing off of a portion of the concrete from the mass of the specimen, the concrete probably lacks necessary plasticity and cohesiveness for the slump test to be applicable.

Supplementary Test Procedure

After completing the slump measurement, tap the side of the specimen gently with the tamping rod. How the concrete mix behaves under this treatment is a valuable indication of its cohesiveness, workability, and placability. A well-proportioned workable mix will gradually slump (fall or flatten out) but still retain its original consistency, whereas a poor mix will crumble, segregate, and fall apart.

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LESSON 1

PRACTICE EXERCISE

Check your understanding of Lesson 1 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct response. Each correct response is referenced to specific portions of the lesson material so you can review any questions you have missed or do not understand before continuing to the next lesson.

1. What percent (in volume) of inert filler material is used in normal concrete?

   A. 60 to 70
   B. 60 to 75
   C. 60 to 80
   D. 60 to 85

2. When air is chemically induced into the mix, what is the air called?

   A. Entrained
   B. Entrapped
   C. Induced
   D. Indrafted

3. Which one of the following is not a limitation of concrete?

   A. Low tensile strength
   B. Thermal movements
   C. Permeability
   D. Watertightness

4. Water has two functions in concrete mix, to effect hydration and to improve workability.

   A. True
   B. False

5. When would a slump test not be used?

   A. When portland cement is used
   B. When the concrete contains admixtures
   C. When the concrete contains aggregate much larger than 2 inches in size
   D. When the concrete contains aggregates much smaller than 2 inches in size

6. After completing the slump test, tap the sides of the specimen gently to check its cohesiveness, workability, and placability.

   A. True
   B. False

LESSON 1
PRACTICE EXERCISE
ANSWER KEY AND FEEDBACK

Item		Correct Answer and Feedback
1.	C.	60 to 80
		Inert filler material, (usually sand and stone or gravel) ... (page 1-2) Aggregates make up from 60 to 80 percent ... (page 1-6)
2.	A.	Entrained
		If air is chemically induced ... (page 1-2)
3.	D.	Watertightness
		Listed below are some principal limitations ... (page 1-3)
4.	A.	True
		Water has two functions in concrete mix,... (page 1-6)
5.	C.	When the concrete contains aggregate much larger than 2 inches in size
		The slump test does not apply if concrete contains ... (page 1-20)
6.	A.	True
		After completing the slump measurement... (page 1-21)

LESSON 2

PROPORTIONING CONCRETE MIXTURES

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will identify the use of the trail batch and absolute volume methods for proportioning concrete mixtures.

TERMINAL LEARNING OBJECTIVE:

ACTION: Identify, plan, and use the trial batch and absolute volume methods for proportioning concrete mixtures.

CONDITION: You are given the materials contained in this lesson.

STANDARD: Correctly answer all the practice exercise questions at the end of the lesson.

REFERENCE: The material contained in this lesson was derived from the following publication: FM 5-742, with change 1.

INTRODUCTION

In Lesson 1, "Concrete Components," you learned the desirable characteristics that we seek in portland cement concrete. This lesson discusses how these characteristics are obtained. In designing a concrete mix, you must answer the following questions concerning your particular job.

1. *What structural qualities do I want my hardened concrete to provide?*

2. *How do I want the plastic concrete to act?*

3. *Are my aggregates suitable? How do they affect the workability of the mix?*

4. *What is the proper mix of ingredients?*

Consider how you would answer each of these questions then continue on and see how your concrete instructors answered them.

1. *What structural qualities do I want my hardened concrete to provide?*

You want your concrete to display strength, durability, and watertightness. Since the w/c ratio affects each of these, you will select a w/c ratio to meet each of these requirements. Also, since air-entrained aids durability and watertightness, you may also specify air-entrained concrete at this time.

2. How do I want my plastic concrete to act?

You want your plastic concrete to have workability, uniformity, and homogeneity. Since the slump test is a measure of workability and uniformity, your next step is to select a slump.

3. Are my aggregates suitable? How do they affect the workability of the mix?

You especially want your sand and gravel to be clean (this you will check). Additionally, you will determine the relative fineness or coarseness of your sand, since the finer the sand the greater the workability. Additionally, you want to make sure that the available gravel is not so large as to induce a plane of weakness in your structure or to bridge the reinforcing steel, causing honeycombing.

4. What is the proper mix of ingredients?

You want to find the amounts of cement, water, sand, and gravel required to give you the qualities in the plastic and hardened concrete you desire. Using the absolute volume mix design procedures, you will determine the preliminary proportions for the components of your concrete. You will have to adjust this mix design at the job site due to the moisture condition of the aggregates.

PART A - METHOD OF CONSIDERATIONS

SELECTING MIX PROPORTIONS

Concrete proportions for a particular application are determined by the concrete's end use and by anticipated conditions at the time of placement. You must strike a balance between reasonable economy and the requirements for placability, strength, durability, density, and appearance which may be in the job specifications. Before proportioning a concrete mixture, you must have certain information about a job, such as the size and shape of structural members, the concrete strength required, and the exposure conditions. Other important factors, discussed below, are the w/c ratio, aggregate characteristics, amount of entrained air, and slump.

FACTORS

Water and Cement Ratio

The w/c ratio is determined by the strength, durability, and watertightness requirements of the hardened concrete. They are usually specified by the structural design engineer, but you can arrive at tentative mix proportions from knowledge of a prior job. Always remember that a change in the w/c ratio changes the characteristics of the hardened concrete. Use Table 2-1 to select a suitable w/c ratio for normal-weight concrete that will meet the anticipated exposure conditions. Note that the w/c ratios in Table 2-2 on page 2-4 are based on concrete strength under certain exposure conditions. If possible, perform tests using job materials to determine the relationship between the w/c ratio you select and strength of the finished concrete. If you cannot obtain laboratory test data or experience records for the relationship, use the data in Table 2-2 as a guide. Enter Table 2-2 at the desired f'_c (specified compressive strength of concrete in pounds per square inch (psi)) and read across to determine the maximum w/c ratio.

You can estimate the values when both exposure conditions and strength must be considered; use the lower of the two indicated w/c ratios. If flexural strength rather than compressive strength is the basis for design, such as a pavement, perform tests to determine the relationship between the w/c ratio and flexural strength. An approximate relationship between flexural and compressive strength is as follows:

$$f'_c = \frac{R^2}{K}$$

Where--

f'_c = compressive strength, in psi
R = flexural strength (modulus of rupture), in psi, third-point loading
K = a constant, usually between 8 and 10

Table 2- 1. Maximum w/c ratio for various exposure conditions.

Exposure Condition	Normal-Weight Concrete, Absolute Water and Cement Ratio by Weight
Concrete protected from exposure to freezing and thawing or application of deicer chemicals	Select w/c on basis of strength, workability, and finishing needs.
Watertight concrete	
In fresh water	0.50
In seawater	0.45
Frost resistent concrete	
Thin sections; any section with less than 2-inch cover over reinforcement and any concrete exposed to deicing salts	0.45
All other structures	0.50
Exposure to sulfates	
Moderate	0.50
Severe	0.45
Placing concrete under water	Not less than 60 lb of cement per cubic yard (386 kg/m^3).
Floors on grade	Select w/c ratio for strength, plus minimum cement requirements; see Table 2-3 on page 2-4.

Table 2-2. Maximum permissible w/c ratios for concrete when strength data from trial batches or field experience is not available.

Specified Compressive Strength f 'c psi*	Maximum Absolute Permissible Water and Cement Ratio, by Weight	
	Non-air-Entrained Concrete	Air-Entrained Concrete
2,500	0.67	0.54
3,000	0.58	0.46
3,500	0.51	0.40
4,000	0.44	0.35
4,500	0.38	**
5,000	**	**

* Twenty-eight day strength. With most materials, the w/c ratios shown will provide average strengths greater than required.

** For strength above 4,500 psi (non-air-entrained concrete) and 4,000 psi (air-entrained concrete), proportions should be established by the trial batch method.

1,000 psi ≈ 7 MPa

Variation in Mixtures

The proportions you arrive at in determining mixtures will vary somewhat depending on which method you use. The variation is due to the empirical nature of the methods and does not necessarily imply that one method is better than another. You start each method by assuming certain needs or requirements and then proceed to determine the other variables. Since the methods begin differently and use different procedures, the final proportions vary slightly. This is to be expected and points out further the necessity of trial mixtures in determining the final mixture proportions. For variations in a mixture, note that for concrete used in slabs or other flatwork, there are minimum cement requirements depending upon the maximum size of the aggregates. See Table 2-3.

Table 2-3. Minimum cement requirements for concrete used in flatwork.

Maximum Size of Aggregate, in	Cement, lb/cy
1 1/2	470
1	520
3/4	540
1/2	590
3/8	610

1 in ≈ 25 mm
100 lb/cy ≈ 60 kg/m^3

Aggregate

- *Use fine aggregate to fill the spaces between coarse-aggregate particles and increase the workability of a mix.* In general, aggregate that does not have a large grading gap nor an excess of any size that does give a smooth grading curve, produces the best mix. Ensure that the fineness modules are between 2.3 and 3.1 (see page 1-8). Ensures that the excess fines, material finer than the No 200 sieve, are limited to less than 3 or 5 percent (see Lesson 1).

- *Use the largest practical size of coarse aggregate in the mix.* The maximum size of coarse aggregate that produces concrete of maximum strength for a given cement content depends on the aggregate source as well as aggregate shape and grading. The maximum size aggregate should not exceed one-fifth the minimum dimension of the member of three-fourths the space between reinforcing bars. For pavement or floor slabs, the maximum size aggregate should not exceed one-third the slab thickness. Equipment limits the aggregate size also, 16S = 3 inches and M919 = 1 1/2 inches.

Entrained Air

Use entrained air in all concrete exposed to freezing and thawing and, sometimes, under mild exposure conditions to improve workability. Always use entrained air in paving and concrete, regardless of climatic conditions. Table 1-5 on page 1-18 gives recommended total air contents of air-entrained concrete. The upper half of Table 1-5 gives the approximate percent of entrapped air in non-air-entrained concrete, and the lower half gives the recommended average, total air-content percentages for air-entrained concrete based on level of exposure.

- *Mild exposure*. This includes indoor and outdoor service in a climate that does not expose the concrete to freezing or deicing agents. When you want air-entrainment for a reason other than durability, such as to improve workability or cohesion or to improve strength in low cement factor concrete, you can use air contents lower than those required for durability.

- *Moderate exposure.* This means service in a climate where freezing is expected but where the concrete is not continually exposed to moisture or free water for long periods before freezing, deicing agents, or other aggressive chemicals. Examples are exterior beams, columns, walls, girders, or slabs that do not contact wet soil or receive direct applications of deicing salts.

- *Severe exposure.* This means service where the concrete is exposed to deicing chemicals or other aggregate agents or where it continually contacts moisture or free water before freezing. Examples are pavements, bridge decks, curbs, gutters, sidewalks, canal linings, or exterior water tanks or sumps.

Slump

The slump test (see Part C on page 1-20) measures the workability and consistency of concrete. Do not use it to compare mixes having completely different proportions or mixes containing different aggregate sizes. When testing different batches of the same mixture, change in slump indicate changes in materials, mix proportions, or water content. Table 2-4 on page 2-6 gives recommended slump ranges.

Table 2-4. Recommended slumps for various types of construction (with vibration).

Concrete Construction	Slump, in	
	Maximum*	Minimum*
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and sub-structure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

* May be increased 1 inch for consolidation by methods such as rods and spades.

1 inch = 25 millimeter (mm)

PART B - TRIAL BATCH METHOD

DETERMINING WATER/CEMENT RATIO

With the w/c amounts determined, add sand and gravel to yield a workable mix. Record the data and repeat the procedure until the concrete has desirable characteristics and a minimum cement content is obtained. This method should be performed well in advance of a project. In the trial batch method of mix design, use actual job materials to obtain mix proportions. The size of the trial batch depends on the equipment and how many test specimens are made. Batches using 10 to 20 pounds of cement may be big enough, although larger batches produce more accurate data. Use machine mixing if possible, since it nearly represents job conditions. Always use a machine to mix concrete containing entrained air. Be sure to use representative samples of aggregate, cement, water, and air-entraining admixture in the trial batch. Prewet the aggregate and allow it to dry to a saturated, surface-dry condition. Place the sample in covered containers to maintain this condition until it is used. This simplifies calculations and eliminates error caused by variations in aggregate moisture content. When the concrete quality is specified in terms of the w/c ratio, the trial batch procedure consist basically of combining paste (water, cement, and usually entrained air) of the correct proportions with the proper amounts of fine and course aggregates to produce the required slump and workability. Calculate the larger quantities per sack or by cubic yard.

USING TRIAL BATCH METHOD (EXAMPLE)

Determine the mix proportions for a concrete retaining wall with the footer exposed to fresh water in a severe climate. The required compressive strength (f'_c is 3,000 psi at 28 days. The minimum wall thickness is 8 inches, with 2 inches of concrete covering the reinforcement. Enter all trial mix data in the appropriate blanks on the trial data worksheet in Figure 2-1 on page 2-8. Table 2-1 on page 2-3, indicates that a maximum w/c ratio of 0.50 by weight satisfies the exposure requirements. Using Type IA (air-entrained) portland cement and a compressive strength of 3,000 psi, Table 2-2 on page 2-4, shows that a maximum w/c ratio of approximately

0.46 by weight satisfies the strength requirements. To meet both specifications, you would select a w/c ratio of 0.46. Since the maximum size of coarse-aggregate must not exceed one-fifth the minimum wall thickness nor three-fourths of the space between the reinforcement and the surfaces, the maximum size of coarse-aggregate you will choose is 1 1/2 inches. Because of the severe exposure conditions, the concrete could contain entrained air. Table 1-5, page 1-18, shows that the recommended air content is 5.5 ± 0.5 percent. Assuming that vibration will consolidate the concrete, Table 2-4 indicates a recommended slump ranging from 1 to 3 inches. The trial batch proportions are now determined. Choosing a batch containing 20 pounds of cement for convenience, the mixing water required is 20 x 0.46 = 9.2 pounds. Select and weigh representative samples of fine and coarse aggregates and record their weights in column (2) of Figure 2-1 on page 2-8.

WORKSHEET FOR CONCRETE TRIAL MIX DATA

1. PROJECT No: ____________
2. STRUCTURE: ____________
3. EXPOSURE CONDITION:
   Severe or Moderate ______ Mild ______
   In Air ________
   In Fresh Water ________
   In Seawater ________
4. TYPE OF STRUCTURE (A-1): ________
   Max. w/c for Exposure: ________
   Max. w/c for Watertightness ________
5. TYPE OF CEMENT: ____________
6. FINENESS MODULUS OF SAND: ________
7. SPECIFIC GRAVITY:
   Sand ____________
   Gravel ____________
8. MAXIMUM SIZE AGGREGATE: ________
9. AIR CONTENT: ______Percent ± ______
10. DESIRED SLUMP RANGE:
    Max. ________ in Min. ________ in
11. STRENGTH REQUIREMENT: ________ psi
    w/c for Strength ____________ By Wt
    Use w/c ______________ By Wt

DATA FOR TRIAL BATCH
(Saturated, surface-dry aggregates)

(1) Material	(2) Initial Wt (lb)	(3) Final Wt (lb)	(4) Wt Used (lb)	(5) Wt for One-Sack Batch	(6) Wt per cy	(7) Remarks
Cement						
Water						
Fine Aggregate						_____Percent of Total Aggregate
Coarse Aggregate						
Air-Entrained Admixture			TOTAL (T) =			

Measured Slump ________ in

Air Content ________ Percent

Workability ________

Unit Wt of Concrete = $w = \frac{A}{B}$

Wt Container Concrete (lb) ________

Wt Container (lb) ________

Wt Concrete = A (lb) ________

Volume Container = B (cf) ________

$\frac{A}{B}$ = —— = lb/cf

Yield = $\frac{T}{W}$ = —— = cf/sack

Figure 2-1. Worksheet for concrete trial mix data.

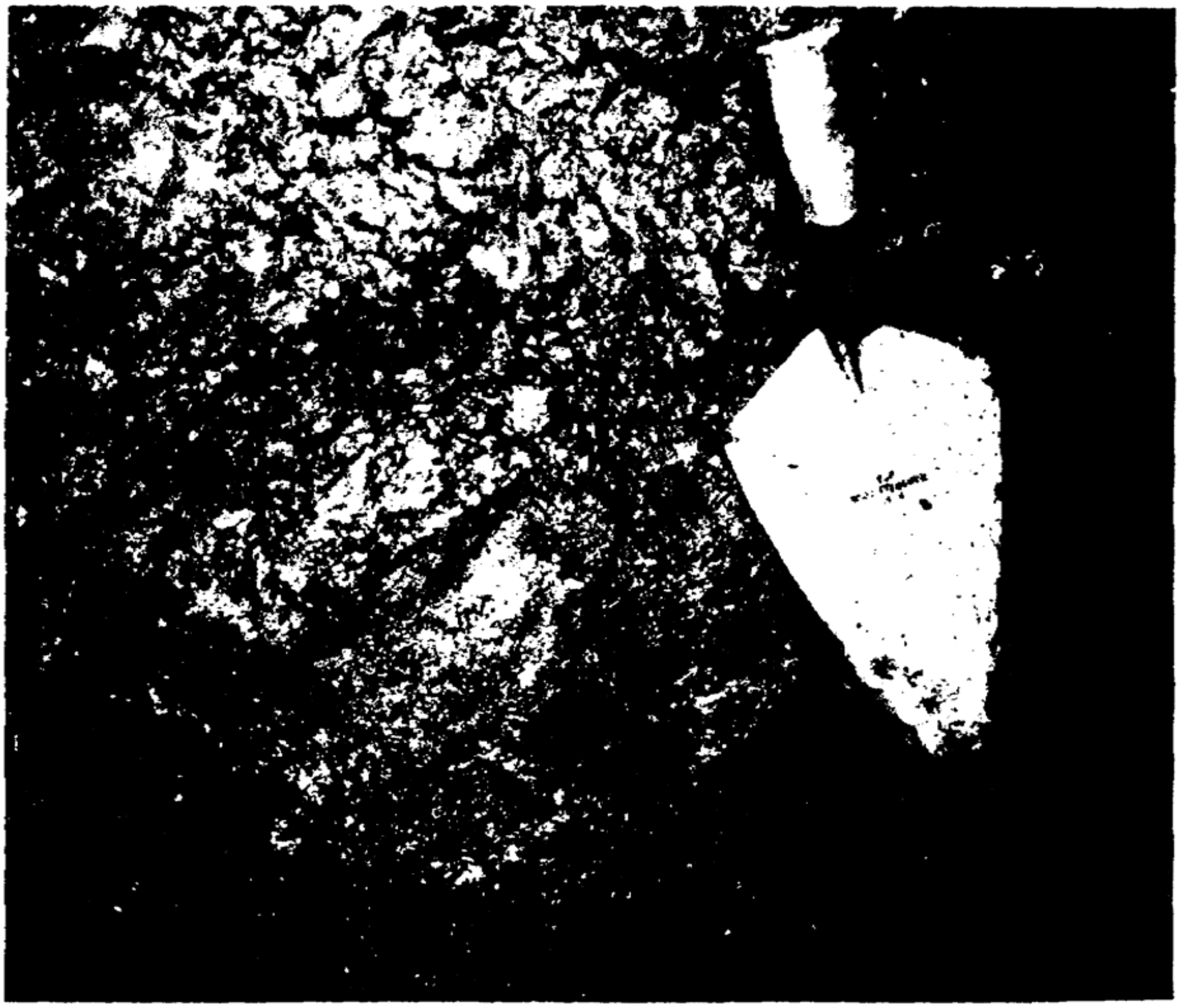
Use all the measured quantities of cement, water, and air-entrained admixture.

NOTE: It is not normal practice to buy air-entrained cement (Type IA) and then add an air-entrained admixture; however, if the only cement available was Type IA and it did not give the needed air content, addition of an air-entraining admixture would be necessary to achieve frost resistance.

Add fine and coarse aggregate until you produce a workable mixture having the proper slump. Figure 2-2 (pages 2-9 through 2-11) shows the appearance of fresh concrete containing both the correct and incorrect amounts of cement-sand mortar (paste). Record the weights of all materials in column (4) of Figure 2-1. Then calculate the weights for both a one-bag batch and per cubic yard and record them in columns (5) and (6). Calculate and record the cement factor in pounds per cubic yard as indicated in Figure 2-1 as well as the percentage of fine aggregate by weight and by volume of total aggregate and the yield of concrete in cubic feet per bag.

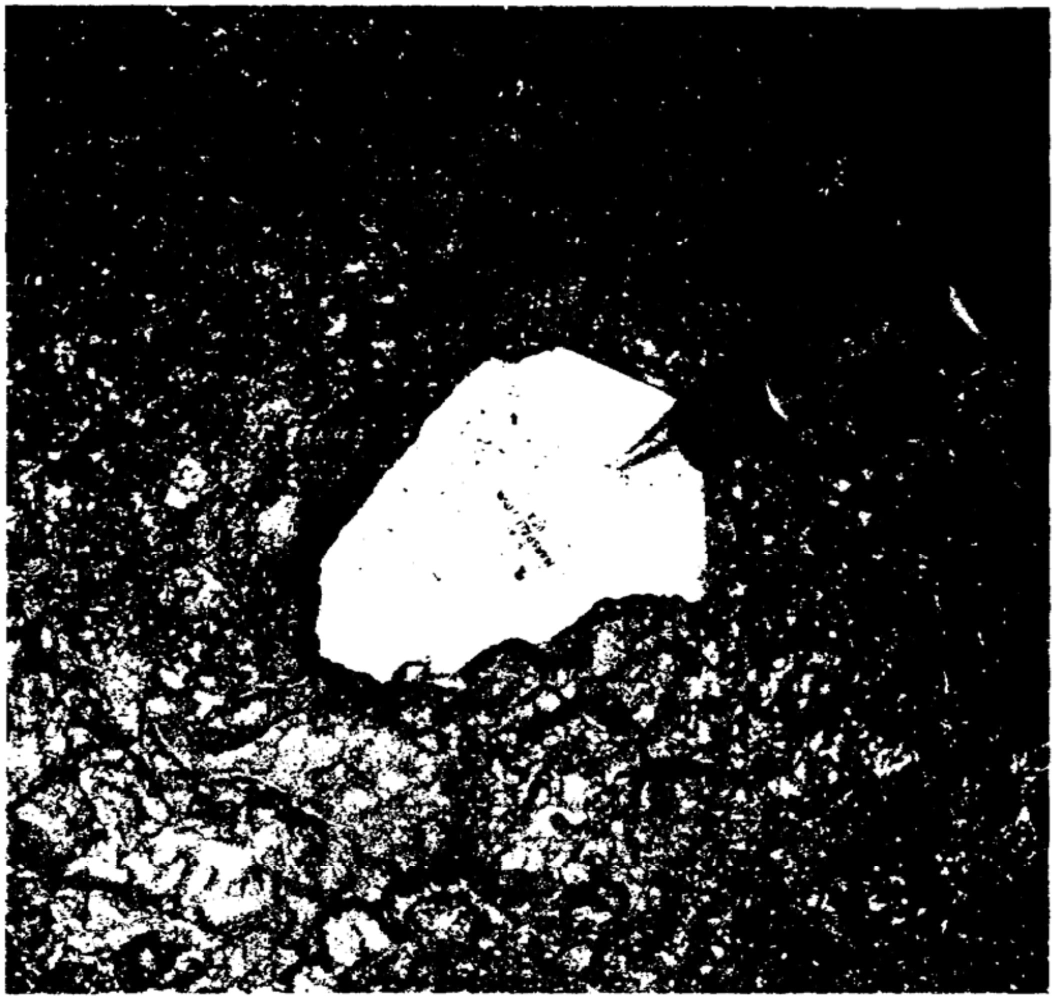
a. A concrete mixture in which there is not sufficient cement-sand mortar to fill all the spaces between coarse-aggregate particles. Such a mixture will be difficult to handle and place and will result in rough, honeycombed surfaces and porous concrete.

Figure 2-2. Appearance of concrete mixes containing correct and incorrect amounts of water.



b. A concrete mixture which contains the correct amount of cement-sand mortar. With light troweling all spaces between coarse-aggregate particles are filled with mortar. Note appearance on edges of pile. This is a good workable mixture and will give maximum yield of concrete with a given amount of cement.

Figure 2-2. Appearance of concrete mixes containing correct and incorrect amounts of mortar. (continued)



c. A concrete mixture in which there is an excess of cement-sand mortar. While such a mixture is plastic and workable and will produce smooth surfaces, the yield of concrete will be low and consequently uneconomical. Such concrete is also likely to be porous.

Figure 2-2. Appearance of concrete mixes containing correct and incorrect amounts of mortar. (continued)

Determine and note the slump, air content, workability, and unit weight of the concrete as shown. To find the most economical proportions, make more trial batches, varying the percentage of fine aggregate. In each batch keep the w/c ratio, aggregate graduations, air content, and slump approximately the same Table 2-5 on page 2-12 summarizes the results of four trial batches made in the laboratory. Figure 2-3 on page 2-13 plots the percentage of fine aggregate used in these mixes against the cement factor. The minimum cement factor (538 pounds per cubic yard) occurs at a fine-aggregate content of about 32 percent of the total aggregate. Since the w/c ratio is 0.46 by weight and the unit weight of the concrete for an air content of 5 percent is about 144 pounds per cubic foot, the final quantities for the mix propositions (per cubic yard) are as follows:

Cement	=	538 lb
Water (538 lb cement x 0.46)	=	247 lb
Total	=	785 lb
Concrete per cy (144 x 27)	=	3,890 lb
Aggregates (3,890 - 785)	=	3,105 lb
Fine aggregates (0.32 x 3,105)	=	994 lb
Coarse aggregate (3,105 - 994)	=	2,111 lb

Table 2-5. Results of laboratory trial mixes.*

Batch Number	Slump, in	Air Content, Percent	Unit Weight, lb/cf	Cement Factor, lb/cy	Fine Aggregates, Percent of Total Aggregate	Workability
1	3	5.4	144	540	33.5	Excellent
2	2 3/4	4.9	144	556	27.4	Harsh
3	2 1/2	5.1	144	549	35.5	Excellent
4	3 1/4	4.7	145	540	30.5	Good

* The w/c ratio selected was 0.46 by weight.

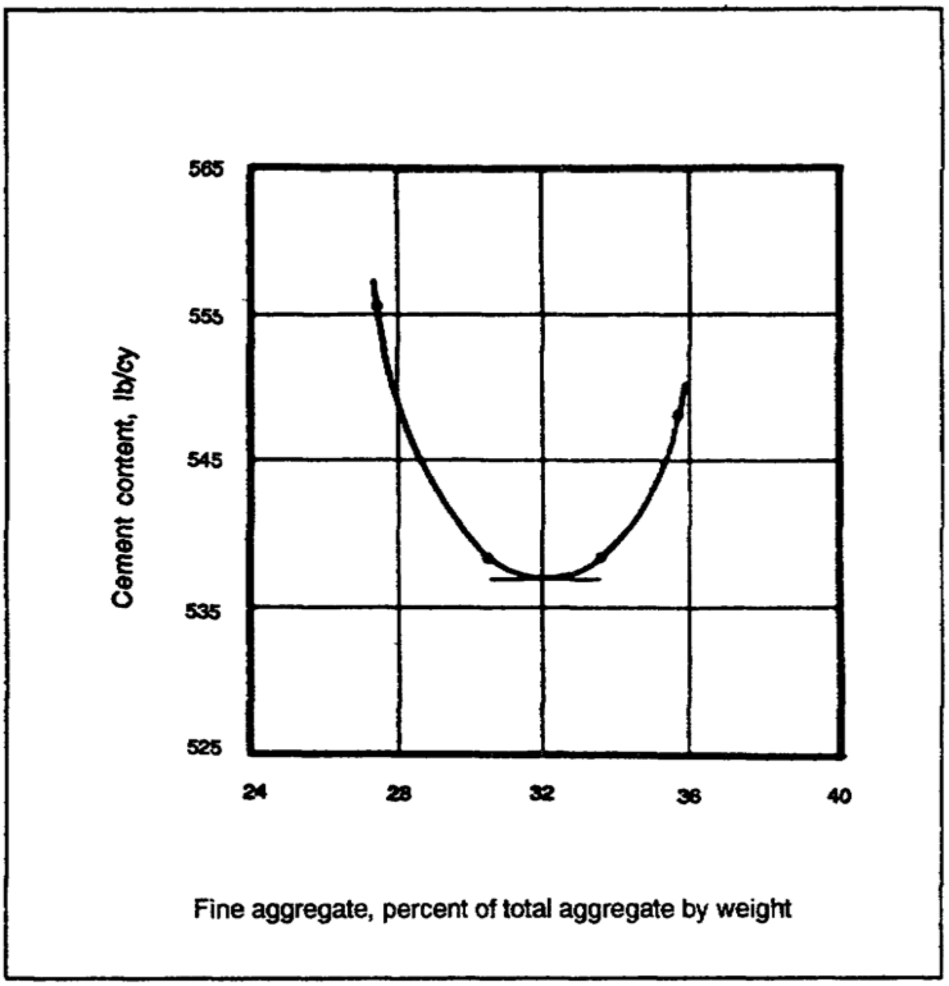


Figure 2-3. Relationship between percentage fine aggregate and cement content for a given w/c ratio and lump.

PART C - ABSOLUTE VOLUME METHOD

BASIC GUIDELINES

This method can be used without any previous data or experience to design a concrete mix. You can also proportion concrete mixtures using absolute volumes. The ACI report, "Recommended Practice for Selecting Proportions for Normal and Heavy-Weight Concrete," ACI 211.1-81, details this method. For this procedure, select the w/c ratio, slump, air content, and maximum aggregate size as you did in the trial batch method. In addition, estimate the water requirement from Table 2-2 on page 2-4. You must get this information before making calculations, such as the specific gravities of fine and coarse aggregate, the dry-rodded unit weight of coarse aggregate, and the FM of the fine aggregate. If the maximum aggregate size and the FM other fine aggregate are known, you can estimate the volume of dry-rodded coarse aggregate per cubic yard from Table 2-6 on page 2-14. Calculate the volume occupied per cubic yard of water, cement, coarse aggregate, and air. Subtract the sum of the absolute volumes of these materials in cubic feet from 27 cubic feet/cubic yard to give the specific volume of fine aggregate.

