

Guide for Measuring, Mixing, Transporting, and Placing Concrete

Reported by ACI Committee 304



American Concrete Institute®



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Advancing concrete knowledge

Guide for Measuring, Mixing, Transporting, and Placing Concrete

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ISBN 978-0-87031-308-0

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This guide presents information on the handling, measuring, and batching of all the materials used in making normalweight, lightweight structural, and heavyweight concrete. It covers both weight and volumetric measuring; mixing in central mixture plants and truck mixers; and concrete placement using buckets, buggies, pumps, and conveyors. Underwater concrete placement and preplaced aggregate concrete are also covered in this guide, as well as procedures for achieving good quality concrete in completed structures.

Keywords: batching; continuous mixing; conveying; heavyweight concretes; lightweight concretes; materials handling; mixing; placing; preplaced aggregate concrete; pumped concrete; tremie concrete; volumetric measuring.

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ACI 304R-00 supersedes ACI 304R-89 and became effective January 10, 2000.
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CHAPTER 1—INTRODUCTION**1.1—Scope**

This guide outlines procedures for achieving good results in measuring and mixing ingredients for concrete, transporting it to the site, and placing it. The first six chapters are general and apply to all types of projects and concrete. The following four chapters deal with preplaced-aggregate concrete, underwater placing, pumping, and conveying on belts. The concluding three chapters deal with heavyweight, radiation-shielding concrete, lightweight concrete, and volumetric-measuring and continuous-mixing concrete equipment.

1.2—Objective

When preparing this guide, ACI Committee 304 followed this philosophy:

- Progress in improvement of concrete construction is better served by the presentation of high standards rather than common practices;
- In many, if not most, cases, practices resulting in the production and placement of high-quality concrete can be performed as economically as those resulting in poor concrete. Many of the practices recommended in this document improve concrete uniformity as well as quality, yielding a smoother operation and higher production rates, both of which offset potential additional cost; and
- Anyone planning to use this guide should have a basic knowledge of the general practices involved in concrete work. If more specific information on measuring, mixing, transporting, and placing concrete is desired, the reader should refer to the list of references given at the end of this document, and particularly to the work of the U.S. Bureau of Reclamation (1981), the U.S. Department of Commerce (1966), the Corps of Engineers (1994a), ASTM C 94, ACI 311.1R, and ACI 318. To portray more clearly certain principles involved in achieving maximum uniformity, homogeneity, and quality of concrete in place, figures that illustrate good and poor practices are also included in this guide.

1.3—Other considerations

All who are involved with concrete work should know the importance of maintaining the unit water content as low as possible and still consistent with placing requirements (Mielenz 1994; Lovern 1966). If the water-cementitious materials ratio (w/cm) is kept constant, an increase in unit water content increases the potential for drying-shrinkage cracking, and with this cracking, the concrete can lose a portion of its durability and other favorable characteristics, such as monolithic properties and low permeability. Indiscriminate addition of water that increases the w/cm adversely affects both strength and durability.

The more a form is filled with the right combination of solids and the less it is filled with water, the better the resulting concrete will be. Use only as much cement as is required to achieve adequate strength, durability, placeability, workability, and other specified properties. Minimizing the cement content is particularly important in massive sections subject to restraint, as the temperature rise associated with the hydration of cement can result in cracking because of the change in volume (ACI 207.1R and 207.2R). Use only as much water and fine aggregate as is required to achieve suitable workability for proper placement and consolidation by means of vibration.

CHAPTER 2—CONTROL, HANDLING, AND STORAGE OF MATERIALS

2.1—General considerations

Coarse and fine aggregates, cement, pozzolans, and chemical admixtures should be properly stored, batched, and handled to maintain the quality of the resulting concrete.

2.2—Aggregates

Fine and coarse aggregates should be of good quality, uncontaminated, and uniform in grading and moisture content. Unless this is accomplished through appropriate specifications (ASTM C 33) and effective selection, preparation, and handling of aggregates (Fig. 2.1), the production of uniform concrete will be difficult (Mielenz 1994; ACI 221R).

2.2.1 Coarse aggregate—The coarse aggregate should be controlled to minimize segregation and undersized material. The following sections deal with prevention of segregation and control of undersized material.

2.2.1.1 Sizes—A practical method of minimizing coarse aggregate segregation is to separate the material into several size fractions and batch these fractions separately. As the range of sizes in each fraction is decreased and the number of size separations is increased, segregation is further reduced. Effective control of segregation and undersized materials is most easily accomplished when the ratio of maximum-to-minimum size in each fraction is held to not more than four for aggregates smaller than 1 in. (25 mm) and to two for larger sizes. Examples of some appropriate aggregate fraction groupings follow:

Example 1

Sieve designations

No. 8 to 3/8 in. (2.36 to 9.5 mm)

No. 4 to 1 in. (4.75 to 25.0 mm)

3/4 to 1-1/2 in. (19.0 to 37.5 mm)

Example 2

Sieve designations

No. 4 to 3/4 in. (4.75 to 19.0 mm)

3/4 to 1-1/2 in. (19.0 to 37.5 mm)

1-1/2 to 3 in. (37.5 to 75 mm)

3 to 6 in. (75 to 150 mm)

2.2.1.2 Control of undersized material—Undersized material for a given aggregate fraction is defined as material that will pass a sieve having an opening 5/6 of the nominal minimum size of each aggregate fraction (U.S. Bureau of Reclamation 1981). In Example 2 in Section 2.2.1.1, it would be material passing the following sieves: No. 5 (4.0 mm), 5/8 in. (16.0 mm), 1-1/4 in. (31.5 mm), and 2-1/2 in. (63 mm). For effective control of gradation, handling operations that do not increase the undersized materials in aggregates significantly before their use in concrete are essential (Fig. 2.1 and 2.2). The gradation of aggregate as it enters the concrete mixer should be uniform and within specification limits. Sieve analyses of coarse aggregate should be made with sufficient frequency to ensure that grading requirements are met. When two or more aggregate sizes are used, changes may be necessary in the proportions of the sizes to maintain the overall grading of the combined aggregate. When specification limits for grading cannot be met consistently, special handling methods should be instituted. Materials tend to segregate during transportation, so rebinding may be necessary. Rescreening the coarse aggregate as it is charged to the bins at the batch plant to remove undersized materials will effectively eliminate undesirable fines when usual storage and handling methods are not satisfactory. Undersized materials in the smaller coarse aggregate fractions can be consistently reduced to as low as 2% by rescreening (Fig. 2.2). Although rescreening is effective in removing undersized particles, it will not regrade segregated aggregates.

2.2.2 Fine aggregate (sand)—Fine aggregate should be controlled to minimize variations in gradation, giving special attention to keeping finer fractions uniform and exercising care to avoid excessive removal of fines during processing.

If the ratio of fine-to-coarse aggregate is adjusted in accordance with ACI 211.1 recommendations for mixture proportioning, a wide range of fine aggregate gradings can be used (Tynes 1962). Variations in grading during production of concrete should be minimized, however, and the ASTM C 33 requirement that the fineness modulus of the fine aggregate be maintained within 0.20 of the design value should be met.

