CHAPTER 4
PROPORTIONING, MIXING AND TRANSPORTING

Table of Contents

This page is intentionally left blank.

4 PROPORTIONING, MIXING AND TRANSPORTING

Introduction

This chapter provides discussion of the contract provisions governing proportioning, mixing and transporting concrete. The objective of the contract provisions is to obtain concrete that is consistent with the accepted mix design (discussed in previous chapter), uniform, homogeneous, workable and in its cured form exhibits the expected structural and aesthetic properties. Experience has shown that the variability within and across batching processes warrants provision for method and quality assurance inspections of process, equipment and materials to assure the quality specified is obtained. Experience has also resulted in the industry's creation of batching, mixing and transporting practices that result in quality, uniform and economical concrete that satisfies the contract provisions. Figure 4-1 shows a typical batch plant.

This chapter discusses the objectives of the provisions contained in the Standard Specifications. The intention is that more thorough understanding of these objectives will improve the bridge engineer's effectiveness in assuring concrete quality and resolving issues of deficiency.

Proportioning

To ensure a quality product, it is essential that the concrete mixture contain the same relative proportions of each ingredient as intended by the mix design. Accurate proportioning is an important element in the concrete production process. In addition, storage and handling of concrete constituent materials can impact how consistent the batched concrete is with the intended mix design.

Figure 4-1. Basic Batch Plant Shows Aggregate, Cement and Supplemental Cementitious Material Storage, Conveyor Feed System, Chemical Admixture Tanks and Dust Collector.

Aggregate Storage and Handling

The provisions for storage and handling are contained in the Standard Specifications. These provisions are warranted because segregation, breakage and contamination can all occur during normal handling and stockpiling operations. Segregation and breakage can occur to such a degree that workability and concrete quality are significantly impacted. Aggregate that is well screened and graded at the aggregate plant may be contaminated, segregated and/or poorly graded by the time it reaches the mixer.

Contamination could be any foreign material but the most common forms of contamination are from materials of different gradations intermingling and from stockpiles (Figure 4-2) that are in contact with the ground. Physical separation between the ground and the stored aggregate and physical separation of materials with different aggregate sizes is the most common prevention.

Figure 4-2. Aggregate Storage Bunkers.

All handling and stockpiling operations will cause some segregation and breakage but good handling and stockpiling practices minimize the impact. If an issue exists or is anticipated, evaluate whether the following practices are being employed.

Reducing the number of times the aggregate is handled and the height from which aggregate is dropped can decrease breakage. Storage bins should be kept as full as practical to minimize breakage and reduce segregation. See Figure 4-3 (a and b) for typical storage bins.

If aggregates are to be stored in stockpiles, some precautions are necessary. To minimize segregation of sizes, stockpiles should be built up in layers of uniform thickness, and the top of the stockpile should be level, not cone-shaped. When building stockpiles, coarse aggregate should fall in such a way that larger particles are not thrown beyond smaller particles, and particles do not run down the stockpile-side slopes.

Figure 4-3a. Aggregate Storage Bins.

Figure 4-3b. Aggregate Storage Bins.

Segregation can be further managed by keeping the aggregate in a number of stockpiles with narrow-grade ranges. Taken to the extreme, each single aggregate size would be stored in its own stockpile. If all aggregate is the same size then it is not possible for segregation to occur. This extreme measure may never be practical but the advantage of separating aggregate stockpiles into narrower grade ranges can be conceptualized. Each time the grading range is reduced the impact of segregation is reduced. Stored in this manner, the final gradation can be created at the time of batching.

Fine aggregate has fewer tendencies to segregate when it is damp. If the fine aggregate is dry and is dropped from a conveyor belt or bucket, even a light wind may blow out the finest particles.

Aggregates from different sources or from different locations in the same pit or material site, should not be placed in the same stockpile. Figure 4-4 provides illustrations of some of the concepts discussed above.