Table 2-6. Volume of coarse aggregate per cubic yard of concrete.

Maximum Size of Aggregate, in	FM of Fine Aggregate			
	2.40	2.60	2.80	3.00
	Coarse Aggregate, cf/cy*			
3/8	13.5	13.0	12.4	11.9
1/2	15.9	15.4	14.8	14.3
3/4	17.8	17.3	16.7	16.2
1	19.2	18.6	18.1	17.6
1 1/2	20.2	19.7	19.2	18.6
2	21.1	20.5	20.0	19.4
3	22.1	21.6	21.1	20.5

* Volumes are based on aggregates in dry-rodded condition as described in the Method of Test for Unit Weight of Aggregate (ASTM C29). These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for concrete pavement construction, the volume of aggregates may be increased about 10 percent. When placement is done by pump, the volume of aggregates should be decreased about 10 percent.

The absolute volume of a material is the volume occupied by the solid particles. For example, consider a 100-pound box of gravel. One way to find the absolute volume of gravel would be to actually measure the volume of water displaced by 100 pounds of gravel. Figure 2-4 shows a container of water before and after gravel is added. If the column is 1 foot by 1 foot and the 100 pounds of gravel displaces 7 inches of water, then the absolute volume of the gravel is 1 foot by 1 foot by 7/12 foot = .583 ft^3.

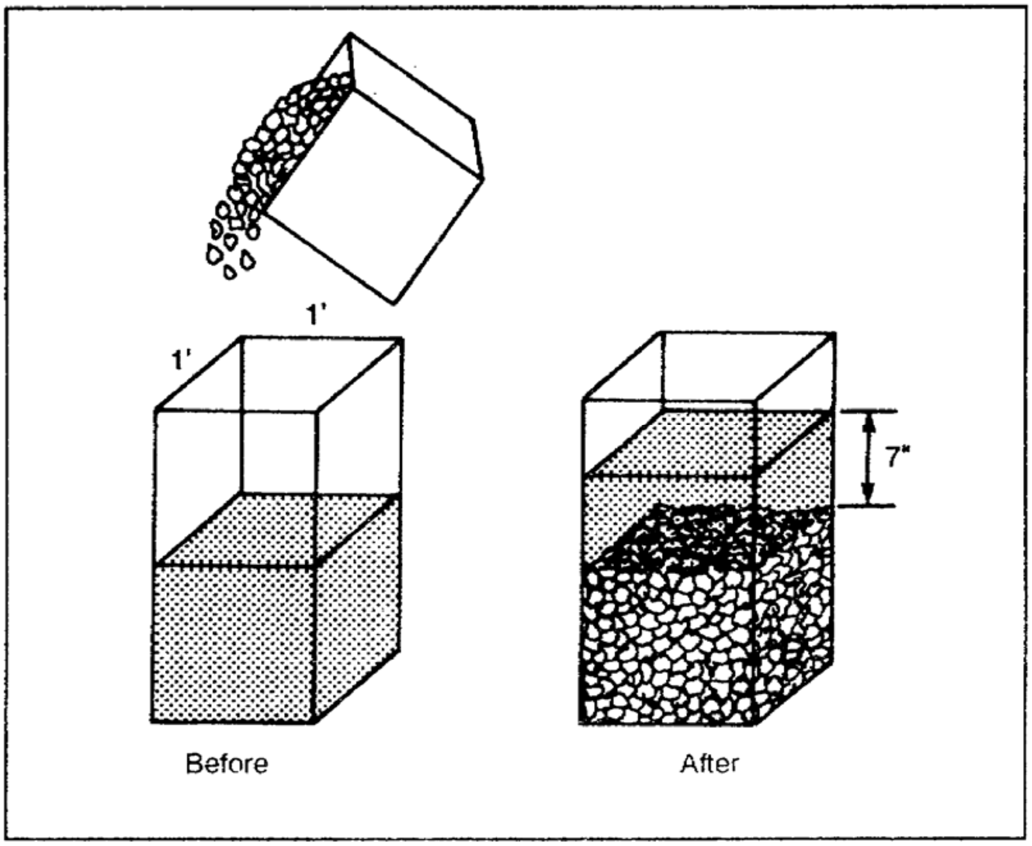


Figure 2-4. Absolute volume.

Another method of determining the absolute volume is to use the concept of specific weight, which is the weight of a solid cubic foot of a material. The specific weight of a cubic foot of material is found by multiplying the specific gravity of the material times the unit weight of water. Suppose your gravel has a specific gravity of 2.75. The specific weight of the gravel would be 2.75 x 62.4 lb/ft^3 = 171.5 lb/ft^3. Thus the absolute volume of that 100 pounds of gravel is--

$$\frac{100}{2.75 \times 62.4 \text{ lb/ft}^3} = .583 \text{ ft}^3$$

USING ABSOLUTE VOLUME METHOD (EXAMPLE)

For a retaining wall, determine the mix proportions using the following specifications and conditions:

Required 28-day compressive strength (f'_c)	=	3,000 psi
Maximum size aggregate	=	3/4-inch
Exposure condition	=	moderate freeze-thaw exposure; exposed to air
FM of fine aggregate	=	2.70
Specific gravity of portland cement	=	3.15
Specific gravity of fine aggregate	=	2.66
Specific gravity of coarse aggregate	=	2.61
Dry-rodded unit weight (DRUW) of coarse aggregate	=	104 lb/cf
DRUW of fine aggregate	=	103 lb/cf
Slump	=	3 inches
Cement	=	Type IA

Estimate Air Content

Refer to Table 1-5, page 1-18.

- Aggregate size = 3/4
- Air-entrained concrete
- Moderate exposure
- Air content = 5 percent

Estimate Mixing-Water Content

Refer to Table 1-5.

- Slump = 3 inches
- Aggregate size = 3/4
- Air-entrained concrete
- Mixing water = 305 lb/cy

Determine Water/Cement Ratio

Check w/c ratios for strength, durability, and watertightness.

Strength.

- Mix design strength = 3,000 psi
- Specified compressive strength
- Design strength (psi) = 3,000; w/c ratio (Table 2-2, page 2-4) = 0.46

Durability (refer to Table 2-1, page 2-3).

- Frost-resistant concrete
- All other structures, w/c = 0.50

Weathertightness.

Freshwater exposure, w/c = 0.50

Select Lowest w/c Ratio

w/c = 0.46

Calculate Cement Content

$$C = \frac{\text{water lb/cy}}{\text{w/c ratio}} = \frac{\text{305 lb/cy}}{0.46} = \text{663.0 lb/cy}$$

Calculate Coarse-Aggregate (CA) Content

Refer to Table 2-6, page 2-14.

- CA size = 3/4
- FM of fine aggregate (FA) = 2.60 (given)
- Determine volume of CA by interpolation of Table 2-6:

FM	2.40	2.60	2.80
Volume of CA (cf/cy) (3/4-inch)	17.8	17.3	16.7

- Weight of CA (G = volume from Table 2-6 x DRUW)
- G = 17.3 x 104 lb/cfs = 1,799 1b/cy

Calculate FA Content by Absolute Volume Method

The absolute volume for any material can be described as for any material.

- **Absolute volume** $= \dfrac{\text{weight of material}}{\text{(specific gravity) (62.4 lb/cf)}}$
- **Absolute volume cement** $= \dfrac{C}{\text{(3.15) (62.4 lb/cf)}} = \dfrac{\text{663.0 lb/cy}}{\text{(3.15) (62.4 lb/cf)}} = \text{3.37 cf/cy}$
- **Absolute volume water** $= \dfrac{W}{\text{(62.4 lb/cf)}} = \dfrac{\text{305 lb/cy}}{\text{(62.4 lb/cf)}} = \text{4.89 cy/cy}$
- **Absolute volume CA** $= \dfrac{G}{(SG_{CA})\text{ (62.4 lb/cf)}} = \dfrac{\text{1,768 lb/cy}}{\text{(2.61) (62.4 lb/cf)}} = \text{10.86 cf/cy}$

- Volume of air = (air content) (7 cf/cy) = (0.05) (27 cf/cy) = 1 35 cf/cy

- Summing

Cement	=	3.37 cf/cy
Water	=	4.89 cf/cy
CA	=	10.86 cf/cy
Air	=	1.35 cf/cy
Partial volume (PV)	=	20.47 cf/cy

- Absolute volume of FA = 27 cf- PV = 27 cf - 20.47 cf/cy = 6.53 cf/cy

- Weight of FA = lb vol of FA x SGFA x 62.4 lb/cf = 6.53 cf/cy x 2.66 x 62.4 lb/cf = 1,083.8 lb/cy

Determine Proportions for First Trial Batch (for 1 cy) by Converting Absolute Volumes to Dry Volumes

		Weight				Volume
• Cement Type IA	=	663.0 lb/cy	÷	94.0 lb/sack	=	7.05 sacks
• Water	=	305 lb/cy	÷	8.33 lb/gal	=	36.6 gallons
• Coarse-aggregate	=	1,768 lb/cy	÷	104.0 lb/cf	=	17.0 cf
• Fine-aggregate	=	1,083 lb/cy	÷	103.0 lb/cf	=	10.5 cf
• Air content	=	5 percent				
• Slump	=	3 inches				

If needed, mix more trial batches to obtain the desired slump and air content while keeping the w/c ratio constant.

VARIATION IN MIXTURES

The proportions you arrive at in determining mixtures will vary somewhat depending on which method you use. The variation is due to the empirical nature of methods and does not necessarily imply that one method is better than another. Start each method by assuming certain needs or requirements and then proceed to determine the other variables. Since the methods begin differently and use different procedures, the final proportions vary slightly. This is to be expected and points out the necessity of trial mixtures in determining the final mixture proportions. For variations in a mixture, note that for concrete used in slabs or other flatwork, there are minimum cement requirements, depending on the maximum size of the aggregates. See Table 2-7. This requirement is normally met in the design procedure but must be checked to ensure compliance.

Table 2-7. Minimum cement requirements for concrete used in flatwork.

Maximum Size of Aggregate, in	Cement, lb/cy
1 1/2	470
1	520
3/4	540
1/2	590
3/8	610
1 in ≈ 25 mm 100 lb/cy ≈ 60 kg/m³	

PART D - ADJUSTMENTS TO THE ORIGINAL DESIGN

ADJUSTMENTS FOR MOISTURE ON AGGREGATES

The initial mix design assumes that the aggregates are saturated and surface-dry (SSD); that is, neither the fine nor the coarse aggregates have any fee water on the surface which would be available as mixing water. This is a laboratory condition and seldom occurs in the field. The actual amount of water on the sand and gravel can only be determined from the material at the mixing site. Furthermore, the moisture content of the aggregates will change over a short period of time; therefore, their condition must be monitored and appropriate adjustments made, as required. A good field test for estimating the free surface moisture (FSM) on fine aggregates follows. Coarse aggregates are free draining and rarely hold more than 2 percent (by weight) FSM even after heavy rains.

FIELD TEST FOR MOISTURE DETERMINATION ON SAND

Sands used as fine aggregate in concrete may contribute a significant amount of moisture to the concrete mix. This moisture must be accounted for by decreasing the mixing water added to the dry materials at the mixer, to maintain the w/c ratio the concrete design calls for. The following procedure can be used as a field test for estimating the amount of moisture on the sand. This procedure allows for some variation in estimating therefore, the percentage of moisture determined is somewhat judgmental.

Procedure

The samples used for this test should be taken from a depth of 6 to 8 inches below the surface of the piled sand. This negates the effect of evaporation at the surface of the pile.

A sample of sand is squeezed in the hand. Open the hand and observe the sample. The amount of FSM can be estimated from the criteria below.

- *Damp sand (0 to 2 percent FSM).* The sample will tend to fall apart. The damper the sand, the more it will cling together. (See Figure 2-5 on page 2-20.)

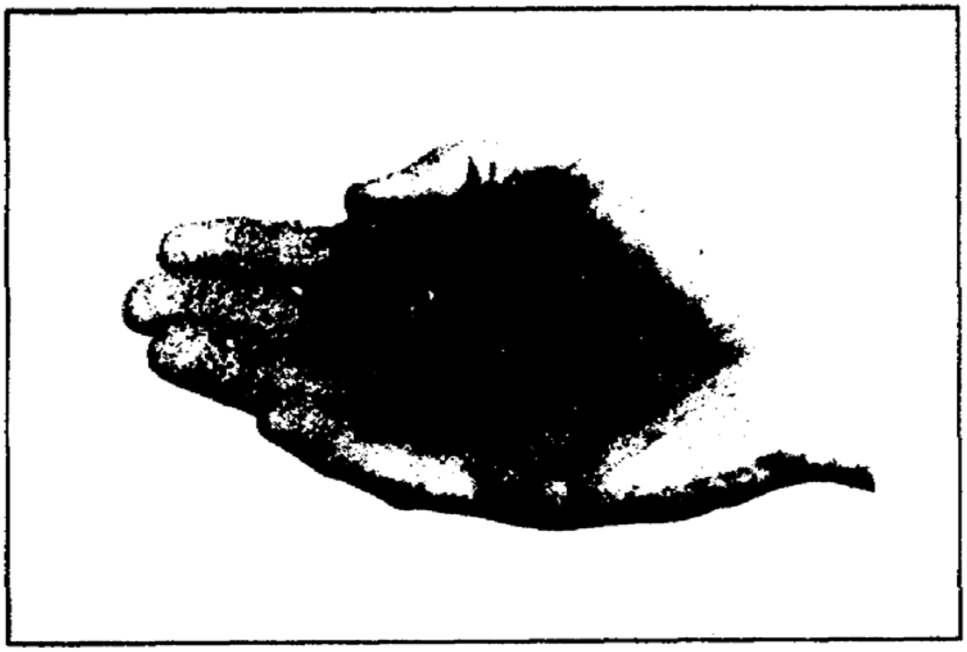


Figure 2-5. Damp sand.

- *Wet sand (3 to 4 percent FSM).* This sample clings together without excess water being forced out. (See Figure 2-6.)

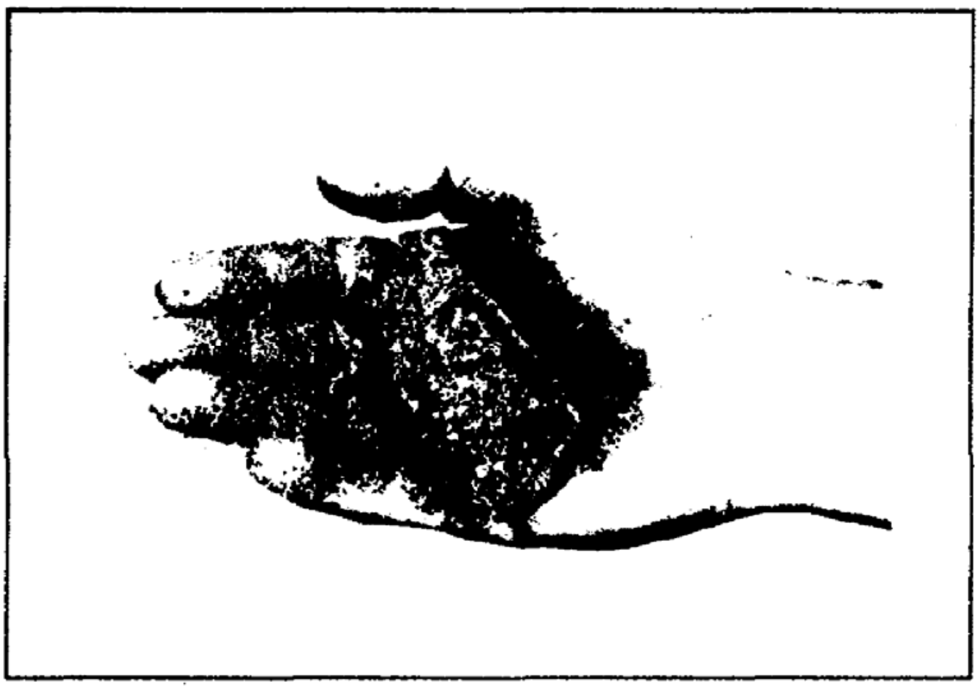


Figure 2-6. Wet sand.

- *Very wet sand (5 to 8 percent FSM).* The ball will glisten or sparkle with water. The hand will have moisture on it and may even drip. (See Figure 2-7.)

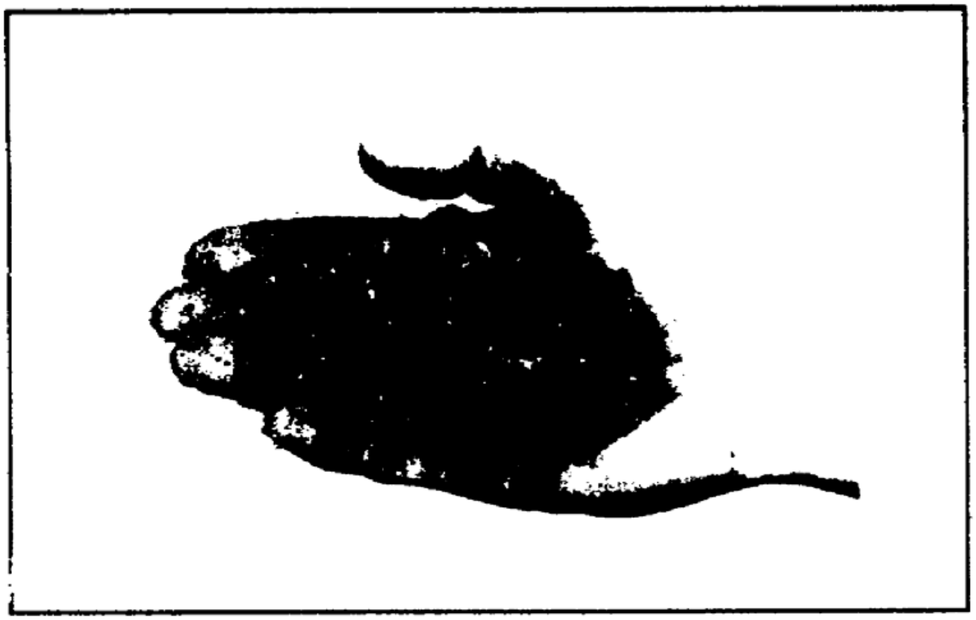


Figure 2-7. Very wet sand.

The percentage of FSM determined by this method approximates the amount of water by the weight of the sand. Use these estimates to adjust the mix design.

Fine aggregates have a tendency to bulk (expand in volume) when wetted and when the mass is disturbed. This factor becomes very important if the concrete is being batched at a mixer by volume; the initial mix design must be adjusted. The procedure for adjusting the mixing water and sand bulking due to free surface moisture is as follows:

- *Determine the approximate FSM of the fine aggregate by the squeeze test.*

- *Estimate the FSM of the coarse-aggregate by observation.* Usually, 2 percent FSM is the maximum amount gravel will hod without actually dripping.

- *Multiply the percentages of FSM on the aggregates by their respective weights per cubic yard.* This will yield the weight of the FSM on the aggregates. If the aggregate has an absorption factor rather than FSM the weight of water needs to be subtracted rather than added.

- *Divide the total weight of the FSM by 8.33 pounds or gallons to determine the number of gallons of water.* Subtract those gallons from the mixing water requirements in the original mix design.

- *Batch the concrete mix by weight.* Account for the weight contributed by the FSM by increasing the total weights of the aggregates per cubic yard by the weights of the FSM.

- *Batch the concrete by volume.* Increase the volume of the fine aggregate by the bulking factor determined from Figure 2-8 on page 2-22. The formula for volume increase is--

  $V_{wet} = V_{dry} \times (1 + BF)$. (V = volume, BF = bulking factor.)

  Coarse aggregates do not bulk; therefore, no adjustment is necessary.

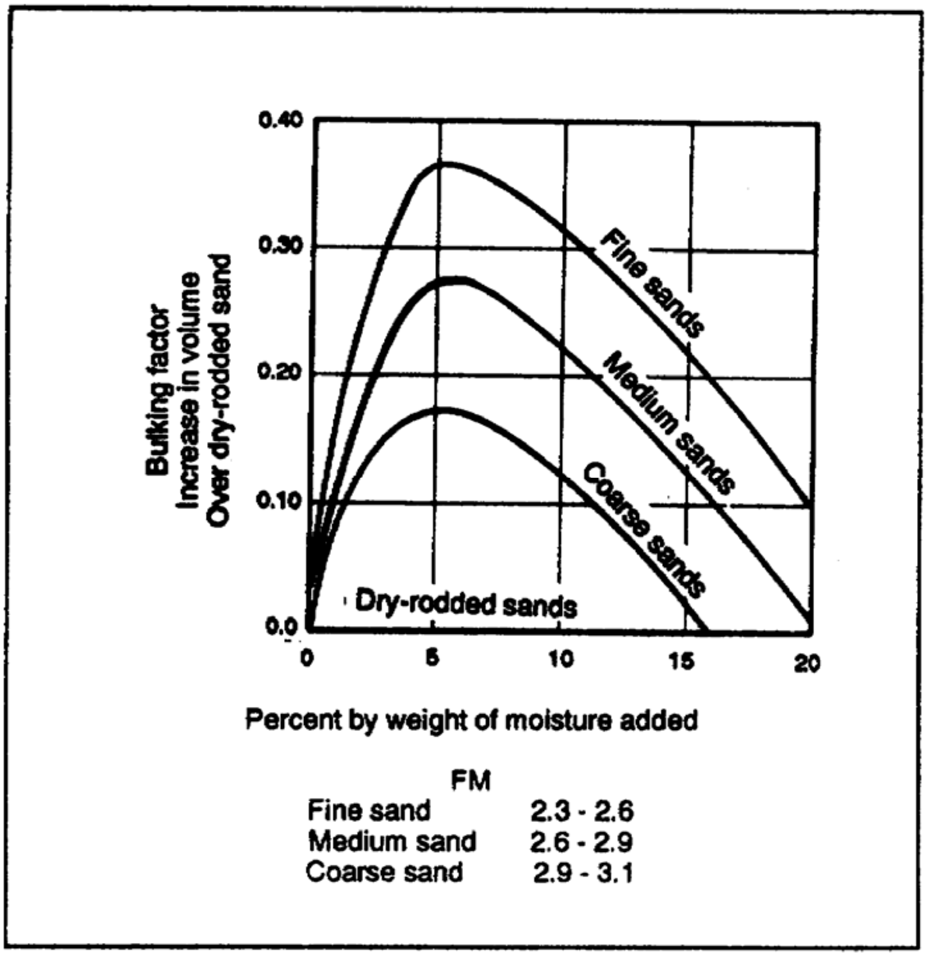


Figure 2-8. Bulking factor curves.

EXAMPLE PROBLEM: Using the final mix proportions, adjust the design mix to account for 6 percent FSM on the fine aggregate (FM = 2.70) and 2 percent FSM on the coarse aggregate. Original mix design was--

Cement	= 7.05 sacks (Type IA)
Water	= 38.6 gallons
CA	= 17.0 f or 1,768 lb/cy
FA	= 10.5 cf or 1,083 lb/cy
Air content	= 5 percent

Step 1. Determine the amount of water (in gallons) on the aggregate.

CA 1,768 lb/cy x 0.02	= 35.36 lb/cy of water
FA 1,083 lb/cy x 0.06	= 64.98 lb/cy of water
Total weight of water	= 100.34 lb/cy

$$\text{Convert to gallons} = \frac{100.34\ \text{lb/cy}}{8.33\ \text{lb/gal}} = 12.04\ \text{gal/cy}$$

Step 2. Reduce the original amount of mixing water by the amount contributed by the aggregates as determined in Step 1. Therefore, 38.6 gallons - 12 gallons = 26.6 gallons of water which must be added to the mix.

Step 3. Adjust the weights of the aggregates by the amount contributed by the water.

CA 1,768 lb/cy + 35.4 lb/cy = 1,803.4 lb/cy
FA 1,083.4 lb/y + 64.98 lb/cy = 1,148.38 lb/cy

Step 4. Adjust the volume of the fine aggregate to reflect the *"bulking"*.

- *Given FM = 2.70.* From Figure 2-8, the FA is considered a medium sand. Select the appropriate moisture content across the bottom of the figure, read up to the appropriate sand curve, and read the correct bulking factor on the left edge. For this example, FSM equals 6 percent and the bulking factor is 0.28.

- *The increase in FA volume is then*--$V_{wet} = V_{dry}$ (1 + BF) = 10.5 cf (1 + .28) = 13.44 cf

- Gravel will not bulk de to its shape and size.

Step 5. The adjusted mix design to account for the actual field conditions is now--

Cement	= 7.05 sacks (Type IA)
Water	= 26.6 gallons
CA	= 17.0 cf or 1,804 lb/cy
FA	= 13.44 c for 1,148 lb/cy
Air content	= 5 percent

It is important to check the moisture content of the aggregates and make appropriate adjustments as conditions change (after rains or periods of dryness or when the new material arrives). This quality-control step assures that the desired concrete is produced throughout the construction phase.

Materials Estimation

After designing the mix, it is necessary to estimate the total amounts of material needed for the job. This is simply done by computing the total volume of concrete to be poured, adding a water factor, and multiplying this volume times the amount of each component in the 1-cubic yard mix design. The mix design is the original based on SSD aggregate condition. The procedure follows:

Step 1. Determine the total volume (in cubic yards) of concrete to be poured.

Step 2. Add an extra amount for waste. If your total volume is 200 cubic yards or less, then add 10 percent. If the total volume is greater than 200 cubic yards, then add 5 percent.

Step 3. Determine the total amount of cement, fine aggregate, and coarse-aggregate by multiplying the amounts of these components needed for 1 cubic yard by the adjusted total volume. Order cement in sacks and sand and gravel in tons.

Step 4. Determine the required amount of water needed for the job. Water is required on concrete projects not only for mixing but for wetting the forms, tool clean up, and curing. A planning factor of 8 gallons of water for each sack of cement is usually sufficient. The reader is cautioned, however, that not all of this water will be used for concrete.

EXAMPLE PROBLEM: Using the mix design determined previously in this chapter, determine the total amount of materials needed to construct the retaining wall shown in Figure 2-9. The 1-cubic-yard mix design is recapped below.

Cement	= 7.05 sacks (Type IA)
Water	= 38.6 gallons
CA	= 17.0 cf or 1,768 lb/cy
FA	= 10.5 cf or 1,083 lb/cy
Air content	= 5 percent

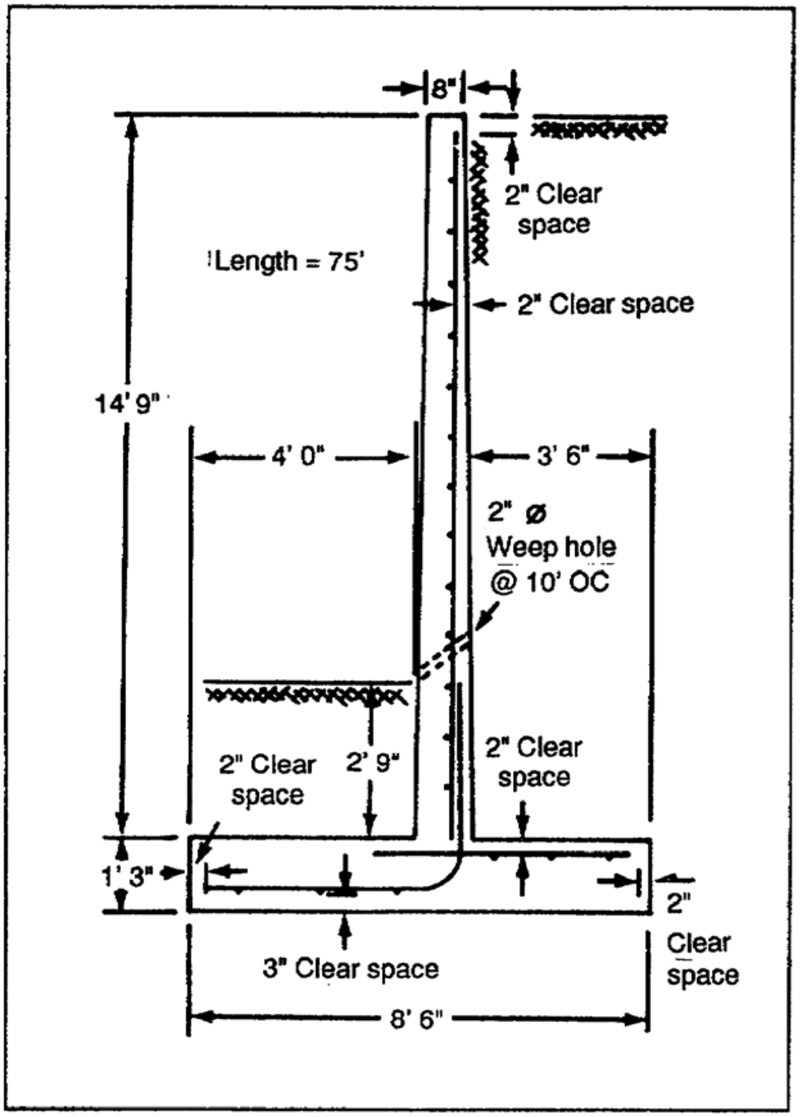


Figure 2-9. Retaining wall.