Give special attention to the amount and nature of material finer than the No. 200 screen (75 μ m sieve). As stated in ASTM C 33, if this material is dust of fracture, essentially free of clay or shale, greater percentages of materials finer than the No. 200 screen (75 μ m sieve) are permissible. If the reverse is true, however, permissible quantities should be significantly reduced. The California sand equivalent test is sometimes used to determine quantitatively the type, amount, and activity of this fine material (Mielenz 1994; ASTM D 2419). Excessive quantities of material finer than the No. 200 screen (75 μ m sieve) increase the mixing-water

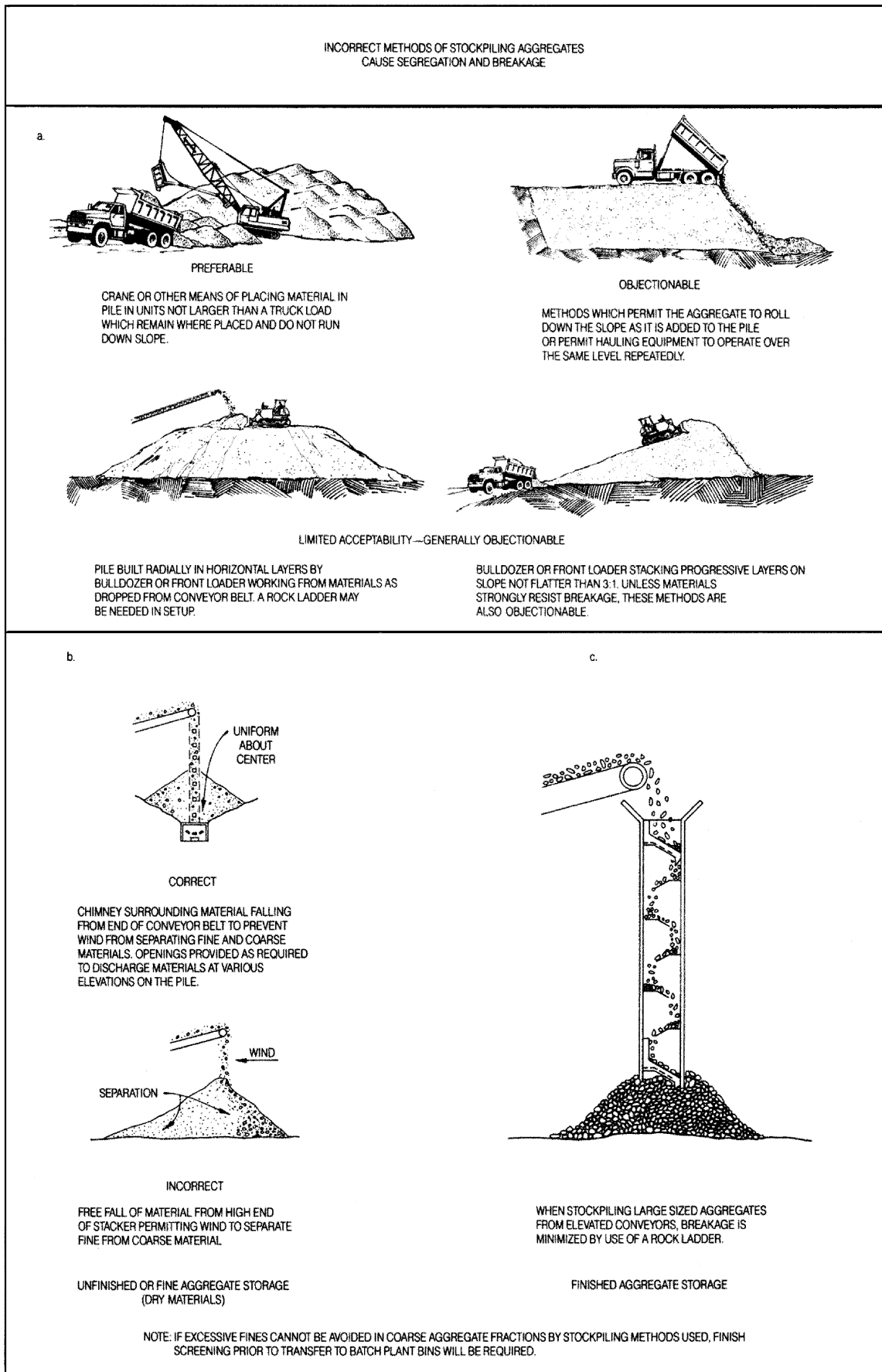


Fig. 2.1—Correct and incorrect methods of handling and storing aggregates.

requirement, rate of slump loss, and drying shrinkage, and therefore decrease strength.

Avoid blending two sizes of fine aggregate by placing alternate amounts in bins or stockpiles or when loading cars or trucks. Satisfactory results are achieved when different size fractions are blended as they flow into a stream from regulating gates or feeders. A more reliable method of control for a wide range of plant and job conditions, however, is to separate storage, handling, and batching of the coarse and fine fractions.

2.2.3 Storage—Stockpiling of coarse aggregate should be kept to a minimum because fines tend to settle and accumulate. When stockpiling is necessary, however, use of correct methods minimizes problems with fines, segregation, aggregate breakage, excessive variation in gradation, and contamination. Stockpiles should be built up in horizontal or gently sloping layers, not by end-dumping. Trucks, loaders, and dozers, or other equipment should not be operated on the stockpiles because, in addition to breaking the aggregate, they frequently track dirt onto the piles (Fig. 2.1). Provide a hard base with good drainage to prevent contamination from underlying material. Prevent overlap of the different sizes by suitable walls or ample spacing between piles. Protect dry, fine aggregate from being separated by the wind by using tarps or windbreaks. Do not contaminate stockpiles by swinging aggregate-filled buckets or clamshovels over the other piles of aggregate sizes. In addition, fine aggregate that is transported over wet, unimproved haul roads can become contaminated with clay lumps. The source of this contamination is usually accumulation of mud between the tires and on mud flaps that is dislodged during dumping of the transporting unit. Bottom-dump trailers are particularly susceptible to causing contamination when they drive through discharged piles. Clay lumps or clay balls can usually be removed from the fine aggregate by placing a scalping screen over the batch plant bin.

Keep storage bins as full as practical to minimize breakage and changes in grading as materials are withdrawn. Deposit materials into the bins vertically and directly over the bin outlet (Fig. 3.1b). Pay particular attention to the storage of special concrete aggregates, including lightweight, high-density, and architectural-finish aggregates. Contamination of these materials has compounding effects on other properties of the concrete in which they are to be used (Chapters 11 and 12).