Where crushers are employed to manufacture smaller aggregate sizes, the crushed material may have harsh, sharp edges. This condition can affect the water demand and workability of the concrete but can also increase the potential of excessive undersizing being created as the sharp edges chip off during handling and mixing operations. Historically, it has been considered advisable to limit the amount of angular and friable aggregate in concrete. California Test 515 was used to control these characteristics in fine aggregates used in concrete produced for State projects. One method of managing this issue is by using tumblers. The crushed aggregate is passed through a revolving cylinder with lifters allowing the chip prone particles to be removed prior to its incorporation into the finished concrete aggregate. Also, rock ladders retard the fall and can be utilized to reduce breakage. A rock ladder is illustrated in Figure 4-4. Also, plasticizers and water reducers can be used to reduce the increased water demand.

Because the impacts of utilizing angular and friable aggregates can be mitigated, the Department changed the Standard Specifications to designate all structure concrete by strength and eliminated the California Test 515 requirement. This change provides additional sand sources for concrete suppliers and the compressive strength acceptance tests provide the State with verification that the sand’s characteristics have been successfully mitigated.

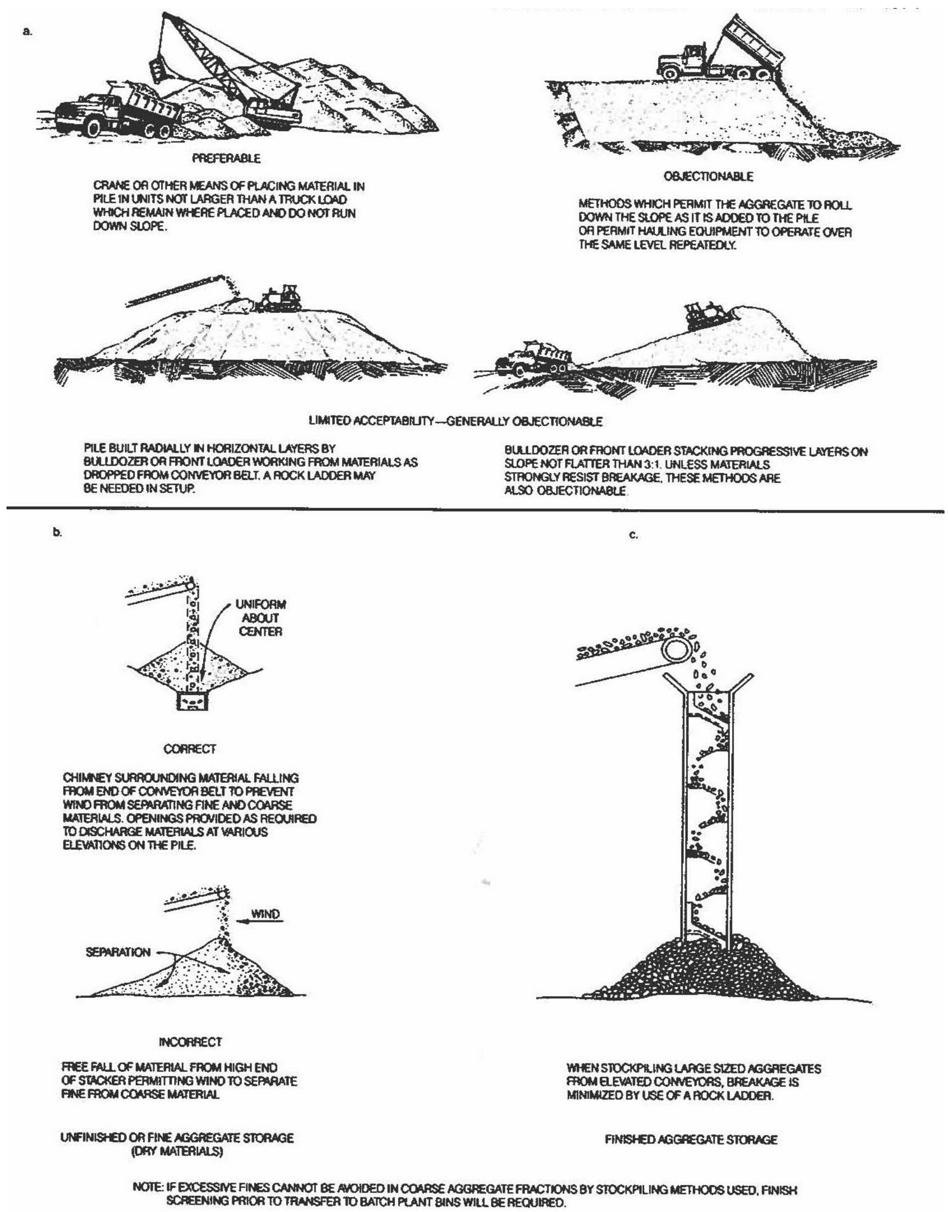


Figure 4-4. Correct and Incorrect Methods of Handling and Storing Aggregates[1].

