Chapter 4

Concrete

This chapter discusses the testing of both fresh and hardened concrete and the construction materials used to mix it. These tests are performed to ensure that the concrete meets design requirements before it is poured. Since there are many factors that contribute to the success of the finished product, all test methods must adhere to ASTM standards.

Further information on concrete types, components, design, and uses in military construction can be found in FM 5-428.

SECTION I. CHARACTERISTICS AND IDENTIFICATION

Concrete is one of the most economical, versatile, and universally used construction materials. It is one of the few building materials that can be produced by the user directly on the job to meet the specific requirements. Concrete is an artificial stone which, when first mixed, forms a plastic or putty-like mixture. This mixture can then be placed into a form and allowed to harden or cure for a prescribed length of time. When cured, the finished concrete is a hard, stone-like material. It is used for pavements, foundations, dams and retaining walls, bridges, and buildings of all types.

DESCRIPTION AND COMPONENTS

Concrete is a mixture of portland cement, fine and coarse aggregates, entrapped or entrained air, and water. During mixing, the cement, air, and water form a fluid paste that contributes to thorough mixing and effective placement of the concrete. The cement and water, when mixed, combine chemically to bind the aggregate particles together. This combining process—called hydration—results in a rapid development of strength in the first few hours after mixing, followed by less rapid gains in strength during the following weeks.

CEMENT

Cement is a substance that hardens with time and holds or entraps objects or particles in a definite relation to each other. For concrete, portland cement usually is used.

Portland cement is a substance that when mixed with water, hardens and binds objects or particles together to form concrete. This process begins immediately and continues as long as moisture and temperature conditions are favorable. As hydration continues, concrete becomes harder and stronger. Most of the hydration takes place during the first 30 days. Hydration can continue well over 50 years but at a much slower rate. References to cement in this manual mean portland cement. The ASTM specifies eight common types of portland cement (ASTM C 150-97). These are adequate for most purposes. The various types of portland cement are known as hydraulic cements because they are capable of hardening and developing strength in the presence of water. These cements include—

- Type I. Cement used for general construction when special properties for any other type are not required.
- Type IA. Air-entraining cement used for the same purposes as Type I, except that air entrainment is desired. Entrained air improves workability and provides resistance to frost action, freezing, and thawing.
- Type II. Cement used for general purposes, especially when moderate sulfate resistance or moderate heat of hydration is desired. It has a lower heat of hydration than the normal Type I, generates heat at a slower rate, and has improved resistance to sulfate attack. Type II cement is used in locations where a high temperature rise in the concrete is objectionable, as in structures of considerable mass such as large piers, heavy abutments, and heavy retaining walls.
- Type IIA. Air-entraining cement used for the same purposes as Type II, except that air entrainment is desired.
- Type III. Cement used when a high strength is needed quickly. This may be due to a demand for early use or in cold-weather construction to reduce the period of protection against low or freezing temperatures.
- Type IIIA. Air-entraining cement used for the same purposes as Type III, except that air entrainment is desired.
- Type IV. Cement used when a low heat of hydration is desired to keep the amount and rate of heat generated to a minimum. Type IV cement develops strength at a slower rate than Type I cement but helps prevent the development of high temperatures in the structure with the attendant danger of thermal cracking later when it cools.
- Type V. Cement used when high sulfate resistance is desired. Sulfates react chemically with the cement compounds, causing undesirable expansion of the mixture. The sulfates may be present in the water used to mix the concrete or may be created by sulfurous gases from nearby industrial areas. The principal source of sulfate attack, however, occurs on foundations and other concrete in contact with the earth in certain regions and is caused by a reaction between the groundwater (containing dissolved reactive minerals or acid) and the hardened cement. Type V cement is low in calcium aluminate and is highly resistant to sulfate attack.

AIR-ENTRAINED CEMENT

Concrete made with air-entrained cement is resistant to severe frost action and to salts used for ice and snow removal. In general, air entrainment may be controlled to a much greater extent by using admixtures with normal cements during mixing. This combination results in concrete with tiny, distributed and separated air bubbles (up to millions per cubic foot). The entrained air bubbles improve the workability of fresh concrete. These bubbles reduce the capillary and water-channel structure within water, which prevents the buildup of damaging water. Air-entrained concrete has greatly increased durability in outdoor locations exposed to freezing weather. Each of the first three Types (I, II, and III) are available as air-entrained. To signify this characteristic, a letter A is added after the type. For example, a Type II cement with an air-entrained admixture is identified as Type IIA.

WATER

Water plays an important part in the concrete mix. Its principal uses are to make the mix workable and to start the chemical reaction. Any material in the water that retards or changes the reaction is detrimental. A good rule of thumb is, "If it's good enough to drink, it may be used for concrete.”

Ordinary Water

The materials found in some types of water include organic compounds, oil, alkali, and acid. Each has an effect on the hydration process.

- Organic material and oil. These compounds tend to coat the aggregate and cement particles and prevent the full chemical action and adherence. The organic material may also react with the cement and create a weakened cementing action, thus contributing to deterioration and structural failure of the concrete.
- Alkalies, acids, and sulfates. Certain limiting amounts of these chemical impurities in the water tend to react adversely with the cement. The result is inadequate cementing and weakened concrete. Water must be substantially free of these chemicals for use in concrete mixing.

Sea Water

The salts in sea water are normally thought of as being corrosive. However, sea water is sometimes used for concrete mixing with satisfactory results. A 10 to 20 percent loss in compressive strength can be expected when using the same amount of sea water as fresh water. This can be compensated for somewhat by reducing the water-cement ratio.

AGGREGATES

The aggregates commonly used for concrete are natural deposits of sand and gravel, where available, or crushed stone. Crushed aggregate may cost more to produce; however, this may be the only way to obtain substantial quantities of large-sized stone. Artificial aggregates such as a blast-furnace slag or specially burned shales and clays are used.

Aggregates are divided into the following types:

- Fine aggregate.
- Coarse aggregate.

When properly proportioned and mixed with cement, these two groups will yield an almost voidless stone that is strong and durable. Aggregate should be equal to or better in strength and durability than the hardened cement paste if it is to withstand the design loads and effects of severe weather.

Fine Aggregates

Fine aggregates are the material that will pass a No. 4 sieve and will be predominantly retained on a No. 200 sieve. To increase workability and for economy as reflected by using less cement, the fine aggregates should have a rounded shape. Their purpose is to fill the voids between coarse-aggregate particles and to modify the concrete's workability. This workability characteristic is discussed more in the description of finished concrete.

Coarse Aggregates

Coarse aggregates are the material that will be retained on a No. 4 sieve. In determining the maximum size of coarse aggregate, other factors must also be considered. The coarser the aggregate used, the more economical the mix, as aggregate costs less than cement. Larger pieces offer less surface area of the particles than an equivalent volume of small pieces. Using the largest permissible maximum size of coarse aggregate permits a reduction in cement and water requirements. One restriction usually assigned to coarse aggregate is its maximum size. Large pieces can interlock and form arches or obstructions within a concrete form. This restricts the area below to a void or at best, fills the area below with the finer particles of sand and cement. This is either a weakened area or a cement-sand concentration that does not leave enough mortar to coat the rest of the aggregate. The capacity of mixing equipment, the spacing of reinforcement, or the minimum width of forms limits the maximum aggregate size. A listing of maximum sizes of coarse aggregate is indicated in Section II of this chapter.

PROPERTIES OF CONCRETE

To combine the ingredients correctly and to form the required concrete, it is essential to know the required physical properties of both the plastic and the hardened concrete. The hardened concrete must have the following properties:

- Strength.
- Durability.
- Watertightness.
- Workability.
- Consistency.
- Uniformity.

The quality and character of the hardened concrete is greatly influenced by the properties of the mix when it is plastic. To attain optimum quality, the plastic mix must be uniform, consistent, and workable. This permits placing the concrete without developing segregation, honeycombing, or other defects in filling the forms or in producing the desired smooth, hard, and resilient surface.

STRENGTH

Strength is the concrete's ability to resist a load in compression, bending, or shear (see Sections IV and V of this chapter). The desired design strength is obtained by proportioning the mixture with correctly graded aggregates, an adequate amount of cement to coat the surface area of the particles, and the proper amount of mixing water. The most important influencing factor on strength is the ratio of water to cement (W/C ratio). For plastic and workable mixes, lower values of the W/C ratio give higher strengths. Two and one-half gallons of water is the minimum amount necessary to hydrate a sack of cement adequately.