2.2.4 Moisture control—Ensure, as practically as possible, a uniform and stable moisture content in the aggregate as batched. The use of aggregates with varying amounts of free water is one of the most frequent causes for loss of control of concrete consistency (slump). In some cases, wetting the coarse aggregate in the stockpiles or on the delivery belts may be necessary to compensate for high absorption or to provide cooling. When this is done, the coarse aggregates should be dewatered to prevent transfer of excessive free water to the bins.

Provide adequate time for drainage of free water from fine aggregate before transferring it to the batch plant bins. The storage time required depends primarily on the grading and particle shape of the aggregate. Experience has shown that a free-moisture content of as high as 6%, and occasionally as

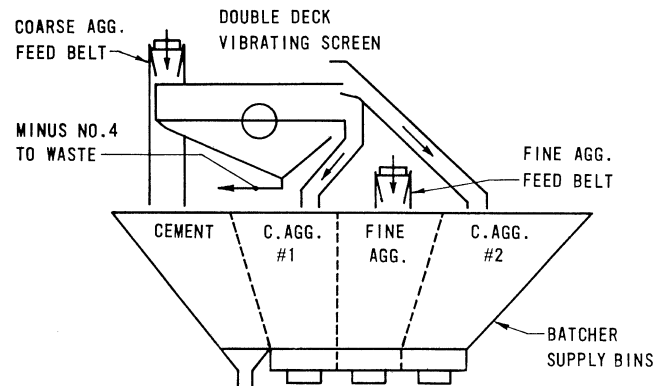


Fig. 2.2—Batching plant rescreen arrangement.

high as 8%, can be stable in fine aggregate. Tighter controls, however, may be required for certain jobs. The use of moisture meters to indicate variations in the moisture of the fine aggregate as batched, and the use of moisture compensators for rapid batch weight adjustments, can minimize the influence of moisture variations in the fine aggregate (Van Alstine 1955, Lovern 1966).

2.2.5 Samples for test—Samples representing the various aggregate sizes batched should be obtained as closely as possible to the point of their introduction into the concrete. The difficulty in obtaining representative samples increases with the size of the aggregate. Therefore, sampling devices require careful design to ensure meaningful test results. Methods of sampling aggregates are outlined in detail in ASTM D 75.

Maintaining a running average of the results of the five to 10 previous gradation tests, dropping the results of the oldest and adding the most recent to the total on which the average is calculated, is good practice. This average gradation can then be used for both quality control and for proportioning purposes.

2.3—Cement

All cement should be stored in weathertight, properly ventilated structures to prevent absorption of moisture. Storage facilities for bulk cement should include separate compartments for each type of cement used. The interior of a cement silo should be smooth, with a minimum bottom slope of 50 degrees from the horizontal for a circular silo and 55 to 60 degrees for a rectangular silo. Silos should be equipped with nonclogging air-diffuser flow pads through which small quantities of dry, oil-free, low-pressure air can be introduced intermittently at approximately 3 to 5 psi (20 to 35 kPa) to loosen cement that has settled tightly in the silos. Storage silos should be drawn down frequently, preferably once per month, to prevent cement caking.

Each bin compartment from which cement is batched should include a separate gate, screw conveyor, air slide, rotary feeder, or other conveyance that effectively allows both constant flow and precise cutoff to obtain accurate batching of cement.

Make sure cement is transferred to the correct silo by closely monitoring procedures and equipment. High accuracy should be controlled during loading and transferring.

Bags of cement should be stacked on pallets or similar platforms to permit proper circulation of air. For a storage period of less than 60 days, stack the bags no higher than 14 layers, and for longer periods, no higher than seven layers. As an additional precaution the oldest cement should be used first.

2.4—Ground slag and pozzolans

Fly ash, ground slag, or other pozzolans should be handled, conveyed, and stored in the same manner as cement. The bins, however, should be completely separate from cement bins without common walls that could allow the material to leak into the cement bin. Ensure that none of these materials is loaded into a cement bin on delivery.

2.5—Admixtures

Most chemical admixtures are delivered in liquid form and should be protected against freezing. If liquid admixtures are frozen, they should be properly rebled before they are used in concrete. Manufacturers’ recommendations should be followed.

Long-term storage of liquid admixtures in vented tanks should be avoided. Evaporation of the liquid could adversely affect the performance of the admixture (ACI 212.3R).

2.6—Water and ice

Water for concrete production can be supplied from city or municipal systems, wells, truck wash-out systems, or from any other source determined to be suitable. If questionable, the quality of the water should be tested for conformance with the requirements given in ASTM C 94. Concrete made with recycled wash water can show variations in strength, setting time, and response to air-entraining and chemical admixtures. Recycled wash water may be required to meet chemical requirements of ASTM C 94. Compensation may be necessary for the solids in recycled water to maintain yield and total water content in the concrete.

The water batcher and the water pipes should be leak-free. If ice is used, the ice facilities, including the equipment for batching and transporting to the mixer, should be properly insulated to prevent the ice from melting before it is in the mixer.

2.7—Fiber reinforcement

Synthetic fiber reinforcement is available in one cubic yard (one cubic meter) or multicubic yard (cubic meter) increments from most manufacturers. These prepackaged units should be readily accessible so they can be added directly to the mixer during the batching process.

Steel fibers are packaged in various sizes; the most common are 50 or 100 lb (23 or 45 kg) increments. Appropriate equipment should be used to disperse the fibers into the mixer to minimize the potential for the development of fiber balls. Steel fibers should be stored so that they are not exposed to moisture or other foreign matter. For more information on working with steel fibers, see ACI 544.3R.

CHAPTER 3—MEASUREMENT AND BATCHING

3.1—General requirements

3.1.1 Objectives—An important objective in producing concrete is to achieve uniformity and homogeneity, as indicated by physical properties such as unit weight, slump, air content, strength, and air-free unit weight of mortar in individual batches and successive batches of the same mixture proportions (U.S. Department of Reclamation 1981, U.S. Department of Commerce 1966, Bozarth 1967, ASTM C 94, Corps of Engineers 1994b). During measurement operations, aggregates should be handled so that the desired grading is maintained, and all materials should be measured within the tolerances acceptable for desired reproducibility of the selected concrete mixture. Another important objective of successful batching is the proper sequencing and blending of the ingredients (U.S. Department of Commerce 1966; Bozarth 1967). Visual observation of each material being batched is helpful in achieving this objective.

3.1.2 Tolerances—Most engineering organizations, both public and private, issue specifications containing detailed requirements for manual, semiautomatic, partially automatic, and automatic batching equipment for concrete (U.S. Bureau of Reclamation 1981; Corps of Engineers 1994b; ASTM C 94; AASHTO 1993). Batching equipment currently marketed will operate within the usual specified batch-weight tolerances when the equipment is maintained in good mechanical condition. The “Concrete Plant Standards of the Concrete Plant Manufacturers Bureau” (Concrete Plant Manufacturers Bureau 1996a) and the “Recommended Guide Specifications for Batching Equipment and Control Systems in Concrete Batch Plants” (Concrete Plant Manufacturers Bureau 1996b) are frequently used for specifying batching and scale accuracy. Batching tolerances commonly used are given in Table 3.1.2.