[1] ACI Committee 304, Guide for Measuring, Mixing, Transporting and Placing Concrete. *ACI304R-00*

After the initial screening to separate the aggregates into the various primary sizes, in many plants, the aggregate will be handled several times as it is moved from stockpiles to bunkers to the batch plant where it is finally used to produce concrete.

Depending on the amount of handling and the durability of the aggregate particles, significant degradation of the coarse aggregate may take place between the initial screening and the actual batching of the concrete. With a very soft aggregate an excessive amount of fine particles may be generated through handling the coarse aggregate which could result in a combined grading that is out of the grading limits for the No. 100 and No. 200 sieves.

To mitigate the effect of degradation of coarse aggregate, plants can install equipment to remove the undersize particles by rescreening the aggregate immediately prior to batching. This process is known as finish screening.

Preliminary tests like the California Test 211 Abrasion of Coarse Aggregate by Use of the Los Angeles Rattler Machine, California Test 214 Soundness of Aggregates by Use of Sodium Sulfate, and California Test 229 Durability Index, provide assurance that the aggregate is of sufficient quality that, with reasonable care in processing and handling, the aggregate will be in an acceptable condition at the time of incorporation into the batched concrete.

Section 6 of the Construction Manual provides the Department's policy on the size, frequency, and location of sampling and testing of concrete materials. Note that aggregate to be used in structure concrete is sampled at the point of incorporation into the batched concrete. This procedure provides assurance that all the processing and handling of the aggregate has not caused significant segregation, contamination or degradation.

Cementitious Material Storage and Handling

According to ACI Guide for Measuring, Mixing, Transporting, and Placing Concrete, 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 non-clogging 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 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.

Bags of cement should be stacked on platforms to permit 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 7 layers. As an additional precaution the oldest cement should be used first.

Supplementary cementitious materials 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.

Weighing and Measuring Equipment

Concrete governed by the Standard Specification Section 90-1.02F require the aggregates and cementitious material to be proportioned by weight. There are some exceptions to this requirement such as Rapid Strength concrete and polyester concrete, which have other specifications governing their production.

Bulk cement and cementitious material are required to be separate and distinct from aggregate weighing equipment. The quantity of water may be weighed or measured by a water meter.

Proportioning by weight is preferred for its accuracy, flexibility and simplicity. The driving factor for requiring proportioning by weight is a phenomenon known as bulking. Bulking is explained as follows: a volume of moist sand in a loose condition weighs much less than the same volume of dry sand. Sand is typically stockpiled in a wet state with surface moisture in the range of 0 to 5% (Mindess and Young) and free moisture content as high as 6 to 8% can be stable in fine aggregate (Committee 304). The reason for these high moisture values is that in addition to the thin film of moisture on the sand particles, water can be held in the interstices between the particles as the result of formation of menisci. This phenomenon is illustrated in Figure 4-5 below. The formation of these menisci creates thicker films of water between particles, pushing them apart and increasing the apparent volume of the aggregate (Mindess and Young). This can result in significant errors if proportions are measured by volume. To a lesser extent, coarse aggregate is also affected.

Therefore, batching by weight is the preferred method because once the moisture content has been determined, then a ton of aggregate is a definite quantity and by using the aggregate's specific gravity the volume it occupies in the concrete can be calculated.