Step 1. Determine the total volume of concrete required. An easy way to do this is to break the project up into simple geometric shapes. Divide the retaining wall into two sections, the wall portion and the footing. A close examination of Figure 2-9 shows the wall cross section is a trapezoid, which is 14 feet 9 inches high, 8 inches wide on one end, and 1-foot wide on the other.

$$\textbf{Wall volume: } (14.75\ ft)\frac{(1\ ft + 0.67\ ft)}{2}(75\ ft) = 923.7\ cf$$

Footing volume: (1.25 ft)(8.5 ft)(75 ft) =' 96.9 cf

Total volume: 1,720.6 cf- 27 cf/cy = 63.7 cy

Step 2. Since the volume is 200 cubic yards or less, the waste factor is 10 percent.

Total volume + waste = (63.7 cy) (1.10) = 70.1 cy

Step 3. Determine the amounts of cement and aggregates needed.

Cement (7.05 sacks/cy) (70.1 cy) = 494.2 sacks
Round this value up to 495 sacks since
you cannot order partial sacks.
CA (1,768 lb/cy) (70.1 cy) = 123,937 lb or 61.9 tons
FA (1,083 lb/cy) (70.1 cy) = 75,918 lb or 37.9 tons

Step 4. Determine the amount of water required for clean up and mixing.

Water required (495 sacks) (8 gal/sack) = 3,960 gallons

Summary of the amounts of materials to be ordered for the project--

Cement	= 495 sacks
Water	= 3,960 gallons
CA	= 62 tons
FA	= 38 tons

LESSON 2
PRACTICAL PROBLEM

Obtain the preliminary proportions for a one-cubic-yard concrete mix to be used in a reinforced-concrete retaining wall to be constructed at Fort Leonard Wood, MO. The climate is severe, and a high-speed vibrator with a 250-cfm air compressor is available. The concrete will be mixed using a M919 concrete mobile mixer, which can handle a maximum size aggregate of 1 1/2 inches.

Specifications:

Strength at 28 days = 3,000 psi
Cement types available -- I, IA, III
Water available from a potable source

Fine aggregate	FM	SG*	BUW*	Percent Fines
Source A	2.50	2.65	120 lb/cf	4
Source B	2.95	2.60	125 lb/cf	6

Coarse aggregate	Type	SG	BUW	MSA*	Percent Fines
Source A	Gravel	2.85	110 lb/cf	2” (-)	0.5
Source B	Gravel	2.60	95 lb/cf	1”(-)	1.0
Source C	Gravel	2.70	103 lb/cf	1/2” (-)	1.3

NOTE: *SG = specific gravity; *BUW = bulk unit weight *MSA = maximum size aggregates

1. Select cement type.

   a. Availability
   b. Climate
   c. Specifications _____

2. Select aggregates.

   a. Fine aggregate

      (1) Fineness modulus _____
      (2) Specific gravity _____
      (3) BUW _____
      (4) Percent fines _____

   b. Coarse-aggregate

      (1) Maximum size aggregate allowable for the project:

      1/5 x T = 1/5 x _____ = _____
      1/3 x D = 1/3 x _____ = _____
      3/4 x Minimum clear space (MCS) = 3/4 x _____ = _____
      MSA for mixing equipment = _____
      MSA for the project (smallest of above) = _____

      (2) Chosen aggregate:

      Type __________
      MSA __________
      Specific gravity __________
      Bulk unit weight __________
      Percent fines __________

3. Select design slump (see Table 2-4 on page 2-6).

   Maximum __________
   Minimum __________

4. Select w/c ratio.

a. Strength (see Table 2-1 on page 2-3) __________

b. Durability and watertighness (see Table 2-1:
Durability __________
Watertightness __________

c. Choose the lowest of the above. Design w/c ratio = _____

5. Select water content and percent of air (sea Table 2-2 on page 2-4)

a. Water content __________

b. Percent of air (entrapped or entrained) __________

6. Calculate cement content

$$\text{Cement} = \frac{\text{water (lbs/cy)}}{\text{w/c ratio}} = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

7. Volume of gravel (see Table 2-6 on page 2-14)

Weight of gravel = BUW x loose volume = _____ x _____ _____

8. Volume of sand.

a. Convert to absolute volume:

(1) $$\text{Cement} = \frac{\text{lbs of cement}}{\text{SG x 62.4}} = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

(2) $$\text{Water} = \frac{\text{lbs of water}}{62.4} = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

(3) $$\text{Gravel} = \frac{\text{lbs of gravel}}{\text{SG x 62.4}} = \_\_\_\_\_\_ = \_\_\_\_\_\_$$

(4) Air = percent of air x 27 = _____ x 27 = _____

(5) PV = summation = _____

b. Absolute volume of sand = 27 - PV = 27 - _____ = ______

c. Weight of sand = absolute volume x SG x 62.4 = _____ x _____ x 62.4 = _____

d. Loose volume sand = $\frac{\text{weight of sand}}{\text{BUW sand}}$ = _____ = _____

9. Preliminary mix proportions for a cubic yard batch.

Summary:

Cement ____________ lbs __________ sacks
Water ____________ lbs __________ gallons

Sand	______________	lbs _________ cubic feet
Gravel	______________	lbs _________ cubic feet
Air	______________	Percent (air-entrained concrete only)
Slump	______________	inches

NOTE: These proportions assume a SSD moisture condition for the aggregate. Adjustment must be made for the actual moisture condition of the aggregates on the job site as outlined in Lesson 2, Part D.

ANSWERS TO PRACTICAL PROBLEM

Specifications:

Strength at 28 days = 3,000 psi
Cement types available - I, IA, III
Water available from a potable source

Fine aggregate	FM	SG	BUW	Percent Fines
Source A	2.50	2.65	120 lb/cf	4
Source B	2.95	2.60	125 lb/cf	6

Coarse aggregate	Type	SG	BUW	MSA*	Percent Fines
Source A	Gravel	2.85	110 lb/cf	2" (-)	0.5
Source B	Gravel	2.60	95 lb/cf	1" (-)	1.0
Source C	Gravel	2.70	103 lb/cf	1/2" (-)	1.3

1. Select cement type.

   a. Availability
   b. Climate
   c. Specifications __1A__

2. Select aggregates.

   a. Fine aggregate

      (1) Fineness modulus __2.50__
      (2) Specific gravity __2.65__
      (3) BUW __120 pcf__
      (4) Percent fines __4__

   b. Coarse aggregate

      (1) Maximum size aggregate allowable for the project:

      1/5 x T = 1/5 x __8"__ = __1 3/5"__
      1/3 x D = 1/3 x __15"__ = __5"__
      3/4 x MCS = 3/4 x __2"__ = __1 1/2"__
      MSA for mixing equipment = __1 1/2"__
      MSA for the project (smallest of above) = __1 1/2"__

      (2) Chosen aggregate

      Type __Gravel (Source B)__
      MSA __1 inch__
      Specific gravity __2.60__
      Bulk unit weight __95 pcf__
      Percent fines __1.0__

3. Select design slump (see Table 2-4 on page 2-6).

Maximum 4 inches
Minimum 1 inch

4. Select w/c ratio.

a. Strength (see Table 2-1 on page 2-3) 0.46

b. Durability and watertighness (see Table 2-2 on page 2-4):
Durability 0.50
Watertightness 0.50

c. Choose the lowest of the above. Design w/c ratio = 0.46

5. Select water content and percent of air (see Table 2-2):

a. Water content 295 lbs
b. Percent of air (entrapped or entrained) 6.0 percent

6. Calculate cement content.

$$\text{Cement} = \frac{\text{water (lbs/cy)}}{\text{w/c ratio}} = \frac{295}{0.46} = 641.3 \text{ lbs}$$

7. Volume of gravel (see Table 2-6 on page 2-14). 18.9 cf
(FM = 2.50; MSA = 1 inch)

Weight of gravel = BUW x loose volume = 95 x 18.9 = 1,795.5 lbs

8. Volume of sand.

a. Convert to absolute volume:

(1) $$\text{Cement} = \frac{\text{lbs of cement}}{\text{SG x 62.4}} = \frac{641.3}{(3.15)(62.4)} = 3.26 \text{ cf}$$

(2) $$\text{Water} = \frac{\text{lbs of water}}{62.4} = \frac{2.95}{62.4} = 0.0472 \text{ cf}$$

(3) $$\text{Gravel} = \frac{\text{lbs of gravel}}{\text{SG x 62.4}} = \frac{1{,}795.5}{(2.60)(62.4)} = 11.07 \text{ cf}$$

(4) Air = percent of air x 27 = 0.06 x 27 = 1.62 cf

(5) PV = summation = 20.68 cf

b. Absolute volume of sand = 27 - PV = 27 - 20.68 = 6.32 cf

c. Weight of sand = absolute volume x SG x 62.4 = 6.32 x 2.65 x 62.4 = 1,045 lbs

d. **Loose volume sand** $= \frac{\text{weight of sand}}{\text{BUW sand}} = \frac{1{,}045}{120} = \underline{8.7\text{ cf}}$

9. Preliminary mix proportions for a cubic yard batch.

Summary:

Cement	641.3	lbs	6.8	sacks
Water	295	lbs	35.4	gallons
Sand	1,045	lbs	8.7	cubic feet
Gravel	1,795.5	lbs	18.9	cubic feet
Air	6	Percent (air-entrained concrete only)		
Slump	4	inches		

NOTE: These proportions assume a SSD moisture condition for the aggregate. Adjustments must be made for the actual moisture condition of the aggregates on the job site as outlined in Lesson 2, Part D.

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LESSON 2

PRACTICE EXERCISE

Check your understanding of Lesson 2 by completing the practice exercise. There is only one correct answer to each questions. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct response. Each correct response is referenced to specific portion of the lesson material so you can review any questions you have missed or do not understand before continuing to the next lesson.

1. Define moderate exposure conditions.

____

____

2. A change in the w/c ratio changes the characteristics of the--

____

____

3. List six of the basic guidelines for employing the Absolute Volume Method for proportioning concrete. (6/11)

____

____

4. Define severe exposure conditions.

____

____

5. List the steps to be followed in estimating the materials needed in a construction project.

____

____

6. List two main criteria for selecting mix proportions. Seven are present in the test.

____

____

7. When testing different batches of the same mixture, changes in slump indicate changes in--

____

____

LESSON 2
PRACTICE EXERCISE
ANSWER KEY AND FEEDBACK

Item | Correct Answer and Feedback

1. Freezing expected but concrete not continually exposed to moisture or free water for long periods before freezing.

   - Moderate exposure. This means ... (page 2-5)

2. Hardened concrete.

   Always remember that a change ... (page 2-2)

3. Combine the paste components as in the Trial Batch Method.
   Determine and produce the required slump.
   Estimate the water requirement (see Table 2-2 on page 2-4).
   Estimate the volume of dry-rodded coarse aggregate per cubic yard (see Table 2-6 on page 2-14).
   Determine the maximum size and FM of the fine aggregate.
   Calculate the volume occupied per cubic yard of concrete by the water, cement, coarse aggregate, and air.
   (6/11 guidelines are presented.)

   This method can be ... (page 2-13)

4. Concrete exposed to deicing chemicals or other aggregate agent or continually exposed moisture or water prior to freezing.

   - Severe exposure. This means ... (page 2-5)

5. Determine the total volume in cubic yards of the concrete to be placed.
   Add an extra amount for waste.
   Determine the total amounts of cement, fine and coarse aggregate by multiplying amounts of these components needed for 1 cubic yard the adjusted total volume.
   Determine the required amount of water needed for the job. (Amount of water is approximately 8 gallons of water per sack of cement needed.)

   Step 1, Step 2, and Step 3 (pages 2-21 and 2-23)

6. Proportions are determined by the concrete's end use.
   Proportions are determined by anticipated conditions at the time of placement.
   Strength, durability, and appearance.
   Placability and economy.

   Concrete proportions for a... (page 2-2)

Item	Correct Answer and Feedback
7.	Materials Mix proportions Water content When testing different batches... (page 2-5)

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LESSON 3

FORM DESIGN AND CONSTRUCTION

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will identify the importance of form and form design and their uses in construction.

TERMINAL LEARNING OBJECTIVE:

ACTION: Identify and plan the design of forms and identify their uses in construction.

CONDITION: You are given the materials contained in this lesson.

STANDARD: Correctly answer all practice exercise questions at the end of the lesson.

REFERENCE: The material contained in this lesson was derived from the following publication: FM 5-742, with change 1.

INTRODUCTION

Forms hold concrete until i se and produces the desired shapes and surface finishes. Forms also protect concrete and support any reinforcing bars. Because forms represent up to one-third of a concrete structure total cost, this lesson is very important.

PART A - FORM DESIGN

PRINCIPLES

Importance of Form Design

Formwork holds concrete until it sets and produces the desired shapes and, sometimes, surface finishes. Forms also protect concrete, aid in curing, and support any reinforcing bars or conduit embedded within it. Because formwork can represent up to one-third of a concrete structure's total cost, this phase of a project is very important. The nature of the structure, availability of equipment and form materials, anticipated reuse of the forms, and familiarity with construction methods all influence the formwork design. To design forms, you must know the strength of the forming materials and the loads they must support. You must also consider the concrete final shape, dimensions, and surface finish.

Form Characteristics

Forms must be tight, rigid, and strong. Loose forms permit either loss of cement, resulting in honeycomb, or loss of water, causing sand streaking. Brace forms enough to align them and make them strong enough to hold the concrete. Take special care in bracing and tying down forms used for such configurations as retaining walls that are wide at the bottom and that taper toward the top. The concrete in this and other types of construction, such as the first pour for walls and columns, tends to lift the form above its proper elevation. To reuse forms, make them easy to remove and replace without damage. The easiest way is to oil the forms before placing the concrete.

Form Materials

Forms are generally made from four different materials: wood, metal, earth, and fiber. Metal forms are more expensive than wood, but are more economical if reused enough. The material you will use is wood.

FORMING

Wall Forms

Figure 3-1 shows the basic parts of a wood form for panel walks.

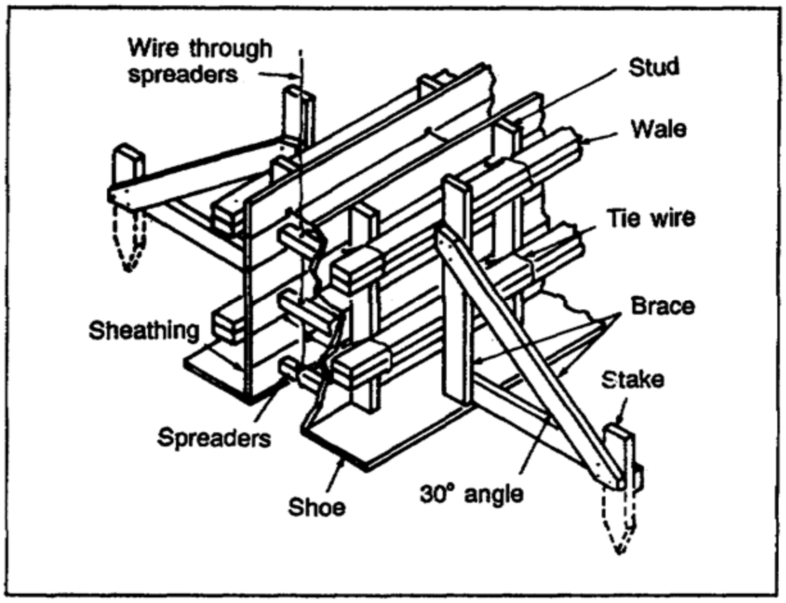


Figure 3-1. Wood form for a concrete panel wall.

- *Sheathing.* Sheathing forms the vertical surfaces of a concrete wall. The sheathing must be watertight. Although sheathing made from tongue-and-groove lumber gives the smoothest and most watertight concrete surface, you can also use plywood or fiber-based hardboard.

- *Studs.* Vertical studs add rigidity to the wall forms. They are made from single 2- by 4-foot or 2- by 6-foot lumber.

- *Wales (walers).* Wales reinforce the studs when they extend upward more than 4- or 5-feet. They should be made from doubled 2- by 4-inch, 2- by 6-inch, or a single 4- by

4-inch piece of lumber, and are lapped at the form corners to add rigidity. Double wales not only reinforce the studs but also tie prefabricated panels together and keep them aligned.

- *Braces.* Although braces are neither part of the form design nor considered as providing any additional strength, they help stabilize the form. Of the many types of braces, the most common is a combination of a diagonal member and a horizontal member nailed to a stake at one end and to a stud or wale on the other. The diagonal member makes a 20- to 60-degree angle with the horizontal member. To add more bracing you can place vertical members (strongbacks) behind the wales, or vertical members in the angle formed by intersecting wales.

- *Spreaders.* Spreaders are small pieces of wood placed between the sheathing panels to maintain the proper wall thickness between them. They are cut to the same length as the wall thickness. Because friction, not fasteners; holds the spreaders in place, you can remove them easily before the concrete hardens. Attach a wire, off centered, securely through the spreaders, as shown in Figure 3-1, to pull them out when the fresh concrete exerts enough pressure against the sheathing to permit removal.

- *Tie wires.* Tie wires secure the formwork against the lateral pressure of the plastic concrete. They always have double strands.

- *Tie rods.* Tie rods are easier to work with and sometimes replace tie wires in the same function.

Column Forms

Figure 3-2 shows the basic parts of a wood for a concrete column.

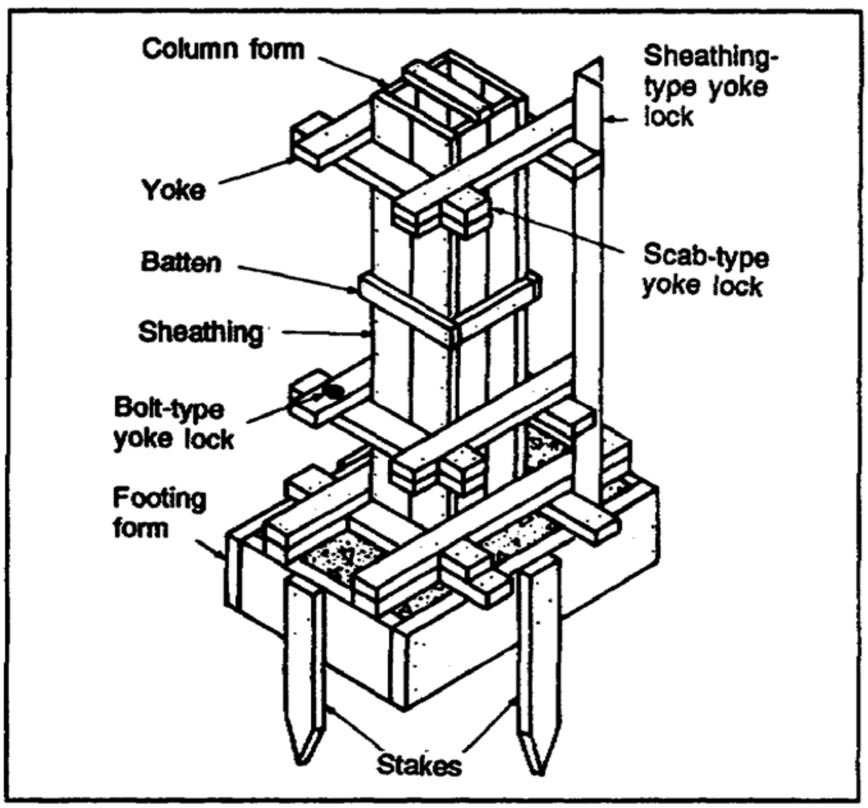


Figure 3-2. Form for a concrete column and footing.

- *Sheathing.* Sheathing runs vertically in column forms to reduce the number of saw cuts. You must nail the corner joints firmly to ensure watertightness.

- *Yokes.* A yoke is a horizontal reinforcement in the form of a rectangle that wraps around a column to prevent concrete from distorting the form. It serves the same purpose as a stud in a wall form. You can lock yokes in place using the sheathing-, scab-, or bolt-type yoke lock. The small horizontal dimensions of a column do not require vertical reinforcement.

- *Battens.* Battens are narrow strips of boards that are placed directly over the joints to fasten the several pieces of vertical sheathing together.

PART B - USING FORM DESIGN PRINCIPLES

BASIS OF FORM DESIGN

Because concrete is in a plastic state when placed in the form, it exerts hydrostatic pressure on the form. Thus, the basis of form design is to offset the maximum pressure developed by the concrete during placing. The pressure depends on the rate of placing and the ambient temperature. The rate of placing affects pressure because it determines how much hydrostatic head builds up in the form. The hydrostatic head continues to increase until the concrete takes its initial set, usually in about 90 minutes. However, because the initial set takes much more time at low ambient temperatures, you must consider the ambient temperature at the time of placing. Knowing these two factors (rate of placing and ambient temperature) plus the specified type of form material, you can calculate a tentative design. The temperature will be assumed for the design. If the actual temperature differs at the job site, adjustment will be made.

PANEL WALL FORM DESIGN

Procedure

It is best to design forms following a step-by-step procedure. Use these steps to design a wood form for a concrete wall.

Step 1. Determine the materials you will use for sheathing, studs, wales, braces, and ties.

Step 2. Determine the mixer output by dividing the mixer yield by the batch time. Batch time includes loading all ingredients, mixing, and unloading. If you use more than one mixer, multiply the mixer output by the number of mixers.

$$\text{Mixer output (cf/hr)} = \frac{\text{mixer yield (cf)}}{\text{batch time (min)}} \times \frac{60\text{ min}}{\text{hr}} \times \text{number of mixers}$$

Step 3. Determine the area enclosed by the form.

Plan area (sf) = Length (L) x Width (W)

Step 4. Determine the rate of placing (vertical feet per hour) (R) of the concrete in the form by dividing the mixer output by the plan area.

$$\text{R (ft/hr)} = \frac{\text{mixer output (cf/hr)}}{\text{plan areas (sf)}}$$

NOTE: For an economical design, try to keep R ≤ 5 ft/hr.

Step 5. Make a reasonable estimate of the placing temperature of the concrete. (Ambient temperature during the season.)

Step 6. Use the rate of placing to determine the maximum concrete pressure by referring to Figure 3-3. First, draw a vertical line from the rate of placing until it intersects the correct concrete temperature line. Then read left horizontally from the point of intersection to the left margin of the graph and determine the maximum concrete pressure in 100 lb/sf.

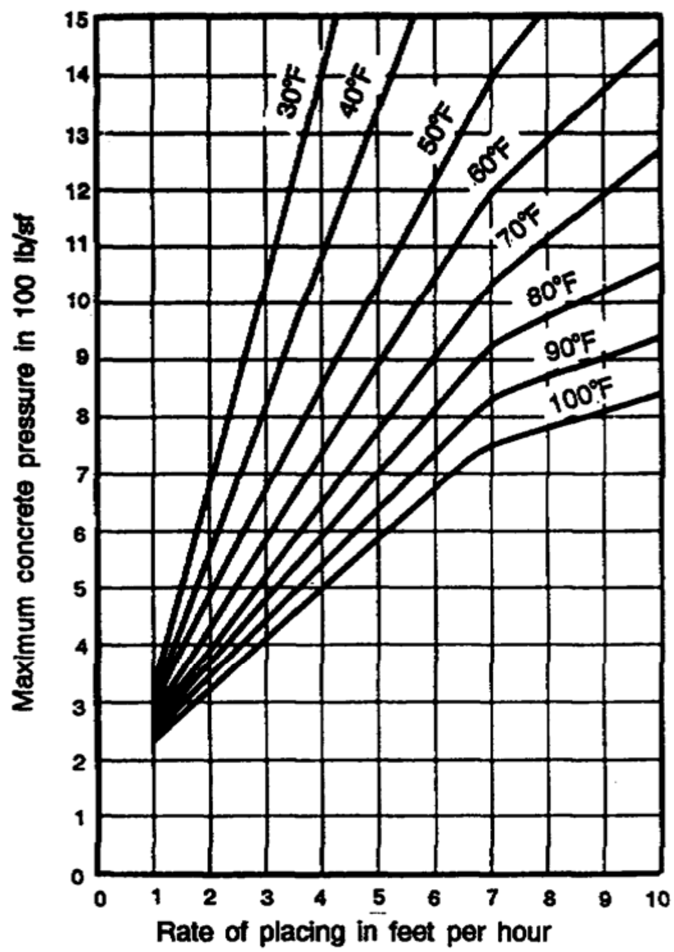


Figure 3-3. Maximum concrete pressure graph.

Step 7. Use Table 3-1 on page 3-6 or Table 3-2 on page 3-7 to find the maximum stud spacing in inches. Use Table 3-1 for board sheathing and Table 3-2 for plywood sheathing. Refer to the column headed Maximum Concrete Pressure and find the value you have for the maximum concrete pressure. If the value you have falls between two values in the column, round it up to the nearest given value. Now move right to the column identified by the sheathing thickness you are using. (Use the strong way for plywood when possible.) This number is the maximum stud spacing in inches.

Table 3-1. Maximum stud (joist) spacing for board sheathing.

Maximum Concrete Pressure, lb/sf	Nominal Thickness of S4S Boards, in			
	1	1 1/4	1 1/2	2
75	30	37	44	50
100	28	34	41	47
125	26	33	39	44
150	25	31	37	42
175	24	30	35	41
200	23	29	34	39
300	21	26	31	35
400	18	24	29	33
500	16	22	27	31
600	15	20	25	30
700	14	18	23	28
800	13	17	22	26
900	12	16	20	24
1,000	12	15	19	23
1,100	11	15	18	22
1,200	11	14	18	21
1,400	10	13	16	20
1,600	9	12	15	18
1,800	9	12	14	17
2,000	8	11	14	16
2,200	8	10	13	16
2,400	7	10	12	15
2,600	7	10	12	14
2,800	7	9	12	14
3,000	7	9	11	13

Table 3-2. Maximum stud (joist) spacing for plywood sheathing, in.

Maximum Concrete Pressure, (lb/sf)	Strong Way 5-Ply Sanded, Face Grain Parallel to Span (in)				Weak Way 5-Ply Sanded, Face Grain Perpendicular to Span, (in)			
	1/2	5/8	3/4	1 (7 Ply)	1/2	5/8	3/4	1 (7 Ply)
75	20	24	26	31	13	18	23	30
100	18	22	24	29	12	17	22	28
125	17	20	23	28	11	15	20	27
150	16	19	22	27	11	15	19	25
175	15	18	21	26	10	14	18	24
200	15	17	20	25	10	13	17	24
300	13	15	17	22	8	12	15	21
400	12	14	16	20	8	11	14	19
500	11	13	15	19	7	10	13	18
600	10	12	14	17	6	9	12	17
700	10	11	13	16	6	9	11	16
800	9	10	12	15	5	8	11	15
900	9	10	11	14	4	8	9	15
1,000	8	9	10	13	4	7	9	14
1,100	7	9	10	12	4	6	8	12
1,200	7	8	10	11	—	6	7	11
1,300	6	8	9	11	—	5	7	11
1,400	6	7	9	10	—	5	6	10
1,500	5	7	9	9	—	5	6	9
1,600	5	6	8	9	—	4	5	9
1,700	5	6	8	8	—	4	5	8
1,800	4	6	8	8	—	4	5	8
1,900	4	5	8	7	—	4	4	7
2,000	4	5	7	7	—	—	4	7
2,200	4	5	6	6	—	—	4	6
2,400	—	4	5	6	—	—	4	6
2,600	—	4	5	5	—	—	—	5
2,800	—	4	4	5	—	—	—	5
3,000	—	—	4	5	—	—	—	5

Step 8. Determine the uniform load on a stud (ULS) by multiplying the maximum concrete pressure by the stud spacing.

ULS (lb/linear ft) = maximum concrete pressure (lb/sf) x maximum stud spacing (in) ÷ 12 (in/ft)

Step 9. Use Table 3-3 to determine the maximum wale spacing. Refer to the column headed Uniform Load (UL) and find the value you have for the ULS. If the value you have falls between two values in the column, round it up to the nearest given value.

Table 3-3. Maximum spacing for wales, ties, stringers, and 4- by 4 inch or larger shores where member to be supported is a single member (in).

Uniform Load (lb/linear ft)	Supported Member Size (S4S), (in)				
	2 by 4	2 by 6	3 by 6	4 by 4	4 by 6
100	60	95	120	92	131
125	54	85	110	82	124
150	49	77	100	75	118
175	45	72	93	70	110
200	42	67	87	65	102
225	40	63	82	61	97
250	38	60	77	58	92
275	36	57	74	55	87
300	35	55	71	53	84
350	32	50	65	49	77
400	30	47	61	46	72
450	28	44	58	43	68
500	27	41	55	41	65
600	24	38	50	37	59
700	22	36	46	35	55
800	21	33	43	32	51
900	20	31	41	30	48
1,000	19	30	38	29	46
1,200	17	27	35	27	42
1,400	16	25	33	25	39
1,600	15	23	31	23	36
1,800	14	22	29	22	34
2,000	13	21	27	21	32
2,200	13	20	26	20	31
2,400	12	19	25	19	30
2,600	12	19	24	18	28
2,800	11	18	23	17	27
3,000	11	17	22	17	26
3,400	10	16	21	16	25
3,800	10	15	20	15	23
4,500	9	14	18	13	21

Now move right to the column identified by the size of stud you are using. This number is the maximum wale spacing in inches.

Step 10. Determine the uniform load on a wale (ULW) by multiplying the maximum concrete pressure by the maximum wale spacing.

ULW (lb/linear ft) = maximum concrete pressure (lb/sf) x maximum wale spacing (in) ÷ 12 (in/ft)

Step 11. Use Table 3-3 on page 3-9 or Table 3-4 (depending on type of wale) to determine the tie spacing based on the ULW. Refer to the column headed Uniform Load and find the value you have for the ULW. If the value you have falls between two values in the column, round it up to the nearest given value. Now move right to the column identified by the size of lumber of wale you are using. This number is the maximum tie spacing in inches, based on wale size. Use Table 3-3 if using single wales (4- by 4-inch lumber). Use Table 3-4 if you are using double wales (2- by 4-inch or 2- by 6-inch lumber).

Table 3-4. Maximum spacing for ties and 4 by 4s or larger shores where member to be supported is a double member (in).