This minimal amount of water is not sufficient to economically provide the needed plasticity and workability for freshly mixed concrete. Additional water must be added to the mixture to improve workability but must be minimized to obtain the desired strength with an economical cement content. Additional water thins the paste content and therefore coats more particles. This increases the yield from each sack of cement and produces a more economical mix. Excessive amounts of water (too high a W/C ratio) weakens the paste by allowing the cement particles to hydrate while suspended in water without being in contact with the aggregate or other cement particles. This water eventually evaporates, leaving holes or voids in the hardened concrete that cause additional losses in strength. Minimum and maximum amounts of water are specified to assure an economical mix with no loss in strength. This ranges from 4 to 8 gallons per sack of cement (94 pounds).

DURABILITY

Durability is the concrete's ability to resist the elements of weathering and loading. The primary elements affecting concrete are wind, abrasion, freezing and thawing, wetting and drying, and the chemical action of salts. As the W/C ratio is increased (4 gallons per sack), more voids develop in the hardened concrete. Therefore, more surface area is available for the detrimental elements to attack, resulting in a less-durable structure. Weak or easily crushed rock or other mineral particles that break down under applied loads introduce internal stresses that cause a breakdown of the concrete. Rocks or mineral particles that are absorptive or susceptible to swelling when saturated will deteriorate when subjected to severe weather conditions. Freezing moisture causes expansion stresses that can easily rupture absorptive rocks. Rocks swollen from the sun's radiant heat and then subjected to shrinkage from sudden cooling by rain or temperature drop may break down from the severe weathering. The concrete aggregate must withstand all these forces of nature.

WATERTIGHTNESS

A well-mixed, well-proportioned concrete presents a solid surface to prevent water penetration. Superficial voids permit some water to enter below the concrete's surface but the water soon meets a dense, solid mass that prevents further penetration. As the W/C ratio is increased, the excess water forms more holes or voids that eventually interconnect to form channels into and throughout the concrete. The end result is a more porous concrete that permits water to pass. For watertightness, 6 gallons of water or less per sack of cement will meet the requirement.

WORKABILITY

Workability is the relative ease of difficulty of placing and consolidating concrete. It is controlled primarily by the amount of each aggregate in proportion to a given quantity of cement paste. As more aggregate is added to a given amount of paste, the mixture becomes harsh and stiff. The increased stiffness makes it more difficult to work the concrete into the forms and around the reinforcing bars. The consistency needed depends on the conditions under which the concrete must be placed and finished. Very dry and stiff mixtures may be placed in most situations where high-frequency vibrations are used to assist in consolidating and compacting fresh concrete. In other situations, difficult placing conditions may require a more fluid concrete mixture to fill narrow forms and to flow around reinforcement.

CONSISTENCY

Concrete is a fluid mixture containing particles of different size, shape, and mass. Heavier particles have a tendency to settle out through the mixture faster than lighter particles. Often the result is a segregated mixture of a very poor quality. When concrete is properly proportioned and mixed and carefully handled, segregation is held to a minimum. The mixture must have the proper proportion of cement/sand mortar to prevent the larger coarse-aggregate particles from separating from the batch during mixing, transporting, and placing. When cement is allowed to drop (free fall) over a considerable distance, it can cause segregation of the mixture. To minimize segregation for drops in excess of 3 to 5 feet, bottom dump buckets should be used to place concrete as close to the final location as possible. See TM 5-742 for construction procedures.

UNIFORMITY

Uniformity refers to a single batch of concrete and to all batches for an entire project. The same amount of each ingredient should be mixed into each batch or a nonuniform structure will result. Design would not be met in all sections of the structure and possible failure of these sections could result. Proper supervision in mixing and handling of the concrete ensures uniformity.

CONCRETE CURING

Concrete does not develop its full strength until the chemical process of curing (hydration) is complete. Cement must have sufficient water to continue its hydration. Curing is the means of keeping water available so the hydration can continue. The curing process takes place over an extended period. The most critical time is the first 7 days. The extent and rate of curing depends on the—

- Temperature within the concrete.
- Presence of moisture.

TEMPERATURE

The ideal temperature for concrete work is between 55° and 70°F. Above this temperature, rapid evaporation of moisture creates serious problems such as—

- Increased water demand.
- Slump loss.
- Decreased setting time.
- Increased tendency for plastic shrinkage cracking.

The hydration process is delayed at lower temperatures. Temperatures below 32°F completely stop the hydration process. Since the chemical reaction gives off some heat, proper methods must be used to keep the heat within the structure during times of low temperatures. Cold-weather construction may require heating the individual ingredients or the concrete and covering the emplaced concrete or providing a heated enclosure. In hot weather, extra care is required to prevent a high temperature rise and rapid drying of the fresh concrete. Spraying the aggregate stockpiles with cool water helps lower the concrete temperature. To keep the water as cool as possible, reflective white or aluminum paint is applied to the water supply lines and storage tanks.

On massive construction projects, such as dams and heavy retaining walls, the mixing water is often kept cool by substituting ice for part of the mixing water. The ice must be melted by the time the concrete is fully mixed and is ready to leave the mixer. Large voids result from unmelted ice in the concrete. Cement replacement materials (such as pozzolans and diatomaceous earth, pumicites, or fly ash) may be used to depress concrete temperature by reducing the heat of hydration in a structure. However, pozzolans vary widely and may have adverse effects on strength, air content, and durability if used in excessive amounts.

MOISTURE

Concrete curing depends on a chemical reaction in the presence of water. Moisture lost during the curing process—by seepage or evaporation—delays or prevents a complete hydration of the cement and ultimately prevents the development of optimum strength and watertightness. Saturating the subgrade on which the concrete will be placed will delay, if not prevent, seepage from occurring. Impervious membranes (plastic or polyethylene sheets) can also be used to prevent seepage through the subgrade. Wood forms should be thoroughly wetted if they have not been otherwise treated with a moisture sealer.

One method of reducing evaporation is to cover the concrete with a material such as straw, burlap, plastic, or a sprayed-on chemical curing compound as soon after finishing as possible. The preferred method of curing is by using continuous sprays and flowing or ponded water after the concrete has set initially so it does not damage the finish. This water application can also be part of the temperature control during cold- and hot-weather concreting. The increase of the concrete's compressive strength with age is shown by the curves in *Figure 4-1, page 4-8*. Note the long-time gain in strength that occurs when proper temperature and moisture conditions are maintained.

CONCRETE ADMIXTURES

Chemical agents or admixtures are available for almost any purpose such as increasing workability, durability, and strength or compensating for inadequate curing conditions.

