## PDHonline Course C291 (4 PDH)

# Concrete Mix Design, Form Design, and Engineering

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# Course Content

## 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.

## 2. CONCRETE PROPERTIES

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 refers to portland cement. A chemical reaction between the portland cement and water, not drying of the mixture, causes concrete to harden to a stone like 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 stone like 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 a mix, as long as it is workable and not too stiff, the stronger, more durable, and watertight the concrete will be. 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.

**Uses.** 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).

**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. 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.

## 3. CONCRETE COMPONENTS

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

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.

There are seven types of portland cements which are listed below:

- *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.

- *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.

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

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.

## 4. WATER

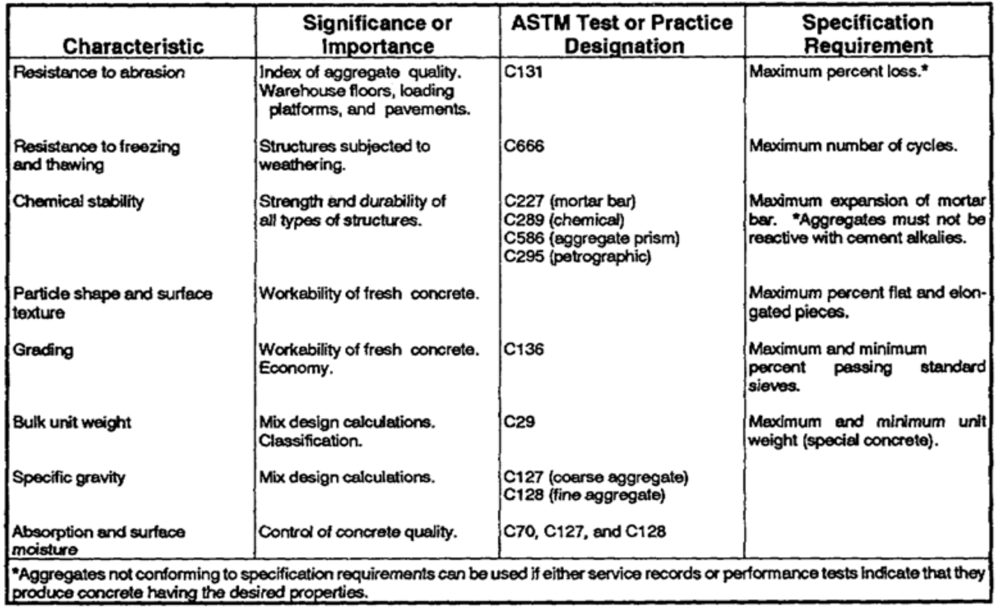
Water has two functions in the concrete mix, to effect hydration and to improve workability.

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 test cylinders made with it have 7 and 28 day strengths, equaling at least 90 percent of the test cylinders 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.

## 5. AGGREGATES

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 and discussed below.

**Table 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)<br>C289 (chemical)<br>C586 (aggregate prism)<br>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)<br>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.

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). Figure 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.

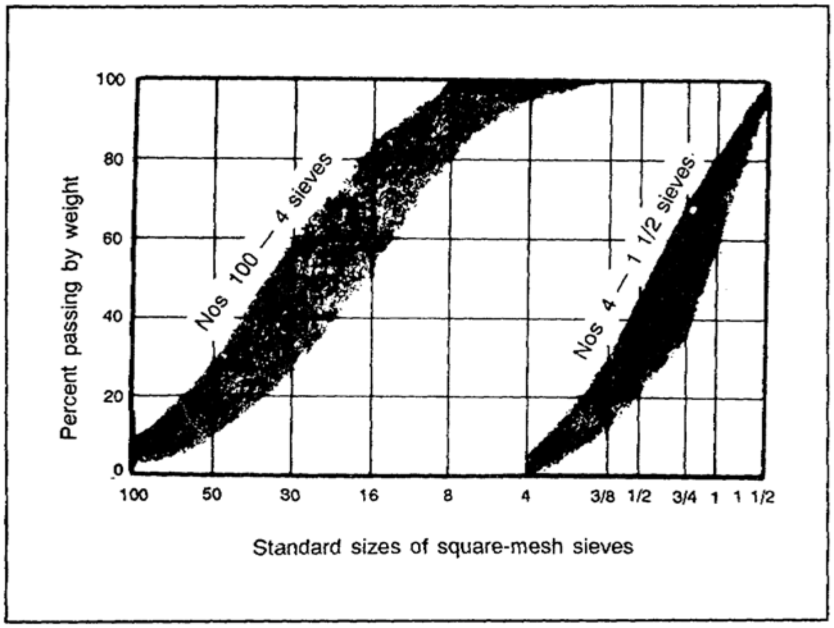


**Figure 1. Limits specified in ASTM C33 for fine-aggregates and for one size of coarse-aggregate.**

- *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 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 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 2. Typical FM calculation.**

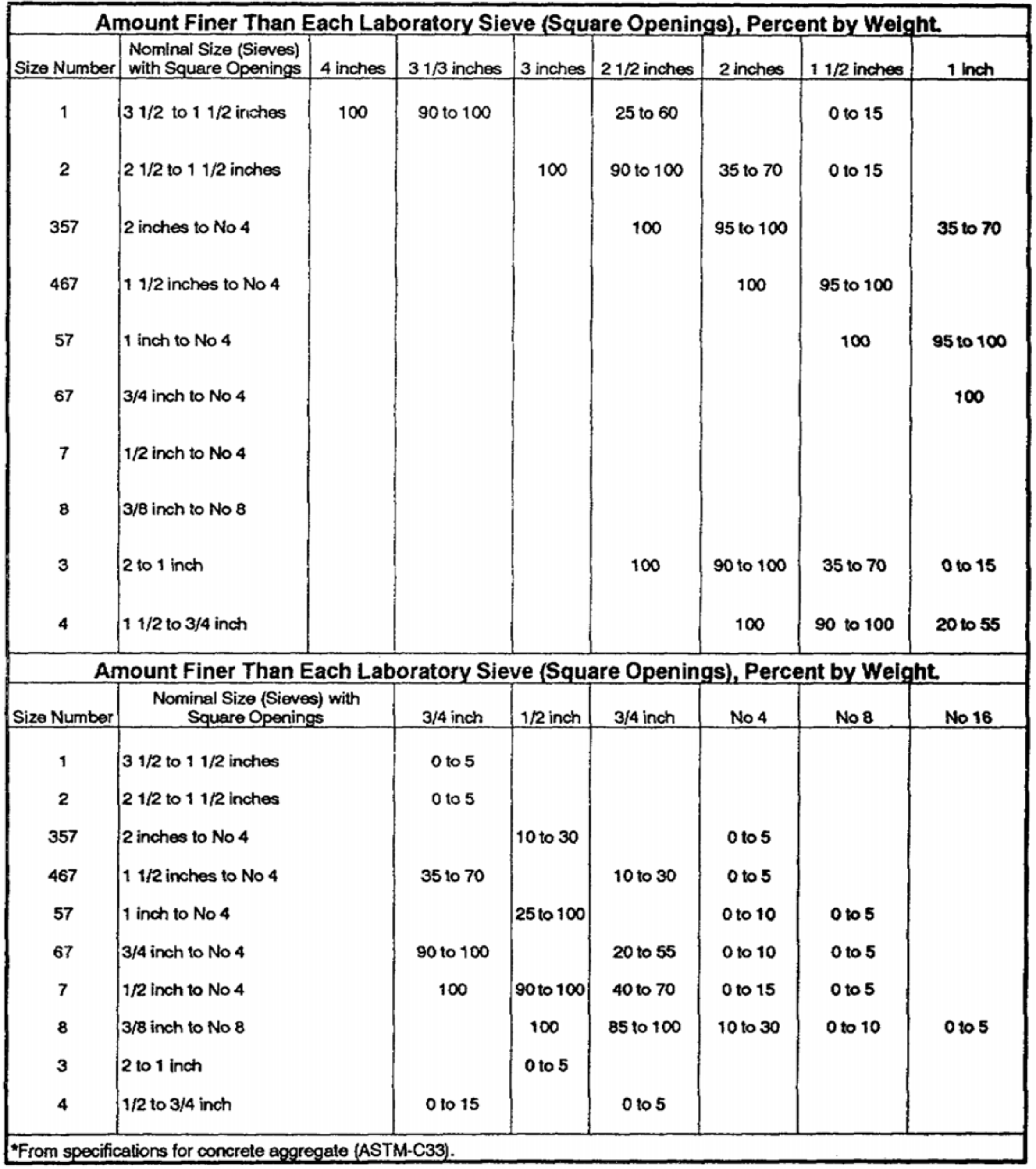
**Table 2. FM ranges for fine aggregate.**

| 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 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 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, 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. 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 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.

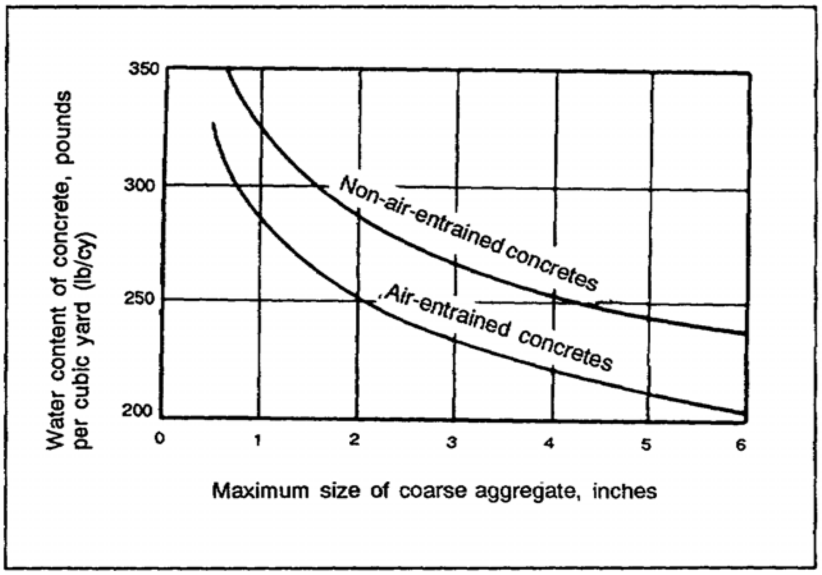


**Figure 3. Water requirement for concrete of a given consistency as a function of coarse-aggregate size.**

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 is 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 must be known to control the net water content of the concrete and determine correct batch weights. The four moisture conditions of aggregates are as follows:

- *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 is the increase in volume caused by surface moisture holding the particles apart. This occurs when damp fine aggregate is handled. Figure 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.

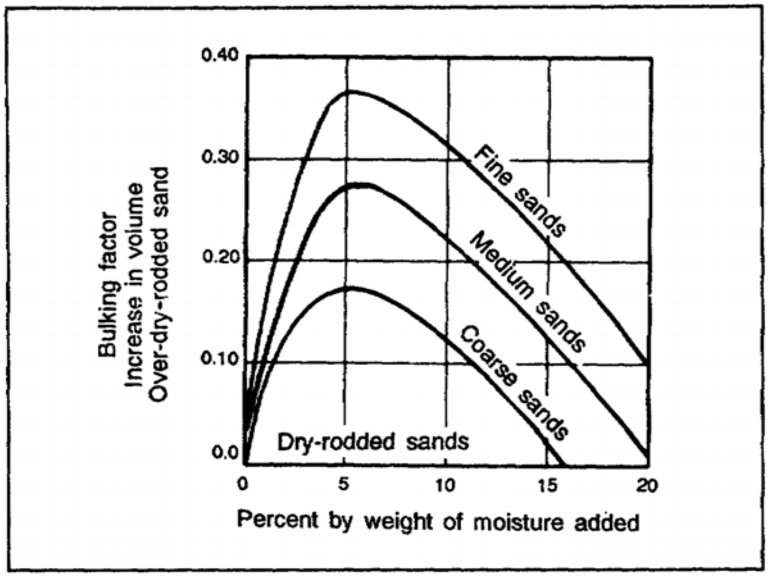


**Figure 4. Variation in fine-aggregate bulking with moisture and aggregate grading.**

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

**Table 4. Impurities in aggregates.**

| Impure Substances | Effect on Concrete | ASTM Test Designation |
|---|---|---|
| Organic impurities | Setting and hardening, may cause deterioration | C40<br>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 |

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.