Uniform Load (lb/linear ft)	Supported Member Size (S4S), (in)				
	2 by 4	2 by 6	3 by 6	4 by 4	4 by 6
100	85	126	143	222	156
125	76	119	135	105	147
150	70	110	129	100	141
175	64	102	124	96	135
200	60	95	120	92	131
225	57	89	116	87	127
250	54	85	109	82	124
275	51	81	104	78	121
300	49	77	100	75	118
350	46	72	93	70	110
400	43	67	87	65	102
450	40	63	82	61	97
500	38	60	77	58	92
600	35	55	71	53	84
700	32	51	65	49	77
800	30	47	61	46	72
900	28	44	58	43	68
1,000	27	43	55	41	65
1,200	25	39	50	38	59
1,400	23	36	46	35	55
1,600	21	34	43	33	51
1,800	20	32	41	31	48
2,000	19	30	39	29	46
2,200	18	29	37	28	44
2,400	17	27	36	27	42
2,600	17	26	34	26	40
2,800	16	25	33	25	39
3,000	15	24	32	24	38
3,400	14	23	30	22	35
3,800	14	21	28	21	33
4,500	12	20	25	19	30

Step 12. Now determine the tie spacing based on the tie strength by dividing the tie breaking strength by the UL on a wale. If you do not know the breaking strength of the tie, Table 3-5 gives the breaking loads for a double-strand wire and tie rods (found in the Army supply system).

$$\text{Tie wire or tie rod spacing (in)} = \frac{\text{tie wire or tie rod strength (lb)} \times \text{(12 in/ft)}}{\text{uniform load on wale (lb/ft)}}$$

If the result does not equal a whole number of inches, round the value down to the next number of inches.

Table 3-5. Average breaking load of tie material (lb).

Steel Wire	
Size of Wire Gauge Number	**Minimum Breaking Load, Double Strand (lb)**
8	1,700
9	1,420
10	1,170
11	930
Barbed Wire	
Size of Each Wire Gauge Number	**Minimum Breaking Load (lb)**
12 1/2	950
13*	660
13 1/2	950
14	650
15 1/2	850
Tie Rod	
Description	**Minimum Breaking Load (lb)**
Snap ties	3,000
Pencil rods	3,000
* Single-strand barbed wire.	

Step 13. Select the smaller of the tie spacings as determined in Steps 11 and 12.

Step 14. Tie wires must be installed at the intersection of studs and wales. Reduce the stud spacing (Step 7) or the tie spacing (Step 13) to conform with this requirement. Tie rods may be placed along the wales at the spacing determined in Step 13 without adjusting the studs. Place the first tie at one-half the maximum tie spacing from the end of the wale.

Step 15. Determine the number of studs on one side of a form by dividing the form length by the maximum stud spacing. Add one to this number and round up to the next integer. The first and last studs must be placed at the ends of the form, even though the spacing between the last two studs may be less than the maximum allowable spacing.

$$\text{Number of studs} = \frac{\text{length of form (ft)} \times 12\ \text{(in/ft)}}{\text{stud spacing (in)}} + 1$$

Step 16. Determine the number of wales for one side of a form by dividing the form height by the maximum wale spacing, and round up to the next integer. Place the first wale one-half of the maximum space up from the bottom and the remainder at the maximum wale spacing

Step 17. Determine the time required to place the concrete by dividing the height of the form by the rate of placing.

Example Problem 1

Design the form for a concrete wall 40 inches long, 2 feet thick, and 10 feet high. An M919 concrete mobile mixer is available, and the crew can produce and place a cubic yard of concrete every 10 minutes. The concrete placing temperature is estimated at 70°F. The form materials you have are 2-by 4-foot lumber, 1-inch board sheathing, and No 9 steel wire.

Solution Steps:

Step 1. Materials available: studs, 2- by 4-foot (single); wales, 2- by 4-foot (doubled); sheathing, 1-inch board; ties, No 9 wire.

Step 2. **Production rate** $= \frac{27\ \text{cf}}{10\ \text{min}} \times \frac{60\ \text{min}}{\text{hr}} = 162\ \text{cf/hr}$

Step 3. Plan area of form = 40 ft x 2 ft = 80 sf

Step 4. **Rate of placing** $= \frac{162\ \text{cf/hr}}{80\ \text{sf}} = 2.025\ \text{ft/hr}$

Step 5. Concrete placing temperature = 70°F

Step 6. Maximum concrete pressure (refer to Figure 3-3, page 3-5) = 400 lb/sf

Step 7. Maximum stud spacing (refer to Table 3-1, page 3-6) = 18 inches

Step 8. **Uniform load on studs** $= 400\ \text{lb/sf} \times \frac{18\ \text{in}}{12\ \text{in/ft}} = 600$ **lb/ linear foot (lf)**

Step 9. Maximum wale spacing (refer to Table 3-3, page 3-9) = 24 inches

Step 10. **UL on wales** $= 400\ \text{lb/sf} \times \frac{24\ \text{in}}{12\ \text{in/ft}} = 800\ \text{lb/lf}$

Step 11. Tie wire spacing based on wale size (refer to Table 3-4, page 3-11) = 30 inches

Step 12. **Tie wire spacing based on wire strength (refer to Table 3-5, breaking strength of No 9 wire = 1,420 lb)** $= \frac{1{,}420\ \text{lb} \times 12\ \text{in/ft}}{800\ \text{lb/lf}} = 21.3$ **(use 21 inches)**

Step 13. Maximum tie spacing = 21 inches

Step 14. Because maximum tie spacing is greater than maximum stud spacing (Step 7), reduce the tie spacing to 18 inches and tie at the intersection of each stud and double wale.

Step 15. **Number of studs per side** $= \frac{40 \text{ ft} \times 12 \text{ in/ft}}{18 \text{ in}} + 1 = 27.7$ **(use 28 studs)**

Step 16. **Number of double wales per side** $= 10 \text{ ft} \times \frac{12 \text{ in/ft}}{24 \text{ in}} = 5$ **wales**

Step 17. **Time required to place concrete** $= \frac{10 \text{ ft}}{2.025 \text{ ft/hr}} = 4.93$ **hr (use 5 hours)**

Example Problem 2

Design the form for a concrete wall 40 feet long, 2 feet thick, and 10 feet high. An M919 concrete mobile mixer is available, and the crew can produce and place a cubic yard of concrete every seven minutes. The concrete placing temperature is estimated at 70°F. The form materials you have are 2- by 4-inch lumber, 3/4-inch plywood, and 3,000-pound (breaking strength) snap ties.

Solution Steps:

Step 1. Materials available: studs, 2 by 4 (single); wales, 2 by 4 (doubled); sheathing, 3/4-inch plywood (strong); ties, 3,000-pound snap ties

Step 2. **Production rate** $= \frac{27 \text{ cf}}{7 \text{ min}} \times \frac{60 \text{ min}}{\text{hr}} = 231.4$ ***cf/hr***

Step 3. Plan area of form = 40 ft x 2 ft = 80 sf

Step 4. **Rate of placing** $= \frac{231.4 \text{ cf/hr}}{80 \text{ sf}} = 2.9$ **ft/hr**

Step 5. Concrete placing temperature = 70°F

Step 6. Maximum concrete pressure (refer to Figure 3-3, page 3-5) = 500 lb/sf

Step 7. Maximum stud spacing (refer to Table 3-2, page 3-7) = 15 inches

Step 8. **UL on studs** $= 500 \text{ lb/sf} \times \frac{15 \text{ in}}{12 \text{ in/lf}} = 625$ **lb/sf (round up to 700 lb/lf)**

Step 9. Maximum wale spacing (refer to Table 3-3, page 3-9, using 700 lb/lf load) = 22 inches

Step 10. **UL on wales** $= 500 \text{ lb/sf} \times \frac{22 \text{ in}}{12 \text{ in/ft}} = 916.6$ **lb/lf (round up to 1,000 lb/lf)**

Step 11. Tie spacing based on wale size (refer to Table 3-4, page 3-11, using 1,000 lb/lf load) = 27 inches

Step 12. **Tie spacing based on tie rod strength (refer to Table 3-5, page 3-12) =**

$$\frac{3{,}000 \text{ lbs} \times 12 \text{ in/ft}}{917 \text{ lb/lf}} = 39.25 \text{ (use 39 inches)}$$

Step 13. Therefore, maximum tie spacing = 27 inches.

Step 14. Because we are using tie rods, it is not necessary to adjust the tie or stud spacing. The first tie rod goes in one-half the spacing from the end and full spacing thereafter.

Step 15. **Number of studs per side** $= \frac{(40 \text{ ft} \times 12 \text{ in/ft})}{15 \text{ in}} = 32 + 1 = 33$ **studs**

Step 16. **Number of double wales per side** $= \frac{(10 \text{ ft} \times 12 \text{ in/ft})}{22 \text{ in}} = 5.45$ **(use 6 wales)**

Step 17. **Time required to place concrete** $= \frac{10 \text{ ft}}{2.9 \text{ ft/hr}} = 3.45$ **hr**

BRACING FOR WALL FORMS

General

Braces are used against wall forms to keep the forms in place and in alignment from mishaps due to external forces (winds, personnel, equipment, vibration, and accidents). An equivalent force due to all of these forces (the resultant force) is assumed to be acting uniformly along the top edge of the form in a horizontal plane. For most military applications, this force is assumed to be 12.5 feet by the wall height. As this force can act in both directions, braces to be used should be equally strong on tension as in compression, or braces should be used on both sides of the wall forms. The design procedure is based on using a single row of braces, and assuming that strong, straight, seasoned lumber will be used. The braces are properly secured against the wall forms and the ground at both ends. Knowing the height of the wall to be built and selecting a material (2 inches or greater) for the braces, determine the maximum safe spacing of these braces (center to center) that will keep the form work aligned.

Nomenclature

See Figure 3-4 on page 3-16.

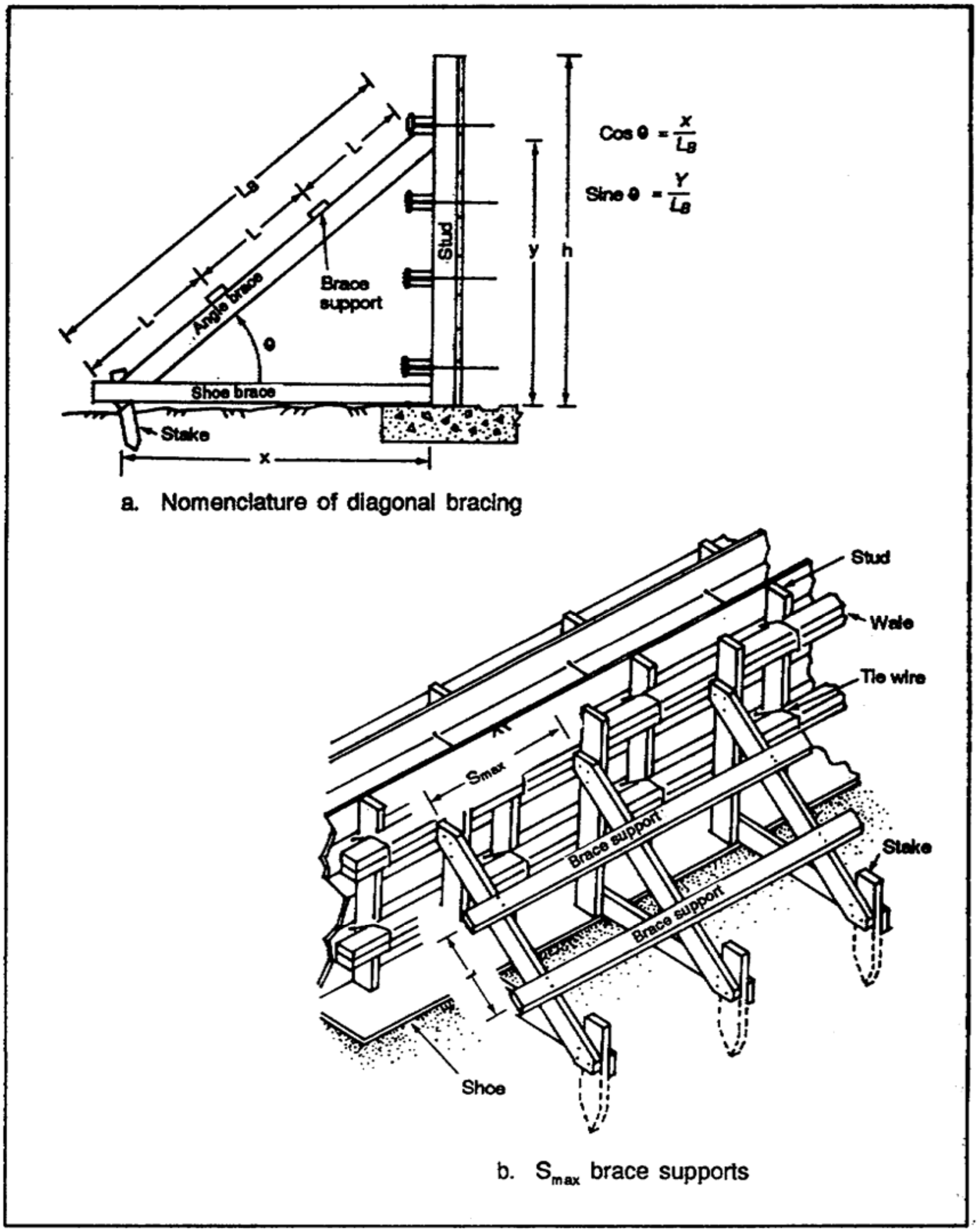


Figure 3-4. Elements of diagonal bracing.

L_B = Total length (feet) of the brace member from end connection to end connection.

L_{max} = The maximum allowable unsupported length of the brace (feet) due to buckling and bending. For all 2-inch material, L_{max} = 6 1/4 feet; for all 4-inch material, L_{max} = 14 1/2 feet.

L = The actual unsupported length (feet) of the brace used.

h = The overall height (feet) of the wall form.

y = The point of application of the brace on the wall form, measured in ft from the base of the form.

θ = The angle, in degrees, that the brace makes with the horizontal. For best effect, θ should be between 20 and 60 degrees.

J = A factor to be applied which includes all constant values (material properties and assumed wind force). It is measured in ft^4. See Table 3-6.

Table 3-6. J factors.

Material (in)	J (ft^4)
2 by 4	2,360
2 by 6	3,710
2 by 8	4,890
2 by 10	6,240
2 by 12	7,590
4 by 4	30,010

S_{max} = The maximum safe spacing of braces (feet), center to center, to support the walls against external forces.

$$S_{max} = \frac{Jy}{h^2 L^2} \times \cos\theta$$

cos =- Cosine; the ratio of the distance from the stake to the wall divided by the length of the brace

sin = Sine; the ratio "y" vided by L_B.

Procedure

The design procedure can best be explained by an example problem.

Example Problem: Determine the spacing of bracing for a wall 10 feet high. Use 2- by 6-inch by 10-foot material attached 6 feet from the bottom to the top of the form.

- Select material = given 2- by 6-inch by 10 foot (uncut)
- J = 3,710 ft^4 (from Table 3-6)
- L_{max} = 6 1/4 feet (because of 2-inch material)
- L_B = 10 feet

- h = 10 ft (from example problem)
- y = 6 feet (from example problem)

Step 1. Determine angle of placement, θ.

$$\sin\theta = \frac{y}{L_B} = \frac{6}{10} = .600$$

$$\theta = \sin^{1}(.600) = .600 = 37°$$

Step 2. Determine L (actual supported length of brace). Since the L_{max} for all 2-inch material is 6 1/4 feet and the brace in this problem is 10 feet long, you will have to use something to support the braces (usually 1- by 4-inch or 1- by 6-inch material). The best position to put this support would be in the middle of the brace, thus given L = 6 feet.

Step 3. Determine S_{max} from the formula.

$$S_{max} = \frac{Jy}{h^2L^2} \times \cos\theta = \frac{(3{,}710 \text{ ft}^4) \times 6 \text{ ft}}{100 \text{ sf} \times 25 \text{ sf}} \times \cos 37° = 7.13 \text{ feet (say 7 feet)}$$

Thus, using 2- by 6-inch by 10-foot braces applied to the wall form at y = 6 feet, you should place these braces no further apart than 7 feet. Remember also that after the braces are properly installed, connect all braces to each other at the center so deflection does not occur.

NOTE: This procedure determines the maximum safe spacing of braces. There is no doctrine that states the braces **must** be placed 7 feet apart--they can be less!

Discussion. To fully understand the procedure, the following points lend insight to the formula:

$$S_{max} = \frac{Jy}{h^2L^2} \times \cos\theta$$

- Derivation of the formula has a safety factor of 3.
- For older or "green" lumber, reduce S_{max} according to judgement.
- For maximum support, attach braces to the top edge of the forms (or as close as practicable). Also, better support will be achieved if θ = 45°.
- Remember to use intermediate supports whenever the length of the brace (L_B) is greater than L_{max}.
- Whenever there are choices of material, the larger size will always carry greater loads.

To prevent overloading of the brace, support should be placed no closer together than 2 feet for all 2-inch material, nor 5 feet for all 4-inch material. This is necessary to prevent crushing of the brace.

OVERHEAD SLAB FORM DESIGN

General

There may be instances where a concrete slab will have to be placed above the ground, such as bunker and culvert roofs. Careful consideration must be given to the design of the formwork because of the danger of failure caused by the weight of plastic concrete and the live load (LL) of equipment and personnel on the forms. The following method employs some of the same procedures used in the wall-form design:

Nomenclature

See Figure 3-6.

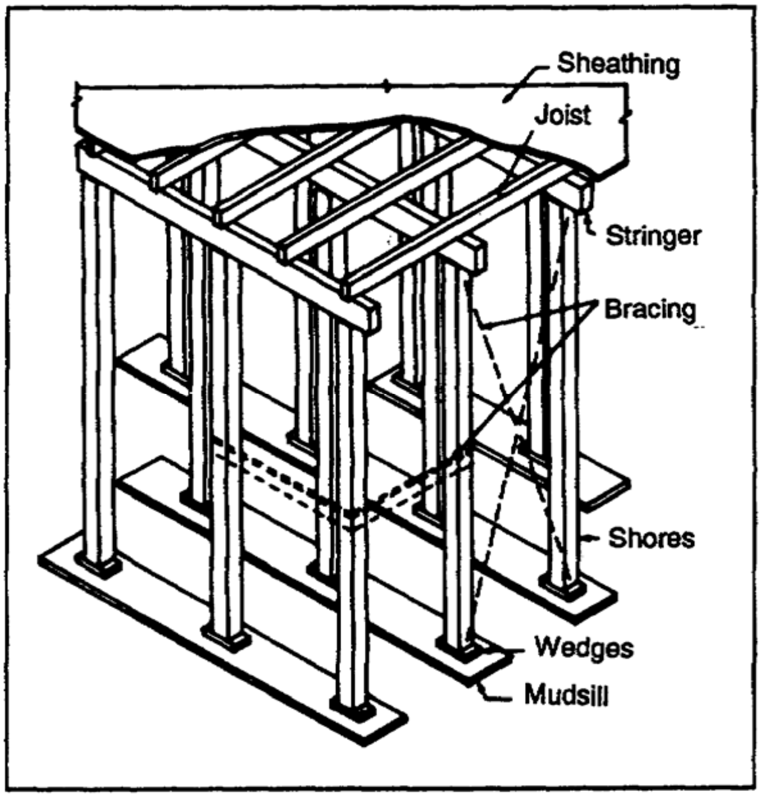


Figure 3-5. Typical overhead slab forms.

- *Sheathing.* Shapes and holds the concrete. Plywood or solid sheet metal is best for use.
- *Joists.* Support the sheathing against deflection. Perform the same function as studs in a wall form. Use 2-, 3-, or 4-inch thick lumber.
- *Stringers.* Support the joists against deflection. Perform the same function as wales in a wall form. Use 2-inch-thick or larger lumber. Stringers do not have to be doubled as wales are.

- *Shores.* Support the stringers against deflection. Perform the same functions as tie in a wall form and also support the concrete at the desired elevation above ground. Use lumber at least as large as the stringer but never smaller than 4 by 4 inches in dimension.

- *Lateral bracing.* May be required between adjacent shores to keep shores from bending under load. Use 1- by 6-inch or larger material for bracing material. Cross or "X" bracing of some type will always be required to support the form work material.

Procedure

Step 1. Specify the materials you will be using for the construction of the overhead roof slab. It is important that anyone using your design will know exactly which materials to use for each of the structural members.

Step 2. Determine the maximum total load (TL) the formwork will have to support. The LL of materials, personnel, and equipment is estimated to be 50 lb/sf unless the formwork will support engine-powered concrete buggies or other power equipment. In this case, a LL of 75 lb/sf will be used. The LL is added with the dead load of the concrete to obtain the maximum TL. The concrete dead load is obtained by estimating the unit weight of concrete at 150 lb/cf. The formulas are--

Total load (TL) = LL + dead load (DL)

LL = 50 lb/sf, or 75 lb/sf with power equipment

$$\text{DL} = 150 \text{ lb/cf} \times \frac{\text{overhead slab thickness (in)}}{12 \text{ in/ft}}$$

Step 3. Determine the maximum joist spacing. Use Table 3-1 on page 3-6, or Table 3-2 on page 3-7, and read the joist spacing based on the sheathing material used, which i the same as for determining the maximum stud spacing for wall-form design. Use the maximum TL in place of the maximum concrete pressure.

Step 4. Calculate the uniform load on the joist. The same procedure is used as for determining UL on structural members in wall-form design.

$$\text{Uniform load on joist (ULJ)} = \frac{\text{TL} \times \text{joist spacing (in)}}{12 \text{ in/ft}}$$

Step 5. Determine the maximum stringer spacing. Use Table 3-3 on page 3-9, and the UL on the joist calculated in Step 4. Round this load up to the next higher load located in the left column of the table, then read right to the column containing the lumber material used as the joist. This is the member to be supported by the stringer. The value at this intersection is the on-center (OC) spacing of the stringer.

Step 6. Calculate the uniform load on the stringer.

$$\text{UL on the stringer } (\text{ULS}_{str}) = \frac{\text{TL} \times \text{maximum stringer spacing (in)}}{12 \text{ in/ft}}$$

Step 7. Determine the maximum shore spacing. Maximum shore spacing is based on the stringer strength. Use Table 3-3, for single stringers, and use Table 3-4 on page 3-11, if stringers are doubled and the UL on the stinger is rounded to the next higher load shown in the left column of the table. To assure the stringer is properly supported read right to the stringer material column. This intersection is the OC spacing of the shore. Maximum shore spacing is also dependent on shore strength and end bearing of the shore on the stringer.

Use the allowable load from Table 3-7 and Table 3-8 on page 3-22, based on the shore strength and the bearing stress strength of the stringer.

NOTE: Unsupported length = height above sill--sheathing thickness--joist thickness--stringer thickness. This length is then rounded up to the next higher table value.

Table 3-7. Allowable load, in pounds, on wood shores, based on shore strength.

Nominal Lumber Size (in)	4 - by 4-inch		4 - by 6-inch		6- by 6-inch	
	*R	**S4S	R	S4S	R	S4S
Unsupported Length (ft)						
4	9,900	9,200	15,300	14,400	23,700	22,700
5	9,900	9,200	15,300	14,400	23,700	22,700
6	9,900	9,200	15,300	14,400	23,700	22,700
7	8,100	7,000	12,500	11,000	23,700	22,700
8	6,200	5,400	9,600	8,400	23,700	22,700
9	4,900	4,200	7,600	6,700	23,700	22,700
10	4,000	3,400	6,100	5,400	23,000	21,000
11	3,300	2,800	5,100	4,500	19,000	17,300
12	2,700	2,400	4,300	3,700	16,000	14,600
13	2,300	2,000	3,600	3,200	13,600	12,400
		l/d = 50		l/d = 50		
14	2,000	1,700	3,100	2,800	11,700	10,700
	l/d = 50		l/d = 50			
15	1,800		2,700		10,200	9,300
16					9,000	8,200
17					7,900	7,300
18					7,100	6,500
19					6,400	5,800
20					5,700	5,200

The above table values are based on wood members with the following strength characteristics: Compression || grain = 750 psi; E = 1,1000,000 psi.

*R indicates rough lumber

**S4S indicates surfaced four sides

Table 3-8. Allowable load on specified shore, based on bearing stresses where the maximum shore area is in contact with the supported member.

Nominal Lumber Size (In)	4- by 4-inch		4- by 6-inch		6- by 6-inch	
	*R	**S4S	R	S4S	R	S4S
C ⊥ of member supported						
250	3,300	3,100	5,100	4,800	7,900	7,600
350	4,600	4,300	7,100	6,700	11,100	10,600
385	5,100	4,700	7,800	7,400	12,200	11,600
400	5,300	4,900	8,200	7,700	12,700	12,100

When the compression perpendicular to the grain of the member being supported is unknown, assume the most critical C ⊥ to the grain.

*R indicates rough lumber

**S4S indicates surfaced four sides

- *Allowable load based on shore strength.* Select the shore material dimensions and determine the unsupported length in feet of the shore. Use Table 3-7 on page 3-21. Read down the left column to the unsupported length (in feet) of the shore; read right to the column of the size material used as the shore. The allowable load for that shore is given in pounds at the intersection of the row and column.

- *Allowable load based on end-bearing area.* Select the size of the shore material and the compression perpendicular ⊥ to the grain of the stringer. If the compression perpendicular to the grain is unknown, use the lowest value provided on the table. Use Table 3-8. Read down the left column to the compression perpendicular to the grain of the stringer material and then right to the column of the shore material. The allowable load between the stringer and the shore will be in pounds.

- *Select the allowable load on the shore.* Compare the two loads just determined and select the lower as the allowable load on the shore. Calculate shore spacing by the following formula:

$$\text{Shore spacing} = \frac{\text{allowable load on shore} \times 12 \text{ in/ft}}{ULS_{str}}$$

Select the most critical shore spacing. Compare the spacing of the shore based on the stringer strength and shore load and select the smaller of the two spacings.

Step 8. Shore bracing check. Verify that the unbraced length (1) of the shore (in inches) divided by the last dimension (d) of the shore does not exceed 50. If l/d exceeds 50, the lateral and cross bracing must be provided. Table 3-1 on page 3-6 indicates the l/d > 50 shore lengths and can be used if the shore material is sound and unspliced.

In any case, it is good engineering practice to provide both lateral and diagonal bracing all shore members if material is available.

Example Problem

Design the form for the roof of a concrete water tank to be 6 inches thick, 20 feet wide, and 30 feet long. The slab will be constructed 8 feet above the floor (to the bottom of the slab). Available materials are 3/4-inch plywood and 4- by 4-inch S4S (surfaced on four sides) lumber. Mechanical buggies will be used to place concrete.

Step 1. Specify the materials for construction. Sheathing 3/4-inch plywood (strong way); joists, 4- by 4-inch (S4S) shores, 4- by 4-inch (S4S); stringers, and 4- by 4-inch (S4S) lumber.

Step 2. Determine the maximum total load.

$$\text{DL} = \text{concrete load} = 150\ \text{lb/sf} \times \frac{6\ \text{in}}{12\ \text{in/ft}} = 75\ \text{lb/sf}$$

LL- = personnel and equipment = 75 lb/sf

TL = DL + LL = 75 lb/sf + 75 lb/sf = 150 lb/sf

Step 3. Determine the maximum joist spacing. Use Table 3-2 on page 3-7.

3/4-inch plywood (strong way) and TL = 150 lb/sf

Joist spacing = 22 inches

Step 4. Calculate the ULJ.

$$\text{ULJ} = \text{TL} \times \frac{\text{joist spacing (in)}}{12\ \text{in/ft}} = 150\ \text{lb lb/sf} \times \frac{22\ \text{in}}{12\ \text{in/ft}} = 275\ \text{lb/lf}$$

Step 5. Determine the maximum stringer spacing. Use Table 3-3 on page 3-9.

Load	= 275 lb/lf
Joist material	= 4- by 4-inch
Maximum stringer spacing	= 55 inches

Step 6. Calculate the uniform load on the stringer (ULS_{str}).

$$\text{ULS}_{str} = \text{TL} \times \frac{\text{maximum stringer spacing (in)}}{12\ \text{in/ft}} = 150\ \text{lb/sf} \times \frac{55\ \text{in}}{12\ \text{in/ft}} = 687.5\ \text{lb/ft}$$

Step 7. Determine the maximum shore spacing (use Table 3-3). Spacing is based on stringer strength. (Use Table 3-4 on page 3-11.)

Load	= 687.5 lb/lf (round up to 700 lb/lf)
Stringer material	= 4- by 4-inch (S4S)
Maximum shore spacing	= 35 inches

Spacing based on the shore strength and end bearing of the shore on the stringer. Use Table 3-7 on page 3-21 and Table 3-8.

- *Allowable load based on shore strength (see Table 3-7).*

Unsupported length = 8 feet - 3/4-inch - 3 1/2 inch - 3 1/2 inches = 7 feet 4 1/4 inches (round up to 8 feet)

Then, for an 8-foot 4-by 4-inch (S4S) piece of lumber, the allowable load = 5,400 lb.

- *Allowable load based on end-bearing stresses (see Table 8 on page 3-22).* Since you do not know what species of wood you are using you must assume the worst case. Therefore, the compression perpendicular the grain = 250, and the allowable load for a 4- by 4-inch (S4S) = 3,100 lb.

- *Select the most critical load.* Since the compression perpendicular to the grain is less than the allowable load on the shore perpendicular to the grain, 3,100 pounds is the critical load.

- *Determine shore spacing based on allowable load.*

$$\text{Shore spacing} = \frac{3{,}100 \text{ lb}}{ULS_{str} \text{ (lb/ft)}} \times 12 \text{ in/ft} = \frac{3{,}100 \text{ lb}}{687.5 \text{ lb/ft}} \times 12 \text{ in/ft} = 54.1 \text{ in}$$

Select the most critical shore spacing. The spacing determined by stringer strength in Step 7 is less than the spacing based on the shore strength determined in Step 7; therefore, the shore spacing to be used is 35 inches.