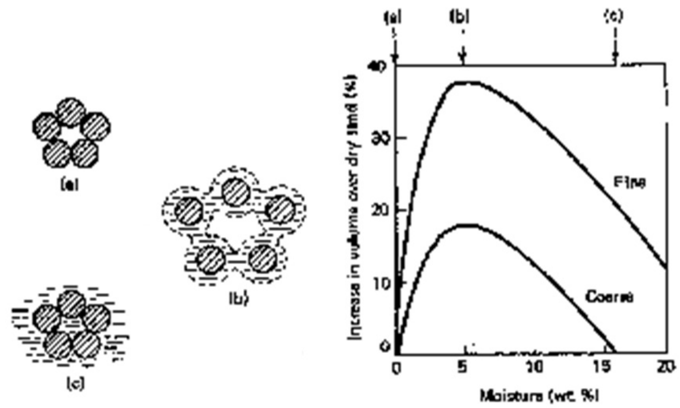


Figure 4-5. Bulking Phenomenon. (Mindess and Young)

Depending on the manner in which the aggregates are weighed, batch plants are of two general types: cumulative weighing and individual weighing. Cumulative weighing plants are equipped with a single weigh hopper and scale for all aggregates, whereas individual weighing plants are equipped with a separate weigh hopper (Figure 4-6) and scales for each size of aggregate.

The weigh hopper pictured is suspended by four hanger eyes, carried by four load cells. The load cells transmit data back to the batch plant control station. One of the load cells is pictured in Figure 4-7.

Figure 4-6. Weigh Hopper Under Aggregate Bins.

Figure 4-7. Load Cell at One Corner of a Weigh Hopper.

All working parts must be in good condition, free from friction, readily accessible for inspection and cleaning, and protected from falling or adhering material. Elements of the weigh hopper must not rub against other elements or the framework of the plant. The weighing container and the gates should be tight against leakage and the weighing system must be firmly supported on an unyielding foundation.

Weigh hoppers should clean themselves thoroughly after each batching cycle; otherwise appreciable amounts of material may become packed in the corners with the result that correct weight will be shown on the scale but something less than full weight will actually reach the mix.

Batch plant scales are relatively rugged and have a high degree of accuracy and reliability. Practically all of the working parts are clearly visible and generally accessible. Required tolerances of accuracy, however, depend on proper maintenance of the scale system. The Standard Specifications Section 9-1.01[2] requires all weighing and measuring devices used to proportion materials be tested and approved in accordance with California Test 109 Method for Testing of Material Production Plants.

[2] 2006 Standard Specifications, or 2010 Standard Specifications, Section 90-1.02B.

Under current Department of Transportation policy, a representative of the District Materials Engineer, on an annual basis, inspects all commercial batch plants furnishing material for State highway projects as prescribed by this test method. The District Materials Testing Branch maintains a file of current California Test 109 test reports for all batch plants within the District. Annual batch plant inspections are scheduled by the District Materials Testing Branch, and the owner of the plant makes arrangements. In most cases, these inspections will not involve field personnel. However, copies of the plant inspection report for a particular batch plant are furnished to projects using materials from that plant.

The testing procedures required by California Test 109 will be performed by a County Sealer of Weights and Measures, a Scale Service Agency, or by a representative of the State Division of Measurement Standards. All test procedures must be performed in the presence of the engineer.

In addition, Standard Specifications Section 9-1 requires the contractor to arrange for testing of proportioning devices as frequently as the engineer may deem necessary to ensure their accuracy. This specification gives job personnel the authority to require a supplemental plant inspection should there be any question as to the accuracy of the weighing and/or measuring equipment. Accordingly, the bridge engineer should request a California Test 109 inspection and report if there is any reason to believe the scales or other measuring or metering devices are not functioning properly. For example, erratic and unexplained variations in mix consistency and/or yield might warrant further inspection and testing of batch plant equipment.

Manual and Automatic Batching

In a manually operated batch plant, the weigh hoppers are equipped with gates that are opened and closed manually, with the accuracy of the weighing operation being dependent on the operator's visual observation of the scale. The gates may be provided with air, hydraulic or electric power assisted devices. Water metering is controlled by hand operated valves.

Most batch plants are equipped with automatic proportioning systems. These automatic systems include a means of entering the batch weights into a control mechanism and gates, which open automatically at the beginning of the weighing cycle for each material and close automatically when the designated weight of that material has been reached. Additionally, the scales are interlocked in such a manner that:

- The charging mechanism cannot be opened until the scale has returned to zero.
- The charging mechanism cannot be opened if the discharge mechanism is open.
- The discharge mechanism cannot be opened if the charging mechanism is open.