## 6. ADMIXTURES

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

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. 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.

**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 are listed below:

- *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.

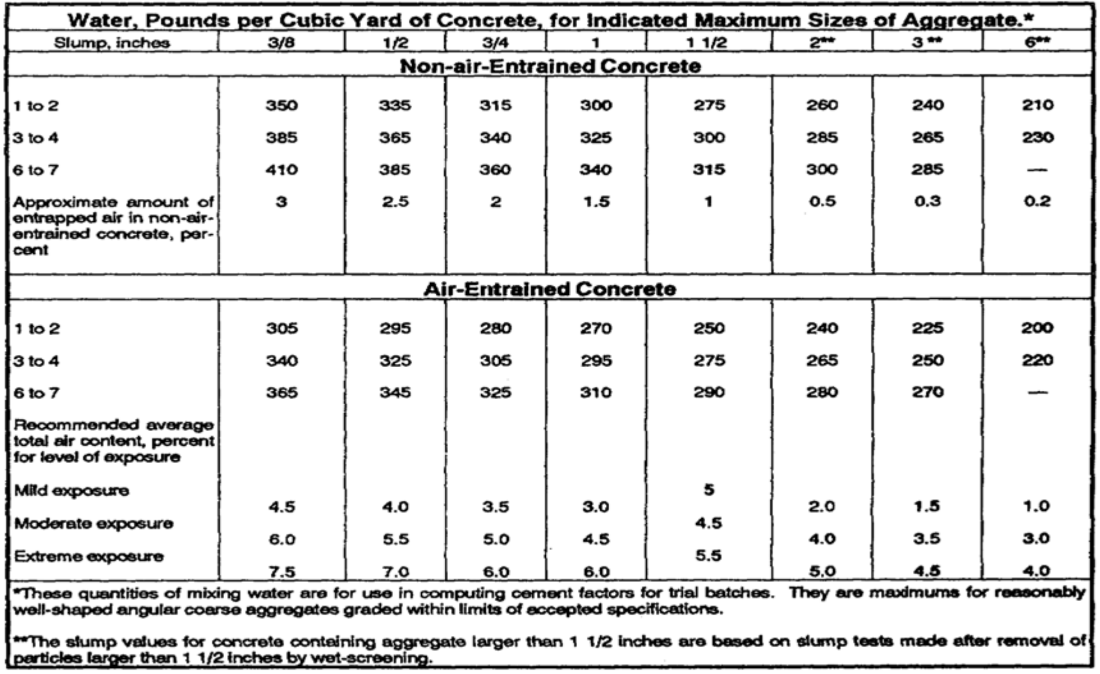
- *Concrete temperature.* The effects of concrete temperature becomes more pronounced as the slump increases. Less air is entrained as concrete temperature increases.

- *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.

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

**Table 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.

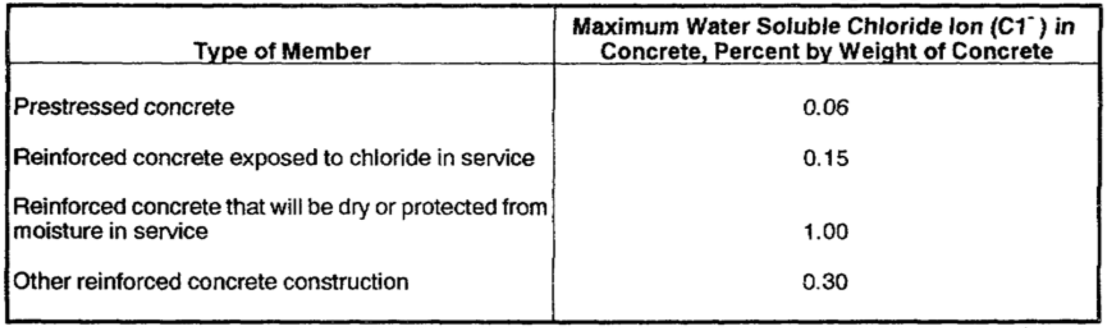
Tests that determine air-entrainment in freshly mixed concrete measure only air volume, not air void characteristics. Make tests regularly during construction, using plastic samples taken immediately after discharge from the mixer and also from already placed and consolidated concrete. Standard methods 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 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 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 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 6 shows the limitations.

**Table 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 |

Pozzolan 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.

## 7. SLUMP TEST

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.

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.

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.

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.

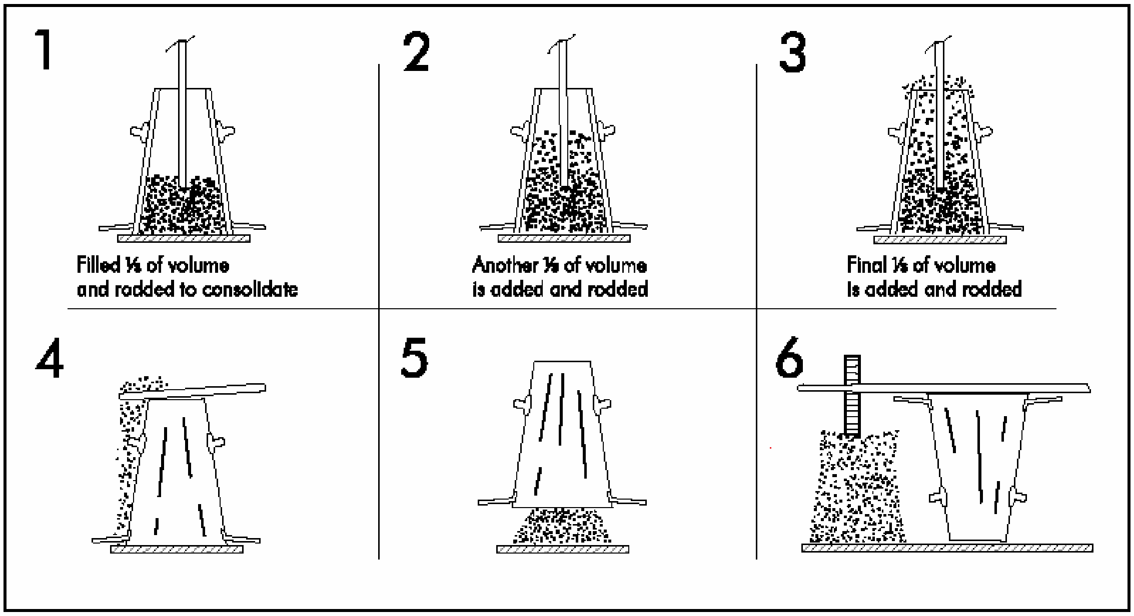


**Figure 5. Measuring slump.**

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.

**Table 7. 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)

## 8. 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.

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 8 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 9 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 9 as a guide. Enter Table 9 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.

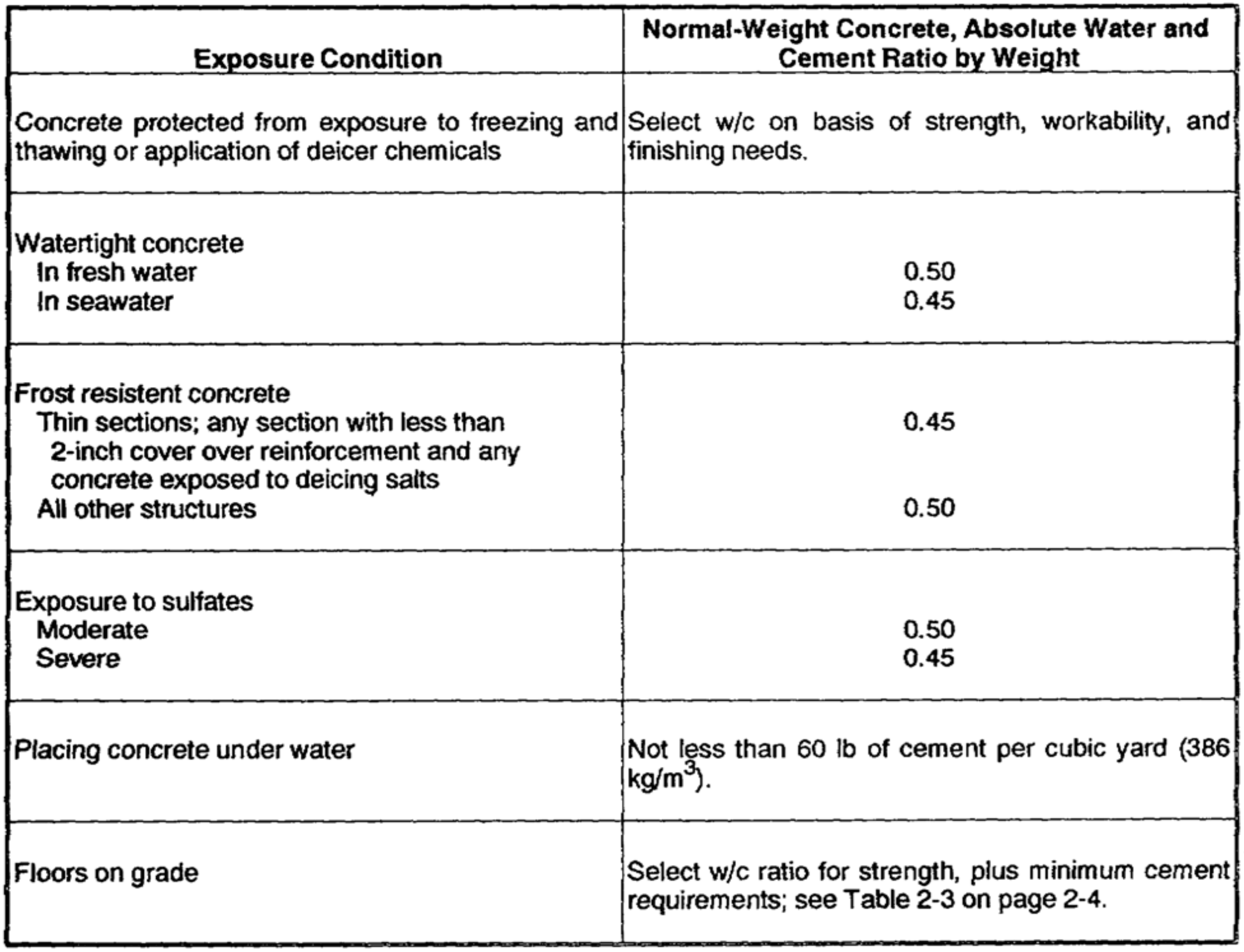
You can estimate the values when both exposure conditions and strength must be considered; use the lower of the two indicated w/c ratios. If flexural strength rather than compressive strength is the basis for design, such as a pavement, perform tests to determine the relationship between the w/c ratio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

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

Where--

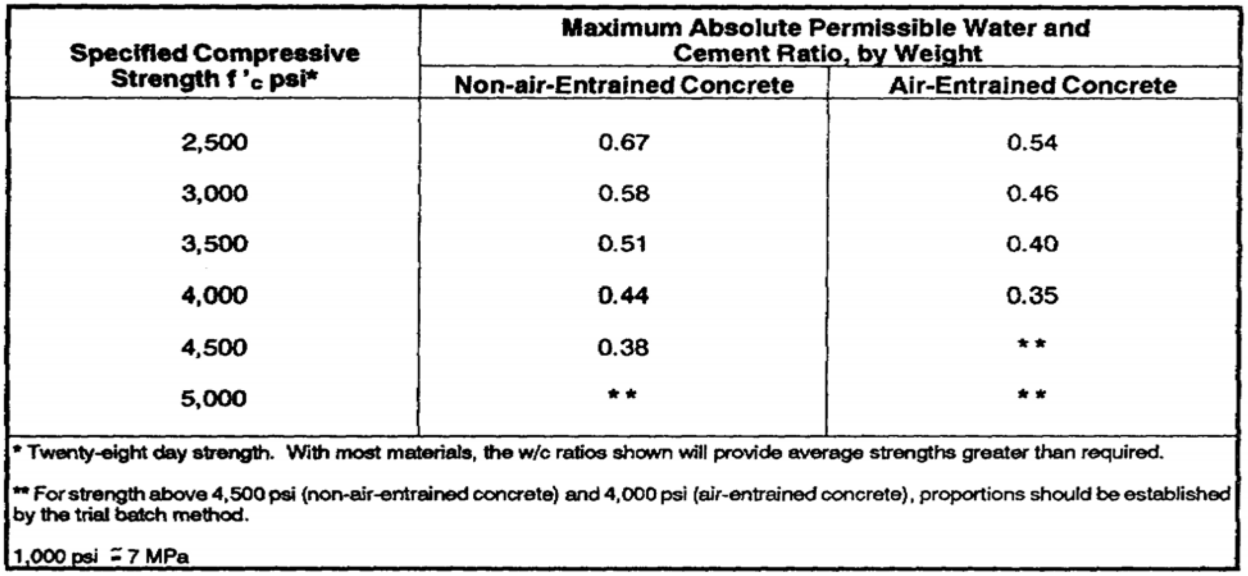
$f'_c$ = compressive strength, in psi
R = flexural strength (modulus of rupture), in psi, third-point loading
K = a constant, usually between 8 and 10