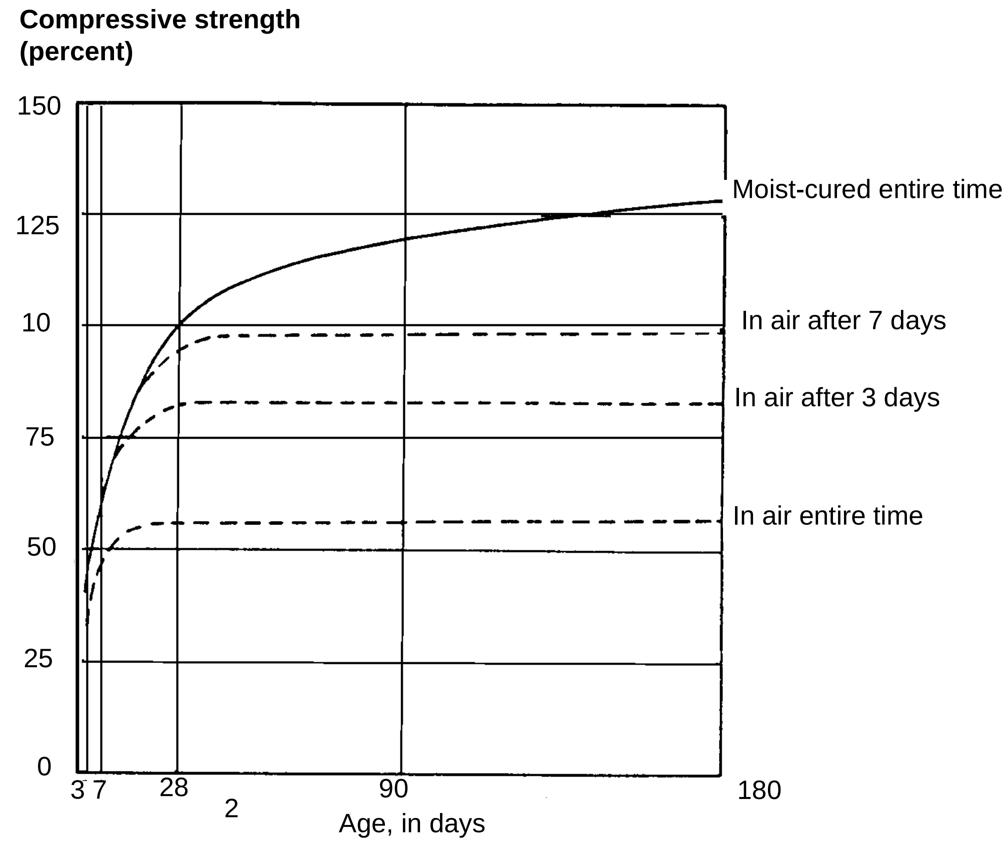

Figure 4-1. Increase of compressive strength with curing age

ACCELERATORS

Sometimes it is desirable to accelerate the hydration process to obtain a high-early strength and a high rate of heat production. This combination is useful for cold-weather concreting operations. The addition of a chemical accelerating admixture (generally calcium chloride) to the concrete mixture produces the desired reactions. The recommended maximum dosage for calcium chloride is 2 percent by weight of cement. The ultimate strength of concrete will be slightly lower with the use of an accelerator.

RETARDERS

Retarders are used when excessively high heat or too-rapid setting of concrete will prevent full hydration of the cement. Many materials retard the setting of concrete, but the most common is hydroxylated carboxylic acid salts. Sugar has also been used quite successfully.

AIR-ENTRAINING AGENTS

The greatest improvement in watertightness and resistance to the disruptive action of freezing and thawing is obtained by incorporating 4 to 7.5 percent by volume of entrained air into the concrete. Workability of fresh concrete is also enhanced by entraining air. Soaps, oils, acids, wood resins, alkali salts, fine pozzolans, and several proprietary compounds are available for use as air-entraining admixtures with hydraulic cement. These agents form very small, uniformly spaced, discrete air voids that relieve the buildup of damaging pressures from the expansion of freezing water into ice.

WATER REDUCERS (PLASTICIZERS)

The concrete's workability is governed by the proportions of cement, water, and aggregate in a concrete mixture. When a reduction of aggregate or an increase in cement is impractical, the concrete's workability can be increased by adding a water-reducing admixture or plasticizer. Another primary characteristic is the strength gained from a decreased water demand. Less water is required for the same workability, which leads to a lower W/C ratio, and therefore higher strength. Water requirements may be reduced as much as 10 percent for most water-reducing admixtures. Air-entraining agents are also considered as plasticizers because the void system reacts as a lubricant in concrete.

SECTION II. AGGREGATE TESTING

Aggregate used in mixing concrete is a mixture of fine and coarse material, usually sand with either natural gravel or crushed rock. It serves as an inert filler to provide the bulk material required. Well-graded aggregates contain particles of all sizes, from the largest permitted by the dimension of the member to be formed to sand fines. The smaller particles fill the spaces between the larger particles, thus providing a dense material that requires a minimum of cement paste for binder. The aggregate materials must be clean and hard, resist weathering, and have no unfavorable reaction with the cement.

An aggregate must provide maximum strength and durability in a concrete mixture. Fineness, coarseness, and aggregate gradation are factors considered when deriving the correct concrete mix for a specific construction purpose. Specific gravity, absorption, and moisture also affect the aggregate's ability to bind well with cement and water in a concrete mix. The components of the final mix (cement, water, and aggregate) must bond adequately for structural strength and must resist weather and loads. Correct aggregate selection also reduces the project's cost. An engineering analysis determines the aggregate best suited for a particular purpose. Testing allows the best selection.

For the aggregate tests to be worthwhile, the samples for testing must be representative of the aggregates to be used. Take aggregate samples as close as possible to the finished product to give the best representative sample of the aggregate. Take a sufficient size and number of samples from the processing-plant's discharge point to represent the material in the stockpile. The sample should consist of at least four times as much material as is needed for the tests and should be reduced to the desired size through splitting and or quartering the sample. Minimum sample sizes can be found in *Table 4-1, page 4-10*.

Table 4-1. Minimum sample sizes

Nominal Maximum Size		Minimum Weight of Test Sample	
mm	**in**	**kg**	**lb**
12.5 or less	1/2 or less	2	4.4
19.0	3/4	3	6.6
25.0	1	4	8.8
37.5	1 1/2	5	11.0
50.0	2	8	18.0
63.0	2 1/2	12	26.0
75.0	3	18	40.0
90.0	3 1/2	25	55.0
100.0	4	40	88.0
112.0	4 1/2	50	110.0
125.0	5	75	165.0
150.0	6	125	276.0

STOCKPILE SAMPLING (ASTM D 75-87)

It is difficult to ensure that unbiased samples are obtained from stockpiles. This is due to the segregation that often occurs when material is stockpiled, with coarser particles rolling to the outside base of the pile. For coarse or mixed coarse and fine aggregates, every effort should be made to enlist the services of power equipment to develop a separate, small sampling pile composed of materials drawn from several increments.

When power equipment is not available, take samples from at least three increments—from the top third, the midpoint, and the bottom third of the pile. Shove a board vertically into the pile just above the sampling point to prevent further segregation. When sampling fine-aggregate stockpiles, remove the outer surface before taking the sample.

Take samples from near the top, middle, and bottom of the stockpile and recombine them to represent their particular stockpile. Push a board into the stockpile just above the points of sampling to prevent the material above the sampling points from falling into the sample and causing size contamination.

Pit samples are sources of sand and gravel. Sample them by channeling exposed faces or channeling in pits if exposures are not available. Take care to ensure that the samples include only materials that are below the overburden or strip zone.

GRADATION DETERMINATION

Gradation of aggregate refers to the distribution of particles of aggregate among various sizes. Aggregates having a smooth grading curve and neither a deficiency nor an excess of any one particle size usually produces mixtures with fewer voids between particles. A too-large proportion of coarse aggregate leaves voids that require more cement paste to fill. This affects the economy of the mix. Too much fine aggregate increases the amount of surface area that must be coated with cement paste. This may weaken the concrete and is uneconomical. Good gradation results in—

- A dense mass of concrete with a minimum volume of voids.
- An economical mix.
- A strong structure.

Optimum strength, water tightness, and durability in the hardened concrete require careful control of aggregate gradation.

A gradation or sieve analysis indicates whether an aggregate's particle-size distribution meets the project's requirements. Dense aggregates can result in a concrete that is denser and stronger and more economical, watertight, and resistant. See ASTM C 136-90 for analysis methods and *Table 4-2 and Tables 4-3* and *4-4, page 4-12*, for recommended size and gradation limits.

Table 4-2. Maximum recommended size of coarse aggregate

Structure	Minimum Dimension (Inches)			
	2 1/2 to 5	**6 to 11**	**12 to 29**	**30 or More**
Reinforced walls, beams, and columns	1/2 to 3/4	3/4 to 1 1/2	1 1/2 to 3	1 1/2 to 3
Unreinforced walls	3/4	1 1/2	3	6
Slabs, heavily reinforced	3/4 to 1	1 1/2	1 1/2 to 3	1 1/2 to 3
Slabs, lightly reinforced	3/4 to 1 1/2	1 1/2 to 3	3	3 to 6
NOTE: Maximum size not to exceed 1/5 of minimum dimension of a wall or similar structure, 1/3 of slab thickness for horizontal slab, or 3/4 of minimum clear spacing between reinforcing bars				

APPARATUS, TEST PROCEDURES, AND CALCULATIONS

The apparatus, test procedures, and calculations required to determine the gradation of aggregate for portland-cement concrete are the same as explained for sieve analysis, except that the No. 4 sieve is taken as the dividing line between fine and course aggregates. The minimum sample size required in the sieve analysis of fine aggregate is 500 grams. The result of this test is a gradation curve for the aggregate concerned.