- The discharge mechanism cannot be opened until the designated weight has been reached within the allowable tolerance.

Although automatic batching is not required for structure concrete work, all automatic batching systems must meet the requirements of Standard Specifications Section 90-1.02F(4)(c).

Moisture Meters

Automatic proportioning devices are required by the Standard Specifications to be equipped with electrically actuated moisture meters to indicate the moisture content of the fine aggregate as it is batched.

Moisture meters of the type specified measure the amount of electrical current passing between a probe in the sand and the steel wall of the weigh hopper. The current measurement is converted to percent moisture to permit direct reading on the indicator scale. See Figure 4-8.

Figure 4-8. Moisture Meter at the Bottom of a Fine Aggregate Bin.

Moisture meters are not required for structure concrete work unless the concrete is produced at an automatic batch plant. This does not mean that moisture compensation is not important. To demonstrate:

Assume that 1 cubic yard mix requires 1,200 pounds of sand, 2,000 pounds of coarse aggregate and 25 gallons of water. A 1% variation in the moisture content of the sand would equal 12 pounds of water (approximately 1.5 gallons). This changes the water required by 6%. A rule of thumb guide has been that 1 gallon added to 1 cubic yard will increase the slump 1 inch.

The above example illustrates that monitoring and managing moisture content in sand is critical to consistent, quality concrete production. Moisture that is unaccounted for can significantly increase the water to cement ratio, decrease strength, increase the slump, increase shrinkage, increase cracking, and increase permeability.

> In Waddell and Dobrowolski: "Keeping sand moisture variations to a minimum is more of an art than a science and requires constant monitoring of the final product and proper response by the plant operator. This job is made easier if the plant is equipped with a moisture meter in the fine aggregate since there is no way that one can work with the current moisture and be drying samples. The moisture meter is only a tool that one must learn to use and does not alter the need for constant monitoring as the results of any sampling are related to the fact that only a very minute portion of the aggregates is sampled. It is not necessary that the meter be highly accurate as it is that the meter be responsive and has a high degree of repeatability. Thus when the meter shows a change, it's time to make an adjustment.
>
> In certain situations the moisture variations in the supply make it impossible to reach the desired slump even with the most conscientious efforts of the plant operator. In these cases the answer is to reduce the design water content and produce a mix with lower slump and then add only enough water on the job…to increase the slump into the desired range."

Reducing variations in the moisture content of the sand is beneficial in controlling water in the mix. Stockpile management can also play a role in controlling moisture. Allowing delivered sand time to reach a stable and uniform moisture content will reduce variation (Staff of Reasearch and Education Association). The Standard Specifications Section 90-1.02F requires that aggregates be dried and drained to a stable moisture content and that the fine aggregate moisture content be no more than 8% at the time of batching.

Chemical Admixtures

Standard Specifications Section 90-1.01D states that chemical admixtures used in the work must be of a type and brand on the Department's Authorized Materials List (http://www.dot.ca.gov/hq/esc/approved_products_list/pdf/Approved_Chem_Admix_List.doc). In addition to this list, the manufacturer's published information and their sales representative can be a valuable source of information pertaining to the performance of chemical admixtures. Most chemical admixtures are in a liquid form. The Standard Specifications Section 90-1.02F(4)(b) includes several requirements for admixture dispensing equipment and procedures at concrete batch plants.

When the use of a liquid admixture is required or contemplated, these requirements should be discussed with the contractor and/or concrete supplier before work begins to ensure that the procedures are understood and that the plant is equipped with the proper dispensing mechanism. Dispensing equipment must have sufficient capacity to contain and measure the total required admixture dosage for the batch (See Figure 4-9 Liquid admixture storage units). Dispensing equipment must be located so that the graduated measuring cylinder is visible to the batch plant operator.

Figure 4-9. Liquid Admixture Storage Units.