**Table 8. 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<br>In fresh water<br>In seawater | <br>0.50<br>0.45 |
| Frost resistent concrete<br>Thin sections; any section with less than 2-inch cover over reinforcement and any concrete exposed to deicing salts<br>All other structures | <br>0.45<br><br>0.50 |
| Exposure to sulfates<br>Moderate<br>Severe | <br>0.50<br>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 9. 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 | * * | * * |

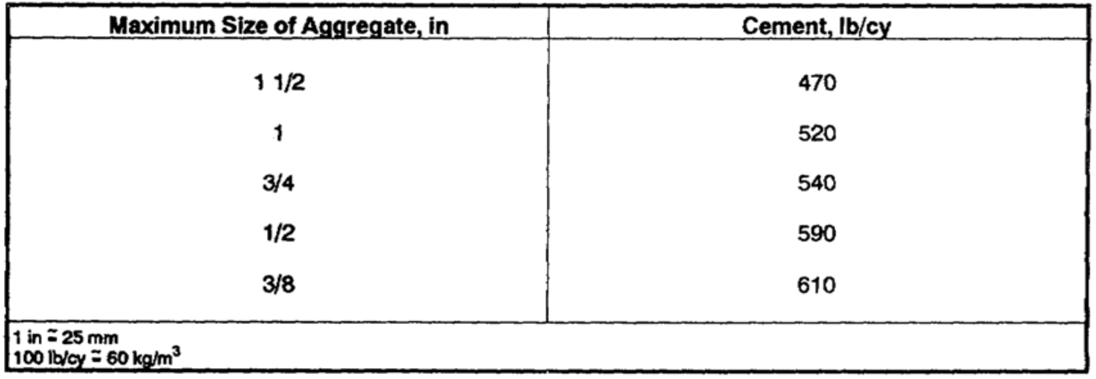
* Twenty-eight day strength. With most materials, the w/c ratios shown will provide average strengths greater than required.

** 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

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 10.

**Table 10. 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 $kg/m^3$

- *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 Ensures that the excess fines, material finer than the No 200 sieve, are limited to less than 3 or 5 percent.

- *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.

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 5 gives recommended total air contents of air-entrained concrete. The upper half of Table 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.

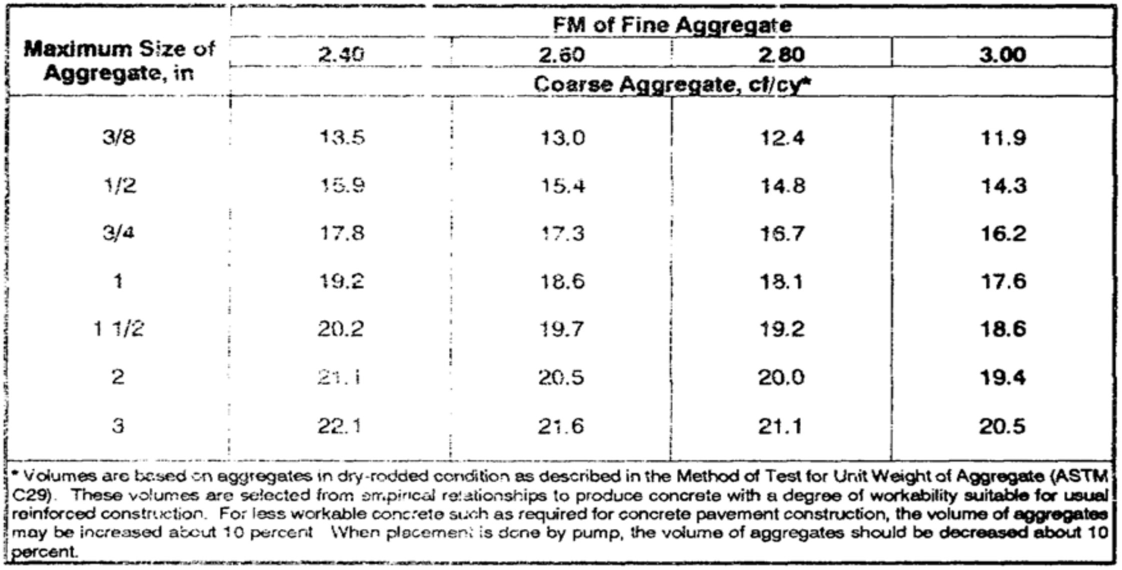
## 9. DETERMINING WATER/CEMENT RATIO

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.

## 10. ABSOLUTE VOLUME METHOD

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, 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 9. 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 11. 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 11. 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 6 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$^3$.

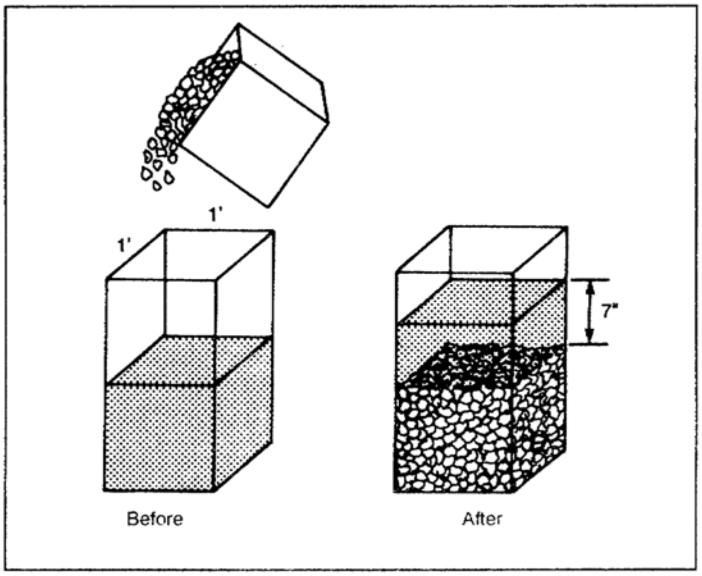


**Figure 6. Absolute volume.**

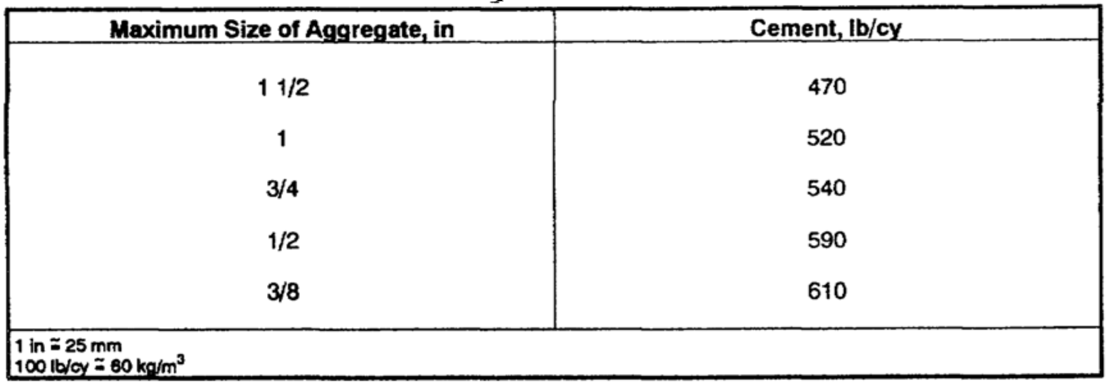
Another method of determining the absolute volume is to use the concept of specific weight, which is the weight of a solid cubic foot of a material. The specific weight of a cubic foot of material is found by multiplying the specific gravity of the material times the unit weight of water. Suppose your 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:

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

## 11. 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 12. This requirement is normally met in the design procedure but must be checked to ensure compliance.

**Table 12. 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$^3$

## 12. 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.

## 13. 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.

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.

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

- *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.

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 7. The formula for volume increase is--

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

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

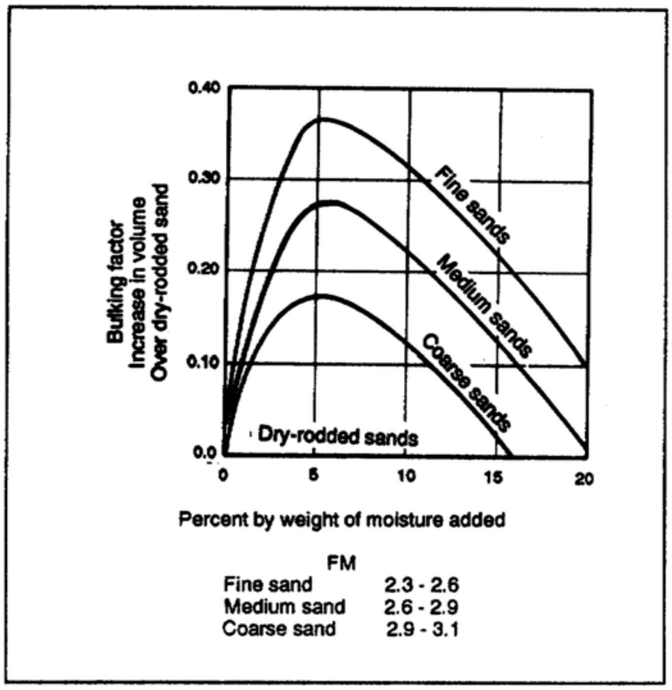


**Figure 7. Bulking factor curves.**

## 14. 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.

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.

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.

Wall Forms are constructed with:

- *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 8, 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.

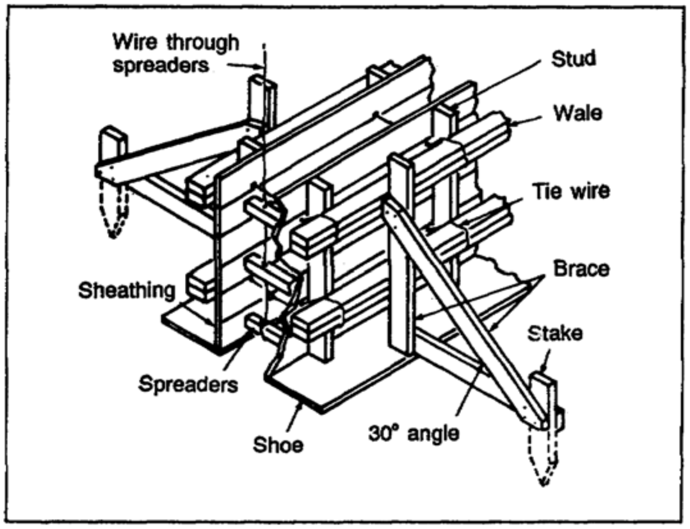


**Figure 8. Wood form for a concrete panel wall.**

Column Forms are constructed with:

- *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.