Other commonly used requirements include: beam or scale divisions of 0.1% of total capacity and batching interlock of 0.3% of total capacity at zero balance (Concrete Plant Manufacturers Bureau 1996a); quantity of admixture weighed never to be so small that 0.4% of full scale capacity exceeds 3% of the required weight; isolation of batching equipment from plant vibration; protection of automatic controls from dust and weather; and frequent checking and cleaning of scale and beam pivot points. With good inspection

Table 3.1.2—Typical batching tolerances

Ingredient	Batch weights greater than 30% of scale capacity		Batch weights less than 30% of scale capacity	
	Individual batching	Cumulative batching	Individual batching	Cumulative batching
Cement and other cementitious materials	±1% of required mass or ±0.3% of scale capacity, whichever is greater		Not less than required weight or 4% more than required weight	
Water (by volume or weight), %	±1	Not recommended	±1	Not recommended
Aggregates, %	±2	±1	±2	±0.3% of scale capacity or ±3% of required cumulative weight, whichever is less
Admixtures (by volume or weight), %	±3	Not recommended	±3	Not recommended



and plant operation, batching equipment can be expected to perform consistently within the required tolerances.

3.2—Bins and weigh batchers

Batch plant bins and components should be of adequate size to accommodate the productive capacity of the plant. Compartments in bins should separate the various concrete materials, and the shape and arrangement of aggregate bins should be conducive to the prevention of aggregate segregation and breakage. The aggregate bins should be designed so that material cannot hang up in the bins or spill from one compartment to another.

Weigh batchers should be charged with easily operated clamshell or undercut radial-type bin gates. Gates used to charge semiautomatic and fully automatic batchers should be power-operated and equipped with a suitable dribble control to allow the desired weighing accuracy. Weigh batchers should be accessible for obtaining representative samples, and they should be arranged to obtain the proper sequencing and blending of aggregates during charging of the mixer.

Illustrations showing proper and improper design and arrangement of batch plant bins and weigh batchers are given in Fig. 3.1.

3.3—Plant type

Factors affecting the choice of the batching systems are: 1) size of job; 2) required production rate; and 3) required standards of batching performance. The production capacity of a batch plant is determined by a combination of the materials handling system, bin size, batcher size, and mixer size and number.

Available weigh batch equipment falls into four general categories: manual; partially automatic; semiautomatic; and fully automatic (Concrete Plant Manufacturers Bureau 1996a).

3.3.1 Manual weigh batching—As the name implies, all operations of weighing and batching of the concrete ingredients are controlled manually. Manual plants are acceptable for small jobs having low batching-rate requirements. As the job size increases, automation of batching operations is rapidly justified. Attempts to increase the capacity of manual plants by rapid batching can result in excessive weighing inaccuracies.

3.3.2 Partially automatic weigh batching—A partially automatic system consists of a combination of batching controls where at least one of the controls for weighing either cement or aggregates is either semiautomatic or automatic as described as follows. Weighing of the remaining materials is manually controlled and interlocking of the batching system to any degree is optional. This system can also lack accuracy when rapid batching is required.

3.3.3 Semiautomatic weigh batching—In this system, aggregate-bin gates for charging are opened by manually operated buttons or switches. Gates are closed automatically when the designated weight of material has been delivered. With satisfactory plant maintenance, the batching accuracy should meet the tolerances given in Section 3.1.2. The system should contain interlocks that prevent batcher charging and discharging from occurring simultaneously. In other words, when the batcher is being charged, it cannot be discharged, and when it is being discharged, it cannot be charged. Visual

confirmation of the scale reading for each material being weighed is essential.

3.3.4 Automatic weigh batching—Automatic weigh batching of all materials is activated by a single starter switch. Interlocks, however, interrupt the batching cycle when the scale does not return to 0.3% of zero balance or when preset weighing tolerances detailed in Section 3.1.2 are exceeded.

3.3.4.1 Cumulative automatic weigh batching—Interlocked sequential controls are required for this type of batching. Weighing will not begin, and it will be automatically interrupted when preset tolerances in any of the successive weighings exceed values such as those given in Section 3.1.2. The charging cycle will not begin when the batcher discharge gate is open, and the batcher discharge cycle will not begin when batcher charging gates are open or when any of the indicated material weights is not within applicable tolerances. Presetting of desired batch weights is completed by such devices as punched cards, digital switches, or rotating dials and computers. Setting of weights, starting the batch cycle, and discharging the batch are all manually controlled. Mixture and batch-size selectors, aggregate moisture meters, manually controlled fine aggregate moisture compensators, and graphic or digital devices for recording the batch weight of each material are required for good plant control (Van Alstine 1955; Lovern 1966). This type of batching system provides greater accuracy for high-speed production than either the manual or semiautomatic systems.

A digital recorder can have a single measuring device for each scale or a series of measuring devices can record on the same tape or ticket. This type of recorder should reproduce the reading of the scale within 0.1% of the scale capacity or one increment of any volumetric batching device. A digital batch-documentation recorder should record information on each material in the mixture along with the concrete mixture identification, size of batch, and production facility identification. Required information can be preprinted, written, or stamped on the document. The recorder should identify the load by a batch-count number or a ticket serial number. The recorder, if interlocked to an automatic batching system, should show a single indication of all batching systems meeting zero or empty balance interlocks. All recorders should produce two or more tickets containing the information stated previously and also leave space for the identification of the job or project, location of placement, sand moisture content, delivery vehicle, driver's signature, purchaser's representative's signature, and the amount of water added at the project site.

3.3.4.2 Individual automatic weigh batching—This system provides separate scales and batchers for each aggregate size and for every other material batched. The weighing cycle is started by a single start switch, and individual batchers are charged simultaneously. Interlocks for interrupting weighing and discharge cycles when tolerances are exceeded, mixture selectors, aggregate moisture meters and compensators, and recorders differ only slightly from those described for cumulative automatic batching systems.