MATERIAL FINER THAN .075 MILLIMETERS (NO. 200 SIEVE)

The extremely fine mineral material (clay, silt, dust, or loam) occurring in most aggregates requires relatively large increases in the amounts of mixing water. Fines tend to work to the surface of concrete and cause cracking upon drying, due to shrinkage. If the fines adhere to the larger aggregate particles, they also tend to interfere with the bond between the aggregate particles and cement-water paste. Specifications limit the amount of such material to a small percentage. ASTM C 117-95 gives the standard test method for fine materials. The apparatus, test procedures, and calculations to determine this percentage are described in the test for impurities. Fine material, not to exceed 3 to 5 percent of the total aggregate weight, is generally not harmful to concrete. For some purposes, a small amount of such fines may improve the workability.

Table 4-3. Desirable gradation for coarse aggregate in concrete

Nominal Sieve Size (Inches)	Percent Passing Indicated Sieve										
	4	3 1/2	3	2 1/2	2	1 1/2	1	3/4	1/2	3/8	No. 4
3 1/2 to 1 1/2	100	90 to 100		25 to 60		0 to 15		0 to 5			
2 1/2 to 1 1/2			100	90 to 100	35 to 70	0 to 15		0 to 5			
2 to 1				100	90 to 100	35 to 70	0 to 15		0 to 5		
2 to No. 4				100	95 to 100		35 to 70		10 to 30		0 to 5
1 1/2 to 3/4					100	90 to 100	20 to 55	0 to 15		0 to 5	
1 1/2 to No. 4					100	95 to 100		35 to 70		10 to 30	0 to 5
1 to No. 4						100	95 to 100		25 to 60		0 to 10
3/4 to No. 4							100	90 to 100		20 to 55	0 to 10
1/2 to No. 4								100	90 to 100	40 to 70	0 to 15
3/8 to No. 4									100	85 to 100	10 to 30

Table 4-4. Desirable gradation for fine aggregate in concrete

Sieve Size US Standard	Percent by Weight Passing
4	95 to 100
8	80 to 100
10	75 to 95
16	50 to 85
20	40 to 75
30	25 to 60
40	20 to 50
50	10 to 30
60	10 to 25
100	2 to 10

FINENESS MODULUS

Fineness modulus is an empirical factor that gives a relative measure of the proportional particle-size distribution of an aggregate's fine and coarse particles. The fineness modulus does not represent any gradation of the material although the process is similar. A 500-gram sample of sand is sieved through a series of sieves (No. 4, 8, 16, 30, 50, and 100). The weight retained on each sieve is converted into a cumulative weight and a cumulative percentage retained, starting with the No. 4 sieve. The sum of the 6 percentages divided by 100 is the fineness modulus. Another procedure for determining the fineness modulus is calculated using the cumulative percentage passing, the usual means of expressing aggregate gradation. The total number of sieves involved times 100 minus the sum of the cumulative percentage passing and divided by 100 gives the fineness modulus. The fineness-modulus values range from 2.20 for fine aggregate to 7.50 for coarse aggregate. Typical values are 2.70 for fine aggregate, 7.40 for coarse aggregate, and 5.80 for 35 to 65 fine-coarse combination. Fineness-modulus ranges for fine aggregate are shown in *Table 4-5*.

Table 4-5. Fineness-modulus ranges for fine aggregates

Fineness Modulus	Designation
2.3 to 2.6	Fine sand
2.6 to 2.9	Medium sand
2.9 to 3.1	Coarse sand

TESTS FOR SPECIFIC GRAVITY, ABSORPTION, AND SURFACE MOISTURE

Perform tests for specific gravity, absorption, and surface moisture on the aggregates before making the necessary calculations to design the concrete mixture. For aggregates used in portland-cement concrete, measure to determine the bulk specific gravity of the aggregates in a saturated, surface-dry (SSD) condition. This is the condition in which the pores in each aggregate particle are filled with water and no excess water is on the particle surface. When used in concrete, this moisture condition of an aggregate can be defined as neither absorbing water from nor contributing water to the concrete mixture. Specific gravity is thus based on determining the total volume occupied by the aggregate particles, including the permeable pore space. Absorption and surface-moisture determinations are necessary to calculate the amount of mixing water used in a concrete mixture.

SPECIFIC GRAVITY AND ABSORPTION OF COARSE AGGREGATE (ASTM C 127-88)

This test method covers the specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity SSD, or apparent specific gravity.

Equipment

Use the following items to perform tests for bulk specific gravity SSD, percent absorption, and surface moisture:

- A balance, sensitive to 0.5 gram, capable of suspending the sample container in water from the center of the weighing platform or pan of the weighing device.
- A wire sample basket or a bucket with a 4- to 7-liter capacity for 1 1/2 -inch or smaller aggregate and a larger basket or bucket for larger aggregate sizes.
- A water tank large enough to hold the basket.
- A pycnometer, 2 to 3 cubic feet.
- A heat source (oven or hot plate).
- A metal sample container.
- A metal spatula.
- An absorbent towel.

Steps

Perform the following steps to determine the bulk specific gravity of coarse aggregate in an SSD condition:

Step 1. Wash a representative sample over the No. 4 sieve to obtain a sample size according to *Table 4-1, page 4-10.*

Step 2. Dry the sample to a constant weight at 110°C $\pm$ 5°.

Step 3. Allow the sample time to cool to 50°C, immerse it in water, and allow it to soak at room temperature for 24 hours.

Step 4. Remove the sample from the water and roll it in a large, absorbent cloth until all visible films of water are removed. The surfaces of the particles will still appear to be slightly damp. The larger fragments may be wiped individually. The aggregate sample is now in an SSD condition. Weigh the sample in air in its SSD condition. Record this and subsequent weights to the nearest 0.5 gram on DD Form 1208.

Step 5. Place the weighed SSD sample immediately in the wire basket container. Determine its weight in water at 23°C $\pm$ 1.7°. Shake the basket or container while it is immersed to remove any entrapped air. This weight is the immersed weight (or weight in water).

Step 6. Calculate the bulk specific gravity in an SSD condition as follows:

$$\frac{B}{B - C}$$

where—

B = weight, in grams, of SSD sample in air

C = weight, in grams, of SSD sample in water

SPECIFIC GRAVITY OF FINE AGGREGATE (ASTM C 128-93)

This test method covers the specific gravity and absorption of fine aggregate. The specific gravity of fine aggregate may be expressed as bulk specific gravity, bulk specific gravity SSD, or apparent specific gravity. For this test method, fine aggregate is defined as material smaller than the No. 4 sieve and larger than the No. 200 sieve.

Equipment

Use the following items to perform this test:

- A pycnometer; 500-milliliter.
- A mold; metal-frustum (half-cone brass mold) water-absorption cone.
- A metal flat-head tamper.

Steps

Perform the following steps to determine the bulk specific gravity of fine aggregate in an SSD condition:

Step 1. Obtain a representative sample weighing about 1,000 grams.

Step 2. Dry the sample to a constant weight at 110°C.

Step 3. Cool the sample to a comfortable handling temperature. Immerse it in water, and allow it to soak for 24 $\pm$ 4 hours.

Step 4. Decant the excess water carefully, ensuring that no loss of fines occurs. Spread the sample on a flat, nonabsorbent surface and stir it to obtain uniform drying. Continue drying the sample until it approaches a surface-dry condition.

Step 5. Place the metal frustum water-absorption cone (half-cone brass mold, see *Figure 4-2*) with the large opening down on a smooth surface and fill it loosely with the aggregate. Lightly tamp the surface (raise the metal tamper about 5 millimeters and allow it to fall under its own weight) of the aggregate 25 times with the metal tamper.