Unless liquid admixtures are added to pre-measured water for the batch, the dispensing equipment must allow the admixture to flow into the stream of batch water (see Figure 4-10 Manifold where liquid admixture enters the stream of batch water). When more than one liquid admixture is used in the mix, a separate measuring and dispensing unit is required for each admixture. The dispensing procedure must be such that the admixtures are added at different times during the batching cycle. When an air-entraining admixture is used with any other liquid admixture, the air-entraining admixture must be the first admixture dispensed into the concrete mixture. It is essential that this batching sequence be followed; otherwise the effectiveness of the air-entraining admixture may be impaired.

Figure 4-10. Manifold Where Liquid Admixture Enters the Stream of Batch Water.

Relative to the other ingredients, liquid admixtures are added to the batch in very small amounts. To ensure accurate proportioning, it is essential that specification requirements governing admixture dispensing procedure and equipment be followed, and that dispensing equipment be well maintained. Evaporation and freezing of the liquid could adversely affect the performance of the admixture. Both conditions should be avoided.

Unless the plant is approved for production of concrete pavement, there is no assurance (and no specification requirement) that the admixture dispensing equipment will be interlocked with the batching control mechanisms. Accordingly, when liquid admixtures are to be used in concrete produced at a batch plant equipped with automatic batching controls, the means by which the admixtures are added should be investigated. If the admixture dispensing equipment is not automated, addition of the admixtures must be carefully controlled to ensure the proper dosage.

Controlling Batch Temperature

Standard Specifications Section 90-1.02G(2) requires that concrete must be 50°F to 90°F immediately prior to placing. Concrete temperatures can be regulated by controlling the temperature of the ingredients. The contribution of each constituent is determined by its temperature, specific heat and weight fraction. This is the basis for Equation (4-01), which can be used to calculate the concrete temperature in either Fahrenheit or Celsius (Mindess and Young):

$$T_{concrete} = H(T_a W_a + T_c W_c) + T_a W_{wa} + T_w W_w \ / \ H(W_a + W_c) + W_{wa} + W_w \qquad (4\text{-}01)$$

Where H = the approximate specific heat of cement and aggregate (925 J/kg°C or 0.22 Btu/lb°F), W_a, W_c, W_{wa}, and W_w are weights (kg or lb) of aggregate, cement, aggregate moisture and mixing water; and T_a, T_c, and T_w are the temperatures of aggregate (including moisture), cement, and mixing water, respectively.

Using the equation, it will become apparent that the high specific heat of water offsets its small fraction of weight so that its contribution to the composite temperature of the concrete is about the same as that of the aggregate. In cooling applications the use of ice makes water even more effective since additional heat is absorbed in the melting of the ice. To capture the effect of the heat of fusion when using ice, the Equation (4-01) is modified as follows

$$T_{concrete} = H(T_a W_a + T_c W_c) + T_a W_{wa} + T_w W_w - F_i W_i \ / \ H(W_a + W_c) + W_{wa} + W_w + W_i \qquad (4\text{-}02)$$

Where W_i = the weight of ice and F_i its latent heat of fusion (335 kJ/kg or 145 Btu/lb).

Cooling Concrete

High concrete temperatures increase the water requirements to maintain a given slump; decrease setting times, and hence the time available for placement, consolidation, and finishing; increase the likelihood of plastic shrinkage; and lower the ultimate strength. Concrete should remain plastic long enough so that each lift can be placed without development of cold joints or discontinuities in the concrete. Air entrainment is also affected. The amount of air-entraining admixture required to produce a given air content increases with temperature.

High concrete temperatures are commonly related to concreting in hot weather. High concrete temperatures may also be an issue in mass concrete and lightweight concrete applications. These issues are discussed in Chapter 7 of this manual.

Many techniques exist for managing high temperatures. They range from simple and inexpensive to more complex and costly. Some simple methods include storing concrete ingredients in the shade, spraying aggregates with water, covering aggregates with reflective covers, and painting water tanks and line white.

More elaborate methods include admixtures, chilling the mixing water (see Figure 4-11 for a picture of a water chiller), using ice as some portion of the mixing water, cooling aggregates with chilled water or air, and vacuum cooling of aggregates. Also, liquid nitrogen at a temperature of –320°F can be used to chill mixing water, aggregates, or concrete (ACI Committee 304). Liquid nitrogen can be used to chill water or injected directly into central or truck mixers to achieve desired temperatures (See Figure 4-12).