3.3.5 Volumetric batching—When aggregates and cementitious materials are batched by volume, it is normally

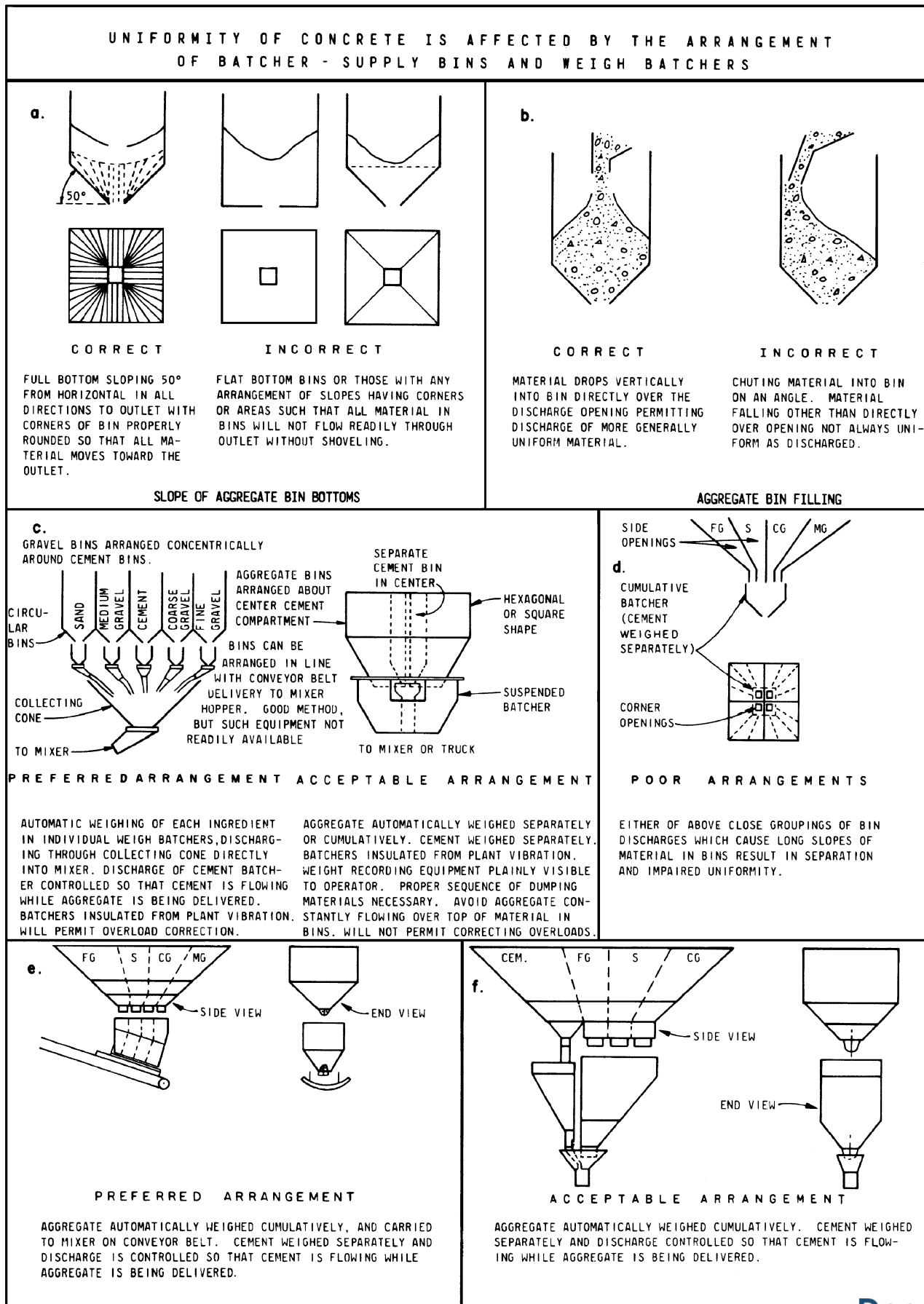


Fig. 3.1—Correct and incorrect methods of batching.

a continuous operation coupled with continuous mixing. Volumetric batching and continuous mixing are covered in Chapter 13.

3.4—Cementitious materials

3.4.1 Batching—For high-volume production requiring rapid and accurate batching, bulk cementitious materials should be weighed with automatic, rather than semiautomatic or manual, equipment. All equipment should provide access for inspection and permit sampling at any time. The bins and weigh batchers should be equipped with aeration devices, vibrators, or both to aid in the smooth and complete discharge of the batch. Return to zero and weighing tolerance interlocks described in Section 3.1.2 should be used. Cement should be batched separately and kept separate from all ingredients before discharging. When both cement and pozzolan or slag are to be batched, separate silos should be used. They can be batched cumulatively, however, if the cement is weighed first.

3.4.2 Discharging—Effective precautions should be taken to prevent loss of cementitious materials during mixer charging. At multiple-stop plants where materials are charged separately, losses can be minimized by discharging the cementitious materials through a rubber drop chute. At one-stop plants, cement and pozzolan can be successfully charged along with the aggregate through rubber telescopic dropchutes. For plant mixers, a pipe should be used to discharge the cementitious materials to a point near the center of the mixer after the water and aggregates have started to enter the mixer. Proper and consistent sequencing and blending of the various ingredients into the mixer during the charging operation will contribute significantly toward the maintenance of batch-to-batch uniformity and, perhaps, reduced mixing time when confirmed by mixer performance tests (U.S. Department of Commerce 1966; Gaynor and Mullarky 1975; ASTM C 94).

3.5—Water and ice measurement

3.5.1 Batching equipment—On large jobs and in central batching and mixing plants where high-volume production is required, accurate water and ice measurement can only be obtained by the use of automatic weigh batchers or meters. Equipment and methods used should, under all operating conditions, be capable of routine measurement within the 1% tolerance specified in Section 3.1.2. Tanks or vertical cylinders with a center-siphon discharge can be permitted as an auxiliary part of the weighing, but should not be used as the direct means of measuring water. For accurate measurement, a digital gallon (liter) meter should be used. All equipment for water measurement should be designed for easy calibration so that accuracy can be quickly verified. Ice-batching equipment should be insulated to avoid melting the ice.

3.5.2 Aggregate moisture determination and compensation—Measurement of the correct total mixing water depends on knowing the quantity and variation of moisture in the aggregate (particularly in the fine aggregate) as it is batched. Aggregate that is not saturated surface dry will absorb mixture water from the concrete. Fine aggregate moisture meters are frequently used in plants and when prop-

erly maintained do satisfactorily indicate changes in fine aggregate moisture content. Use of moisture meters in fine sizes of coarse aggregate is also recommended if these materials vary in moisture content. Moisture meters should be calibrated to oven-dried samples for optimum consistency of readings. Moisture meters should be recalibrated monthly or whenever the slump of the concrete produced is inconsistent.

Moisture-compensating equipment can also be used that can reportion water and fine aggregate weights for a change in aggregate moisture content, with a single setting adjustment. Compensators are usually used on the fine aggregate, but occasionally are also used on the small coarse aggregate size fractions. The moisture setting on the compensators is made manually with calibration dials, buttons, or levers. The use of moisture compensators is recommended when used in conjunction with calibrated moisture meters or regularly performed conventional moisture-control tests. Under these conditions, compensators can be useful tools for maintaining satisfactory control of the fine aggregate and the mixing water content.

Most computer-controlled batching systems now have software that interlocks moisture meters or compensating equipment with the measuring of fine aggregate and water. Readings are taken automatically and incorporated into the batching of these ingredients. Some systems work with an individual reading, whereas others can continuously record moisture as the fine aggregate is batched. Regardless of the system used, the software should impose user-defined upper and lower moisture limits and alert the operator when moisture values are outside those limits. Proper maintenance and calibration of equipment is essential to satisfactory performance and consistent production of concrete.