Step 8. Shore deflection check.

l = 8 feet - 3/4-inch - 3 1/2 inches - 3 1/2 inches = 7 foot 4 1/4 inches = 88.25 inches

d = least dimension of 4- by 4-inch (S4S) lumber = 3.5 inches

$$l/d = \frac{88.25 \text{ in}}{3.5 \text{ in}} = 25.21 < 50 \text{ in}$$

Lateral bracing is not required. Cross bracing is always required.

Step 9. Summary.

Sheathing:	1/4-inch plywood (strong way)
Joists:	4- by 4-inch (S4S) lumber spaced 22 inches OC
Stringers:	4- by 4-inch (S4S) lumber spaced 55 inches OC
Shores:	4- by 4-inch (S4S) lumber spaced 35 inches OC
Lateral braces:	Not required

Column Form Design

Procedure. Use these steps to design a wood form for a concrete column.

Step 1. Determine the materials you will use for sheathing, yokes, and battens. (Standard materials for column forms are 2- by 4-inch and 1-inch sheathing.)

Step 2. Determine the column height.

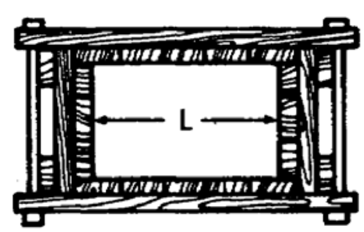
Step 3. Determine the largest cross-sectional column dimension.

Step 4. Determine the maximum yoke spacings by referring to Table 3-9. First, find the column height in feet in the first column. Then move right horizontally to the column heading the largest cross-sectional dimension of the column you are constructing. The center-to-center spacing between the second yoke and the base yoke is the lowest value in the interval that falls partly in the correct column height line. You can obtain all subsequent yoke spacing by reading up this column to the top. These are maximum yoke spacings; you can place yokes closer together.

Table 3-9. Column yoke spacing using 2- by 4-inch and 1-inch sheathing.

Column Height ft: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Largest Cross-Sectional Dimension, in (L)							
16	18	20	24	28	30	32	36
31	29	27	23	21	20	19	17
31	28	26	23	21	20	19	17
30	28	26	23	20	19	18	17
29	26	24	22	18	18	17	15
21	20	19	16	15	18	13	12
20	18	16	14	13	12	12	11
18	16	15	13	12	12	10	10
15	15	14	12	10	10	10	8
14	13	12	11	9	9	8	8
13	12	11	10	9	8	8	7
13	12	11	9	9	8	8	7
12	11	10	9	8	8	7	7
	11	10	9	8	7	7	6
		10	8	8	7	7	6
		9	8	7	7	6	6
			8	6	6	6	6



Step 5. Adjust the final spacing to match the top height of the column.

Example Problem 3

Determine the yoke spacing for a 9-foot column whose largest cross-sectional dimension is 36 inches. Construction materials are 2- by 4-inch and 1-inch sheathing.

Solution Steps:

Step 1. Materials available = 2- by 4-inch and 1-inch sheathing

Step 2. Column height = 9 feet

Step 3. Largest cross-sectional dimension = 36 inches

Step 4. Maximum yoke spacings (refer to Table 3-9 on page 3-25) starting from the base yoke are 8, 8, 10, 11, 12, 15, 17, 17, and 10 inches. The spacing between the top two yokes is reduced due to the limits of the column height.

LESSON 3
PRACTICAL PROBLEMS

Problem 1: Concrete Wall Form Design

Design the forms for a concrete wail 4 feet high, 40 inches long and 18 inches thick. Two 16-S mixers are available, each producing 16 cubic feet of concrete every 4 minutes. Materials available are l-inch plywood sheathing used the strong way, 2-by 4-inch studs, double wales, and 3000# tie rods. The estimated concrete temperature is 60°F.

Problem 2: Concrete Wall Form Deign

Design the forms for a concrete retaining wall that is 120 feet long, 1-foot wide, and 12 feet high. You have an M919 concrete mobile mixer available and you have estimated your production rate at 12 cubic yards of concrete per hour. You are to construct the forms from 3/4-inch plywood, 2- by 6-inch studs, 2- by 6-inch double wales, and No 8 tie wire. The concrete temperature is estimated at 50°F.

Problem 3: Brace Design

Determine the maximum spacing for braces for the wall in Problem No 2. The brace material is 2- by 6-inch by 12-foot. You will have to connect the braces 2 feet below the top of the form. A Natural Trigonometric Functions (Trig Table) (see Table 3-10) is provided, if needed.

Table 3-10. Natural trigonometric functions.

Angle (deg)	Sine	Cosine	Tangent	Angle (deg)	Sine	Cosine	Tangent
0	0.00000	1.00000	0.00000				
1	0.01774	0.99985	0.01745	46	0.71934	0.69466	1.0355
2	0.03490	0.99939	0.03492	47	0.73135	0.68200	1.0724
3	0.05234	0.99863	0.05241	48	0.74314	0.66913	1.1106
4	0.06976	0.99756	0.06993	49	0.75471	0.65606	1.1504
5	0.08715	0.99619	0.08749	50	0.76604	0.64279	1.1917
6	0.10453	0.99452	0.10510	51	0.77715	0.62932	1.2349
7	0.12187	0.99255	0.12278	52	0.78801	0.61566	1.2799
8	0.13917	0.99027	0.14054	53	0.79863	0.60181	1.3270
9	0.15643	0.98769	0.15838	54	0.80902	0.58778	1.3764
10	0.17365	0.98481	0.17633	55	0.81915	0.57358	1.4281
11	0.19801	0.98163	0.19438	56	0.82904	0.55919	1.4826
12	0.20791	0.97815	0.21256	57	0.83867	0.54464	1.5399
13	0.22495	0.97437	0.23087	58	0.84805	0.52992	1.6003
14	0.24192	0.97029	0.24933	59	0.85717	0.51504	1.6643
15	0.25882	0.96592	0.26795	60	0.86603	0.50000	1.7320
16	0.27564	0.96126	0.28674	61	0.87462	0.48481	1.8040
17	0.29237	0.95630	0.30573	62	0.88295	0.46947	1.8807
18	0.30902	0.95106	0.32492	63	0.89101	0.45399	1.9626
19	0.32557	0.94552	0.34433	64	0.89879	0.43837	2.0503
20	0.34203	0.93969	0.36397	65	0.90631	0.42262	2.1445
21	0.35837	0.93358	0.38386	66	0.91354	0.40674	2.2460
22	0.37461	0.92718	0.40403	67	0.92050	0.39073	2.3558
23	0.39073	0.92050	0.42447	68	0.92718	0.37461	2.4751
24	0.40674	0.91354	0.44523	69	0.93358	0.35837	2.6051
25	0.42262	0.90631	0.46631	70	0.93969	0.34202	2.7475
26	0.43837	0.89879	0.48773	71	0.94552	0.32557	2.9042
27	0.45399	0.89101	0.50952	72	0.95106	0.30902	3.0777
28	0.46947	0.88295	0.53171	73	0.95630	0.29237	3.2708
29	0.48481	0.87462	0.55431	74	0.96126	0.27564	3.4874
30	0.50000	0.86603	0.57735	75	0.96592	0.25882	3.7320
31	0.51504	0.85717	0.60086	76	0.97029	0.24192	4.0108
32	0.52992	0.84805	0.62487	77	0.97437	0.22495	4.3315
33	0.54464	0.83867	0.64941	78	0.97815	0.20791	4.7046
34	0.55919	0.82904	0.67451	79	0.98163	0.19081	5.1445
35	0.57358	0.81915	0.70021	80	0.98481	0.17365	5.6713
36	0.58778	0.80902	0.72654	81	0.98769	0.15643	6.3137
37	0.60181	0.79863	0.75355	82	0.99027	0.13917	7.1154
38	0.61566	0.78801	0.78128	83	0.99255	0.12187	8.1443
39	0.62932	0.77715	0.80978	84	0.99452	0.10453	9.5144
40	0.64279	0.76604	0.83910	85	0.99619	0.08715	11.430
41	0.65606	0.75741	0.86929	86	0.99756	0.06976	14.301
42	0.66913	0.74314	0.90040	87	0.99863	0.05234	19.081
43	0.68200	0.73135	0.93251	88	0.99939	0.03490	28.634
44	0.69466	0.71934	0.96569	89	0.99985	0.01745	57.290
45	0.70711	0.70711	1.0000	90	1.00000	0.00000	Infinite

Problem 4: Overhead Slab Form Design

Design the forms for the roof of a concrete water tank which will be 6 inches thick, 20 feet wide, and 30 feet long. The slab will be constructed 10 feet above the floor of the tank. Available materials are 1- by 6-inch boards and 4- by 4-inch lumber, both S4S. The slab is to be finished using hand tools.

Problem 5: Column Form Design

Design the forms for a rectangular column 24 by 28 inches and 15 feet high. Materials are 1-inch board sheathing and 2-inch by 4-foot lumber. (See Figure 3-6 on page 3-28.) From the information given figure the following:

Materials used ____
Height of column ___________________
Largest cross-sectional dimension of column ________________
Yoke spacing _________________________________

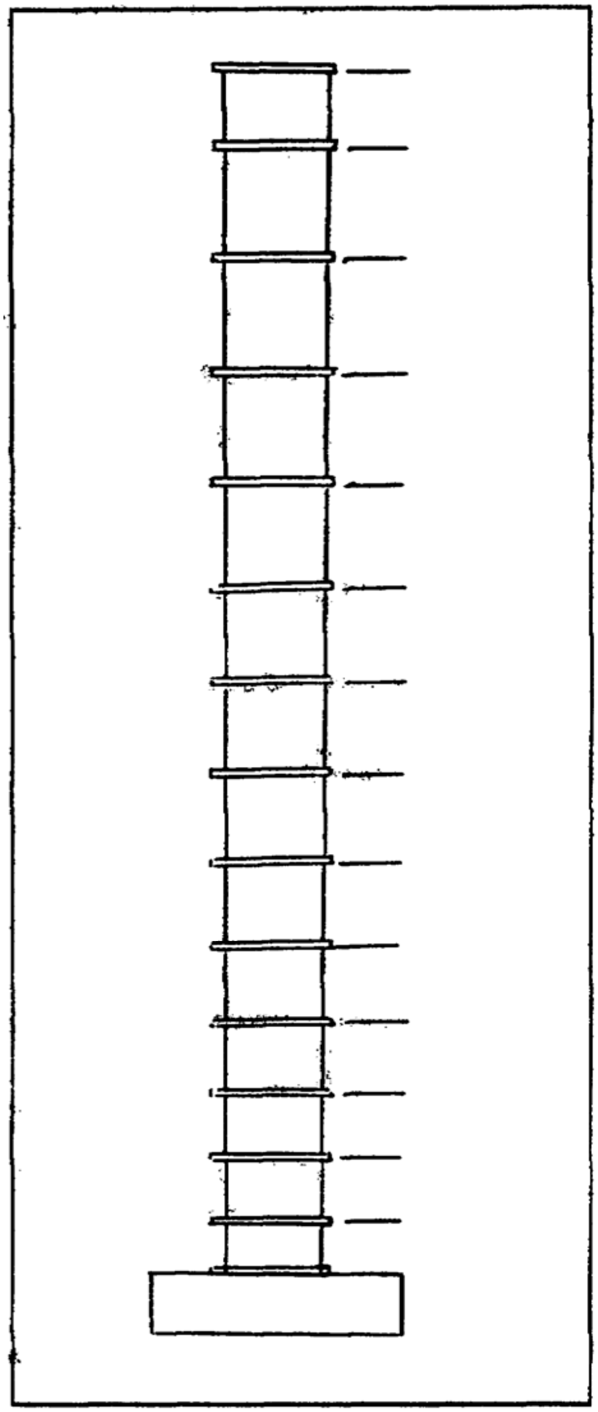


Figure 3-6. Column form design.

Answer: Problem 1

1. Material: 1-inch plywood, 2- by 4-inch studs and wales, 3000# tie rods

2. Mixer output: $\frac{(16\ cf)(60\ min/hr)(2\ mixers)}{4\ min} = 480\ cu\ ft/hr$

3. Plan area: (40 ft)(1.5 ft) = 60 sq ft

4. Rate of placement: $\frac{480\ cf/hr}{60\ sf} = 8\ ft/hr$ reduce to 5 ft/hr for economy

5. Concrete temperature: 60°F

6. Maximum concrete pressure: 900 lb/sq ft (see Figure 3-2 on page 3-3).

7. Maximum stud spacing: 14 inches (see Table 3-2 on page 3-7).

8. Uniform load on a stud: $\frac{(900\ psf)(14\ in)}{12\ in/ft} = 1{,}050\ lb/ft$

9. Maximum wale spacing 17 inches (see Table 3-4 on page 3-11).

10. Uniform load on a wale: $\frac{(900\ psf)(17\ in)}{12\ in/ft} = 1{,}275\ lb/ft$

11. Tie spacing (wale): 23 inches (see Table 3 on page 3-12).

12. Tie spacing (tie strength): $\frac{(3{,}000\ lb)(12\ in/ft)}{1{,}275\ in/ft} = 28\ inches$

13. Maximum tie spacing

14. Compare stud-tie spacing: N/A

Summary:

Sheathing:	1-inch plywood (Strong)	N/A
Studs:	Single 2- by 4-inch	14 inches
Wales:	Double 2- by 4-inch	17 feet
Ties:	3000# rods	23 inches

Discussion: In Step 4 we reduced the rate of placement from 8 feet per hour to 5 feet per hour for economy of design; this should be accomplished by reducing the size of the batches during mixing.

Answer: Problem 2

1. Materials: 3/4-inch plywood (strong way), 2-by 6-inch single studs, 2- by 6-inch double wales, and No 8 tie wire for ties.

2. Mixer output: 12 cy/hr x 27 cf/cy = 324 cf/hr

3. Plan area: (120 ft) (1 ft) = 120 sf

4. Rate of placement: $\frac{324\ cf/hr}{120\ sf} = 2.7\ ft/hr$

5. Concrete temperature: 50°F

6. Concrete pressure: 640 psf (See Figure 3-2 on page 3-3.)

7. Maximum stud spacing: 13 inches (See Table 3-2, page 3-7.)

8. Uniform load on a stud: $\frac{(640\ psf)(13\ in)}{12\ in/ft} = 693\ lb/ft$

9. Maximum wale spacing: 36 inches (See Table 3-3, page 3-9.)

10. Uniform load on a wale: $\frac{(640\ psf)(36\ in)}{12\ in/ft} = 1{,}920\ lb/ft$

11. Tie spacing (wale): 30 inches (See Table 3-4 on page 3-11.)

12. Tie spacing (tie strength): $\frac{(1{,}700\ lb)(12\ in/ft)}{1{,}920\ lb/ft} = 10\ inches$

(**NOTE:** 1,700 pounds is from Table 3-5 on page 3-12.)

13. Maximum tie spacing: 10 inches

14. Tie-stud adjustment: reduce stud spacing to 10 inches.

Summary:

Sheathing:	3/4-inch plywood (strong way)
Studs:	Single 2- by 6-inch 10 inches OC
Wales:	Double 2- by 6-inch 36 inches OC
Ties:	No. 8 tie wire 10 inches OC

Answer: Problem 3

Given information:

Materials: 2- by 6- by 12 inches
$J = 3{,}710\ ft^4$ (See Table 3-7 on page 3-21.)
$L_{max} = 6.25^1$ (2-inch material)
$L_B = 12$ feet
H = 12 feet
Y= 10 feet

1. Angle of placement, 0: Sine 0 = $\frac{10'}{12} = 0.8333$

$$0 = Sine^{-1}(0.8333)\ Y \simeq 56^\circ$$

2. L = 6 ft (brace support placed at the mid point of the braces)

$$3.\ S_{max} = \frac{(3{,}710)(10)}{(12^2)(6^2)} \cos 56^\circ = \frac{(3{,}710)(10)}{(144)(36)} (0.55919) = 4 \text{ feet}$$

Answer: Problem 4

1. Available materials: 1- by 6-inch S46
   4- by 4-inch S4S

2. Determine loads: Assume a live load is 50 lb/sf. The dead load is 150 lb/cf.

DL = 150 (1/2-foot) = 75 psf
LL = 50 lb/sf
TL = DL + LL = 125 psf

3. Go to Table 3-1 on page 3-6 for 1- by 6-inch sheathing for maximum concrete pressure of 125 psf. Maximum joist spacing is 26 inches.

4. Uniform load on the joists:

$$\text{ULJ} = \frac{\text{TL joist spacing}}{12 \text{ in/ft}} = \frac{125 \text{ psf } (26 \text{ in})}{12 \text{ in/ft}} = 271 \text{ lb/ft}$$

5. Determine maximum stringer spacing using Table 3-3, page 3-9: 55 inches

6. Calculate the uniform load on the stringer (ULS_{str}).

$$(ULS_{str}) = \frac{\text{TL maximum stringer spacing (in)}}{12 \text{ in/ft}} = \frac{125\,(55)}{12} = 573 \text{ lb/ft}$$

7. Determine the maximum shore spacing.

From Table 3-3, with a uniform load of 573 lb/ft to 600 lb/ft, the spacing is 37 inches.

Evaluate the maximum shore spacing based on the shore strength. Find supported strength.

10' - 3/4” - 3 1/2” - 3 1/2” = 9’ 4 1/2” to the nearest whole number is 10 feet

Allowable load according to Table 3-7 on page 3-21 for the unsupported length of 10 feet is 3,400 (using 4- by 4-inch S4S).

Evaluate the maximum allowable load based on end-bearing area. (Since the C⊥ is unknown, use the lowest value provided in Table 3-8 on page 3-22.)

C⊥ 250 for a 4 by 4 (S4S) the allowable load is 3,100 lb.

Select the allowable load on the shore. (Compare and select the lower.)

$$\text{Shore spacing} = \frac{\text{Allowable load on shore}}{ULS_{str}} = \frac{(3{,}100 \text{ lb})\ (12 \text{ in/ft})}{537 \text{ lb/ft}} = 69.27 \text{ inches}$$

Select the most critical spacing which would be 37 inches from using the information above.

8. Shore bracing check:

_=_ the unsupported length (in) where 1 = 120” since 120” - 3/4” - 3 1/2” - 3 1/2” = 112 1/4”

d _=_ is the least dimension of the shore. Since the lumber is a 4- by 4-inch S45 member, the least dimension (d) is d = 3 1/2 inches

$$\frac{l}{d} = \frac{112\ 1/4}{3\ 1/2} = 32.07 < 50$$

Lateral bracing is not required.

9. Summary:

Sheathing:	1-inch- boards (S4S)
Joists:	4- by 4-inch (S4S) at 26 inches OC
Stringers:	4- by 4-inch (S4S) at 55 inches OC
Shores:	4- by 4-inch (S4S) at 37 inches OC

***NOTE:** The nominal thickness of a 1-inch by the piece of lumber (for example, (1- by 2-inch, 1-by 3-inch, 1- by 4-inch, is 3/4-inch). The nominal thickness of a 4-inch by piece of lumber (for example, 4- by 1-inch, 4- by 2-inch, 4- by 3-inch, is 3 1/2 inches). Consult FM 5-34 for the nominal or actual dimensions of lumber.

Answer: Problem 5

Materials: 1-inch board sheathing
2- by 4-inch yokes

Column height: 15 feet

Largest cross-sectional dimension: 28 inches

Yoke spacings: From the bottom up (in inches): 8, 8, 8, 9, 9, 9, 10, 12, 13, 15, 18, 20, 21, 20. The last spacing, 20 inches, was determined by subtracting all the previous spacings from the total height of the column, in inches (180 inches - 160 inches = 20 inches).

LESSON 3
PRACTICE EXERCISE

Check your understanding of Lesson 3 by completing the practice exercise. There is only correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct response. Each correct response is referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

1. List five reasons why form design is very important in the construction process.

____
____
____
____
____

2. List three characteristics that should be considered in form design and construction.

____
____
____

3. List four materials from which forms can be made.

____
____
____
____

4. List the basic information needed to design a wall form.

____
____
____

Questions 5 through 9 concern **Overhead Slab Form Design**

5. **Given:** The maximum total load for a slab is 300 pounds per square foot, and you are using 2- by 6-inch lumber for sheathing and 4- by 4-inch lumber for joists. Determine the maximum joist spacing, in inches.

A. 55
B. 53
C. 39
D. 35

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6. Determine the uniform load on joist if the maximum total load is 200 psf and the joists are spaced every 3.5 feet.

A. 700 lb/sf
B. 700 lb/ft
C. 600 lb/ft
D. 58 lb/ft

7. **Given**: Maximum total load = 150 psf. Sheathing = 1-inch plywood in the strong direction. Joists: 2- by 4-inch. Stringers: single 4- by 4-inch. Determine the maximum stringer spacing in inches.

A. 49
B. 32
C. 27
D. 25

8. Determine the uniform load on the stringers if the maximum total load is 275 per square foot, the sheathing is 3/4-inch plywood in the weak direction, the joists are 4- by 4-inch at 15 inches on center, and the stringers are 4- by 6-inch at 49 inches on center.

A. 1,123 lb/ft
B. 1,405 lb/ft
C. 1,506 lb/ft
D. 4,125 lb/ft

9. Determine the allowable load (in pounds) on the shore based on end-bearing stresses between the shore and the stringer, if you are using 4- by 4-inch stringers and 6- by 6- by 10-inch shores. The stringers can carry 350 pounds per square inch in compression perpendicular (CY) to their grain. Both members are made with rough lumber.

A. 6,700
B. 7,100
C. 11,100
D. 23,000

LESSON 3

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item		Correct Answer and Feedback
1.		Formwork holds concrete until it sets. Formwork produces the desired shape. Formwork produces surface finished if desired. Formwork protects concrete from the elements. Formwork aids curing. Formwork supports accessories.
		Importance of Form Design. (page 3-1)
2.		Forms must be tight, rigid, and strong. Forms must be braced sufficiently to align them and make them strong enough to hold the concrete. Forms should be made so they can be easily removed and replaced without damage for refuse.
		Form Characteristics. (page 3-2)
3.		Wood Metal Earth Fiber, paper, or plastic
		Form Materials. (page 3-2)
4.		Rate of placing Expected ambient temperature Specified type of form material
		Knowing these two factors ... (page 3-4)
5.	D.	2-inch concrete pressure = 300 psf
		Table 3-1. (page 3-6)
6.	B.	$\frac{(200\ \text{psf})(42\ \text{in})}{12\ \text{in/ft}} = 700\ \text{lb/ft}$
		Step 4. (page 3-20)

Item Correct Answer and Feedback

7. B. Joist spacing = 27 inches

$$ULJ = \frac{(150 \text{ psf})(27 \text{ in})}{12 \text{ in/ft}} = 337.5 \text{ lb/ft}$$

Table 3-2.

SS = 32 inches (See Table 3-3 at 350 lb/ft, 2- by 4-inch joists).

8. A. $$\frac{(275 \text{ psf})(49 \text{ in})}{12 \text{ in/ft}} = 1{,}123 \text{ lb/ft}$$

9. B Maximum contact area is 4- by 6-inch for this combination.
(See Table 3-8 on page 3-22, C1 = 350, 4- by 6-inch (R))

Table 3-8. (page 3-22).

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LESSON 4

CONSTRUCTION PROCEDURES

OVERVIEW

LESSON DESCRIPTION:

In this lesson you will identify construction plan procedures for concreting operations.

TERMINAL TRAINING OBJECTIVE:

ACTION: Identify and plan construction procedures for concreting operations.

CONDITION: You are given the materials contained in this lesson.

STANDARD: Correctly answer all practice exercise questions at the end of the lesson.

REFERENCE: The material contained in this lesson was derived from the following publication: FM 5-742, with change 1.

INTRODUCTION

In this lesson, you will work your way through a complete construction procedure, beginning with reconnaissance through quality control and inspection. You will also investigate the site for any unusual characteristics that can cause construction problems, such as undesirable soil or rock base. By anticipating and considering such problems beforehand, you can avoid construction delay.

PART A - RECONNAISSANCE, SITE PREPARATION, AND EXCAVATION PROCEDURES

RECONNAISSANCE

Determining Possible Difficulties

Make a thorough and efficient reconnaissance of the construction site as the first step in any construction procedure. Note possible problems in clearing and draining the site or in transporting and storing materials. Also, investigate the site for any unusual characteristics that can cause construction problems, such as undesirable soil or rock base. By anticipating and considering such problems beforehand, you can avoid construction delays.

Route Selection

Local traffic patterns, the quality of existing roads and bridges, and the equipment you will use all affect the selection of the best route to the construction site. Make maximum use of the existing road network, since you can generally save time and effort by repairing or improving an existing road rather than constructing a new one. When possible, select an alternate route also.

Locating Water and Aggregate

Locate the nearest or most convenient source of suitable mixing water. Note any alternate sources in case subsequent tests show that your first choice is unsuitable. Whenever possible, use local sand and gravel sources. Locate these sources and specify any necessary tests.

Time Estimation

Estimate the time for site preparation carefully during your reconnaissance of the area. A good estimate assures that the proper equipment is available at both the place and time of need.

SITE PREPARATION

Building Approach Road

Most new construction takes place on undeveloped land. Therefore, you must build approach roads to deliver materials t the site. Even though these are temporary roads, construct them carefully to withstand heavy loads. Because the routes may become permanent roads later, build enough lanes to permit free traffic flow to and from the construction site.

Land Clearing

This consists of removing all trees, downed timber, brush, and other vegetation and rubbish from the site; digging up surface boulders and other material embedded in the ground; and disposing of all materials cleared. To clear the site of large timber and boulders, you may need heavy equipment as well as hand equipment, explosives, and burning by fire.

Adequate Drainage

Important in areas having high groundwater tables and for carrying off rain water during actual construction. You can use either a well-point system or mechanical pumps to withdraw surface and subsurface water from the building site.

Locating the Building Site

Stake out the building site after clearing and draining the land. The batter board layout is satisfactory in the preliminary construction phases with this method, place batter boards approximately 2 to 6 feet outside of each corner of the site. Then drive nails into the boards and extend strings between them to outline the building area.

STOCKPILING CONSTRUCTION MATERIALS

Concrete Materials

Locate and stockpile the quantities of sand, gravel, admixture, and cement required. Take measures (elevate and cover) to keep cement dry. In operations requiring large quantities of concrete, both aggregate and cement batching plants are essential. Build up and maintain stockpiles of aggregate both at the batching plant and at the crushing and screening plant. The batching plant stockpiles prevent shortages caused by temporary production or transportation difficulties and also allows the fine aggregates to reach a fairly stable and uniform moisture content and bulking factor. Large stockpiles are usually rectangular for ease in computing volumes. They are flat on top to retain gradation uniformity and to avoid segregation caused by dumping aggregate so that it runs down a long slope. Be sure to maintain enough cement at the cement batching plant. The amount of concrete required by the project and the placement rate determine the size of the stockpiles. If you will use admixtures, make sure that enough are on hand.

Lumber at Construction Sites

Stockpile plenty of formwork and scaffolding materials at the construction site. The size and quantity of lumber you store depends on the type of forms and scaffolding you plan to use.

Batching Plants

The initial location of the aggregate, cement, and water; the aggregate quality; and the location of the work can all affect where you position the cement batching plant. Depending on these conditions, you can operate the cement batching plant at the same place as the aggregate batching plant or closer to the mixer. After developing a layout, position the batching plant within crane reach of the aggregate stockpiles and astride the batch truck routes. Although the crushing and screening plant is normally located at the pit, it can be operated at the batching plant or at a separate location. If the road is good, a hillside location permits gravity handling of materials without excessive new construction and may eliminate the need for cranes or conveyors.

Safety Facilities

Plan, and in some cases construct, the safety facilities during site preparation. They include overhead canopies and guardrails both to protect personnel from falling debris and to prevent anyone from falling into open excavations. Certain sites, such as those where landslides may occur, require additional safety facilities.

PART B - PLAN FORMWORK USED IN CONSTRUCTION PROJECTS

MANAGEMENT ASPECTS

To perform a proper analysis, you must have a working knowledge of the equipment necessary for the formwork job and a good idea of how much work the form builders can turn out per unit of time.

EQUIPMENT

The average formwork job requires claw hammers, pinchbars, handsaws, a table saw, levels, plumb lines, and carpenter's squares. Make sure these tools are readily available.

TECHNIQUES

Develop standardized methods for constructing, erecting, and stripping forms to the maximum extent possible. This saves time and material and simplifies design problems.

TIME ELEMENT

A carpenter of average skill can build and erect 10 square feet of wood forms per hour. This figure increases as the worker becomes more skilled in form construction. It also varies with the tools and materials available and the type of form. Some forms, such as those for stairways, require considerable physical support from underneath. Such forms take more man-hours and materials to build than simpler forms. For carpenters to move from one level to another frequently requires additional time. Therefore, increased manpower support at the ground level increases efficiency.

PART C - MIXING, HANDLING, TRANSPORTATION, PLACEMENT, FINISHING, AND CURING OF CONCRETE

MIXING

Principles

You must follow established and well-defined concrete mixing procedures to produce good quality finished concrete. You can never overcome oversights in this phase of concrete construction, whether caused by lack of competent and conscientious supervision or inattention to detail. Whoever is in charge of construction must know the concrete mixing procedures and make sure that they are followed. The extra effort and care this requires are small in relation to the benefits.

Measuring Mix Materials

Concrete of uniform quality requires measuring the ingredients accurately. Check equipment accuracy periodically and adjust when necessary. Check admixture dispensers daily because errors in admixture measurements, particularly overdoes, can cause serious problems in both fresh and hardened concrete.

Cement

Concrete mixes normally call for sacked cement as the unit of measure.

Aggregate

Measure aggregate for each batch accurately, either by weight or by volume. Measurement by weight is the most reliable because the accuracy of volume measurement depends on an exact knowledge of the amount of moisture in the sand. Nevertheless, sometimes measurement by volume is more practical.