Figure 4-11. Water Heater/Chiller.

Figure 4-12. Liquid Nitrogen Being Injected Into a Transit Truck to Cool the Concrete.

On a weight basis the mix water has the greatest effect on the final concrete temperature. This stems from its higher specific heat, which is about five times as high as for the other concrete-making materials. However, be weight, there is usually about ten times more aggregate than water in structure concrete.

Concrete can be cooled to a moderate extent by using chilled mixing water. The quantity of cooled water cannot exceed the mixing water requirement. The maximum reduction in concrete temperature that can be obtained is approximately 10°F. The concrete temperature equations above can be used when all variables are known but in general, if all other variables are held constant, to obtain a 1°F drop in concrete temperature the mix water temperature must be reduced by 3.6°F. For example, a concrete producer would chill the 70°F mix water down to 52°F to lower the concrete temperatures from 80°F to 75°F.

If a water chiller is not available, or the desired reductions in mix temperature involve chilling the water beyond its freezing point (32°F), ice can be used. The amount of cooling is limited by the amount of mixing water available for ice substitution. For most concrete, the maximum temperature reduction is approximately 20°F. For correct proportioning the ice must be weighed. Ice has a two-way cooling effect. First it draws heat from the concrete for melting of the ice, and then the resulting water at 32°F provides continued cooling capacity. The temperature equation to be used when ice is utilized has been provided above but, as a general rule, for every 1°F drop in concrete temperature desired, replace 2% of the total mix water with ice. For example, to cool a concrete mix containing 280 pounds per cubic yard (pcy) of water from 80°F down to 60°F, replace 40% (112 pcy) of the mix water with ice. The ice must be added directly into the concrete as part of the mixing water. With ice crushed from 0.06 inch to 0.1 inch in thickness, melting takes place in about 30 seconds.

When ice is used as a portion of the mixing water, care must be taken not to exceed the total requirements of mixing water and to verify that all the ice has melted at the time of discharge. A situation occurred where ice purchased in unit weight bags actually exceeded the weight shown on the bag and led to unintentionally exceeding the total required water. If ice is used it must be proportioned by weight as it occupies a greater volume than the same mass in liquid form. Additionally, because ice readily sublimes, bagged ice is usually packaged with a greater mass of ice than is reported on the bag and loses mass over time. If used, the weight must be verified to accurately proportion the water.

Admixtures can also be useful in controlling temperature. The moment cement contacts water, hydration begins and heat is liberated. ASTM C 494, Types D and G water reducing and retarding admixtures are beneficial in hot weather concreting due to their ability to slow the chemical reaction between water and cement and decrease the water required for a given workability.

Chilled water, ice and admixtures, used either in combination or separately, are all helpful tools for successful hot weather concreting. For more information on this topic refer to ACI 305, "*Hot Weather Concreting*."

Because of the low specific heat and relatively small mass of cementitious material in a mix its effect on the concrete temperature is minor. It requires approximately a 10°F change in the cementitious material temperature to change the concrete temperature 1°F. (Kosmatka and Panarese). The temperature of cement should not be disregarded though, see Chapter 1 of this manual for the discussion of false set and its relationship to cement temperature.

Heating Concrete

In cold weather where there is a risk of freezing the concrete, slow development of strength, and excessive thermal stresses upon cooling to ambient temperatures.

To deliver concrete within the specified temperature range, it may be necessary to heat one or more of the concrete ingredients. Overheating should be avoided as it may accelerate chemical action, cause excessive loss of slump, and increase the water requirement for a given slump. Also, the warmer the concrete is placed, the greater the drop to ambient temperatures. Correspondingly there will be a greater decrease in volume and increase in thermal stresses.

The Standard Specifications limit the heating of aggregate and water to 150°F.

Mixing and Transporting

Contract requirements governing the mixing and delivery of concrete are found in Standard Specifications Section 90-6.01[3].