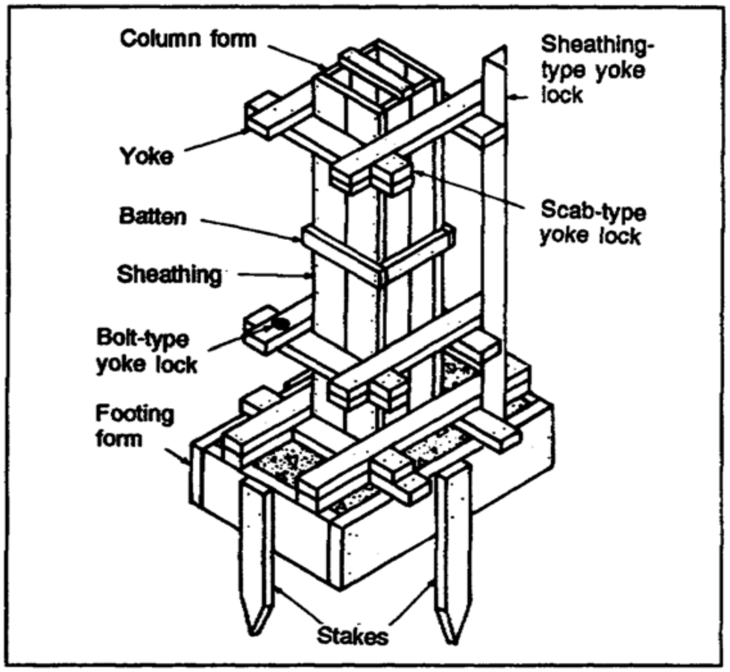


**Figure 9. Form for a concrete column and footing.**

## 15. 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.

## 16. PANEL WALL FORM DESIGN

When designing forms follow a step-by-step procedure using the following:

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

*Step 2.* Determine the concrete output by dividing the mixer truck yield by the delivery time. Delivery time includes loading all ingredients, mixing, and unloading. If more than one mixer truck is used, multiply the output by the number of mixer trucks.

$$\textbf{Mixer truck output (cf/hr)} = \frac{\textbf{mixer truck yield}}{\textbf{delivery time (min)}} \times \frac{\textbf{60 min}}{\textbf{hr}} \times \textbf{number of mixer trucks}$$

*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.

$$\textbf{R (ft/hr)} = \frac{\textbf{mixer truck output (cf/hr}}{\textbf{Plan area (sf)}}$$

For an economical design, try to keep $R \le 5$ 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 10. 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.

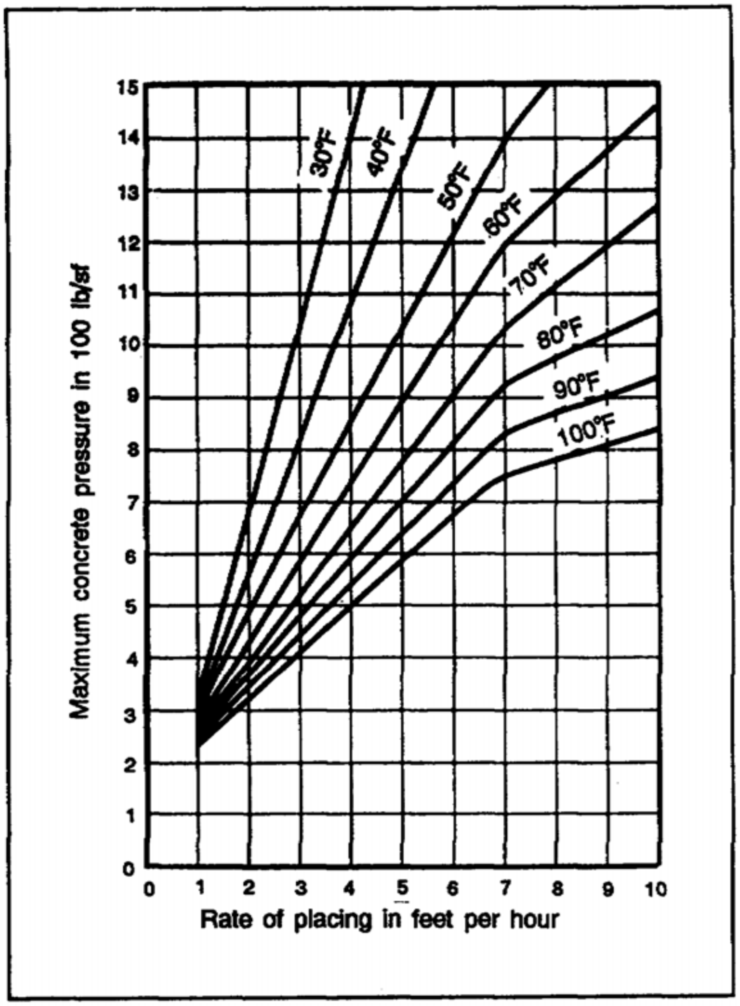
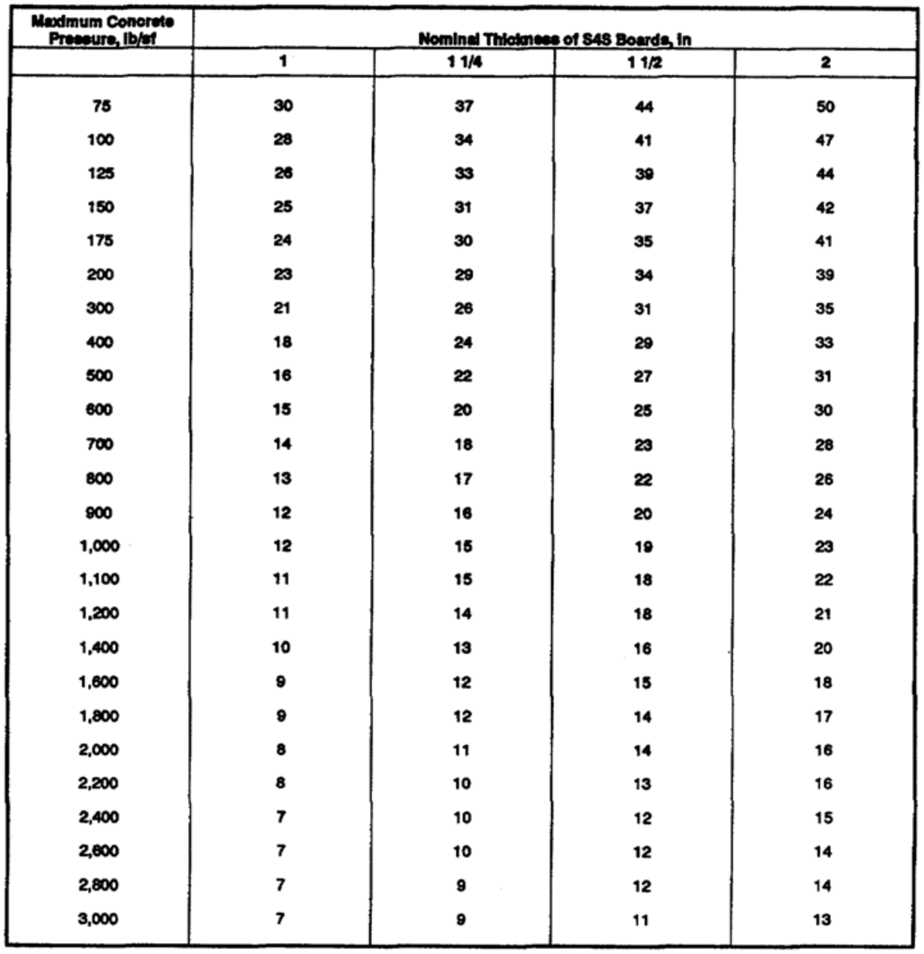


**Figure 10. Maximum concrete pressure graph.**

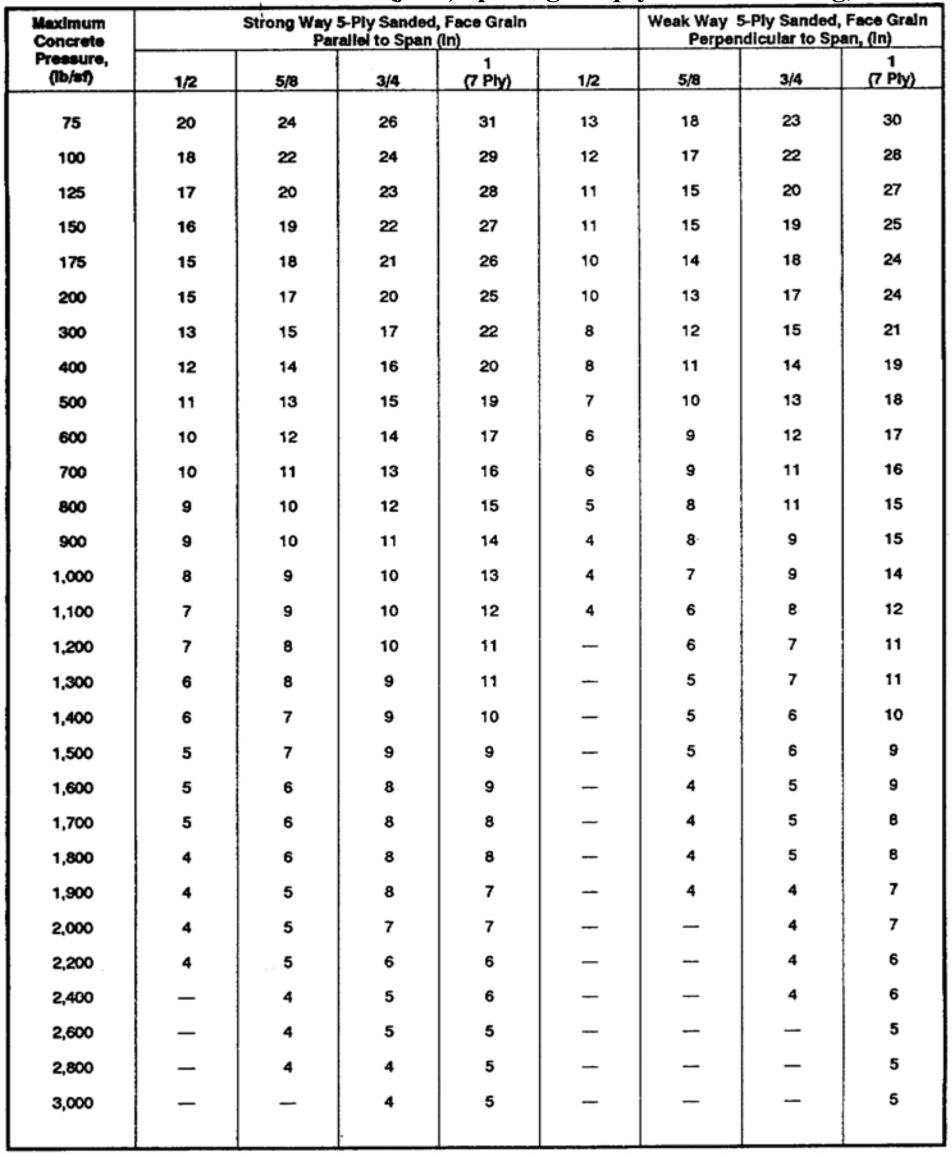
*Step 7.* Use Table 13 or Table 14 to find the maximum stud spacing in inches. Use Table 13 for board sheathing and Table 14 for plywood sheathing. Refer to the column headed Maximum Concrete Pressure and find the value you have for the maximum concrete pressure. If the value you have falls between two 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 13. 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 14. 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 15 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 15. 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 15 or Table 16 (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 15 if using single wales (4- by 4-inch lumber). Use Table 16 if you are using double wales (2- by 4-inch or 2- by 6-inch lumber).