- *Measurement by weight.* On comparatively small jobs, you can use platform scales placed on the ground to weigh aggregate. Construct runways as shown in Figure 4-1, so that a wheelbarrow can be run onto one side of the scale and off the other easily. With practice, you can fill a wheelbarrow so accurately that adding or removing material to obtain the correct weight is seldom necessary. Always place the same weight of aggregate on each wheelbarrow so that the quantity per batch equals the same number of wheelbarrow loads. You need not load a wheelbarrow to capacity.

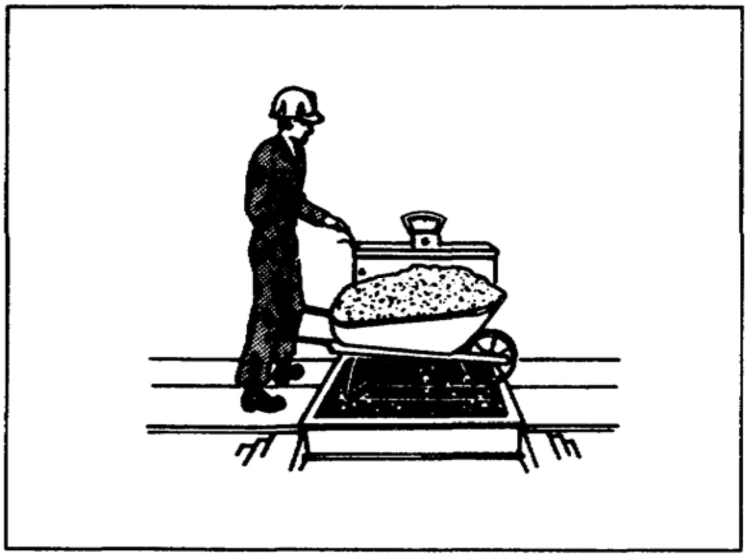


Figure 4-1. Measuring aggregate by weight.

- *Measurement by volume.* You can measure aggregate by volume using a 1-cubic-foot measurement box built on-site or a wheelbarrow. Wheelbarrows having the 2- to 3-cubic foot capacities are also available in the engineering units. The M919 measures aggregate to volume.

Water

You must measure mixing water accurately for every batch. If the aggregate contains too much moisture, be sure to take this into account when adding mixing water. The water tanks on the M919 are adjusted by means of the flowmeter.

Hand Mixing

Although a machine generally does the mixing, some hand mixing is always necessary. You need a clean surface for this purpose, such as a clean, even, paved surface or a wood platform having tight joints to prevent paste loss, like the one shown at the top of Figure 4-2 on page 4-6. Moisten the surface and level the platform, and spread the coarse aggregate over the cement as shown at the top of Figure 4-2. Use either a hoe (see middle of Figure 4-2) or a square-pointed, D-handled shovel to mix the materials. Turn the dry materials at least three times until the color of the mixture is uniform. Add water slowly while you turn the mixture again at least three times or until you obtain the proper consistency. Although one worker can mix 1 cubic yard of concrete by hand in about 1 hour, this is not economical for batches of more than 1 cubic yard. Instead, two workers facing each other should work their way through the pile and keep their shovels close to the platform surface while turning the materials. You can also mix in a hoe box, as shown at the bottom of Figure 4-2.

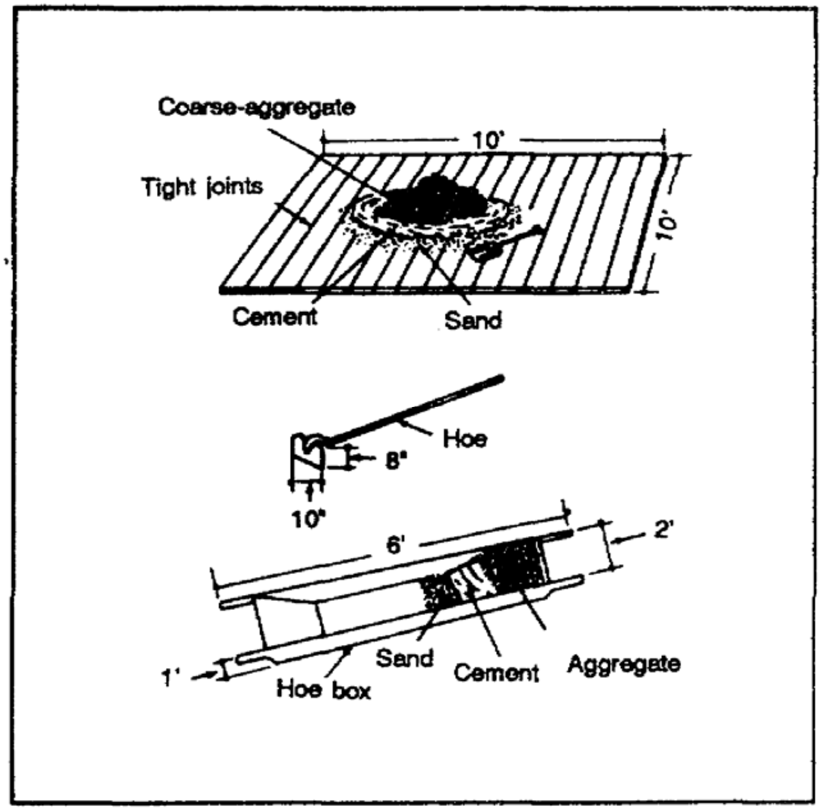


Figure 4-2. Hand mixing concrete.

Machine Mixing and Delivery

The methods of mixing and delivering concrete ingredients and the types and sizes of equipment available vary greatly. Power concrete mixers normally produce one batch about every 3 minutes, including charging and discharging. Actual hourly output varies from 10 to 20 batches per hour. A mixer's cubic-foot rating usually reflects the number of cubic feet of useable concrete that the machine mixes in one batch, except that most mixers can handle a 10 percent overload. The stationary 16-cubic-foot mixer and the M919 concrete mobile mixer (see Figure 4-3) unit are table(s) of organization and equipment (TOE) in engineer construction battalions and are well-suited for troop construction projects.

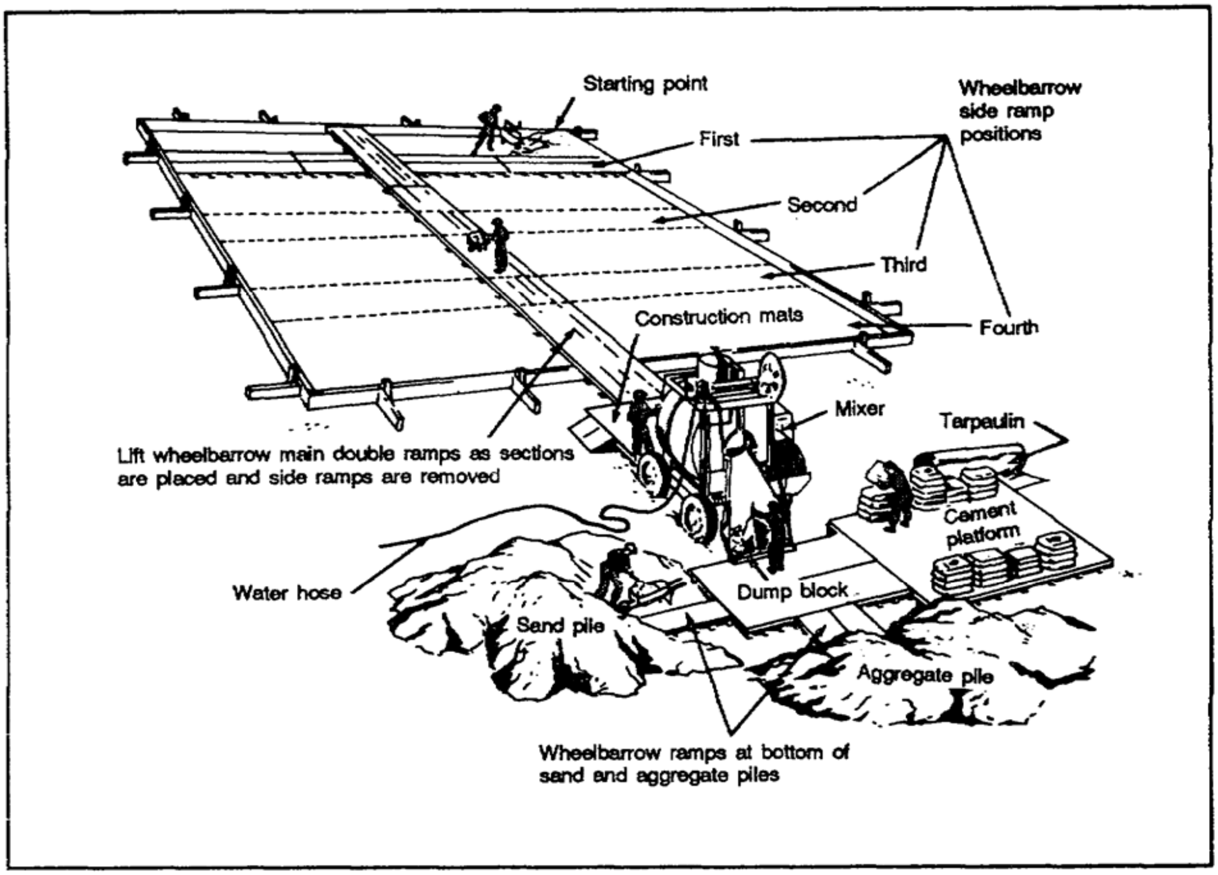


Figure 4-3. Typical on-site arrangement of mixing equipment and materials.

MIXING METHODS

- *Site mixed.* Method used for delivering plastic concrete by chute, pump, truck, conveyor, or rail dump cars.

- *Central-plant mixed.* Method used for delivering plastic ready-mix in either open dump trucks or mixer trucks.

- *Central-plant batched (weighed and measured).* Method used for mixing and delivering "dry-batched" ready-mix by truck.

- *Portable mixing plants.* Method used for large building or paving projects distant from sources of supply.

MIXER TYPES

- *Stationary mixers (including both on-site mixers and central mixers in ready-mix plants).* They are available in various sizes and may be tilting or nontilting, with open top, revolving blades, or paddles.

- *Mobile mixers (including both truck- and trailer-mounted mixers).* A truck mixer may pick up concrete from the stationary mixer in a partially or completely mixed state. In the latter case, the truck mixer functions as an agitator. Truck mixers generally deliver concrete from a centrally located stationary mixer to the construction site or pick up materials at a batching plant and mix the concrete enroute to the job site. Trailer-mounted mixers are commonly used to patch concrete pavements and for fillets and curve widening during pavement construction. A battery of trailer-mounted mixers can serve either as a central mix plant for large-scale operations or in conjunction with a central mix plant.

Operating the 16-Cubic-Foot Mixer

Table 4-1 gives the physical characteristics of a typical 16-cubic-foot mixer. You need ten soldiers and one noncommissioned officer for normal operation of such a mixer. The crew handles the aggregate, sand, cement and water and also operates the mixer. The noncommissioned officer supervises the overall operation. The crew should produce about 10 cubic yards of concrete per hour, depending on their experience, the location of materials, and the mixer's discharge rate. You would need at least one platoon to operate the overall project pictured in Figure 4-3 on page 4-7.

Table 4-1. Physical characteristics of a typical 16-cubic-foot mixer.

Physical Characteristics	Concrete Mixer, Gas-Driven, Liquid-Cooled End-Discharge, Trailer-Mounted, and Four Pneumatic-Tired Wheels	Physical Characteristics	Concrete Mixer, Gas-Driven, Liquid-Cooled End-Discharge, Trailer-Mounted, and Four Pneumatic-Tired Wheels
Drum capacity:	16 cf	Drum dimensions:	
Hourly production	10 cy	Diameter (in)	57
Rating (sacks per batch)	2	Length (in)	46
Power unit:		Overall dimensions (in):	
Horsepower	26	Length	158
Fuel consumption (gal/hr)	0.5	Width	96
		Height	119
Water tank:			
Supply (gal)	None		
Measuring (gal)	26	Weight (lb)	7,150

- *Charging the mixer.* You can charge mixers in two ways: by hand or with a mechanical skip (see Figure 4-4), which most mixers have. When using the skip, first deposit the aggregate, cement, and sand (in that order) into the skip, and then dump it into the mixer while mixing water runs into the mixing drum. You can place the sand on top of the pile in the skip so that you do not lose too much cement as the batch dumps into the mixer. A storage tank on top of the mixer measures the mixing water into the drum a few seconds before the skip dumps. This discharge also washes down the mixer between batches.

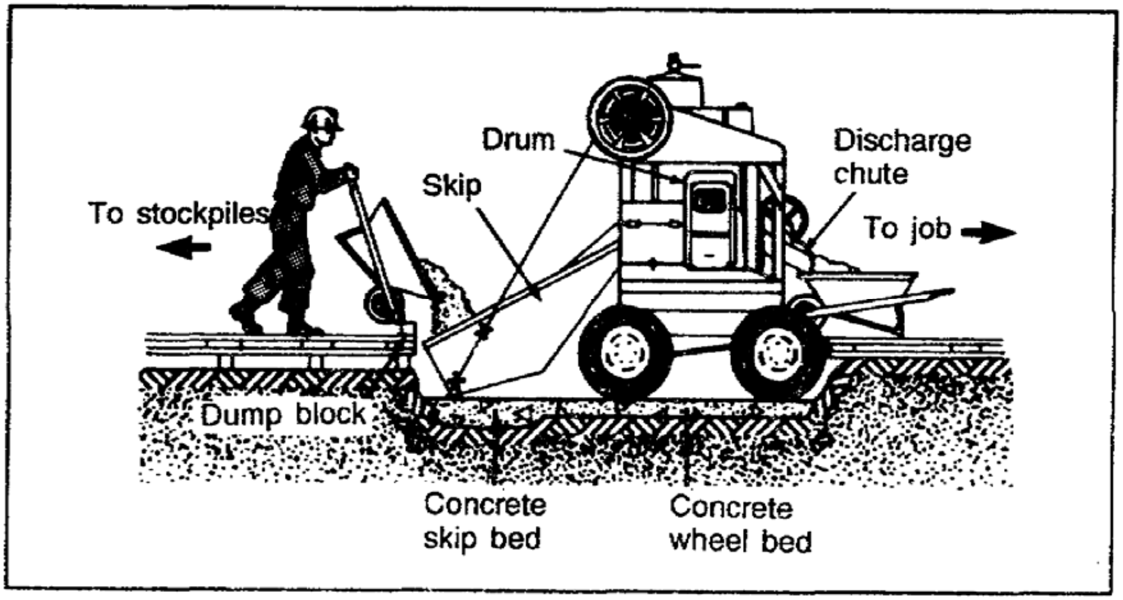


Figure 4-4. Charging mixer with mechanical skip.

- *Discharging the mixer.* When the mix is ready for discharge from the mixer, move the discharge chute into place to receive the concrete from the drum. Concrete that is somewhat dry tends to cling to the top of the drum and not drop onto the chute in time. Very wet concrete may not carry up high enough on the drum to drop onto the chute. You can correct these problems by adjusting the mixer speed. Increase the speed for very wet concrete and decrease the speed for dry concrete.

- *Mixing time.* The mixing time starts when water runs into the dry mixture, which should be during the first quarter of the mixing period. The minimum mixing time per batch of concrete is 1 minute, unless the batch exceeds 1 cubic yard. Each additional 1 cubic yard of concrete, or fraction thereof requires an additional 15 seconds of mixing time.

- *Cleaning and maintaining the mixer.* Clean the mixer daily if it operates continuously or following each period of use if it operates less than 1 day. The exterior cleaning process goes faster if you coat the outside of the mixer with form oil before you use it. Knock off all accumulated concrete on the mixer exterior and wash it down with a hose. Mixer blades that are worn or coated with hardened concrete provide less efficient mixing action. Replace badly worn blades, and do not allow hardened concrete to accumulate in the mixer drum. Clean it out whenever you shut it down for more than 1 1/2 hours. To do this, place a volume of coarse aggregate equal to one-half the mixer capacity in the drum and allow it to revolve for about 5 minutes. Then discharge the aggregate and flush out the drum with water. Never strike the discharge chute, drum shell, or skip to remove aggregate or hardened concrete because concrete adheres more readily to dents and bumps.

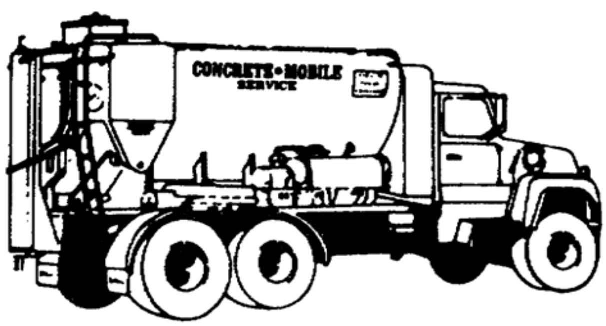
Operating the M919 Concrete Mobile Mixer Unit

The concrete mobile mixer unit is a combination material transporter and on-site mixing plant. Table 4-2 on page 4-10 gives its physical characteristics and overall dimensions. The special body is mounted on an M900 truck chassis. The unit carries enough unmixed material to produce up to 8 cubic yards of fresh concrete. Because the unit is precisely calibrated, you can produce mixes that meet or exceed both the ACI and American Association of State Highway and Transportation Officials' (AASHTO) standards for design strength. The unit operates on either an intermittent or continuous basis, although continuous operation depends on raw material availability at the site. Certain control settings for the mix operations vary from truck to truck and from site to site.

Table 4-2. Physical characteristics of the M919 concrete mobile mixer unit.

Physical Characteristics	
Capacity	8 cy
Hourly Production	16 cy
Rating (sacks per batch)	Varies
Power unit	M919 series Cummins engine powered by power takeoff from the truck transmission
Water tank	400 gal
Cement bin	63 cf
Sand bin	128 cf
Gravel bin	182 cf
Hi flo admix tank	42 gal
Lo flo admix tank	12 gal
Dry admix bin	2.35 cf
Overall Dimensions and Weight	
Length	374 in
Width	96 in
Height	142 in
Weight (empty)	37,540 lb

*Note: Use the dials on the rear and sides of the M919 to control concrete mixes by regulating the amounts of sand, gravel, water, and admixes.



HANDLING AND TRANSPORTATION

Principles

Concrete consistency depends on the placing conditions, but handling and transporting methods can affect its consistency. Therefore, if placing conditions allow a stiff mix, choose equipment that can handle and transport such a mix without affecting its consistency. You must carefully control each handling and transporting step to maintain concrete uniformity within a batch, and from batch to batch, so that the completed work is consistent throughout.

Handling Techniques

Figure 4-5 shows several right and wrong ways to handle concrete to prevent segregation of the aggregates and paste. Segregation causes honeycomb concrete or rock pockets. Segregation occurs because concrete contains aggregates of different particle sizes and specific gravities. When placed in a bucket, the denser particles tend to settle to the bottom and the water rises to the top.

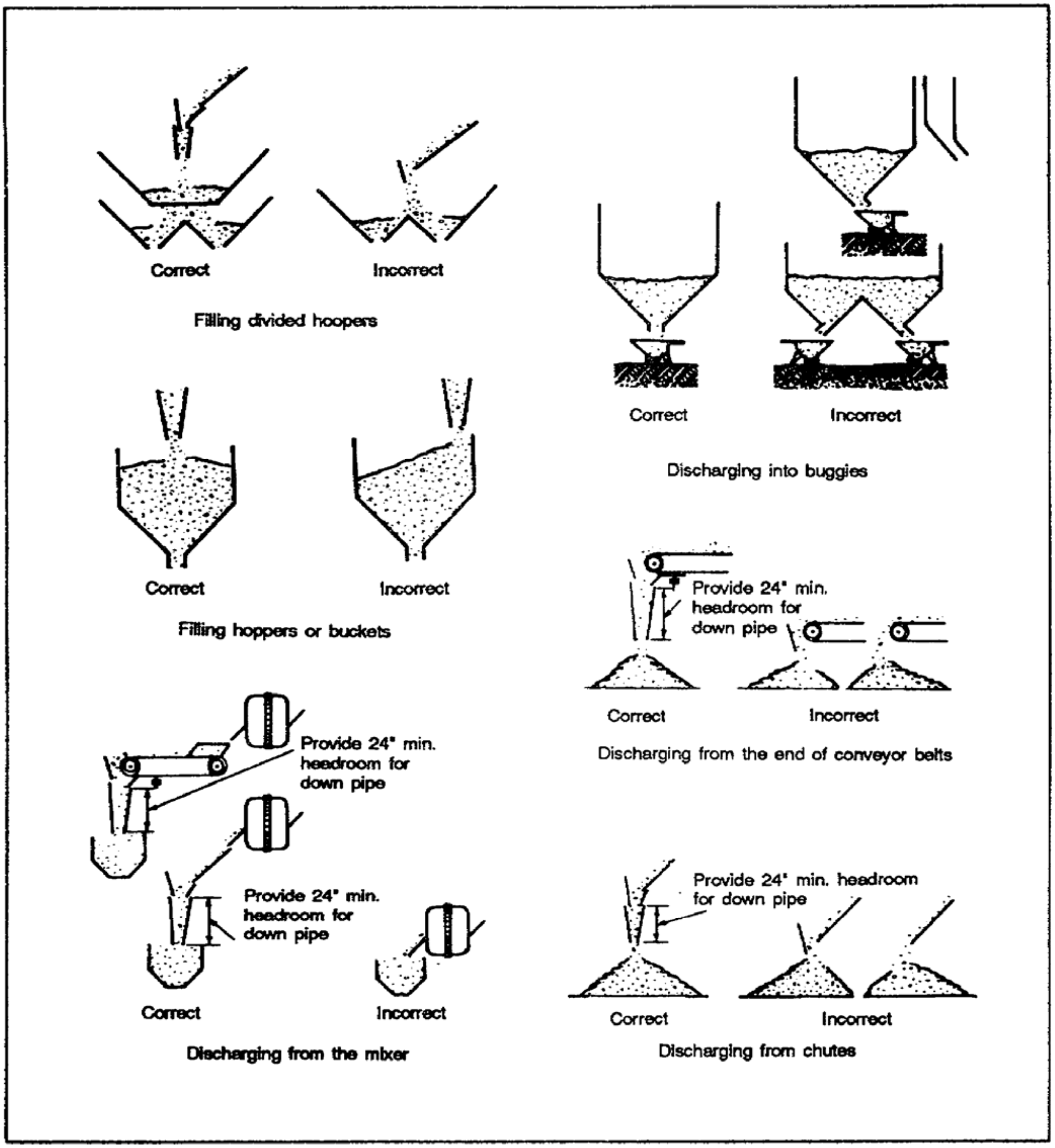


Figure 4-5. Concrete handling techniques to prevent segregation.

Transportation Requirements

The three main requirements for transporting concrete from the mixing plant to the job site are--

- *Speed.* Fast transportation does not allow concrete to dry out or lose workability or plasticity between mixing and placing.

- *Minimum material segregation.* To produce uniform concrete, you must take steps to reduce segregation of the aggregates and paste to a minimum and prevent the loss of fine material, cement, or water.

- *No delays.* Organize the transportation to eliminate delays in concrete placement that cause undesirable fill planes or construction joints.

PLACEMENT

Importance of Proper Procedures

You cannot obtain the full value of well-designed concrete without using proper placing and curing procedures. Good concrete placing and compacting techniques produce a tight bond between the paste and coarse aggregate and fill the forms completely, both of which contribute to the full strength and best appearance.

PRELIMINARY PREPARATION

General

Preparation before concrete placement includes compacting, trimming, and moistening the subgrade; erecting the forms; and setting the reinforcing steel. Moistening the subgrade is especially important in hot weather to prevent water extraction from the concrete.

Preparing Forms

Just before placement, check the forms for both tightness and cleanliness. Check the bracing to make sure the forms will not move during placing. Make sure that the forms are coated with suitable form oil or coating material so the concrete will not stick to them. Remember, in an emergency, you can moisten the forms with water to prevent concrete from sticking. Forms exposed to the sun for some time dry out and the joint tend to open up. Saturating the forms with water helps to close the joints.

Depositing Fresh Concrete on Hardened Concrete

To obtain a good bond and a watertight joint when depositing new concrete on hardened concrete, make sure that the hardened concrete is nearly level, is clean and moist, and that some aggregate particles are partially exposed. If the surface of the hardened concrete is covered by a soft layer of mortar or laitance (a weak material consisting mainly of lime), remove it. Wet sandblasting and washing is the best way to prepare old surfaces, if you can remove the sand deposit easily. Always moisten hardened concrete before placing any new concrete; saturate dried-out concrete for several hours. Never leave pools of water on the old surface when depositing fresh concrete on it.

PLACING CONCRETE

Principles

The principles of proper concrete placement include--

- *Segregation.* Avoid segregation during all operations from the mixer to the point of placement, including final consolidation and finishing.

- *Consolidation.* Thoroughly consolidate the concrete, working solidly around all embedded reinforcement and filling all form angles and corners.

- *Bonding.* When placing fresh concrete against or hardened concrete, make sure that a good bond develops. Use of a bonding agent is usually required.

- *Temperature Control.* Take appropriate steps to control the temperature of fresh concrete from mixing through final placement and protect the concrete from temperature extremes after placement.

- *Maximum Drop.* To save time and effort, you may be tempted to simply drop the concrete directly from its delivery point regardless of form height. However, unless the free fall into the form is less than 5 feet, use vertical pipes, suitable drop chutes, or baffles. Figure 4-6 on page 4-14 suggests several ways to control concrete fall and prevent honeycombing and other undesirable results.

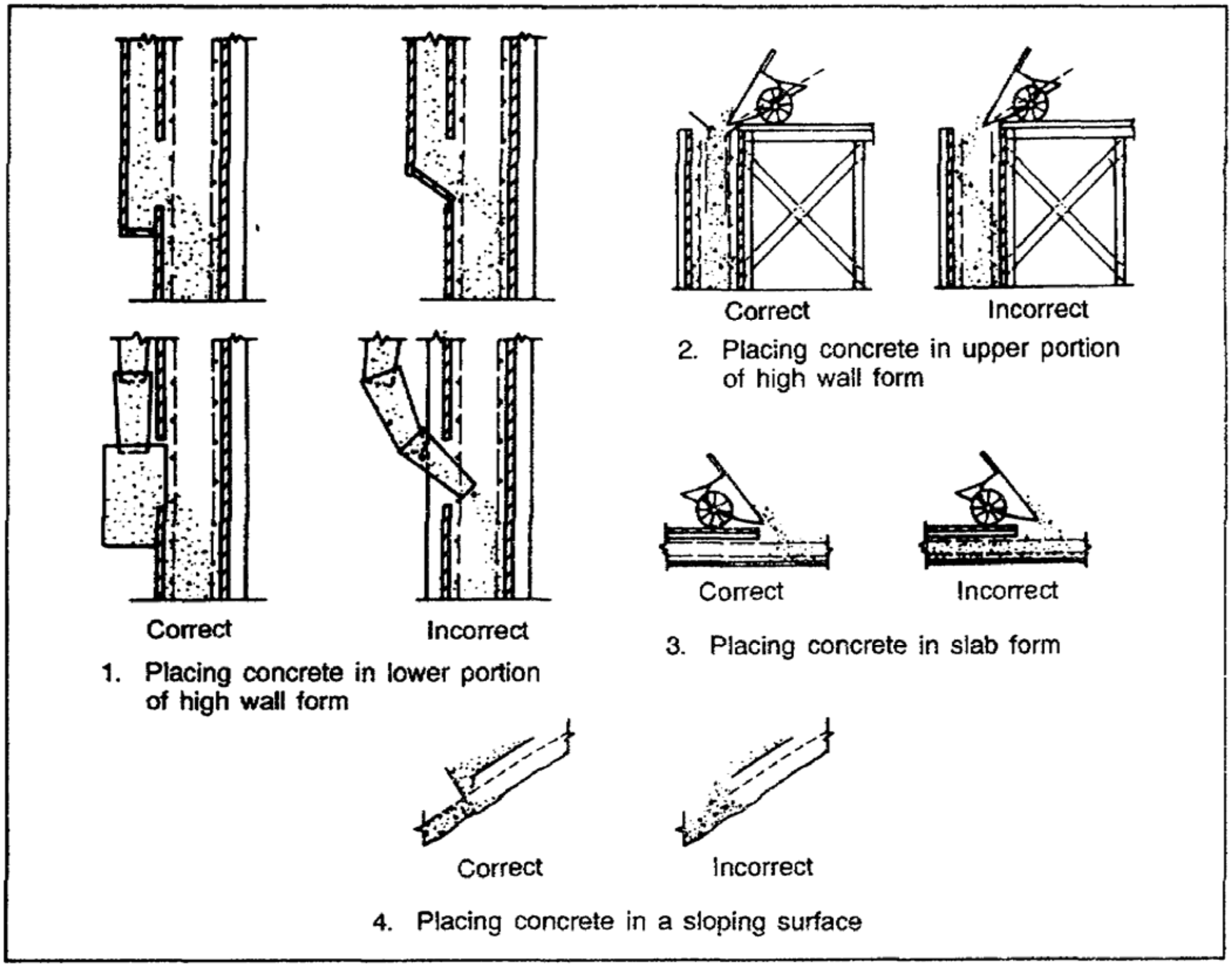


Figure 4-6. Concrete placing techniques.

Layer Thickness

Try to place concrete in even horizontal layers; do not puddle or vibrate it into the form. Place each layer in one operation and consolidate it before placing the next one to prevent honeycombing or voids, particularly in wall forms containing considerable reinforcement. Use a mechanical vibrator or a hand spading tool for consolidation. Take care not to over vibrate because segregation and a weak surface can result. Do not allow the first layer to take its initial set before adding the next layer. Layer thickness depends on the type of construction, the width of the space between forms, and the amount of reinforcement. When depositing from buckets in mass concrete work, the layers should be from 15 to 20 inches thick. For reinforced-concrete members, the layers should be from 6 to 20 inches thick.