3.5.3 Total mixing water—In addition to the accurate weighing of added water, uniformity in the measurement of total mixing water involves control of such additional water sources as mixer wash water, ice, and free moisture in aggregates. One specified tolerance (ASTM C 94) for accuracy in measurement of total mixing water from all sources is $\pm 3\%$.

The operating mechanism in the water measuring devices should be such that leakage (dribbling or water trail) will not occur when the valve is closed. Water tanks on truck mixers or other portable mixers should be constructed so that the indicating device will register, within the specified accuracy, the quantity of water discharged, regardless of the inclination of the mixer.

3.6—Measurement of admixtures

Batching tolerances (Section 3.1.2) and charging and discharge interlocks described previously for other mixture ingredients should also be provided for admixtures. Batching and dispensing equipment should be readily capable of calibration. When timer-activated dispensers are used for large-volume admixtures such as calcium chloride, a container with a sight tube calibrated to show admixture quantity (usually referred to as a “calibration tube”) should be used to allow visual confirmation of the volume being batched. In practice, calibration tubes are usually used for admixtures.

Refer to ACI 212.3R for additional information on recommended practices in the use and dispensing of admixtures in concrete.

3.7—Measurement of materials for small jobs

If the concrete volume on a job is small, establishing and maintaining a batch plant and mixer at the construction site may not be practical. In such cases, using ready-mixed concrete or mobile volumetric batching and continuous mixing equipment may be preferable. If neither is available, precautions should be taken to properly measure and batch concrete materials mixed on the job site. Bags of cementitious materials should be protected from moisture and fractional bags should not be used unless they are weighed. The water-measuring device should be accurate and dependable, and the mixer capacity should not be exceeded.

3.8—Other considerations

In addition to accurate measurement of materials, correct operating procedures should also be used if concrete uniformity is to be maintained. Ensure that the batched materials are properly sequenced and blended so that they are charged uniformly into the mixture (U.S. Department of Commerce 1966; Bozarth 1967). Arrange the batching plant control room, if possible, with the plant operator's station located in a position where the operator can closely and clearly see the scales and measuring devices during batching of the concrete, as well as the charging, mixing, and discharging of the mixtures without leaving the operating console. Some common batching deficiencies to be avoided are: overlapping of batches; loss of materials; loss or hanging up of a portion of one batch, or its inclusion with another.

CHAPTER 4—MIXING AND TRANSPORTING

4.1—General requirements

Thorough mixing is essential for the production of uniform, quality concrete. Therefore, equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work. Recommendations on maximum aggregate size and slump to be used for various types of construction are given in ACI 211.1 for concretes made with ASTM C 150 and C 595M cements, and in ACI 223R for concretes made with ASTM C 845 expansive hydraulic cements. Sufficient mixing, transporting, and placing capacity should be provided so that unfinished concrete lifts can be maintained plastic and free of cold joints.

4.2—Mixing equipment

Mixers can be stationary parts of central mixture plants or of portable plants. Mixers can also be truck mounted. Satisfactorily designed mixers have a blade or fin arrangement and drum shape that ensure an end-to-end exchange of materials parallel to the axis of rotation or a rolling, folding, and spreading movement of the batch over itself as it is being mixed. For additional descriptions of some of the various mixer types, refer to the publications of the Concrete Plant Manufacturers Bureau (1996c) and of the Truck Mixer Manufacturers Bureau (1996).

The more common types of mixing equipment are:

4.2.1 Tilting drum mixer—This is a revolving drum mixer that discharges by tilting the axis of the drum. In the mixing mode, the drum axis can be either horizontal or at an angle.

4.2.2 Nontilting drum mixer—This is a revolving drum mixer that charges, mixes, and discharges with the axis of the drum horizontal.

4.2.3 Vertical shaft mixer—This is often called a turbine or pan-type mixer. Mixing is accomplished with rotating blades or paddles mounted on a vertical shaft in either a stationary pan or one rotating in the opposite direction to the blades. The batch can be easily observed and rapidly adjusted, if necessary. Rapid mixing and low overall profile are other significant advantages. This type of mixer does an excellent job of mixing relatively dry concretes and is often used for laboratory mixing and by manufacturers of concrete products.

4.2.4 Pugmill mixers—These mixers are defined in ACI 116R as “a mixer having a stationary cylindrical mixing compartment, with the axis of the cylinder horizontal, and one or more rotating horizontal shafts to which mixing blades or paddles are attached.” Although this is an accurate definition, there are many types, styles, and configurations. Pugmills can have single or double shafts. They can have a curved blade configuration or a paddle configuration that is vertical to the shaft. In either case, they are designed to fold and move the concrete from one end of the pugmill to the other.

These mixers are suitable for harsh, stiff concrete mixtures. They have primarily been used in the production of concrete block units, cement-treated bases, and roller compacted concrete. Newer versions of these mixers are used in the production of normal- and high-strength concrete, with slumps of up to 8 in. (200 mm).

4.2.5 Truck mixers—There are two types of revolving drum truck mixers currently in use—rear discharge and front discharge. The rear-discharge, inclined-axis mixer predominates. In both, fins attached to the drum mix concrete in the mixing mode and also discharge the concrete when drum rotation is reversed.

4.2.6 Continuous mixing equipment—Two types of continuous mixing equipment are available. In the first type, all materials come together at the base of the mixing trough. Mixing is accomplished by a spiral blade rotated at a relatively high speed inside the enclosed trough, which is inclined at 15 to 25 degrees from the horizontal. These can be mobile, mounted either on a truck chassis or a trailer, or stationary. The second type is a continuous-feed pugmill mixer generally used for roller-compacted concrete and cement-treated base. Aggregates, cement, and fly ash are measured by weight or volume and fed into the charging end of the pugmill by variable-speed belts. Water is metered either from an attached tank or an outside source. Mixing is accomplished by paddles attached to one or two rotating horizontal shafts. The mixture is lifted and folded as it is moved from the charging end to the discharging end of the pugmill, where the completed mixture is discharged onto an elevated conveyor belt for easy loading into trucks. These types of continuous-feed mixers can be used for normal

concretes as well. These would be considered semimobile plants as they are mounted on wheels and can be broken down for transport. Refer to Chapter 13 for additional information on continuous mixing equipment.

4.2.7 Separate paste mixing—Experimental work has shown that the mixing of cement and water into a paste before combining these materials with aggregates can increase the compressive strength of the resulting concrete (Mass 1989). The paste is generally mixed in a high-speed, shear-type mixer at a w/cm of 0.30 to 0.45 by mass. The premixed paste is then blended with aggregates and any remaining batch water, and final mixing is completed in conventional concrete mixing equipment.

4.3—Central-mixed concrete

Central-mixed concrete is mixed completely in a stationary mixer and then transferred to another piece of equipment for delivery. This transporting equipment can be a ready-mixed truck operating as an agitator, or an open-top truck body with or without an agitator. The tendency of concrete to segregate limits the distance it can be hauled in transporters not equipped with an agitator. If a truck mixer or a truck body with an agitator is used for central-mixed concrete, ASTM C 94 limits the volume of concrete charged into the truck to 80% of the drum or truck volume.