**Table 16. Maximum spacing for ties and 4 by 4s or larger shores where member to be supported is a double member (in).**

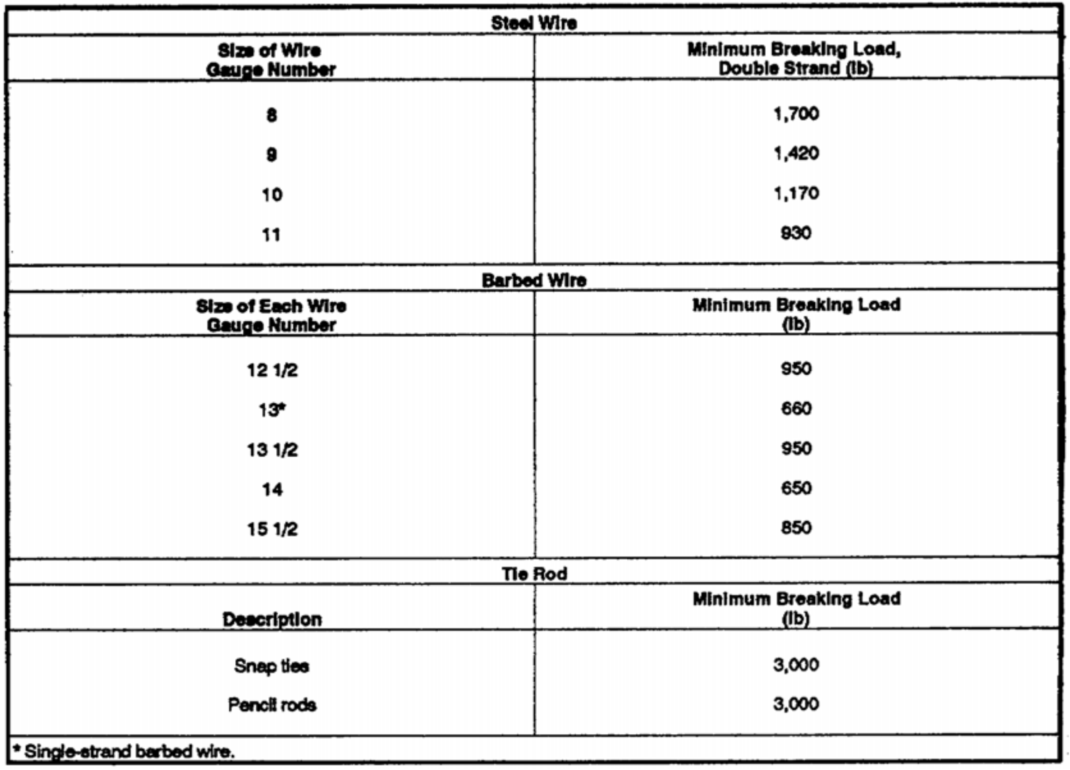
| Uniform Load (lb/linear ft) | Supported Member Size (S4S), (in) | | | | |
|---|---|---|---|---|---|
| | 2 by 4 | 2 by 6 | 3 by 6 | 4 by 4 | 4 by 6 |
| 100 | 85 | 126 | 143 | 222 | 156 |
| 125 | 76 | 119 | 135 | 105 | 147 |
| 150 | 70 | 110 | 129 | 100 | 141 |
| 175 | 64 | 102 | 124 | 96 | 135 |
| 200 | 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 17 gives the breaking loads for a double-strand wire and tie rods (found in the Army supply system).

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

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

**Table 17. 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.

$$\textbf{Number of studs} = \frac{\textbf{length of form (ft) x 12 (in/ft)}}{\textbf{Stud spacing (in)}} + \textbf{1}$$

*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.

The following steps are used to design a wood form for a concrete column.

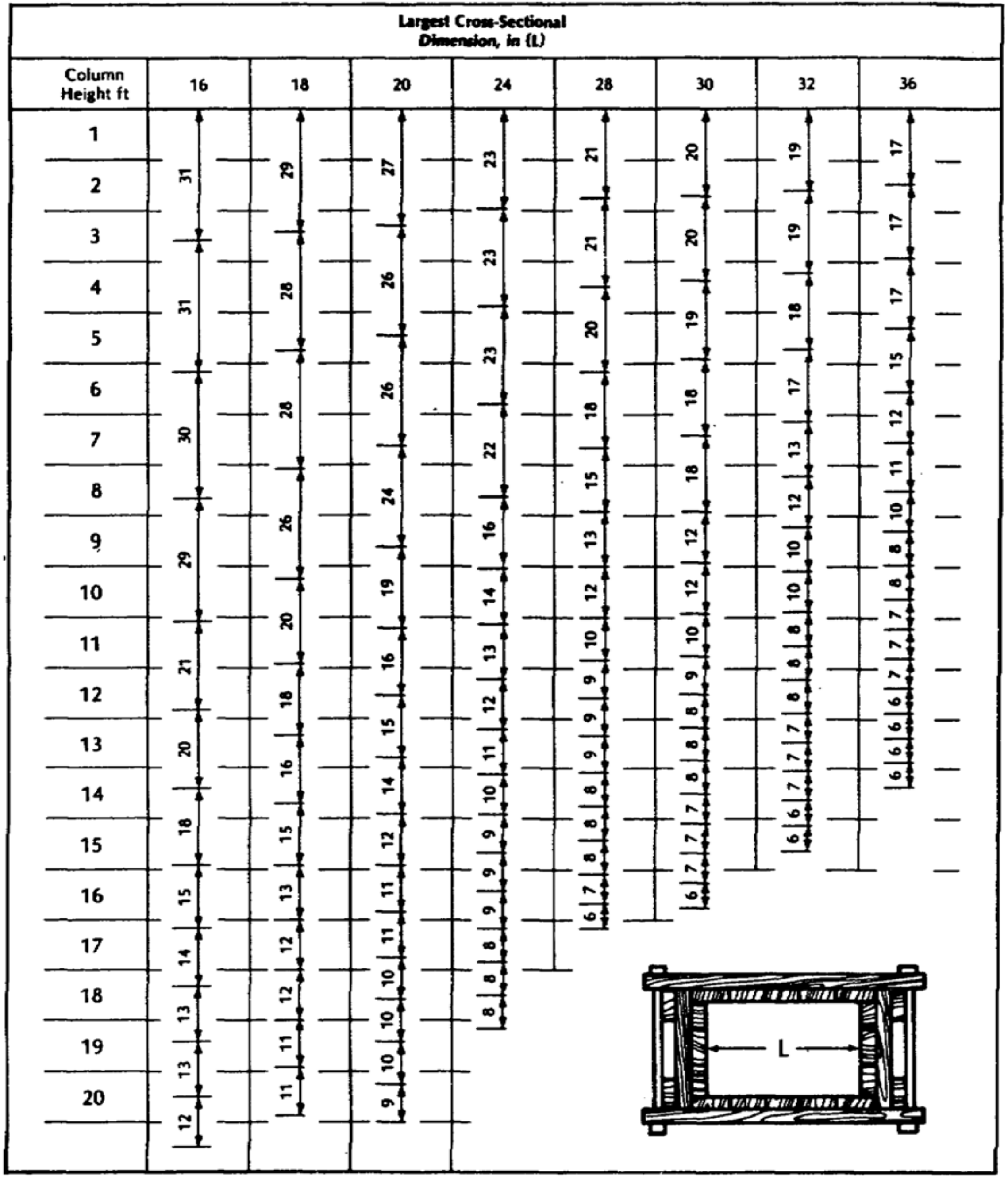
*Step 1.* Determine the materials you will use for sheathing, yokes, and battens. (Standard materials for column forms are 2- by 4-inch and 1-inch sheathing.)

*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 32. 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.

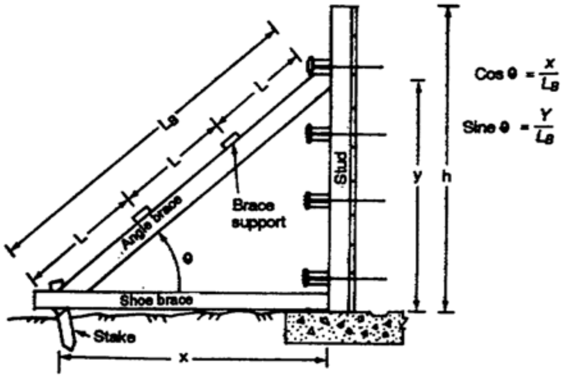
**Table 32. Column yoke spacing using 2 by 4 inch and 1inch sheathing.**



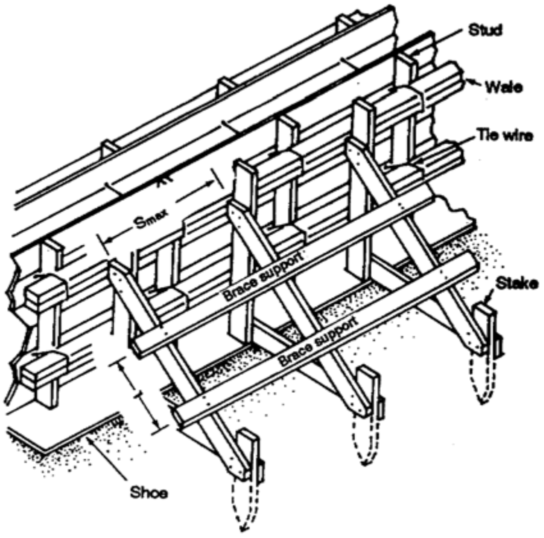
*Step 5.* Adjust the final spacing to match the top height of the column.

## 17. BRACING FOR WALL FORMS

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 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.



a. Nomenclature of diagonal bracing



b. $S_{max}$ brace supports

Figure 11. 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.

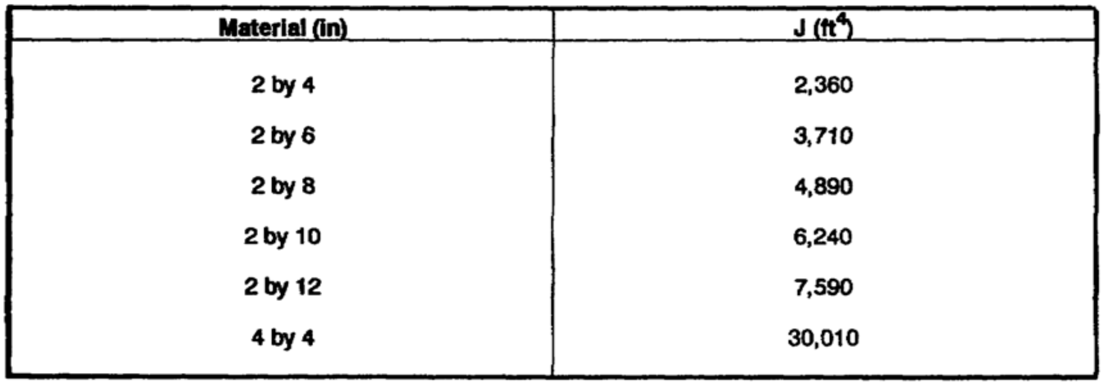
h = The overall height (feet) of the wall form.

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 18.

**Table 18. 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.

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

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 $L_B$.

The design procedure is best explained by the example problem below:

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 18)
- $L_{max}$ = 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, $\theta$.

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

$\theta$= $\sin^1$ (.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.

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

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:

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

- 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 $\theta = 45°$.
- 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.

## 18. OVERHEAD SLAB FORM DESIGN

There may be instances where a concrete slab will have to be placed above the ground. 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:

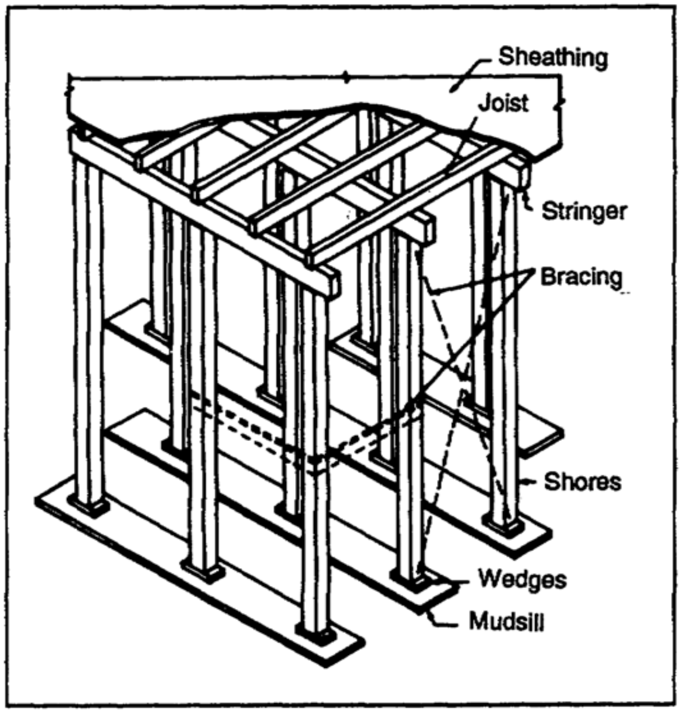


**Figure 12. Typical overhead slab forms.**

- *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.