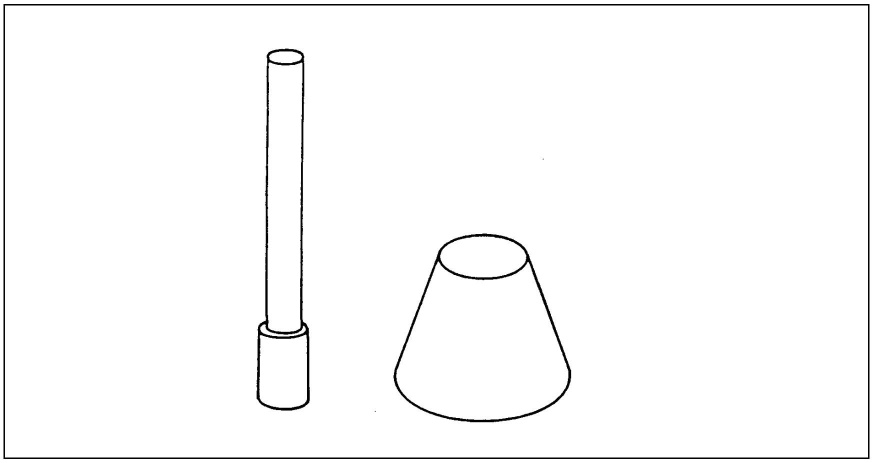

Figure 4-2. Water-absorption cone and tamping rod

Step 6. Remove the loose sand from around the base and lift the mold vertically. The fine aggregate is at the SSD condition when it slightly slumps when you lift the mold. If the material does not slump, continue the drying, accompanied by constant stirring. Repeat the cone tests at frequent intervals until the cone of fine artillery slumps slightly upon removal of the water-absorption cone.

Step 7. Weigh 500 ± 10 grams of the SSD sample, and introduce it into a partially water-filled 500-milliliter pycnometer. Agitate the sample to remove all entrapped air bubbles. Adjust the water temperature to 23°C ± 1.7° and fill the pycnometer to 90 percent of its calibrated capacity. Roll, invert, and agitate the pycnometer 15 to 20 minutes to eliminate the air bubbles. Fill the pycnometer to calibrated capacity, weigh it, and record the weight to the nearest 0.1 gram.

Step 8. Calculate the bulk specific gravity in an SSD condition as follows:

$$\frac{S}{B + S - C}$$

where—

B = weight, in grams, of pycnometer filled with water to calibrated capacity

S = weight, in grams, of SSD specimen

C = weight, in grams, of pycnometer filled with the sample and water to calibrated capacity

COARSE- AND FINE-AGGREGATE ABSORPTION

Absorption in aggregates is the aggregate's ability to steal moisture from the concrete-mix design until its thirst or attraction is satisfied.

Equipment

The following procedure is a continuation of the specific-gravity determinations; therefore, the same equipment shall be used.

Steps

Perform the following steps to determine the percent absorption of coarse and fine aggregates.

Step 1. Weigh the coarse aggregate in water and the fine aggregate in the pycnometer.

Step 2. Remove the aggregates and dry to a constant weight at a temperature of 110°C ± 5°.

Step 3. Weigh and record the oven-dried samples.

Step 4. Calculate the percent of absorption using the following formula:

$$P = \frac{S - A}{A} \times 100$$

where—

P = absorption of the aggregate, in percent

S = weight of SSD specimen, in grams

A = weight of SSD sample in the oven-dried state, in grams

The percent absorption represents the moisture content (oven-dried basis) of the aggregate when it is in an SSD condition.

SURFACE MOISTURE

Surface moisture is the excess moisture remaining after the absorption requirement of the aggregate has been met. This excess moisture determines how much water is added to the concrete mix to meet the required W/C ratio for the proper strength requirements. Perform this test just before mixing the concrete as designed. This allows for adjusting the water, coarse-, and fine-aggregate weights to retain design integrity.

Surface moisture is the water present in both the fine and coarse aggregates, exceeding that which corresponds to an SSD condition. This water will become part of the mixing water when the aggregate is used in making concrete. The amount of mixing water used must be corrected to allow for its presence. See ASTM C 566-89 and ASTM C 70-79.

SECTION III. FRESH-CONCRETE TESTS

After concrete is first mixed, a slump test and an air-content test are performed and used as a control measure to determine the concrete's quality and consistency throughout a project.

Take samples of concrete for test specimens at the mixer by repeatedly passing a receptacle through the entire discharged stream until sufficient concrete is collected into the pan. In the case of ready-mixed concrete, take samples from the transporting vehicle while it's discharging the concrete (see *Figure 4-3*).

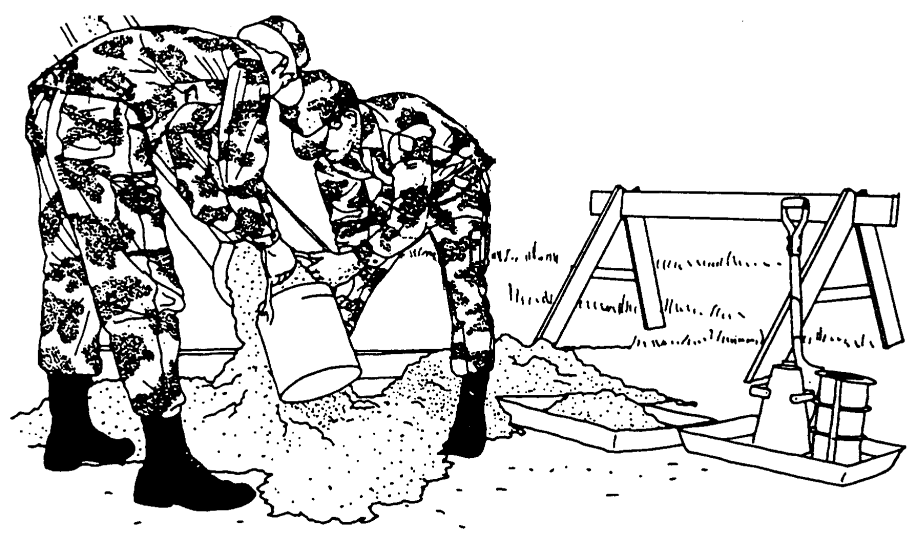

Figure 4-3. Sampling concrete from a truck mixer

The contents of a paving mixer should be discharged into a pile and sample material taken by a shovel from at least five different portions of the pile. The sample of concrete from which test specimens are made will be representative of the entire batch. Obtain two or more samples by repeatedly passing a scoop or pail through the discharging stream of concrete from the middle portion of the batch to obtain the amount of material required by the test method. Transport the samples to the testing site. To counteract segregation, mix the concrete with a shovel until the concrete is uniform in appearance. Note the truck, time, and location of the placement of the concrete for future reference. In the case of paving concrete, samples may be taken from the batch immediately after depositing on the subgrade. Take at least five samples from different portions of the pile, and mix these samples thoroughly to form the test specimen.

SLUMP TEST (ASTM C 143-90A)

When the mixture appears to have reached the desired consistency, perform a slump test. This method of testing covers the procedure to be used in the laboratory and in the field for determining the consistency of concrete, which is a characteristic of workability. It is not an exact method, but it gives sufficiently accurate results.

Use this test to measure the consistency of a concrete mix by measuring the vertical distance that the concrete settles to the nearest 1/4 inch.

NOTE: This test is not applicable when there is a considerable amount of aggregate over 1 1/2 inches in the concrete.

EQUIPMENT

Use the following items to perform this test in a field or simulated field environment:

- A ruler.
- A scoop.
- A trowel.
- A water source.
- A flat, smooth surface.
- A slump cone with tamping rod.
- A pencil.
- Paper.

STEPS

Perform the following steps to determine the slump:

Step 7. Moisten the inside of the slump cone and place it on a flat, moist, nonabsorbent (rigid) surface. Hold it in place during filling by standing on the two foot pieces.

Step 8. Fill the slump cone to one third of its volume (2 5/8 inches high) with plastic concrete.

NOTE: From steps 2 to 10, a total time of no more than 2 1/2 minutes should elapse.

Step 9. Rod the concrete by applying 25 evenly distributed strokes, penetrating the full depth of the first layer in the slump cone.

Step 10. Add a second layer of concrete to the slump cone until two thirds of its volume is filled (about 6 1/8 inches high).

Step 11. Rod the second layer in the same manner as the first, with the rod just penetrating the underlying layer.

Step 12. Add the third and last layer of concrete, overfilling if possible.

Step 13. Rod the third layer following the procedure in step 5. If the concrete height subsides below the top of the cone, add additional concrete to keep it above the top of the mold.