Sometimes the central mixer will partially mix the concrete with the final mixing and transporting being done in a revolving-drum truck mixer. This process is often called “shrink mixing” as it reduces the volume of the as-charged mixture. When using shrink mixing, ASTM C 94 limits the volume of concrete charged into the truck to 63% of the drum volume.

4.4—Truck-mixed concrete

Truck mixing is a process by which previously proportioned concrete materials from a batch plant are charged into a ready-mixed truck for mixing and delivery to the construction project. To achieve thorough mixing, total absolute volume of all ingredients batched in a revolving drum truck mixer should not exceed 63% of the drum volume (Truck Mixer Manufacturers Bureau 1996; ASTM C 94).

4.5—Charging and mixing

The method and sequence of charging mixers is of great importance in determining whether the concrete will be properly mixed. For central plant mixers, obtaining a preblending or ribboning effect by charging cement and aggregates simultaneously as the stream of materials flow into the mixer is essential (U.S. Department of Commerce 1966; Bozarth 1967; Gaynor and Mullarky 1975).

In truck mixers, all loading procedures should be designed to avoid packing of the material, particularly sand and cement, in the head of the drum during charging. The probability of packing is decreased by placing approximately 10% of the coarse aggregate and water in the mixer drum before the sand and cement.

Generally, approximately 1/4 to 1/3 of the water should be added to the discharge end of the drum after all other ingredients have been charged. Water-charging pipes should be of proper design and of sufficient size so that water enters

at a point well inside the mixer and charging is complete within the first 25% of the mixing time (Gaynor and Mullarky 1975). Refer to Section 4.5.3.1 for additional discussion of mixing water.

The effectiveness of chemical admixtures will vary depending upon when they are added during the mixing sequence. Follow the recommendations of the admixture supplier regarding when to add a particular product. Once the appropriate time in the sequence is determined, chemical admixtures should be charged to the mixer at the same point in the mixing sequence for every batch. Liquid admixtures should be charged with the water or on damp sand, and powdered admixtures should be ribboned into the mixer with other dry ingredients. When more than one admixture is used, each should be batched separately unless premixing is allowed by the manufacturer.

Synthetic fiber reinforcement can be added any time during the mixing process as long as at least 5 min of mixing occurs after the addition of the synthetic fibers.

4.5.1 Central mixing—Procedures for charging central mixers are less restrictive than those necessary for truck mixers because a revolving-drum central mixer is not charged as full as a truck mixer and the blades and mixing action are quite different. In a truck mixer, there is little folding action compared with that in a stationary mixer. Batch size, however, should not exceed the manufacturer's rated capacity as marked on the mixer name plate.

The mixing time required should be based on the ability of the mixer to produce uniform concrete throughout the batch and from batch to batch. Manufacturers' recommendations and other typical recommendations, such as 1 min for 1 yd³ (3/4 m³) plus 1/4 min for each additional cubic yard (cubic meter) of capacity can be used as satisfactory guides for establishing initial mixing time. Final mixing times, however, should be based on the results of mixer performance tests made at frequent intervals throughout the duration of the job (U.S. Bureau of Reclamation 1981; U.S. Department of Commerce 1966; ASTM C 94; CRD-C 55). The mixing time should be measured from the time all ingredients are in the mixer. Batch timers with audible indicators used in combination with interlocks that prevent under- or over-mixing of the batch and discharge before completion of a preset mixing time are provided on automatic plants and are recommended on manual plants. The mixer should be designed for starting and stopping under full-load conditions.

4.5.2 Truck mixing—Generally, 70 to 100 revolutions at mixing speed are specified for truck mixing. ASTM C 94 limits the total number of revolutions to a maximum of 300. This limits the grinding of soft aggregates, loss of slump, wear on the mixer, and other undesirable effects that can occur in hot weather. Final mixing can be done at the producer's yard, or, more commonly, at the project site.

If additional time elapses after mixing and before discharge, the drum speed is reduced to the agitation speed or stopped. Then, before discharging, the mixer should be operated at mixing speed for approximately 30 s to enhance uniformity.

Mixer charging, mixing, and agitating speeds vary with each truck and mixer-drum manufacturer. ASTM C 94 requires that these speeds and the mixing and agitating capacity of each drum be shown on a plate attached to the unit.

Maximum transportation time can be extended by several different procedures. These procedures are often called dry batching and evolved to accommodate long hauls and unavoidable delays in placing by attempting to postpone the mixing of cement with water. When cement and damp aggregate come in contact with each other, however, free moisture on the aggregate results in some cement hydration. Therefore, materials cannot be held in this manner indefinitely.

In one method, the dry materials are batched into the ready-mixed truck and transported to the job site where all of the mixing water is added. Water should be added under pressure, preferably at both the front and rear of the drum with it revolving at mixing speed, and then mixing is completed with the usual 70 to 100 revolutions. The total volume of concrete that can be transported in truck mixers by this method is the same as for regular truck mixing, approximately 63% of the drum volume (Truck Mixer Manufacturers Bureau 1996; ASTM C 94).

Another approach to accommodate long hauls is to use extended-set admixtures. The concrete is mixed and treated with the admixture before leaving the plant. The admixture dosage is typically selected to wear off shortly after the concrete arrives at the placement site, allowing the concrete to set normally. In some instances, an accelerator is added to activate the concrete once it arrives at the placement site. Concrete has been transported over 200 miles (320 km) using this technique.

4.5.3 Water

4.5.3.1 Mixing water—The water required for proper concrete consistency (slump) is affected by variables such as amount and rate of mixing, length of haul, time of unloading, and ambient temperature conditions. In cool weather, or for short hauls and prompt delivery, problems such as loss or variation in slump, excessive mixing water requirements, and discharging, handling, and placing problems rarely occur. The reverse is true, however, when rate of delivery is slow or irregular, haul distances are long, and weather is warm. Loss of workability during warm weather can be minimized by expediting delivery and placement and by controlling the concrete temperature. Good communication between the batching plant and the placement site is essential for coordination of delivery. It may be necessary to use a retarder to prolong the time the concrete will respond to vibration after it is placed. When feasible, all mixing water should be added at the central or batch plant. In hot weather, however, it is better to withhold some of the mixing water until the mixer arrives at the job. With the remaining water added, an additional 30 revolutions at mixing speed is required to adequately incorporate the additional water into the mixture. When loss of slump or workability cannot be offset by these measures, the procedures described in Section 4.5.2. should be considered.

4.5.3.2 Addition of water on the job—The maximum specified or approved w/cm should never be exceeded.

If all the water allowed by the specification or approved mixture proportions has not been added at the start of mixing, it may be permissible, depending upon project specifications, to add the remaining allowable water at the point of delivery. Once part of a batch has been unloaded, however, it becomes impractical to determine what w/cm is produced by additional water.