Follow the steps outlined below for overhead slab forms:

*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 13, or Table 14, 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 15, 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.

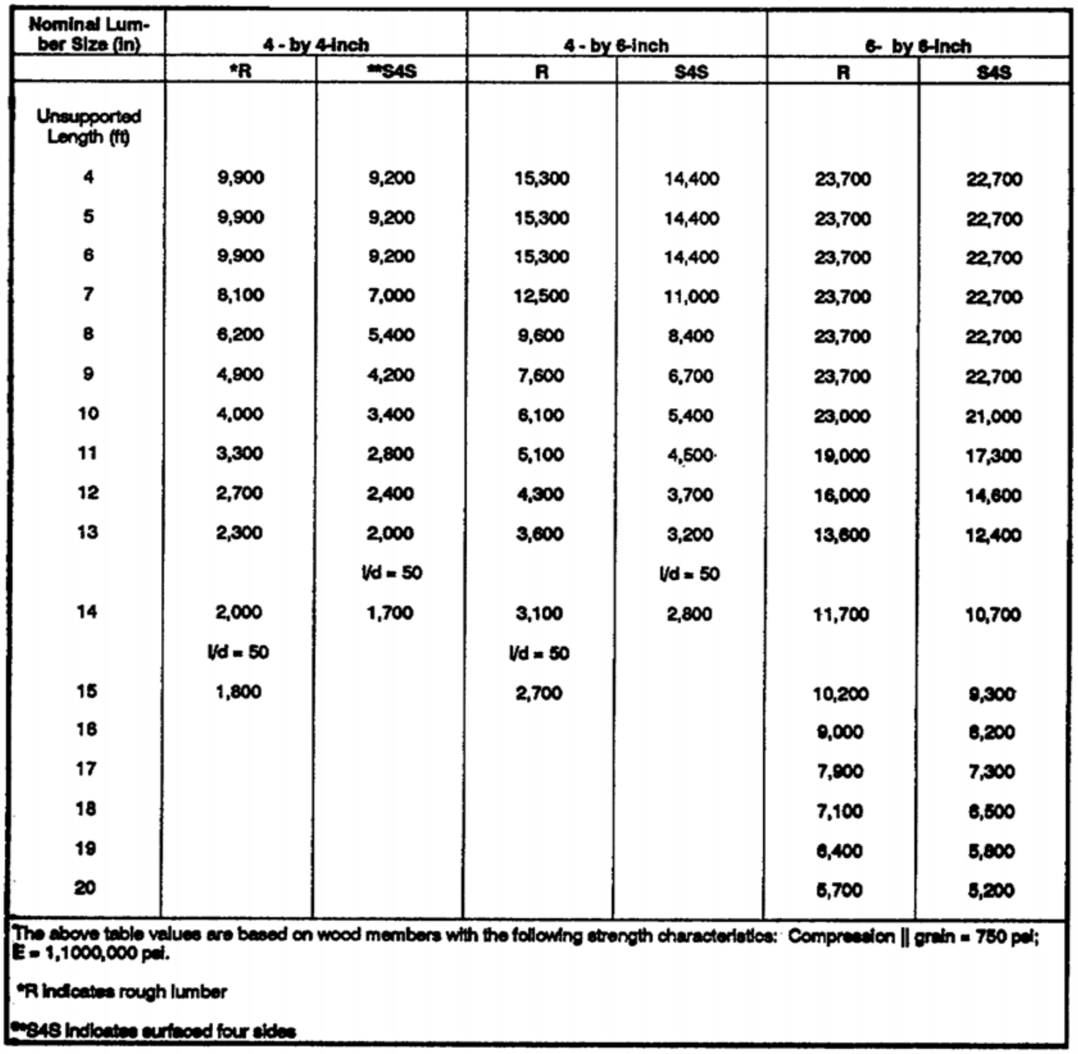
$$\text{UL on the stringer } (\text{ULS}_{\text{str}}) = \frac{\text{TL} \times \text{maximum stringer spacing (in)}}{12 \text{ in/ft}}$$

*Step 7.* Determine the maximum shore spacing. Maximum shore spacing is based on the stringer strength. Use Table 15, for single stringers, and use Table 14, if stringers are doubled and the UL on the stinger is rounded to the next higher load shown in he 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 19 and Table 20, 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 19. Allowable load, in pounds, on wood shores, based on shore strength.**



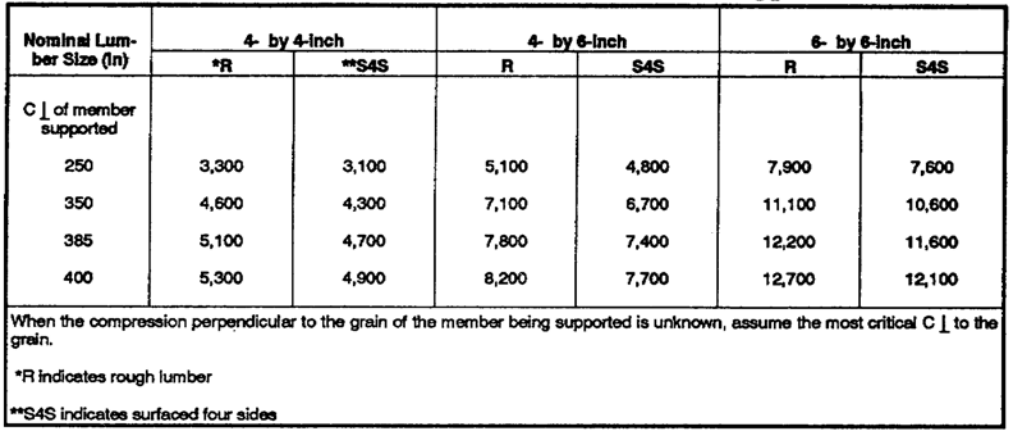
| Nominal Lumber Size (in) | 4 - by 4-inch | | 4 - by 6-inch | | 6- by 6-inch | |
|---|---|---|---|---|---|---|
| | *R | **S4S | R | S4S | R | S4S |
| Unsupported Length (ft) | | | | | | |
| 4 | 9,900 | 9,200 | 15,300 | 14,400 | 23,700 | 22,700 |
| 5 | 9,900 | 9,200 | 15,300 | 14,400 | 23,700 | 22,700 |
| 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 20. 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 19. 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 20. 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:

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

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 13 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.

## 18. CONSTRUCTION PROCEDURES

Make a thorough and efficient inspection and review 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.

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.

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.

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

## 19. SITE PREPARATION

Most new construction takes place on undeveloped land. Therefore, new approach roads are required 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 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 is 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.

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.

## 20. STOCKPILING CONSTRUCTION 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.

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.

If there is a batching plant 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.

Plan, and in some cases construct, 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.

## 21. PLAN FORMWORK USED IN CONSTRUCTION PROJECTS

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.

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

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.

## 22. MIXING, HANDLING, TRANSPORTATION, PLACEMENT,FINISHING, AND CURING OF CONCRETE

The following are types of mixing methods and mixers used for construction:

- *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.

- *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.

- *Charging the mixer.* You can charge mixers in two ways: by hand or with a mechanical skip, 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.

- *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.

## 23. HANDLING AND TRANSPORTATION

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.

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.

## 24. PLACEMENT

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.

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.

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.

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.

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.

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. Care should be taken 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.

When compacting concrete 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.

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.

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. When placing walls, be sure to remove the spreaders as you fill the forms.

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

When placing 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.

## 25. CONSOLIDATING CONCRETE

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.

The best compacting tool is a mechanical vibrator. 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.

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 through the layer just placed, on into the layer underneath several inches. Continue spading or puddling until the coarse aggregate disappears into the concrete.

## 26. FINISHING

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.

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 13. 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.

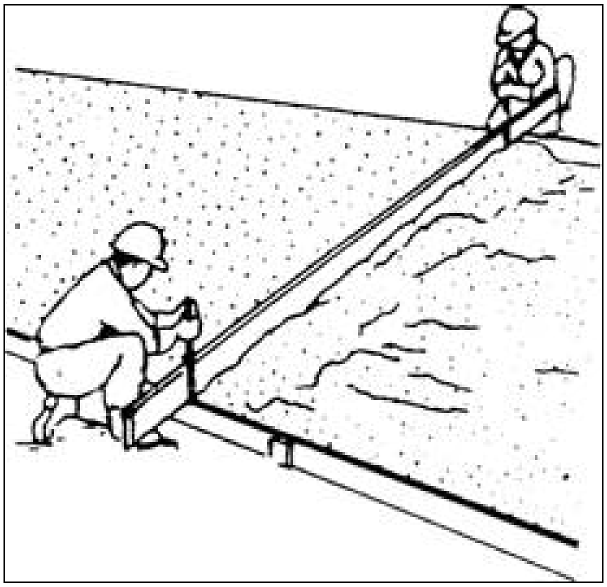
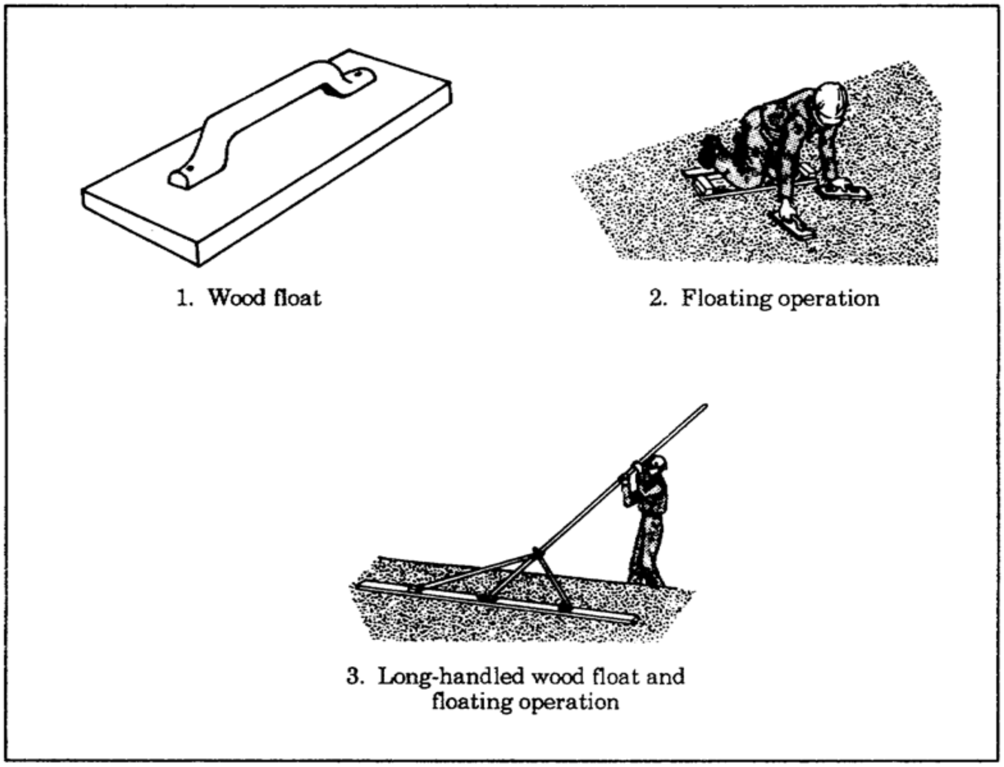


**Figure 13. Screeding.**

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 14 is shown in use in view 2 of Figure 14. 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 14. Use aluminum magnesium floats the same way as the wood float, aluminum magnesium floats 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.



1. Wood float

2. Floating operation

3. Long-handled wood float and floating operation

**Figure 14. Wood floats and floating operations.**

For a dense smooth finish, follow floating with steel troweling (see Figure 15) 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.