Step 14. Strike off the excess concrete with a screeding and rolling motion of the tamping rod so the cone is completely filled.

Step 15. Remove the slump cone from the concrete.

a. Place the hands on the handles and press downward.

b. Step off the footholds.

c. Raise the cone carefully and quickly in a vertical direction. Raise the cone a distance of 12 inches within 5 to 7 seconds by a steady upward lift with no lateral or twisting motion.

d. Place the cone directly beside the slumped concrete. At this point about 2 1/2 minutes should have elapsed since the start of filling in step 2.

Step 10. Measure and record the slump immediately (see *Figure 4-4).*

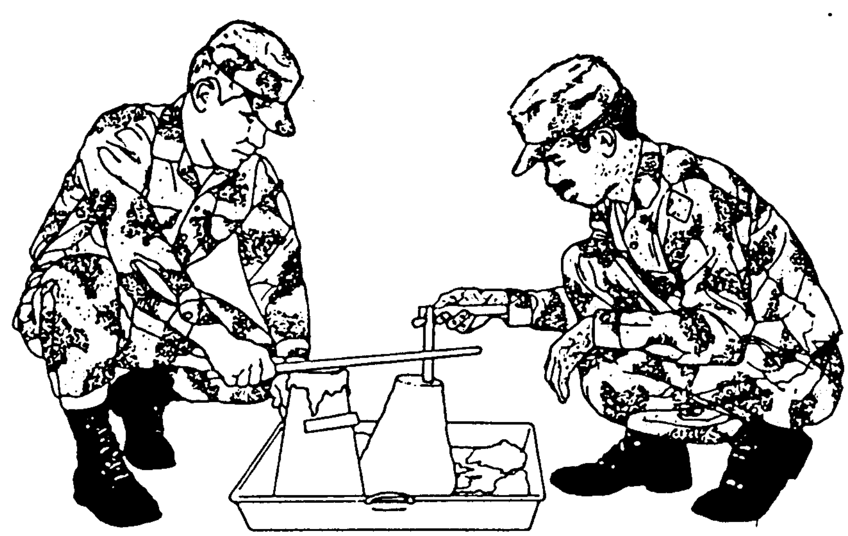

Figure 4-4. Measuring the slump of fresh concrete

a. Place the tamping rod along the top of the cone so it projects over the concrete.

b. Measure the slump from the bottom of the rod to the top center of the concrete with a ruler.

c. Record the slump to the nearest 1/4 inch.

SUPPLEMENTARY TEST PROCEDURE

After completing the slump measurement, gently tap the side of the specimen with the tamping rod. The behavior of the concrete under this treatment is a valuable indication of the cohesiveness, workability, and placeability of the mix. A well-proportioned, workable mixture will gradually slump to lower elevations and retain its original identity. A poor mix will crumble, segregate, and fall apart. Slump is usually indicated in the project specifications as a range, such as 2 to 4 inches, or as a maximum value not to be exceeded. When it is not specified, an approximate value can be selected from the list in *Table 4-6*.

Table 4-6. Recommended slumps for various types of construction

Types of Construction	Slump, in Inches	
	Maximum *	**Minimum**
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Pavements and slabs	4	1
Mass concrete	2	1

*** May be increased 1 inch for consolidation by hand methods such as rodding and spading.**

AIR-CONTENT TEST (ASTM C 231-97)

Add an air-entraining admixture to the concrete mix so that enough air will be entrained to improve the mixture's workability, durability, watertightness, and freeze-thaw resistance but not enough to substantially reduce the strength. Air-entrained cements may also be available for use in some military situations. The desired amount of air is generally from 4.0 to 7.5 percent of the total mix.

Perform this test to determine the percentage (± 0.5 percent) of entrained air in a plastic (fresh) concrete sample.

EQUIPMENT

Use the following items to perform this test in a field or simulated field environment:

- An air-entrainment meter with 5 percent calibration cup and instructions.
- A trowel.

- A tamping rod (5/8 inch in diameter and 24 inches long with a rounded end).
- A sample of plastic (fresh) concrete.
- Water.
- Oil.
- Rags.
- A pail.
- A mixing pan (from the concrete test set).
- A kitchen scoop.
- Paper.
- A pencil.
- A rubber mallet.

STEPS

There are many different air-entrainment meters currently fielded and replacements of old equipment may not be the same. For this reason, it is recommended that the steps outlined in the manufacturer's user's manual be followed.

SECTION IV. FLEXURAL-STRENGTH TEST (MODULUS OF RUPTURE)

The flexural strength of hardened concrete is measured by using a simple concrete beam and third-point loading mechanism. The flexural strength is determined by calculating measured breaks of the beam and is expressed as a modulus of rupture in psi.

TEST BEAMS

Beam forms for casting test beams from fresh concrete are available in many sizes. The most commonly used size is 6 x 6 x 21 inches. Although equipment for obtaining sawed specimens may not be available, the test may be performed on beams sawed from existing concrete structures for evaluation purposes.

FORMING THE BEAMS (ASTM C 192-90A)

Assemble a standard 6- x 6- x 21-inch concrete-beam mold and lightly oil the inside. Fill the mold with two layers of concrete from the production batches, each about 3 inches deep. Consolidate each layer by rodding, using one stroke per 2 square inches (63 per layer), evenly distributed over the layer's surface. Tap the sides lightly 10 to 15 times with a rubber mallet to close the voids left by rodding. Lightly spade the concrete along the mold's sides with a trowel to help remove surface voids. When rodding the second layer, penetrate the first layer about 1/2 inch. Strike off the top surface with a straightedge, and finish it with a wood or magnesium float.

TAKING THE SPECIMENS

Take test specimens at least once for each 100 cubic yards or fraction thereof, for each class of concrete placed in any one day, or as directed in the project specifications. Make at least three specimens for each test age and mixture design being evaluated in the lab. Additional specimens may be made for future testing. Test ages are normally 14 and 28 days for flexural-strength tests. For testing field-placed concrete, a minimum of two specimens for each test age is required.

CURING THE BEAMS

Place a suitable identifying label on the finished surface of the specimens. Cover the entire specimens—still in the mold—with a double thickness of wet burlap. Ensure that the specimens remain on site and are undisturbed for an initial curing period (the first 16 to 48 hours after molding). After this curing period, move them to the testing laboratory and remove them from the molds for further curing. The most satisfactory curing range for concrete is 68° to 86°F, with 73.4°F being the most favorable temperature. Moist-cure the beams in saturated lime water, totally submerged in a wet-tank humidity room, or keep them wet until they are tested.

FLEXURAL-STRENGTH TEST (ASTM C 78-94)

Perform this test to determine the flexural strength (modulus of rupture) of the test specimen to $\pm$ 10 psi. Record the specimen identification, modulus of rupture, any defects noted, and specimen's age.

EQUIPMENT

Use the following items to perform this test in a laboratory environment:

- The flexural-strength test apparatus.
- A concrete beam, 6 x 6 x 21 inches.
- A measuring tape.
- A stopwatch.
- Pens.
- Pencils.
- Paper.
- Safety goggles.
- A proving-ring with proving-ring calibration and constant.
- Specimen identification.
- A calculator.

STEPS

Perform the following steps to determine the flexural strength. Wear safety goggles throughout this test.

Step 1. Assemble the test apparatus and check for functional operation (see *Figure 4-5*).

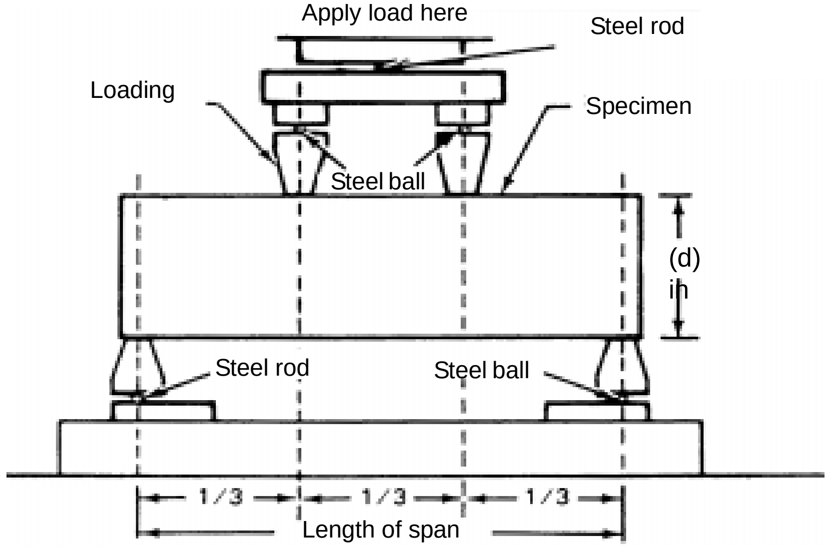

Figure 4-5. Apparatus for flexural-strength test

Step 2. Measure the length of span and record the measurement on a piece of paper. The length of span is determined by measuring the distance from center to center of the two loading points (or supports) on the base of the apparatus (see *Figure 4-5*). The normal length of specimen is 21 inches and the normal length of span is 18 inches.