The production of concrete of excessive slump or adding water in excess of the proportioned w/cm to compensate for slump loss resulting from delays in delivery or placement should be prohibited. Persistent requests for the addition of water should be investigated.

Where permitted, a high-range water-reducing admixture (superplasticizer) can be added to the concrete to increase slump while maintaining a low w/cm (Cement and Concrete Association 1976; Prestressed Concrete Institute 1981). Addition of the admixture can be made by the concrete supplier or the contractor by a variety of techniques. When this admixture is used, vibration for consolidation is reduced. In walls and sloping formed concrete, however, some vibration is necessary to remove air trapped in the form. Use of this admixture can also increase form pressure.

4.5.3.3 Wash water—Most producers find it necessary to rinse off the rear fins of the mixer between loads and wash and discharge the entire mixer only at the end of the day. Hot weather and unusual mixture proportions can require washing and discharge of wash water after every load. Rinse water should not remain in the mixer unless it can be accurately compensated for in the succeeding batch. Rinse water can be removed from the mixer by reversing the drum for 5 to 10 revolutions at medium speed. Pollution-control regulations make it increasingly difficult to wash out after every load and have created an interest in systems to reclaim and reuse both wash water and returned concrete aggregates.

ASTM C 94 describes the reuse of wash water based on prescribed tests. Particular attention is necessary when admixtures are being used because the required dosages can change dramatically. When wash water is used, admixtures should be batched into a limited quantity of clean water or onto damp sand.

Wash water can also be treated using extended-set admixtures. In this case, a limited amount of wash water is added to a drum after all solid materials are discharged. Typically 50 gal. (200 L) instead of the normal 500 gal. (2000 L) are used. The admixture is added to the drum and the drum is rotated to ensure that all surfaces are coated. This treated wash water can be left in the truck overnight or over a weekend. The next morning or after the weekend, concrete can be batched using the treated wash water as part of the mixing water. Given the small amount of the admixture used for this application, use of an activating admixture is not usually required.

4.6—Mixture temperature

Batch-to-batch uniformity of concrete from a mixer, particularly with regard to slump, water requirement, and air content, also depends on the uniformity of the concrete temperature. Controlling the maximum and minimum concrete temperatures throughout all seasons of the year is important.

Concrete can be cooled using ice, chilled mixing water, chilled aggregates, or liquid nitrogen. In-place concrete temperatures as low as 40 F (4 C) are not unusual.

Liquid nitrogen at a temperature of -320 F (-196 C) can be used to chill mixture water, aggregates, or concrete (Anon. 1977). Liquid nitrogen has been injected directly into central mixers, truck mixers, or both to achieve required concrete temperatures (Anon. 1988). Concrete can be warmed by using heated water, aggregates, or both. Recommendations for control of concrete temperatures are discussed in detail in ACI 305R and 306R.

4.7—Discharging

Mixers should be capable of discharging concrete of the lowest slump suitable for the structure being constructed, without segregation (separation of coarse aggregate from the mortar). Before discharge of concrete transported in truck mixers, the drum should again be rotated at mixing speed for about 30 revolutions to reblend possible stagnant spots near the discharge end into the batch.

4.8—Mixer performance

The performance of mixers is usually determined by a series of uniformity tests made on samples taken from two or three locations within the concrete batch after it has been mixed for a given time period (U.S. Bureau of Reclamation 1981, ASTM C 94 and CRD-C 55). Mixer performance requirements are based on allowable differences in test results of samples from any two locations or a comparison of individual locations with the average of all locations. The procedures published by Gaynor and Mullarky (1975) are an excellent reference.

Among the many tests used to check mixer performance, the following are the most common: air content; slump; unit weight of air-free mortar; coarse aggregate content; and compressive strength.

Another important aspect of mixer performance is batch-to-batch uniformity of the concrete, which is also affected by the uniformity of materials and their measurement as well as by the efficiency of the mixer. Visual observation of the concrete during mixing and discharge from the mixer is an important aid in maintaining a uniform mixture, particularly with a uniform consistency. Some consistency-recording meters, such as those operating from the amperage draw on the electric motor drives for revolving-drum mixers, have also proven to be useful. The most positive control method for maintaining batch-to-batch uniformity, however, is a regularly scheduled program of tests of the fresh concrete, including unit weight, air content, slump, and temperature. All plants should have facilities and equipment for conveniently obtaining representative samples of concrete for routine control tests in accordance with ASTM C 172. Although strength tests provide an excellent measure of the efficiency of the quality control procedures that are employed, the strength-test results are available too late to be of practical use in controlling day-to-day production.

4.9—Maintenance

Mixers should be properly maintained to prevent mortar and dry material leakage. Inner mixer surfaces should be kept clean and worn blades should be replaced. Mixers not meeting the performance tests referenced in Section 4.8 should be taken out of service until necessary maintenance and repair corrects their deficient performance.

4.10—General considerations for transporting concrete

4.10.1 General—Concrete can be transported by a variety of methods and equipment, such as pipeline, hose, conveyor belts, truck mixers, open-top truck bodies with and without agitators, or buckets hauled by truck or railroad car. The method of transportation should efficiently deliver the concrete to the point of placement without losing mortar or significantly altering the concrete's desired properties associated with *w/cm*, slump, air content, and homogeneity. Various conditions should be considered when selecting a method of transportation, such as: mixture ingredients and proportions; type and accessibility of placement; required delivery capacity; location of batch plant; and weather conditions. These conditions can dictate the type of transportation best suited for economically obtaining quality in-place concrete.

4.10.2 Revolving drum—In this method, the truck mixer (Section 4.2.5) serves as an agitating transportation unit. The drum is rotated at charging speed during loading and is reduced to agitating speed or stopped after loading is complete. The elapsed time before discharging the concrete can be the same as for truck mixing and the volume carried can be increased to 80% of the drum capacity (ASTM C 94).

4.10.3 Truck body with and without an agitator—Units used in this form of transportation usually consist of an open-top body mounted on a truck, although bottom-dump trucks have been used successfully. The metal body should have smooth, streamlined contact surfaces and is usually designed for discharge of the concrete at the rear when the body is tilted. A discharge gate and vibrators mounted on the body should be provided at the point of discharge for control of flow. An agitator, if the truck body is equipped with one, aids in the discharge and ribbon-blends the concrete as it is unloaded. Water should never be added to concrete in the truck body because no mixing is performed by the agitator.

Use of protective covers for truck bodies during periods of inclement weather, proper cleaning of all contact surfaces, and smooth haul roads contribute significantly to the quality and operational efficiency of this form of transportation. The maximum delivery time specified is usually 30 to 45 min, although weather conditions can require shorter or permit longer times.

Trucks that have to operate on muddy haul roads should not be allowed to discharge directly on the grade or drive through the discharged pile of concrete.

4.10.4 Concrete buckets on trucks or railroad cars—This is a common method of transporting concrete from the batch plant to a location close to the placement area of a mass concrete placement. A crane then lifts the bucket to the point of placement. Occasionally, transfer cars operating on