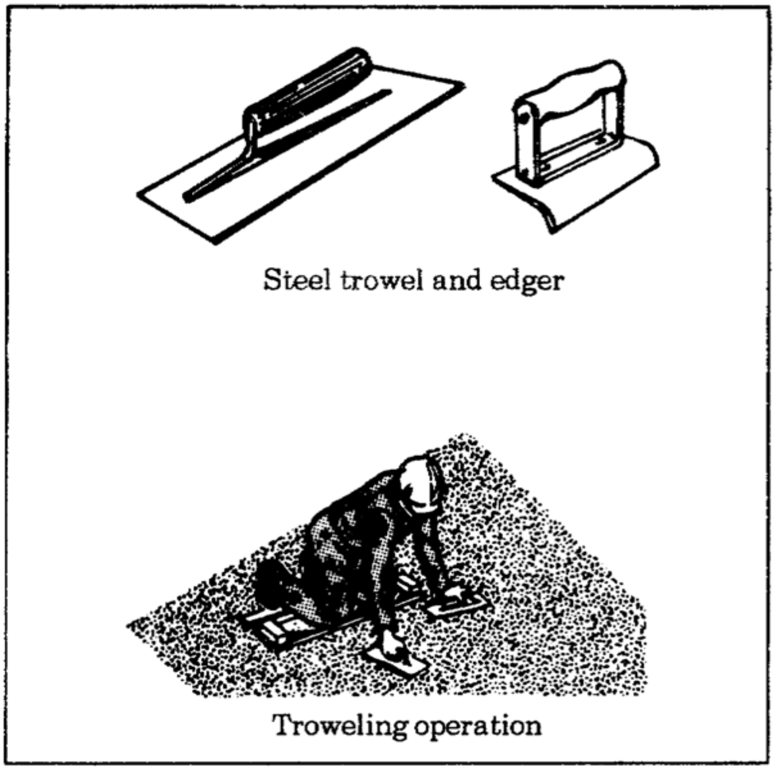


**Figure 15. Steel finishing tools and troweling operation.**

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.

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.

## 27. CURING

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* 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.

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 16 shows how moist curing affects the compressive strength of concrete.

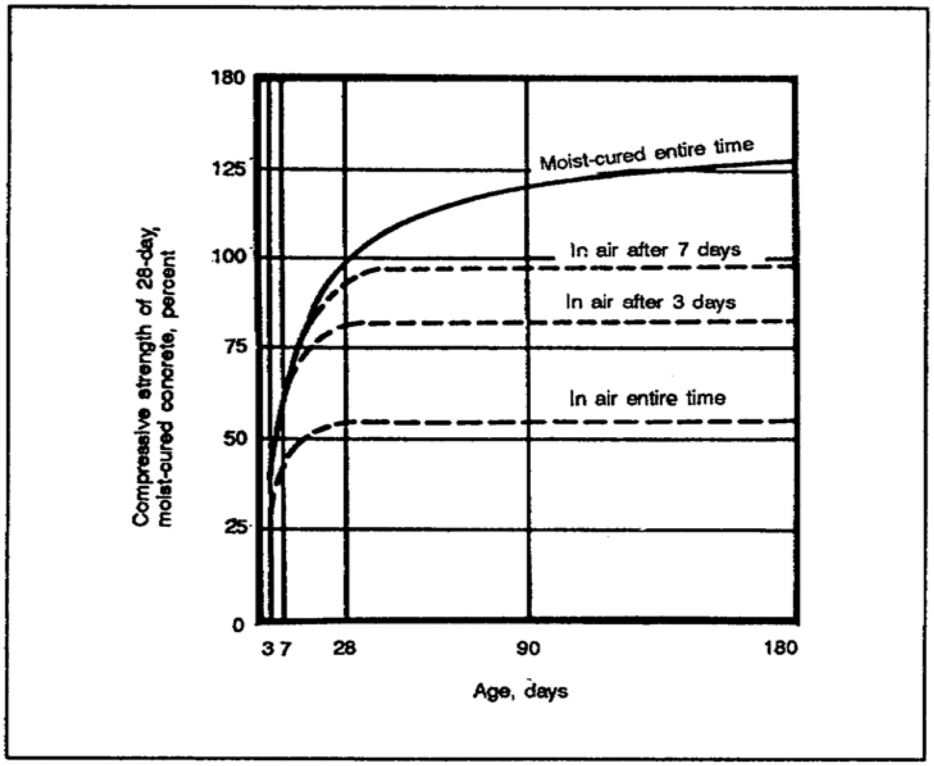
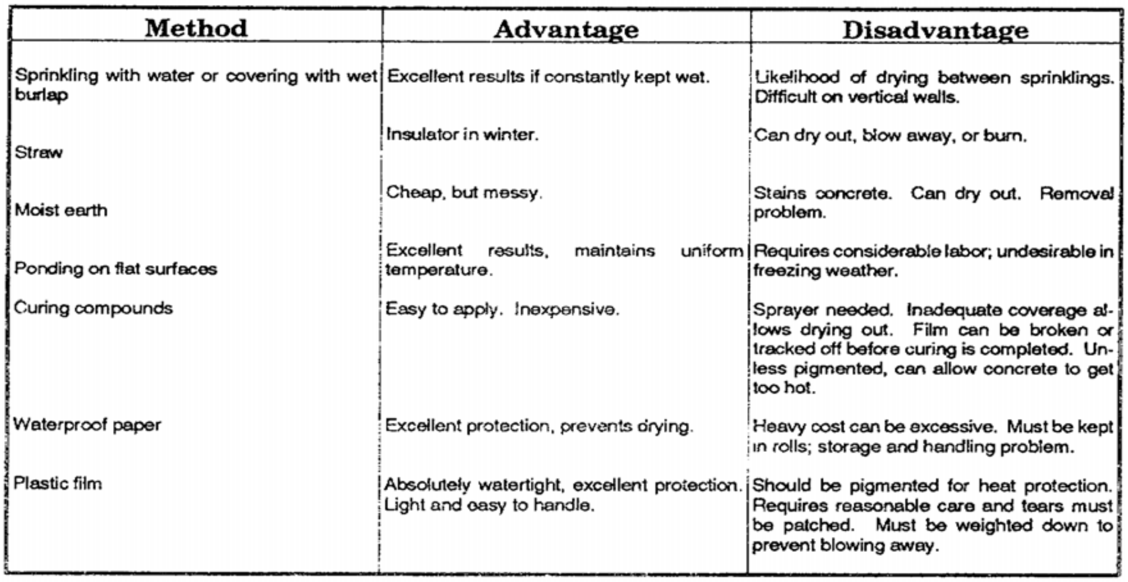


**Figure 16. Moist curing effect on compressive strength of concrete.**

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 21 list several of these effective curing methods and their advantages and disadvantages.

**Table 21. 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. |

## 28. TEMPERATURE EFFECTS ON CONCRETE

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.

Because high temperatures accelerate hardening, a particular concrete consistency generally requires more mixing water than normal. Figure 17 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.

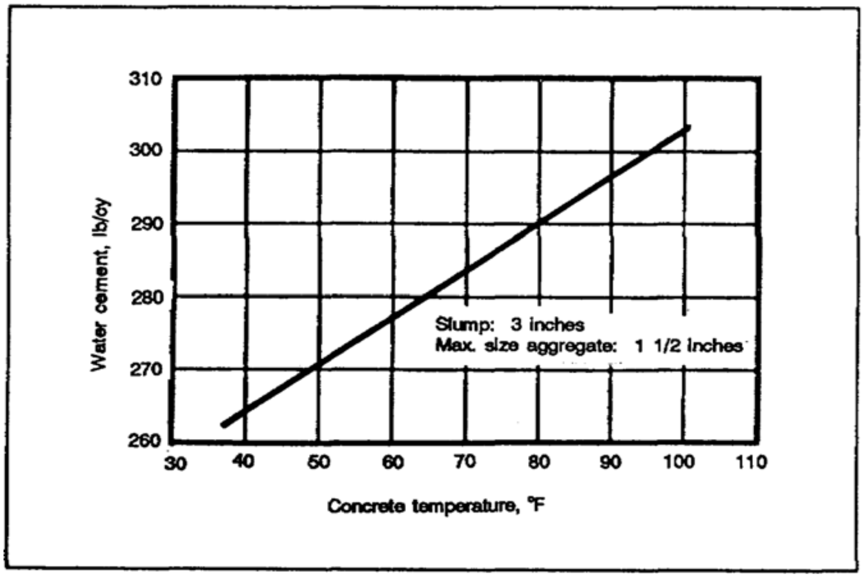


**Figure 17. Relationship between concrete temperature and mixing water.**

Figure 18 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 18.

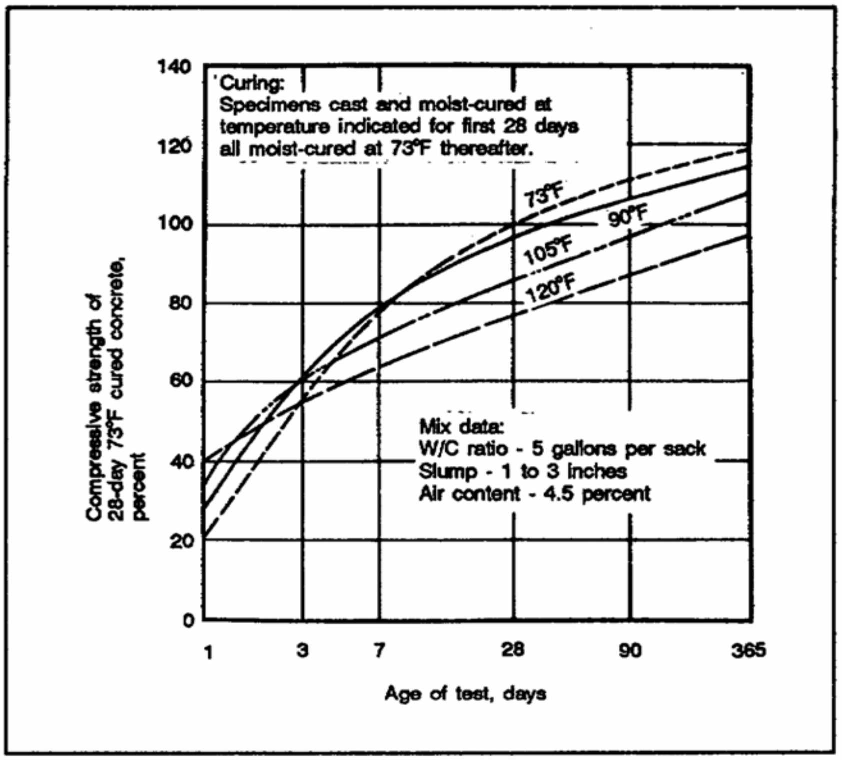


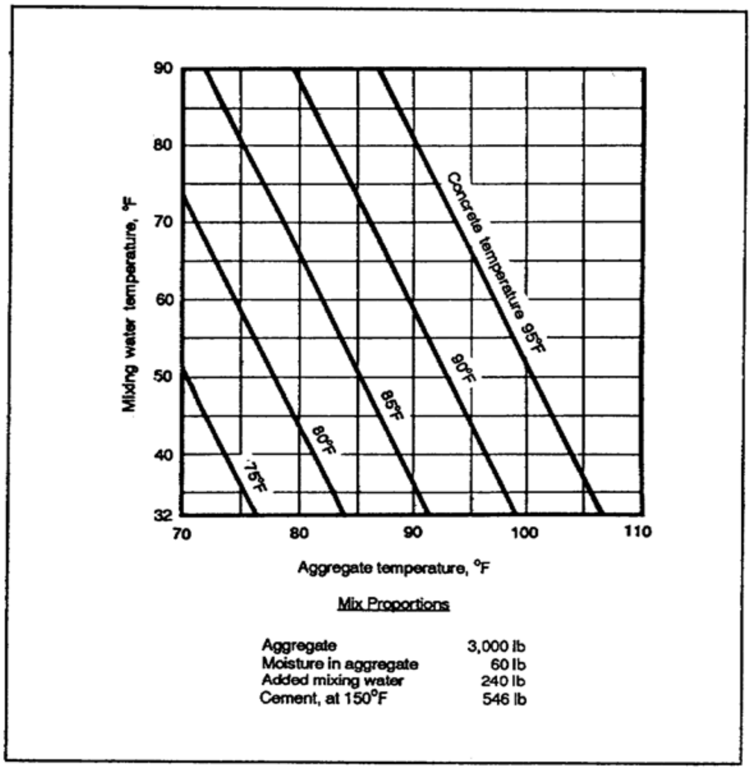
**Figure 18. Effects of high temperature on concrete compressive strength at various stages.**

## 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.

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 19 shows the effects of the mixing water and aggregate temperatures on the temperature of fresh concrete. The temperature of fresh concrete can be lowered 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.



| | |
|---|---|
| Aggregate | 3,000 lb |
| Moisture in aggregate | 60 lb |
| Added mixing water | 240 lb |
| Cement, at 150°F | 546 lb |

**Figure 19. Mixing water temperatures required to produce concrete of required temperatures.**

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.