Compacting

First, place concrete into its final position as nearly as possible. Then work the concrete thoroughly around reinforcement and embedded fixtures, into the corners, and against the sides of the forms. Because paste tends to flow ahead of aggregate, avoid horizontal movements that result in segregation.

Placing Rate

To avoid too much pressure on forms for large projects, the filling rate should not exceed 5 vertical feet per hour except for columns. Coordinate the placing and compacting so that the concrete is not deposited faster than it can be compacted properly. To avoid cracking during settlement, allow an interval of at least 4 hours, but preferably 24 hours, between placing columns and walls and placing the slabs, beams, and girders they support.

Wall Construction

When constructing walls, beams, or girders, place the first batches of each layer at the ends of the section, then proceed toward the center to prevent water from collecting at the form ends and corners. For walls, stop off the inside form at the construction level. Overfill the form for about 2 inches and remove the excess just before the concrete sets to ensure a rough, clean surface. Before placing the next lift of concrete, deposit a 1/2- to 1-inch-thick layer of sand-cement mortar. Make the mortar with the same water content as the concrete and with a slump of about 6 inches to prevent stone pockets and help produce a water girth joint. See view 1 of Figure 4-6. When placing walls, be sure to remove the spreaders as you fill the forms.

Slab Construction

When constructing slabs, place the concrete at the far end of the slab first, and then place subsequent batches against previously-placed concrete, as shown in view 3 of Figure 4-6. Do not place the concrete in big piles and then move it horizontally to its final position because these practices result in segregation.

Placing Concrete on Slopes

View 4 of Figure 4-6 shows how to place concrete on slopes. Always deposit the concrete at the bottom of the slope first, then proceed up the slope placing each new batch against the previous one. When consolidated, the weight of the new concrete increases the compacting of the previously placed concrete.

CONSOLIDATING CONCRETE

Principles

Except for concrete placed underwater, you must compact or consolidate all concrete after placement. Consolidation eliminates rock pockets and air bubbles and brings enough fine material both to the surface and against the forms to produce the desired finish. You can use such hand tools as spades, puddling sticks, or tampers, but mechanical vibrators are best. Any compacting device must reach the bottom of the form and be small enough to pass between reinforcing bars. The process involves carefully working around all reinforcing steel with the compacting device to ensure proper embedding of reinforcing steel in the concrete. Be careful not to displace the reinforcing steel because the strength of the concrete member depends on proper reinforcement location.

Vibration

The best compacting tool is a mechanical vibrator, as shown in Figure 4-7 on page 4-16. Vibrators consolidate concrete by pushing the coarse aggregate downward, away from the point of vibration. Vibrators allow placement of mixtures that are to, stiff to place any other way, such as those having a 1- or 2-inch slump. Stiff mixtures are more economical because they require less cement and present fewer segregation or excessive bleeding problems. However, do not use a mix so stiff that it requires too much labor to place it. The vibrators available in engineer construction battalions are called *internal vibrators* because the vibrating element is inserted into the concrete. An external vibrator is applied to the form and is powered by an electric motor, a gasoline engine, or compressed air. When using an internal vibrator, insert it approximately in 18-inch intervals into air-entrained concrete for 5 to 10 seconds and into non-air-entrained concrete for 10 to 15 seconds. The exact period of time that you should leave a vibrator in the concrete depends on its slump. Overlap the vibrated areas somewhat at each insertion. When possible, lower the vibrator into the concrete vertically and allow it to descend by gravity. The vibrator should not only pass through the layer just placed but penetrate several inches into the layer underneath to ensure a good bond between the layers. Vibration does not normally damage the lower layers, as long as the concrete disturbed in these lower layers becomes plastic under vibratory action. You will know that you have consolidated the concrete enough when a thin line of mortar appears along the form near the vibrator, the coarse-aggregate disappears into the concrete, or the paste appears near the vibrator head. Withdraw the vibrator vertically at about the same rate that it descended. Some hand spading or puddling should accompany all vibration. Do not vibrate mixes that you can consolidate easily by spading because segregation may occur; you should not vibrate concrete that has a slump of 5 or 6 inches. Also, do not use vibrators to move concrete any distance in the form.

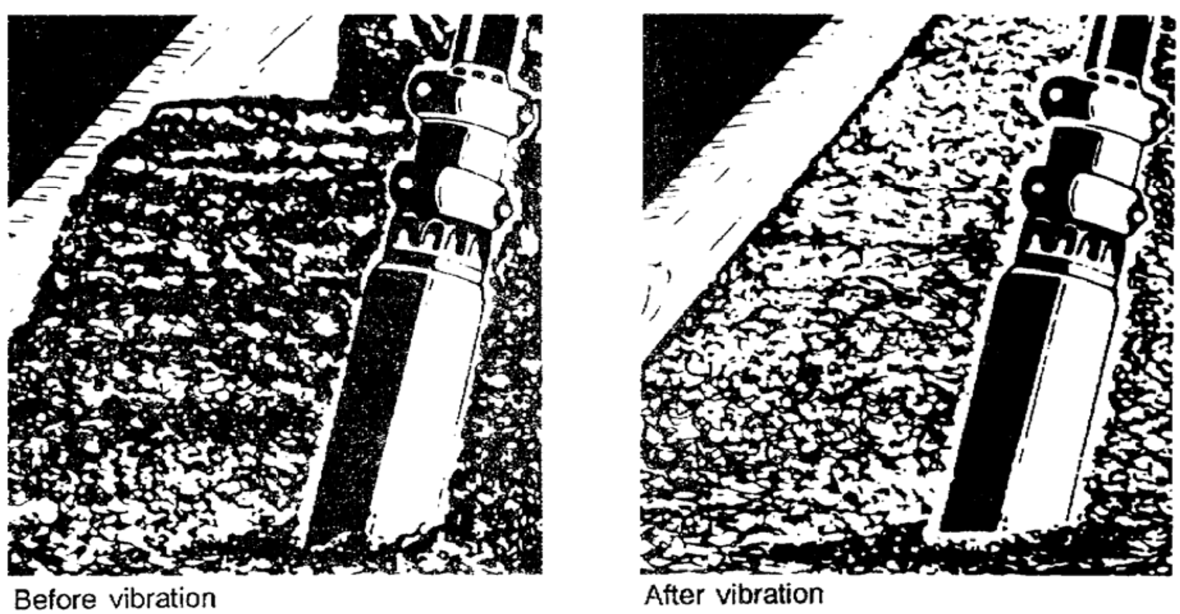


Figure 4-7. Using a vibrator to consolidate concrete.

Hand Methods

Manual consolidation methods require spades, puddling sticks, or various types of tampers. To consolidate concrete by spading, insert the spade downward along the inside surface of the forms, as shown in Figure 4-8, through the layer just placed, on into the layer underneath several inches. Continue spading or puddling until the coarse aggregate disappears into the concrete.

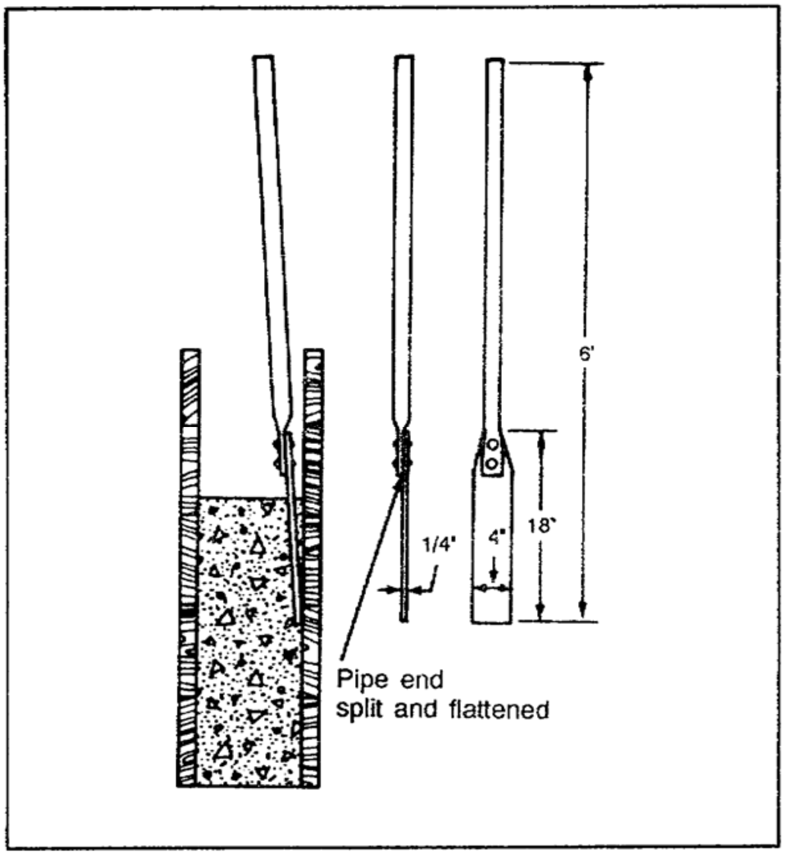


Figure 4-8. Consolidation by spading and a spading tool.

FINISHING

Purpose

The finishing process provides the desired final concrete surface. There are many ways to finish concrete surfaces, depending on the effect required. Sometimes you only need to correct surface defects, fill bolt holes, or clean the surface. Unformed surfaces may require only screeding to make the proper contour and elevation or a broomed, floated, or troweled finish may be specified.

FINISHING OPERATIONS

Screeding

The top surface of a floor slab, sidewalk, or pavement is rarely placed at the exact specified elevation. Screeding brings the surface to the correct elevation by striking of the excess concrete. Use a tool called a *screed*, which is a template having a straight lower edge to process a flat surface or a curved lower edge to produce a curved surface. Move it back and forth across the concrete using a sawing motion as shown in Figure 4-9 on page 4-18. With each sawing motion, move the screed forward a short distance along the forms. (The screed rides on either wood or metal strips established as guides.) This forces the excess concrete built up against the screed face into the low spots. If the screed tends to tear the surface, as it may on air-entrained concrete due to its sticky nature, either reduce the rate of forward movement or cover the lower edge of the screed with metal, which will stop the tearing action in most cases. You can hand screed surfaces up to 30 feet wide, but the efficiency of this method diminishes on surfaces more than 10 feet wide. Three workers (excluding a vibrator operator) can screed approximately 200 square feet of concrete per hour. Two of the workers can operate the screed while the third pulls excess concrete from the front of the screed.

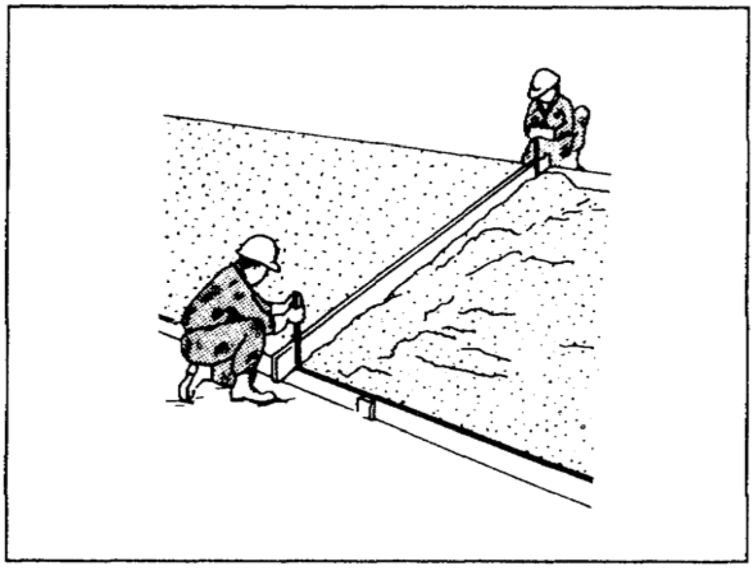


Figure 4-9. Screeding operation.

Floating

If you require a surface smoother than that obtained by screeding, work the surface sparingly using either a wood or aluminum magnesium float or a finishing machine. The wood float in view 1 of Figure 4-10 is shown in use in view 2 of Figure 4-10. Begin floating immediately after screeding, while the concrete is still plastic and workable, and before any bleed water appears on the surface. Floating has three purposes: to embed aggregate particles just beneath the surface, to remove slight imperfections and high and low spots, and to compact the concrete at the surface in preparation for other finishing operations. Do not overwork the concrete while it is still plastic or you will bring an excess of water and paste to the surface. This fine material will form a thin, weak layer that will scale or wear off under use. To produce a coarse texture as the final finish, you usually have to float the surface a second time after it partially hardens. Use a long-handled wood float for slab construction, as shown in view 3 of Figure 4-10. You use an aluminum magnesium float the same way as the wood float, but it gives the finished concrete a much smoother surface. To avoid cracking and dusting of the finished concrete, begin aluminum floating when the water sheen disappears from the freshly placed concrete surface. Do not use either cement or water as an aid in finishing the surface.

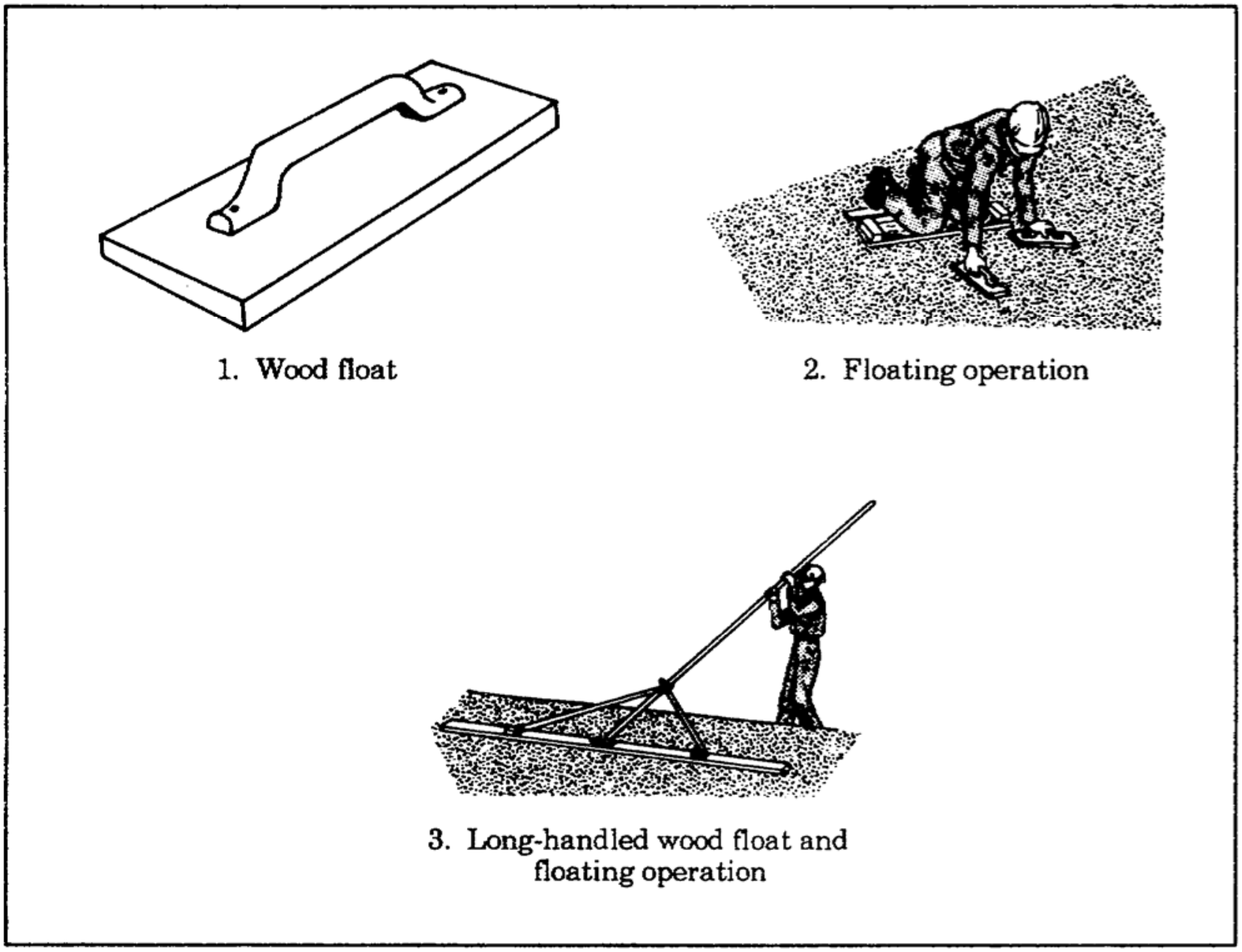


Figure 4-10. Wood floats and floating operations.

Troweling

For a dense smooth finish, follow floating with steel troweling (see Figure 4-11 on page 4-20) when the moisture film or water sheen disappears from the floated surface and the concrete has hardened enough to prevent fine material and water from working to the surface. But delay this operation as long as possible. Too much troweling too soon tends to produce crazing and reduces durability. However, too long a delay in troweling makes the surface hard to finish properly. Troweling should leave the surface smooth, even, and free from marks and ripples. Avoid wet spots if possible. When they do occur, do not resume finishing operations until the water has been absorbed, evaporated, or mopped up. When a wear-resistant and durable surface is required, it is poor practice to spread dry cement on the wet surface to absorb excess water. You can obtain a surface that is fine-textured, but not slippery, by a second light troweling over the surface with a circular motion immediately following the first regular troweling, keeping the trowel fiat against the surface. When a "hard steel-troweled finish" is specified, follow the first regular troweling with a second troweling only after the concrete is hard enough that no paste adheres to the trowel and passing the trowel over the surface produces a ringing sound. During this final troweling, tilt the trowel slightly and exert heavy pressure to compact the surface thoroughly. Hair cracks usually result from a concentration of water and fines at the surface due to overworking the concrete during finishing operations. Too rapid drying or cooling aggravates such cracking. You will usually close cracks that develop before troweling by pounding the concrete with a hand float.

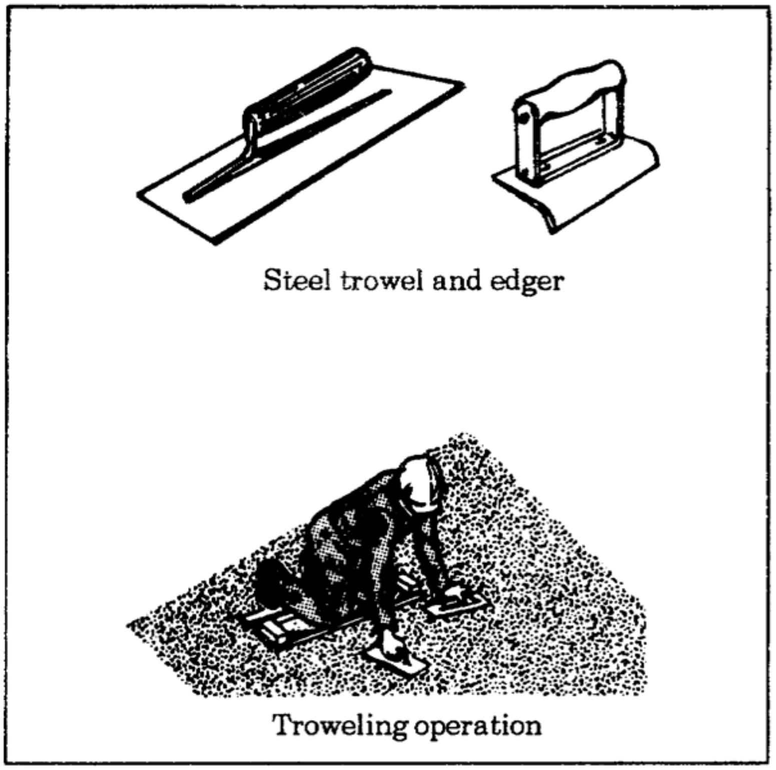


Figure 4-11. Steel finishing tools and troweling operation.

Brooming

You can produce a nonskid surface by following the floating operation (after waiting 10 to 15 minutes) by brooming the concrete before it hardens thoroughly. When severe scoring is not desirable, such as in some floors and sidewalks, you can produce the broomed finish using a hairbrush after troweling the surface once to a smooth finish. However, when rough scoring is specified, use a still broom made from either steel or coarse fiber. The direction of scoring when brooming should be at right angles to the direction of the traffic.

Rubbing

The most uniform and attractive surface requires a rubbed finish, although you can produce a surface having a satisfactory appearance simply by using plywood or lined forms. As soon as the concrete hardens, rub the surface first with coarse carborundum stones so that the aggregate does not pull out. Then, allow the concrete to cure before the final rubbing with finer carborundum stones. Keep the concrete damp while rubbing. To properly cure any mortar used as an aid in this process and left on the surface, keep it damp for 1 to 2 days after it sets. Restrict the mortar layer to a minimum because it is likely to scale off and mar the surface appearance.

CURING

Hydration

Adding water to portland cement to form the water-cement paste that holds concrete together starts a chemical reaction that makes the paste into a bonding agent. This reaction, called *hydration*, produces a stonelike substance--hardened cement paste. Both the rate and degree of hydration and the resulting strength of the final concrete, depend on the curing process that follows placing and consolidating the plastic concrete. Hydration continues indefinitely at a decreasing rate as long as the mixture contains water and the temperature conditions are favorable. Once the water is removed, hydration ceases and cannot be restarted.

CURING FACTORS

Importance

Curing is the period of time from consolidation to the point when the concrete reaches its design strength. During this period, you must take certain steps to keep the concrete moist and as near to 73°F as practicable. The properties of concrete, such as freeze and thaw resistance, strength, watertightness, wear resistance, and volume stability, cure or improve with age as long as you maintain the moisture and temperature conditions favorable to continued hydration.

Length of Curing Period

The length of time that you must protect concrete against moisture loss depends on the type of cement used, mix proportions, required strength, size and shape of the concrete mass, weather, and future exposure conditions. The period can vary from a few days to a month or longer. For most structural use, the curing period for cast-in-lace concrete is usually 3 days to 2 weeks, depending on conditions such as temperature, cement type, and mix proportions. Bridge decks and other slabs exposed to weather and chemical attack usually require more extended curing periods. Figure 4-12 shows how moist curing affects the compressive strength of concrete.

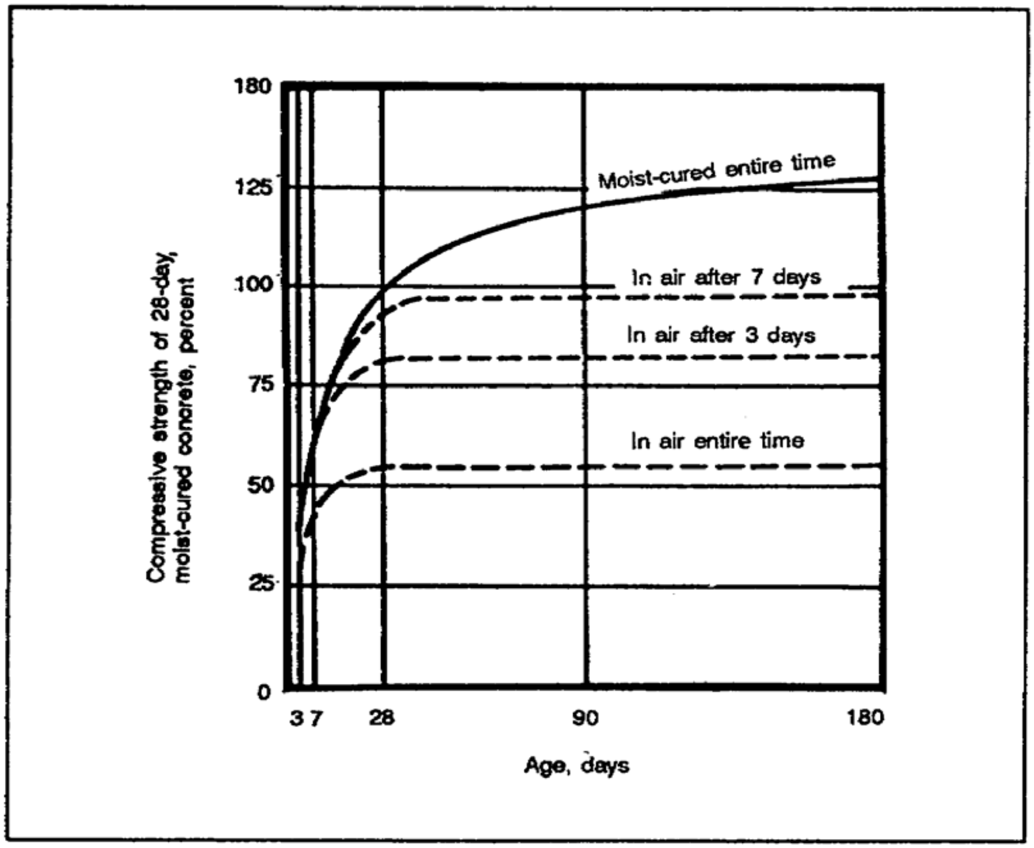


Figure 4-12. Moist curing effect on compressive strength of concrete.

Curing Methods

Several curing methods will keep concrete moist and, in some cases, at a favorable hydration temperature. They fall into two categories: those that supply additional moisture and those that prevent moisture loss. Table 4-3 list several of these effective curing methods and their advantages and disadvantages.

Table 4-3. Curing methods.

Method	Advantage	Disadvantage
Sprinkling with water or covering with wet burlap	Excellent results if constantly kept wet.	Likelihood of drying between sprinklings. Difficult on vertical walls.
Straw	Insulator in winter.	Can dry out, blow away, or burn.
Moist earth	Cheap, but messy.	Stains concrete. Can dry out. Removal problem.
Ponding on flat surfaces	Excellent results, maintains uniform temperature.	Requires considerable labor; undesirable in freezing weather.
Curing compounds	Easy to apply. Inexpensive.	Sprayer needed. Inadequate coverage allows drying out. Film can be broken or tracked off before curing is completed. Unless pigmented, can allow concrete to get too hot.
Waterproof paper	Excellent protection, prevents drying.	Heavy cost can be excessive. Must be kept in rolls; storage and handling problem.
Plastic film	Absolutely watertight, excellent protection. Light and easy to handle.	Should be pigmented for heat protection. Requires reasonable care and tears must be patched. Must be weighted down to prevent blowing away.

PART D - TEMPERATURE EFFECTS ON CONCRETE

HOT-WEATHER CONCRETING

Concreting in hot weather poses some special problems, such as strength reduction and cracking of flat surfaces due to too-rapid drying. Concrete that stiffens before you can consolidate it is caused by too-rapid setting of the cement and too much absorption and evaporation of mixing water. This leads to difficulty in finishing flat surfaces. Therefore, limitations are imposed on placing concrete during hot weather and on the maximum temperature of the concrete because quality and durability suffer when concrete is mixed, placed, and cured at high temperatures. During hot weather, take steps to limit concrete temperature to less than 90ºF, but you can have problems even with concrete temperatures less than 90°F. The combination of hot, dry weather and high winds is the most severe condition, especially when placing large exposed slabs.

EFFECTS ON HIGH CONCRETE TEMPERATURES

Mixing Water Requirements

Because high temperatures accelerate hardening, a particular concrete consistency generally requires more mixing water than normal. Figure 4-13 shows a linear relationship between an increase in concrete temperature and the increase in mixing water required to maintain the same slump. However, increasing water content without increasing cement content results in a higher w/c ratio, which has a harmful effect on the strength and other desirable properties of hardened concrete.

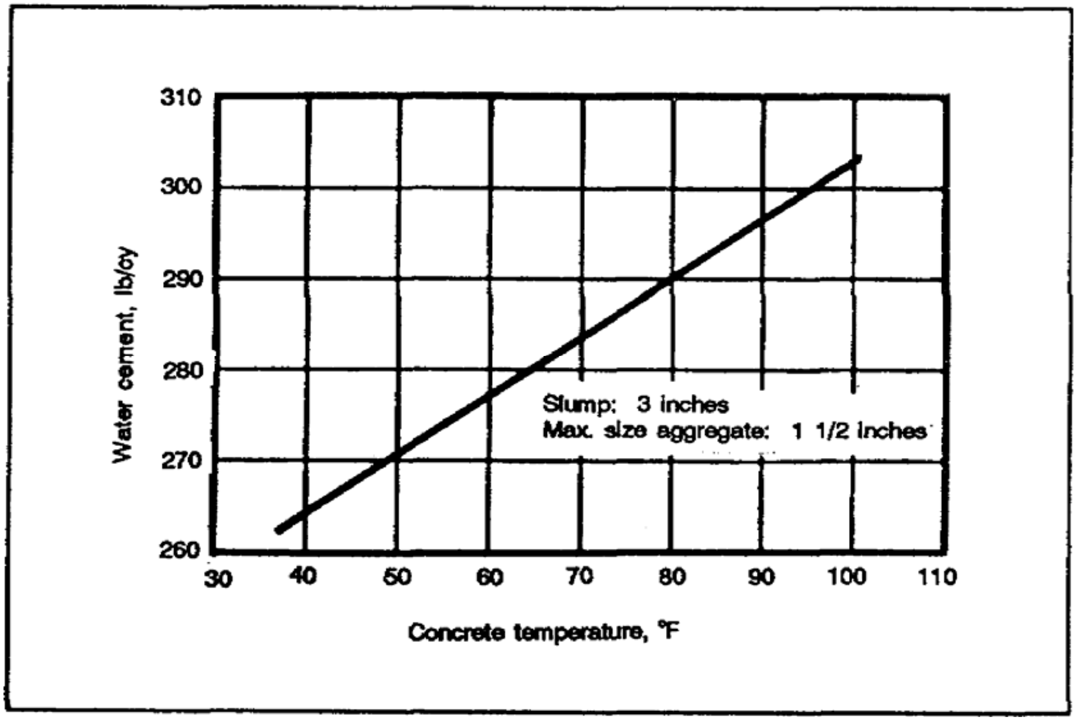


Figure 4-13. Relationship between concrete temperature and mixing water.