Step 3. Place the specimen in the tester and bring the loading surface into contact with the test specimen (see *Figure 4-5).*

Step 4. Zero the gauge. Some apparatus are equipped with a hydraulic pump and corresponding gauge while others are equipped with a loading jack and proving ring.

Step 5. Apply a load at a continuous rate that constantly increases the extreme fiber stress between 125 and 175 psi per minute. This is an approximate load of 1,500 to 2,100 pounds per minute.

Step 6. Obtain the total load, in pounds, at the time of specimen failure, and record the weight on the paper provided. On machines equipped with hydraulics, take the reading directly from the gauge. For machines equipped with a proving ring, this reading is the product of the dial-gauge reading and the proving-ring constant.

Step 7. Determine and record the width and depth of the specimen, in inches, at the point of failure (normally 6 x 6 inches).

Step 8. Determine the point of failure in the specimen, and calculate the modulus of rupture. If the specimen fails outside the middle third of the span length by more than 5 percent of the total span length, then the specimen is considered unusable and should be discarded (not more than 0.9 inches for an 18-inch span (18 x 0.05 = 0.9).

a. Use the following formula to calculate the modulus of rupture if the specimen fails within the middle third of the span length:

$$R = \frac{P \times L}{b \times d^2}$$

where—

R = modulus of rupture, in psi

P = applied load, in pounds

L = length of span, in inches

b = width of specimen at failure point, in inches

d = depth of specimen at failure point, in inches

b. Use the following formula to calculate the modulus of rupture if the specimen fails outside the middle third of the length of span by not more than 5 percent of the span length:

$$R = \frac{3P \times a}{b \times d^2}$$

where—

R = modulus of rupture, in psi

P = applied load, in pounds

b = width of specimen at failure point, in inches

d = depth of specimen at failure point, in inches

a = distance between the failure point and the nearest support, measured along the centerline of the bottom of the specimen, in inches

Step 9. Record the following information about the test (some information may be unavailable at the time of the test):

- Specimen's identification number.
- Average width to the nearest 0.05 inch.
- Average depth to the nearest 0.05 inch.
- Span length, in inches.
- Maximum applied load, in pounds.
- Modulus of rupture, to the nearest 10 psi.
- Curing history (how the specimen was cured) and apparent moisture content of the specimen at the time of the test.
- Any defects noted in the specimen.
- The age of the specimen.

SECTION V. COMPRESSIVE-STRENGTH TEST

The compressive strength of hardened concrete, as measured by compression tests on standard forms of cylindrical specimens, is used in the design of structures. Compressive-strength tests are made on concrete trial mixtures to evaluate the performance of available materials and to establish mixture proportions that give the required strength. Strength tests are used also to control the quality of concrete being manufactured in the field. Compressive strength is defined as the average of the strengths of all cylinders of the same age made from a sample taken from a single batch of concrete. At least two cylinders are required to constitute a test. Therefore, a minimum of four specimens are required if tests are to be made at 7 and 28 days. The test results will be the average of the strengths of the two specimens tested at 28 days.

CASTING A CONCRETE CYLINDER

The standard test specimen is a cylinder 6 inches in diameter by 12 inches long, capped with a suitable material to provide smooth, bearing surfaces on each end. Load is applied to the end surfaces through metal platens on the testing machine (cylinder breaker), causing compressive stress in the longitudinal direction of the cylinder.

Make the cylinders as near as possible to the place where they will be stored for the first 16 to 48 hours. Sufficient concrete (about 1 cubic foot) for the desired number of cylinders must be available in the trial mixture or field sample. Material from the air-content test must not be reused, since this may be contaminated with excess water. Use appropriate sampling procedures for procuring your sample as stated in Section III.

EQUIPMENT

Use the following items and information to perform this test in a field or simulated field environment:

- A tamping rod (5/8 inch in diameter and 24 inches long with a rounded end).
- A sample of fresh concrete.
- A trowel.
- Oil.
- Rags.
- A disassembled cylinder mold.
- A sheet of plastic or burlap.
- A kitchen scoop.
- A pan (24 inches wide x 24 inches long x 3 inches deep).
- A grease pencil.

- Waterproof paper tags.
- Gummed labels.
- An ink pen.
- Paper.
- Water.
- The test-specimen number.
- The origin of a concrete sample.

STEPS

Perform the following steps to produce and label a concrete cylinder for testing:

Step 1. Prepare the mold.

a. Clean and dry the mold.

b. Oil the mold lightly.

c. Assemble the mold.

Step 2. Make the cylinder.

a. Fill the mold one-third full with fresh concrete.

b. Consolidate the concrete by applying 25 evenly distributed strokes over the mold's surface area with the tamping rod. The tamping rod must totally penetrate the layer of concrete.

c. Tap the side of the mold 8 to 10 times with the tamping rod.

d. Add concrete to the mold so as to fill it two-thirds full.

e. Apply 25 evenly distributed strokes to the mold's surface area using the rounded end of the tamping rod, which must pass entirely through the second layer of concrete and 1 inch into the preceding layer.

f. Tap the side of the mold 8 to 10 times with the tamping rod.

g. Add concrete to the mold to slightly overfill it.

h. Repeat step 2e. The tamping rod must pass entirely through the top layer and 1 inch into the preceding layer.

i. Tap the side of the mold 8 to 10 times with the tamping rod.

j. Trowel off the concrete so that it is flush with the top of the mold and smoothly finished.

Step 3. Label the mold. The label should include, as a minimum, all of the following information:

- The specimen number.
- The date the cylinder was made.
- The project or placement that the concrete came from.

The system of labeling is optional. The information should be recorded on a paper tag or gummed label and attached to the mold.

Step 4. Cover the cylinder with plastic or wet burlap to maintain moisture in the sample. The covering should be tight around the cylinder but should not make contact with the fresh concrete.

Step 5. Allow the cylinder to cure undisturbed for 24 hours.

Step 6. Remove the covering and the mold from the cylinder after 24 (± 8) hours.

Step 7. Transfer the label from the mold to the concrete cylinder. The label itself may be transferred or the information may be recorded directly on the cylinder with a grease pencil.

Step 8. Cure the cylinder.

NUMBER OF SPECIMENS

The number of specimens tested depends on the job specifications. If no requirement is listed in the specifications, a minimum of 2 will be molded for each test age for each 100 cubic yards, or fraction thereof, of each class of concrete placed in any one day. A third specimen may be taken to assist in determining when forms may be removed. The test specimens must remain on site and undisturbed for an initial curing period (the first 16 to 48 hours after molding). Normally the test ages are 7 and 28 days for compressive strength tests.

CURING AND STORING CYLINDERS

After an initial curing period for 16 to 48 hours, remove (from the jobsite) specimens that are intended for checking the strength of laboratory trial mixtures or to serve as the basis for acceptance or quality control of field concrete. Take them to the testing laboratory and moist-cure them at 73.4°F. Store them in moist rooms, in damp sand or sawdust, or in limewater to maintain free water on all surfaces of the specimen at all times.

Occasionally, test specimens are made in the field to determine when forms may be removed. Form these in addition to the specimens formed for strength determination. Give these specimens (as much as possible) the same protection from the elements on all surfaces as is given to the portions of the structure that they represent. Store them in or on the structure as near as possible to the point of use. Test them in the moist condition resulting from the specified curing treatment. Specimens intended for testing to determine when a structure may be put into use are removed from the molds at the same time the forms are removed from the structure.