## 29. COLD-WEATHER CONCRETING

Concrete can be placed during the winter months, however various steps are necessary 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 22. 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 22. 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 22 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 22 for the time periods given in Table 23. 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 23. 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.

Figure 20 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.

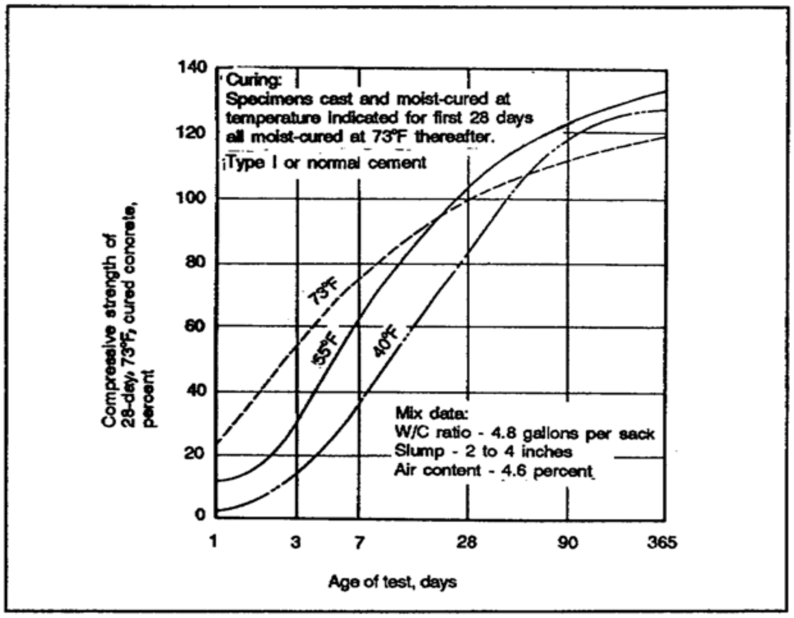


**Figure 20. Effects of low temperature on concrete compressive strength at various ages.**

Figure 21 shows that the early strengths achieved by Type III or higher early-strength cement are higher than those achieved by Type I cement.

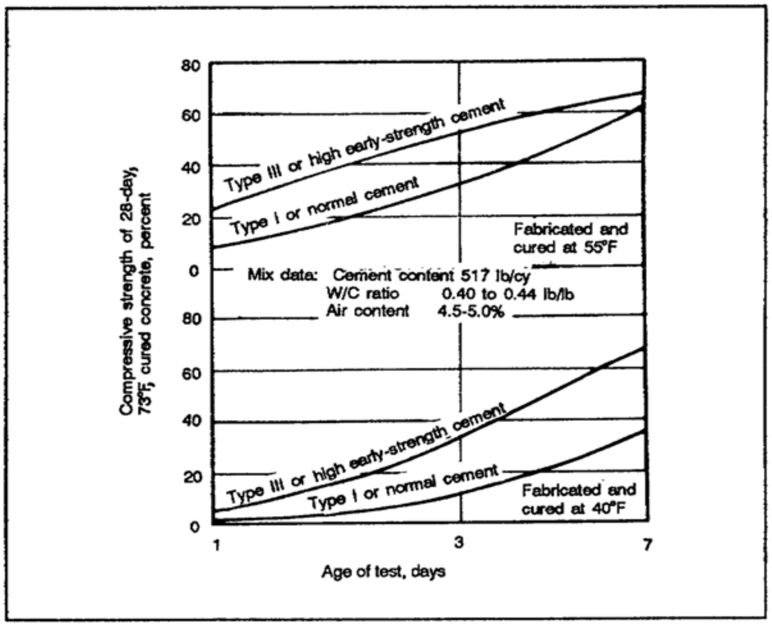


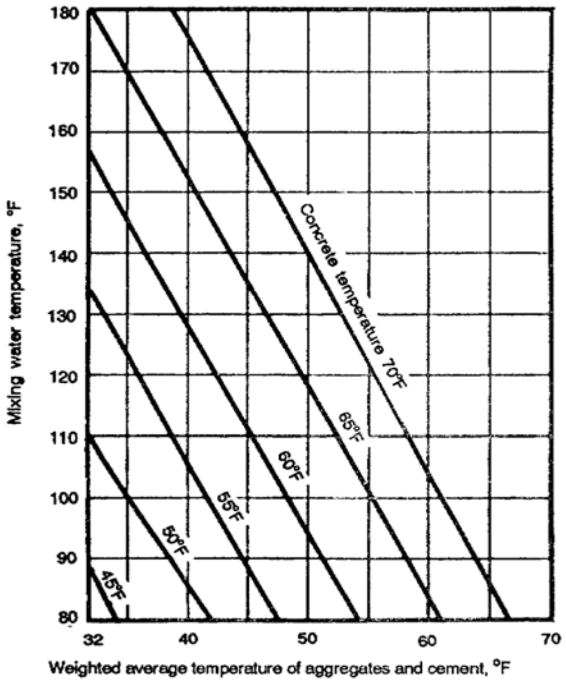
**Figure 21. Relationships between early compressive strengths of portland cement types and low curing temperatures.**

## 30. COLD-WEATHER TECHNIQUES

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 22 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 22, 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 22. Effects of temperature of materials on temperature of fresh concrete.**

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.

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.

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.

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. 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.

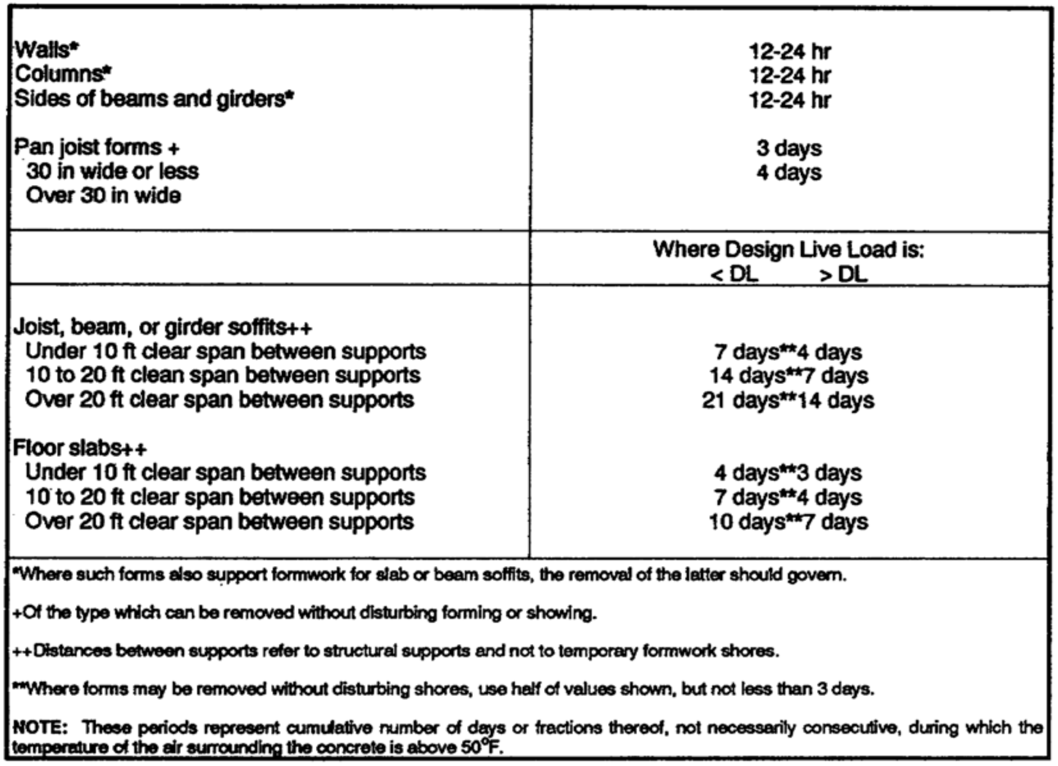
## 31. FORM REMOVAL AND STRIPPING

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 24 for recommended stripping time. After removing forms, check for concrete defects and repair all deficiencies.

**Table 24. 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:<br>< 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.

# 32. DESIGN EXAMPLES

*EXAMPLE PROBLEM 1:* 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 7, 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 2:* Using the mix design determined previously in this chapter, determine the total amount of materials needed to construct the retaining wall shown in Figure 23. 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

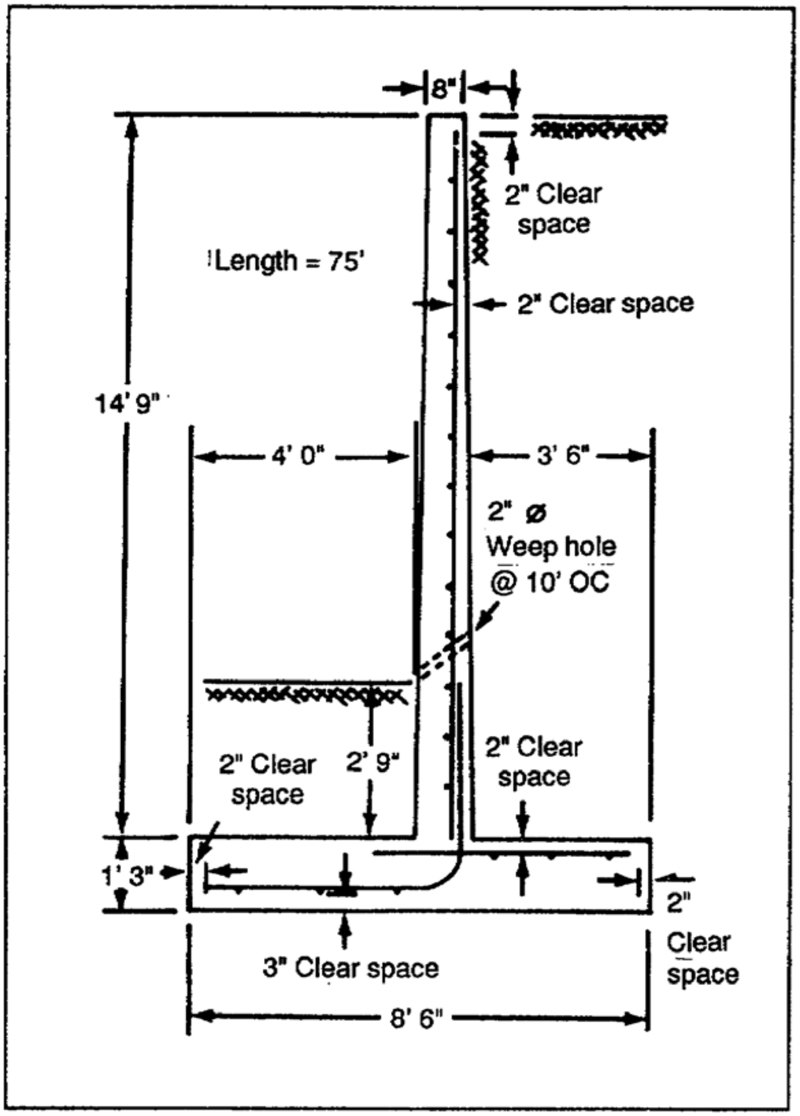


**Figure 23. Retaining wall.**

*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

*Example Problem 3:* 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 14.

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 14.

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

*Step 6.* Calculate the uniform load on the stringer ($\text{ULS}_{\text{str}}$).

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

*Step 7.* Determine the maximum shore spacing (use Table 15). Spacing is based on stringer strength. (Use Table 16)

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 19 and Table 20.

- *Allowable load based on shore strength (see Table 19).*

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).* 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 |

*Example Problem 4:* 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 32) 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.