Compressive Strength of Concrete

Figure 4-14 on page 4-24 demonstrates the effects of high concrete temperatures on compressive strength. Tests using identical concretes having the same w/c ratio show that while higher concrete temperatures increase early strength, the reverse happens at later ages. If water content is increased to maintain the same slump (without changing the cement content), the reduction in compressive strength is even greater than that shown in Figure 4-14.

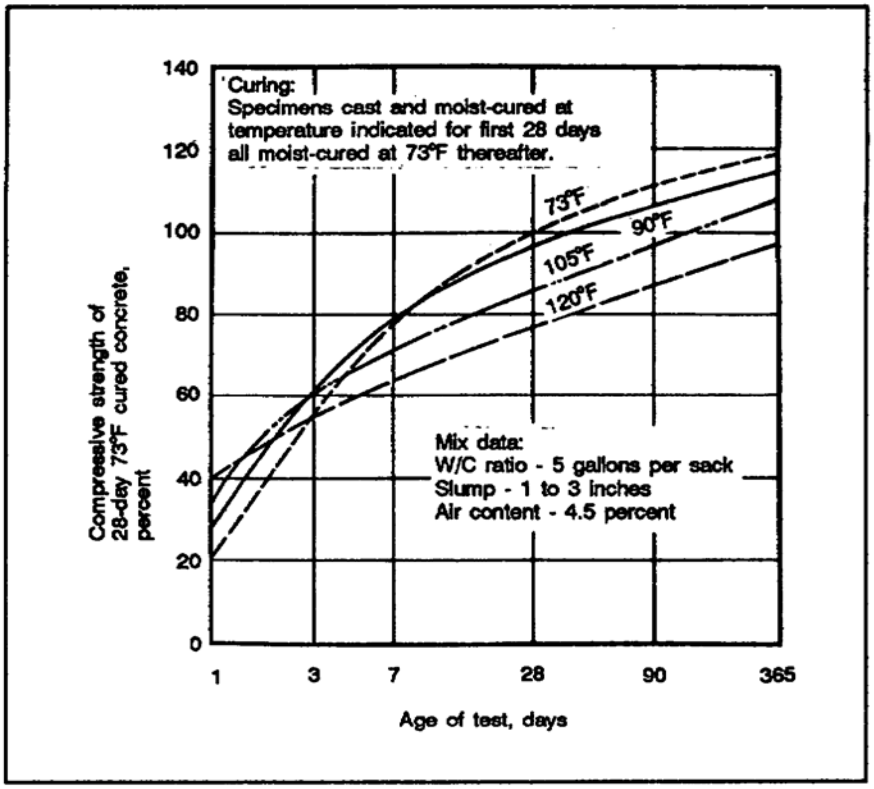


Figure 4-14. Effects of high temperature on concrete compressive strength at various stages.

Cracking

In hot weather, the tendency for cracks to form increases both before and after hardening. Rapid water evaporation from hot concrete can cause plastic shrinkage cracks even before the surface hardens. Cracks can also develop in the hardened concrete because of increased shrinkage due to a higher requirement and because of the greater difference between the high temperature at the time of hardening and the low temperature to which the concrete later drops.

Cooling Concrete Materials

The most practical way to obtain a low concrete temperature is to cool the aggregate and water as much as possible before mixing. Mixing water is easier to cool and is also more effective, pound for pound, in lowering concrete temperature. However, because aggregate represents 60 to 80 percent of the concrete' total weight, the concrete temperature depends primarily on the aggregate temperature. Figure 4-15 shows the effects of the mixing water and aggregate temperatures on the temperature of fresh concrete. You can lower the temperature of fresh concrete by--

- *Using cold mixing water.* In extreme cases, you can add slush ice to chill the water.
- *Cooling.* Cool coarse-aggregate by sprinkling, thereby avoiding too much mixing water.
- *Insulating.* Insulate mixer drums or cool them with sprays or wet burlap coverings. Insulate water supply lines and tanks or painting them white.

- *Shading.* Shade those materials and facilities not otherwise protected from the heat.

- *Working only at night.*

- *Using Type II or Type IV cement.*

- *Sprinkling.* Sprinkle forms and reinforcing steel and subgrade with cool water just before placing concrete.

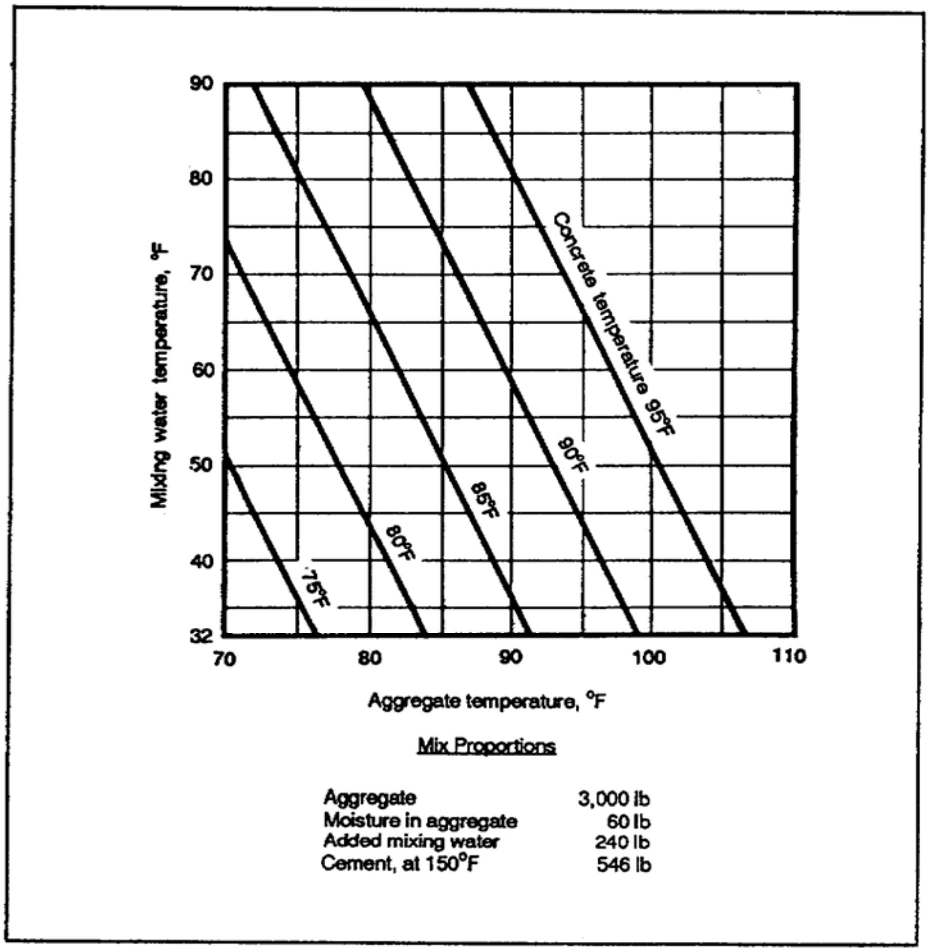


Figure 4-15. Mixing water temperatures required to produce concrete of required temperatures.

Special Precautions

High temperatures increase the hardening rate, thereby shortening the length of time available to handle and finish the concrete. This means you must transport and place the concrete as quickly as practicable and take extra care to avoid cold joints when placing it. Proper curing is especially important in hot weather due to the greater danger of crazing and cracking. But curing is also difficult in hot weather because water evaporates rapidly from the concrete and the efficiency of curing compounds is reduced. Leaving forms in place is not a satisfactory way to prevent moisture loss when curing concrete in hot weather because water evaporates rapidly from the concrete and the efficiency of curing compounds is reduced. Loosen the forms as soon as possible without damaging the concrete, and cover the concrete with water.

Then frequent sprinkling, the use of wet burlap, and other similar means of retaining moisture for longer periods are the best methods to use.

COLD-WEATHER CONCRETING

Freeze Protection

You need not suspend concreting during the winter months, if you take the necessary steps to protect the concrete from freezing in temperatures of 40°F or lower during placing and the early curing period. In your prior planning, include provisions for heating the plastic concrete and maintaining favorable temperatures after placement. The temperatures of fresh concrete should not be less than that shown in lines 1, 2, and 3 of Table 4-4. Note that lower temperatures are given for heavier mass sections than thinner sections, since less heat dissipates during the hydration period. Because additional heat is lost during transporting and placing, the freshly mixed concrete temperatures given are higher for cold weather.

Table 4-4. Recommended concrete temperatures for cold-weather construction (air-entrained concrete).*

Line	Placing and Curing Conditions		Section Size, Minimum Thickness (in)		
			< 12 in	12-36 in	36-72 in
1	Minimum temperature, fresh concrete as mixed for weather indicated, °F	Above 30°F	60	55	50
2		0° to 30°F	65	60	55
3		Below 0°F	70	65	60
4	Minimum temperature, fresh concrete as placed, °F		55	50	45
5	Maximum allowable gradual drop in temperature throughout first 24 hours after end of protection, °F		50	40	30

*Adapted from Recommended Practice for Cold Weather Concreting (ACI 306R-78).

To prevent freezing, the temperature of the concrete should not be less than that shown in line 4 of Table 4-4 at the time of placement. To ensure durability and strength development, you may need to provide further thermal protection to make sure that subsequent concrete temperatures do not fall below the minimums shown in line 5 of Table 4-4 for the time periods given in Table 4-5. Concrete temperatures over 70°F are seldom necessary because they do not give proportionately longer protection from freezing, since the heat loss is greater. Besides, high concrete temperatures require more mixing water for the same slump, and this contributes to cracking due to shrinkage.

Table 4-5. Recommended duration of protection for concrete placed in cold weather (air-entrained concrete)*.

Degree of Exposure to Freeze-Thaw	Normal Concrete**	High Early-Strength Concrete†
No Exposure	2 days	1 day
Any Exposure	3 days	2 days

*Protection for durability at temperature indicated in line 4, Table 5-6, adapted from Recommended Practice for Cold Weather Concreting (ACI 306R-78).

**Made with Type I, II, or normal cement.

†Made with Type III or high early-strength cement, or an accelerator, or an extra 100 lb of cement.

Effects on Low Concrete Temperatures

Figure 4-16 demonstrates that temperature affects the hydration rate of cement; low temperatures retard hardening and compressive strength gain. The graph shows that the strength of concrete mixed, placed, and cured at temperatures below 73°F is lower than concrete cured at 73°F during the first 28 days but becomes higher with age and eventually overtakes the strength of the concrete cured at 73°F. Therefore, you must cure concrete placed at temperatures below 73°F longer. Remember that strength gain practically stops when the moisture required for hydration is removed.

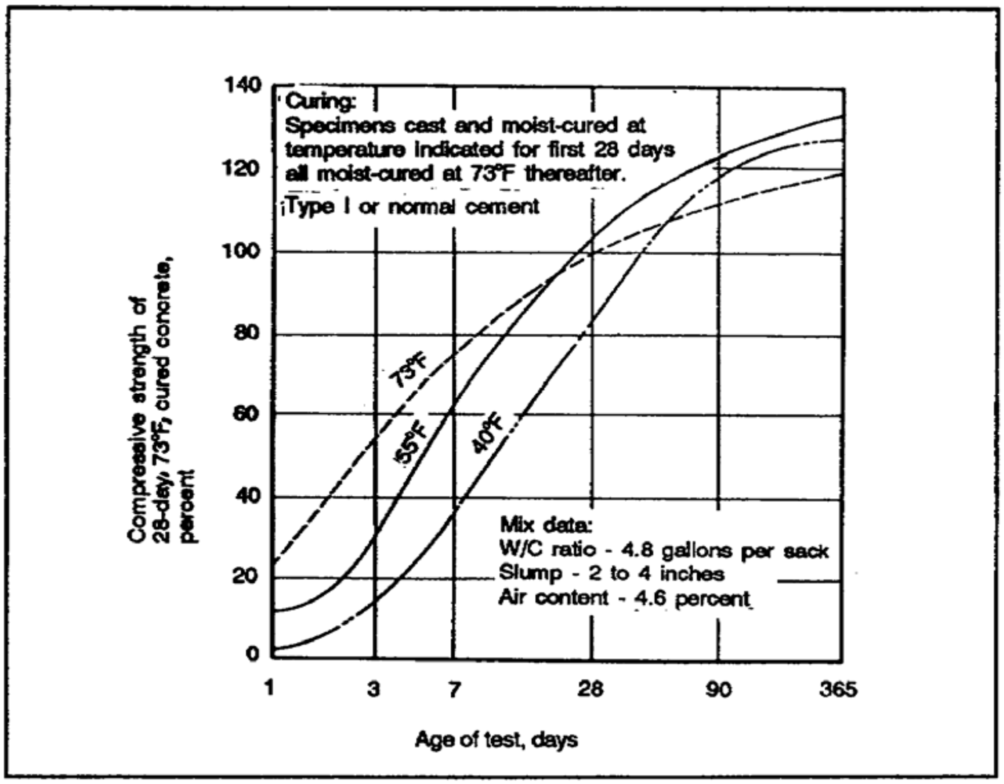


Figure 4-16. Effects of low temperature on concrete compressive strength at various ages.

Figure 4-17 shows that the early strengths achieved by Type III or higher early-strength cement are higher than those achieved by Type I cement.

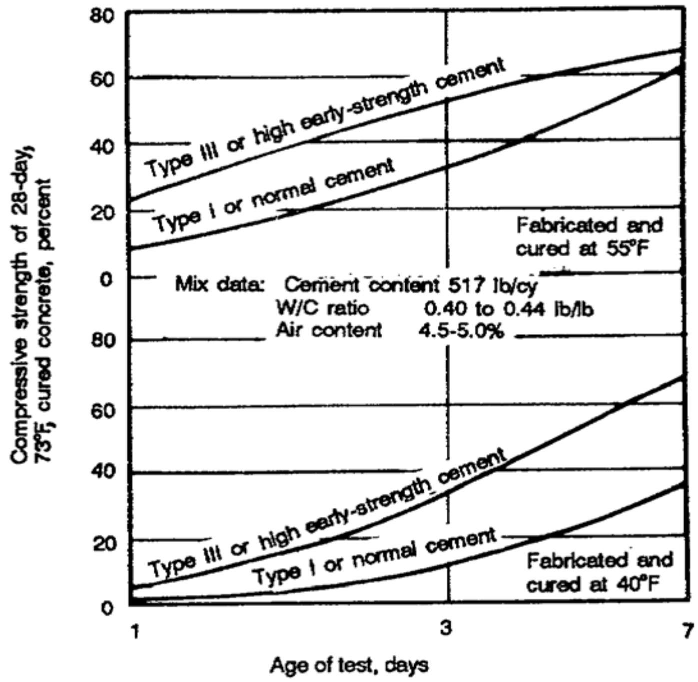


Figure 4-17. Relationships between early compressive strengths of portland cement types and low curing temperatures.

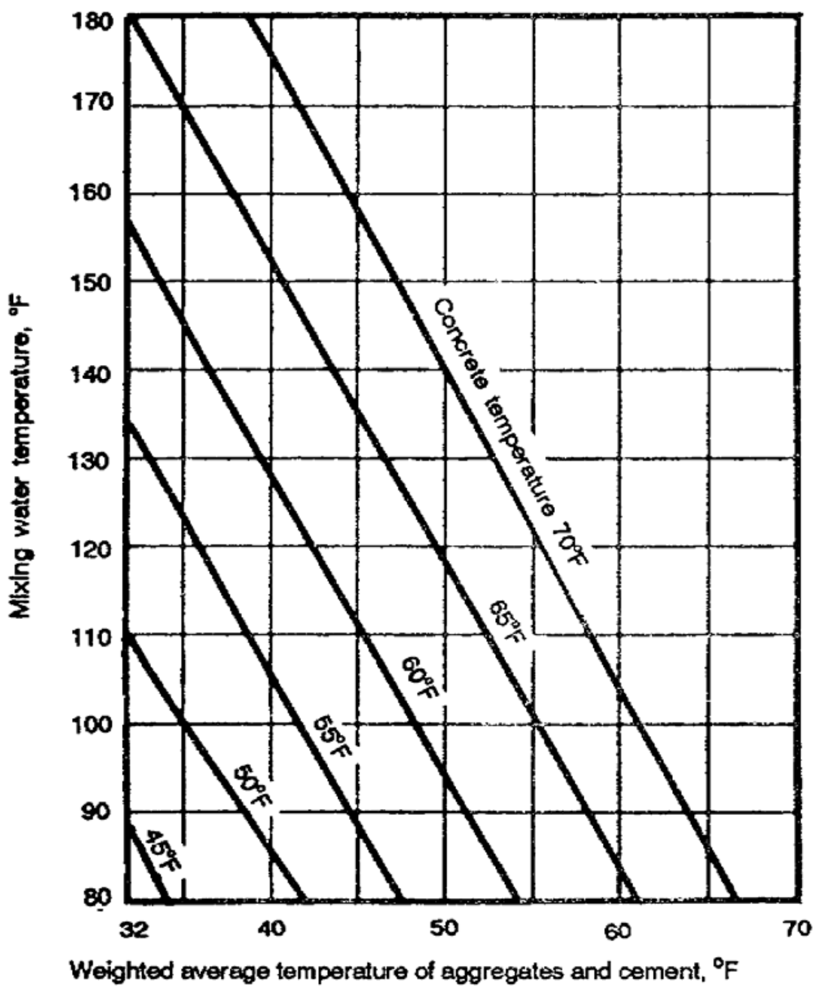
COLD-WEATHER TECHNIQUES

Heating Concrete Ingredients

Thawing frozen aggregate makes proper batching easier and avoids pockets of aggregate in the concrete after placement. If you thaw aggregate in the mixer, check for too much water content. You seldom need to heat aggregate in temperatures above freezing. But at temperatures below freezing, you can produce concrete having the required temperature by heating the fine-aggregate only.

- *Heating aggregate.* You can use any of several methods to heat aggregate. One for small jobs is to pile it over metal pipes containing fires. The average temperature of the aggregate should not exceed 1500F. Or, you can stockpile aggregate over circulating steam pipes. Cover the stockpiles with tarpaulins to retain and distribute the heat. You can also inject live steam directly into a pile of aggregate, but the resulting variable in moisture content can cause problems in controlling the amount of mixing water.

- *Heating water.* Mixing water is easier to heat because it can store five times as much heat as solid materials having the same weight, although aggregate and cement weigh much more than water. You can use the water's stored heat to heat other concrete ingredients. When you heat either aggregate or water above 100°F, combine them in the mixer first before adding the cement Figure 4-18 shows how the temperature of its ingredients affects the temperature of fresh concrete. This graph is reasonably accurate for most ordinary concrete mixtures. As shown in Figure 4-18, mixing water should not be hotter than 180°F so that, in some cases, you must heat both aggregate and water. For example, if the weighted average temperature of aggregate is below 36°F and the desired fresh concrete temperature is 70°F, you should heat the water to its maximum temperature of 180°F and also heat the aggregate to make up the difference.



Mix Proportions:

Aggregate	3,000 lb
Moisture in aggregate	60 lb
Added mixing water	240 lb
Cement	564 lb

Figure 4-18. Effects of temperature of materials on temperature of fresh concrete.

Using High Early-Strength Cement

High early-strength, Type II cement produces much higher hydration temperatures, which can offset some of the cold weather effects. Other benefits include early reuse of forms and shore removal, cost savings in heating and protection, earlier flatwork finishing, and earlier use of the structure.

Using Accelerators

Do not substitute accelerators for proper curing and frost protection. Also, do not try to lower the freezing point of concrete with accelerators (antifreeze compounds or similar products) because the large quantities required seriously affect compressive strength and other concrete properties. However, you can use small amounts of additional cement, or such accelerators as calcium chloride, to speed up concrete hardening in cold weather as long as you use no more than 2 percent of calcium chloride by weight of cement. But be careful in using accelerators containing chlorides where an in-service potential of corrosion exists, such as in prestressed concrete or where aluminum inserts are planned. When sulfate-resisting concrete is required, use an extra sack of cement per cubic yard rather than calcium chloride.

Preparing for Placement

Never place concrete on a frozen subgrade because severe cracks due to settlement usually occur when the subgrade thaws. If only a few inches of the subgrade is frozen, you can thaw the surface by burning straw, by steaming, or, if the grade permits, by spreading a layer of hot sand or other granular material. Be sure to thaw the ground enough to ensure that it will not refreeze during the curing period.

Curing

Concrete in forms or covered by insulation seldom loses enough moisture at 40 to 50°F to impair curing. Forms distribute heat evenly and help prevent drying and overheating. Leave them in place as long as practicable. However, when using heated enclosures during the winter, you must moisten curing concrete to offset the drying effects. Keep the concrete at a favorable temperature until it is strong enough to withstand both low temperatures and anticipated service loads. Concrete that freezes shortly after placement is permanently damaged. But if concrete freezes only once at an early age, favorable curing conditions can restore it to nearly normal, although it will neither weather as well nor be as watertight as concrete that is never frozen. Air-entrained concrete is less susceptible to freeze damage than non-air-entrained concrete (see TM 5-349 for details of cold weather concreting). Three methods of maintaining proper curing temperatures are described below:

- *Live steam.* When fed into an enclosure, live steam is an excellent and practical curing aid during extremely cold weather because its moisture offsets the rapid drying that occurs when very cold air is heated. You can use a curing compound after removing the protection if the air temperature is above freezing.

- *Insulation blankets or bats.* The manufacturers of these materials can usually provide information on how much insulation is necessary to protect curing concrete at various temperatures. Because the concrete's corners and edges are the most likely to freeze, be sure to check them frequently to determine the effectiveness of the protective covering.

- *Heated enclosures.* You can use wood, canvas, building board, plastic sheets, or other materials to enclose and protect curing concrete at below-freezing temperatures. You can also build a wood framework and cover it with tarpaulins or plastic sheets. Make sure enclosures are sturdy and reasonably airtight and allow for free circulation of warm air. You must provide adequate minimum temperatures during the entire curing period. The easiest way to control the temperature inside the enclosure is with live steam. Unless they are properly vented, do not use carbon-dioxide-producing heaters (salamanders or other fuel-burning heaters) when placing concrete for 24 to 26 hours afterwards.

FORM REMOVAL AND STRIPPING

Basic Considerations

Careless workers can cancel out the value of good detailing and planning by indiscriminate use of the wrecking bar. A pinch bar or another metal tool should never be placed against exposed concrete to wedge forms loose. If it is necessary to wedge between the concrete and the forms, only wooden wedges should be used.

As a rule, wall forms should not be removed until the concrete has thoroughly hardened, but specified curing should begin as early as possible in warm weather. Ties may be removed as early as 24 hours after casting to loosen forms slightly and permit entry of curing water between form and concrete. Ornamental molds must be left in place until they can be removed without damage to the concrete surface. In cold weather, removal of formwork should be deferred or formwork should be replaced with insulation blankets to avoid thermal shock and consequent crazing of the concrete surface.

See Table 4-6 on page 4-32 for recommended stripping time. After removing forms, check for concrete defects and repair all deficiencies.

Table 4-6. Recommended form stripping times.

Walls*	12-24 hr	
Columns*	12-24 hr	
Sides of beams and girders*	12-24 hr	
Pan joist forms +		
30 in wide or less	3 days	
Over 30 in wide	4 days	
	Where Design Live Load is:	
	< DL	> DL
Joist, beam, or girder soffits++		
Under 10 ft clear span between supports	7 days**	4 days
10 to 20 ft clean span between supports	14 days**	7 days
Over 20 ft clear span between supports	21 days**	14 days
Floor slabs++		
Under 10 ft clear span between supports	4 days**	3 days
10 to 20 ft clear span between supports	7 days**	4 days
Over 20 ft clear span between supports	10 days**	7 days

*Where such forms also support formwork for slab or beam soffits, the removal of the latter should govern.

+Of the type which can be removed without disturbing forming or showing.

++Distances between supports refer to structural supports and not to temporary formwork shores.

**Where forms may be removed without disturbing shores, use half of values shown, but not less than 3 days.

NOTE: These periods represent cumulative number of days or fractions thereof, not necessarily consecutive, during which the temperature of the air surrounding the concrete is above 50°F.

LESSON 4
PRACTICE EXERCISE

Check your understanding of Lesson 4 by completing the practice exercise. There is only one correct answer to each question. Try to answer all of the questions without referring to the lesson materials.

When you have completed all of the questions, turn the page and check your answers against the correct response. Each correct response s referenced to specific portions of the lesson material so that you can review any questions you have missed or do not understand, before continuing to the next lesson.

When you have completed all four lessons and your review, you can continue to the examination.

1. List three specific considerations of reconnaissance in construction site location.

2. List five considerations necessary for site preparation.

3. List two methods employed to measure aggregates for batching.

4. Correct concrete handling techniques must be employed to prevent--

5. List three main concrete transportation requirements.

6. List the principles of proper concrete placement.

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7. Present two methods for consolidating concrete.

8. List five finishing operations.

9. Present two categories of assuring adequate moisture for curing.

10. List three effects of high concrete temperatures.

11. Present two special concerns in cold weather concreting.

LESSON 4
PRACTICE EXERCISE
ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback
1.	Route selection Locating water and aggregate Time estimation Route Selection. (page 4-1) Locating Water and Aggregate. (page 4-2) Time Estimation. (page 4-2)
2.	Building approach roads Clearing and draining the site Stockpiling construction materials Positioning of batching plant Location and construction of safety facilities Site Preparation (page 4-2)
3.	Measurement by weight Measurement by volume Aggregate. Measure aggregate ... (page 4-4)
4.	Segregation Handling Techniques (page 4-10)
5.	Speed Minimum material segregation No delays The three main requirements... (page 4-12)
6.	Avoid segregation Proper consolidation Proper bonding between placements Control temperature Principles. The principles of proper ... (page 4-13)
7.	Mechanical vibrators Hand spading, puddling, or tamping The best compacting tool ... (page 4-15) Manual consolidation methods require... (page 4-16)

Item	Correct Answer and Feedback
8.	Screeding Floating Troweling Brooming Rubbing Screeding. (page 4-17) Floating. (page 4-18) Troweling. (page 4-19) Brooming. (page 4-20) Rubbing. (page 420)
9.	Methods that supply additional moisture Methods that prevent moisture loss Curing Methods (page 4-22)
10.	Mixing water requirements increase Compressive strength of concrete charge Cracking occurs Mixing Water Requirements (page 4-23) Compressive Strength of Concrete (page 4-23) Cracking (page 4-24)
11.	Freeze protection Longer curing time Freeze protection (page 4-26) Therefore, you must... (page 4-27)

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APPENDIX A - LIST OF COMMON ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACCP	Army Correspondence Course Program
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
AWR	answer weight reference
BF	bulking factor
BUW	bulk unit weight
CA	calculate aggregate
cf	cubic foot (feet)
cfm	cubic foot per minute
cos	cosine
cosine	The ratio of the distance from the stake to the wall divided by the length of the brace.
cu ft	cubic foot (feet)
cy	cubic yard(s)
cf/cy	cubic foot per cubic yard
d	dimension
deg	degree(s)
DL	dead load
DRUW	dry-rodded unit weight
DSN	defense switching network
F	Fahrenheit
FA	fine aggregate
FM	field manual; fineness modules
FSM	free surface moisture

ft	foot (feet)
gal	gallon(s)
h	The actual unsupported height of the brace used (feet).
in	inch(es)
IPD	Institute for Professional Development
J	A factor to be applied which includes all constant values (material properties and assumed wind force).
k	A constant, usually between 8 and 10.
kg/m^3	kilogram(s) per cubic meter
l	length
L	The actual unsupported length of the brace used (feet).
lb	pound(s)
L_B	length of the brace
lb/cy	pounds per cubic yard
lb/ft	pounds per foot
lb/sf	pounds per square foot
lf	linear foot
lin	linear
LL	live load
L_{max}	The maximum allowable unsupported length of the brace due to buckling and bending (feet).
max	maximum
MCS	minimum clear space
min	minimum
mm	millimeter(s)
MSA	maximum size aggregate
No	number
Nos	numbers

θ	The angle, in degrees, that the brace makes with the horizontal.
OC	on-center
psf	pounds per square foot
psi	pounds per square inch
PV	partial volume
R	Rate of placing; flexual strength (modulus of rupture), in psi, third-point loading; rough lumber.
RYE	retirement year ending
S_{max}	The maximum safe spacing of braces, center-to-center, to support the walls against external forces (feet).
SG	specific gravity
sin	sine
sine	The ratio "y" divided by L_B.
SSD	saturated, surface-dry
SSN	social security number
T	total
TOE	table(s) of organization and equipment
TL	total load
UL	uniform load
ULJ	uniform load on joist
ULS	uniform load on a stud
ULS_{str}	uniform load on the stringer
ULW	uniform load on a wale
V	volume
W	width
w/c	water/cement

wt	weight
y	The point of application of the brace on the wall form, measured in feet from the base of the form.

APPENDIX B - LIST OF SYMBOLS

°	degrees
x	times or by
=	equal
+	plus
<	less than
#	number
'	foot; feet
"	inch; inches
@	approximately or at
%	percent
>	greater than
≅	is congruent to
±	plus or minus
÷	divided by
⊥	perpendicular to
≃	perspective to
≡	defined as
≤	less than or equal to
‖	parallel to
θ	the angle in degrees that the brace makes with the horizontal
Cl^-	maximum water soluble chloride ion in concrete by weight of concrete
f'_c	specified compressive strength of concrete, psi
kg/m^3	kilogram(s) per cubic meter
MPa	megapascal(s)
SG_{FA}	specific gravity of fine aggregate

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APPENDIX C - PUBLICATION EXTRACTS

ACI 211.1-81, 1990
ACI 306R-78, 1978
ACI 318-83, 1983
ASTM C29, 1990
ASTM C33, 1990
ASTM CI50, 1986
FM 5-34, 14 September 1987
FM 5-742, 14 March 1985
TM 5-349, 19 February 1962

Use the above publication extracts to take this subcourse. At the time we wrote this subcourse, these were the current publications. In your own work situation, always refer to the latest official publications.

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