When shipping specimens from the field to the laboratory for testing, pack them in a sturdy wooden box or other suitable container surrounded by wet sawdust or wet sand. Provide protection from freezing during storage or shipment. Moist curing is continued when the specimens are received in the laboratory.

CAPPING CYLINDERS

Plane the ends of compression-test specimens within 0.002 inch and within 0.5 degree of being perpendicular to the axis of the cylinder.

Cap (with neat cement) specimens formed in strong metal molds having accurately flat baseplates 2 to 4 hours after molding. Make a stiff paste of portland cement and water at the time the cylinder is molded so that the capping mixture will shrink before application. Remove any free water or laitance a (layer of fine particles on the surface) from the end of the specimen. Apply the paste to the top of the concrete and work it with a flat plate until it is smooth and level with the top of the mold.

Grind hardened concrete specimens to smooth the ends or cap them with a material having greater compressive strength than the concrete. Prepared mixtures of sulfur and granular materials, special high-strength gypsum plasters, and neat high-early strength cement are satisfactory capping materials (ordinary low-strength plaster of paris, compressible rubber, or fibrous materials are not suitable for caps). Apply the selected material in a plastic state and finish it to the desired plane surface by applying glass or metal plates and squeezing out excess material to provide a cap that is as thin as possible.

Apply sulfur caps in time to harden at least 2 hours before testing. Plaster caps cannot be stored over 4 hours in the moist room. Age neat cement caps 6 days or more in the moist room (2 days when Type II cement is used). During capping, protect moist-cured specimens against drying by covering them with wet burlap. There are numerous alternatives to sulfur caps listed in ASTM C 617-94. The metal cap with a rubber membrane is not an ASTM-approved method; however, specific guidelines for their use are under review by the ASTM. The test procedures used in this manual refer to the metal caps due to their availability within the supply system. If you must use sulfur caps, ensure that sulfur vapors are not inhaled while heating the capping compound. Ensure that there is adequate ventilation and that respiratory protection is used. Used sulfur capping compound is a hazardous material and must be properly disposed of.

DETERMINING COMPRESSIVE STRENGTH OF A CYLINDRICAL SPECIMEN (ASTM C 39-96)

Perform this test to determine the compressive strength of the concrete cylinder to within breakage and to determine anything unusual about the break.

EQUIPMENT

Use the following items to perform this test in a well-ventilated laboratory:

- A concrete cylinder (6 inches in diameter and 12 inches in height).
- A concrete capping set.
- Heat-resistant gloves.
- Capping compound.

- A ruler accurate to 0.01 inch.
- Calipers with at least a 6-inch opening.
- Paper.
- Pencils.
- Safety goggles and protective apron.
- A face shield.
- Oil.
- Rags.
- A calculator.
- A concrete compression tester with a 250,000-pound capacity.
- A hammer (ball peen or carpenter's).

STEPS

Perform the following steps to determine the concrete cylinder's compressive strength:

Step 1. Prepare the concrete cylinder.

NOTE: If rubber-filled metal is used, go to step 1j.

a. Melt the capping compound in the melting pot. Ensure that you melt enough compound to make several caps.

b. Clean and lightly oil the baseplate of the capping apparatus.

c. Set the baseplate into the capping-apparatus stand.

d. Pour a small amount of the heated (liquid) capping compound into the baseplate.

e. Position the cylinder at midheight against the backrest of the capping apparatus. Slowly lower the cylinder into the baseplate while keeping the cylinder flush against the backrest. If the cylinder is not kept flush with the backrest while capping, the caps and the cylinder will not be perpendicular, and a proper break will not occur.

f. Remove the cylinder from the capping apparatus once the capping compound has solidified.

g. Inspect the cap for uniformity and defects. If you see any defects, remove the cap and recap the cylinder; then return to step 1a.

h. Repeat steps 1a through 1g for the uncapped end of the cylinder.

i. Determine and record the average diameter of the concrete cylinder. The average diameter is the average of two diameters taken perpendicular to each other at midheight of the cylinder.

j. Clean and examine the bearing surface of the steel cap (if used) for nicks, gouges, and warping. Check the rubber inserts for tears, rips, cuts, and gouges. Replace them if they are in poor condition or if the maximum number of serviceable uses has been exceeded. Place the steel cap firmly on the cylinder's ends.

Step 2. Prepare the compression tester (see *Figure 4-6*).

a. Clean the tester's bearing plates (loading surfaces).

b. Check the tester for proper operation.

c. Set the gauge to zero.

Step 3. Place the capped cylinder into the compression tester and center it on the bearing plates. Secure the protective cage around the cylinder.

Step 4. Apply the test load at a rate of 20 to 50 psi per second, not to exceed 50 psi per second (50 psi per second is about equivalent to a load [gauge reading] of 1,400 pounds per second).

Step 5. Read the gauge and record the load applied at the time of failure.

Step 6. Inspect the broken cylinder and record the following information:

- Identification number.
- Diameter.
- Cross-sectional area, in square inches.
- Maximum load applied, in pounds.
- Compressive strength, calculated to the nearest 10 psi.
- Type of break (see *Figure 4-7*).
- Defects in either specimen or caps.
- Age of specimen.

Step 7. Calculate and record the compressive strength of the cylinder using the following formula:

$$\textit{Compressive strength} = \frac{P}{A}$$

where—

P = load at time of failure, in pounds

$A = \pi r^2$

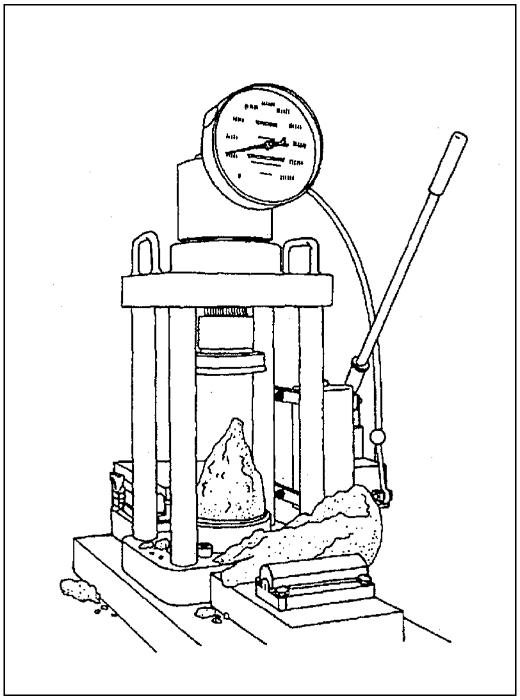

Figure 4-6. Compression tester

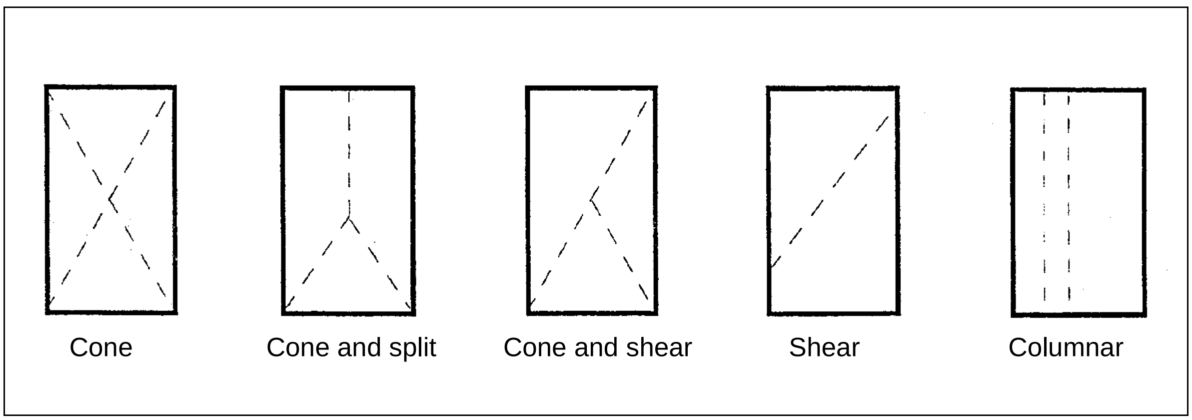

Figure 4-7. Types of fractures