All concrete used on State highway projects must be mixed in mechanically operated mixers, except that when permitted by the engineer, batches up to but not exceeding 1/3 cubic yard may be mixed by hand. See Standard Specifications Section 90-6.05[4] for requirements governing the use of hand-mixed concrete.

When mixing concrete, the objective is to obtain a workable mixture in which the various ingredients are uniformly distributed and the aggregate particles are uniformly and completely coated with the cement paste. All commercially manufactured concrete mixers are capable of meeting this objective, provided they are not overloaded, are maintained in good operating condition, and are operated at the mixing speed recommended by the manufacturer.

When charging the mixer, a small amount of water should enter the drum ahead of the solid materials. The remaining water should be added uniformly over the entire charging period.

Care must be taken to avoid loss of material during the charging cycle. Cement in particular must be charged by means that will prevent wind loss or the accumulation of cement particles on the surface of conveyors or hoppers, or any other condition that would vary or reduce the amount of cement in the mixture.

When charging truck mixers, a sock is often used to direct the material into the truck loading chute. The sock, usually made of rubber or canvas, funnels the material into the drum and prevents spillage during the charging operation (see Figures 4-13 and 4-14). If the sock is torn or badly worn, material may escape and be wasted on the ground, with a consequent loss of cement or other materials.

[3] 2006 Standard Specifications, or 2010 Standard Specifications, Section 90-1.02G.
[4] 2006 Standard Specifications, or 2010 Standard Specifications, Section 90-1.02G(5).

Figure 4-13. Sock Used at a Truck Mixer Charging Chute.

Figure 4-14. Sock Used at a Truck Mixer Charging Chute.

Equipment used to supply water to the mixer must be constructed and arranged so that the amount of water added can be accurately measured. Tanks used to measure water must be designed so that water cannot enter the tank while water is being discharged into the mixer. The amount of water added as indicated by a measuring device must be within 1.5% of the actual amount of water discharged into the mixer. The equipment must provide a means of checking the amount of water delivered by direct discharge into a container of known volume.

If retarding or air-entraining admixtures are being used, they should be added to each batch at the same time in the charging cycle. If this is not done, significant variation (from batch to batch) in the time of initial set or the percentage of entrained air may occur. When an air-entraining admixture is used with any other liquid admixture, the air-entraining admixture is typically added first. It is prudent to acquire the manufacturer's mixing recommendations whenever multiple admixtures are used in a mix design.

Mixers should not be loaded in excess of the manufacturer's rated capacity, nor should they be operated at speeds that exceed the speed designated by the manufacturer as mixing speed. Increasing production by speeding up or overloading the mixer may result in inadequately mixed concrete and should not be permitted.

Concrete mixers must be capable of producing uniform concrete. Uniformity is determined by differences in penetration or slump.

The difference in penetration and slump is found by performing the respective tests on 2 samples of mixed concrete from the same batch or truck mixer load. The maximum allowable variations are provided in Standard Specifications Section 90-1.02G(6). Similarly, the variation in the proportion of coarse aggregate is determined from the results of tests on 2 samples of mixed concrete from the same batch or truck mixer load, and may not exceed 170 pounds per cubic yard computed in accordance with California Test 529. The use of mixing equipment that cannot produce concrete meeting these requirements should not be permitted. (See Standard Specifications Section 90-1.02A)

Ready-Mixed Concrete

Ready-mixed concrete is defined as concrete that is batched, mixed and delivered to the job while in a plastic state.

Modern batching equipment and transit-mix trucks make it possible to deliver accurately proportioned concrete, mixed and ready to deposit into the forms, to virtually any location where concrete construction is contemplated. Virtually all of the concrete used in structure construction on State highway projects is ready-mixed.

Ready-mixed concrete is further classified according to the method by which the concrete is mixed and delivered. These classifications are central-mixed concrete, shrink-mixed concrete, and transit-mixed concrete.

The term “central-mixed” describes ready-mixed concrete that is mixed completely at a stationary plant, and then transported to the point of delivery in truck agitators or, when warranted by job conditions or circumstances, in non-agitating, truck-hauling equipment.

The term “shrink-mixed” describes ready-mixed concrete that is partially mixed in a stationary mixer, and then transferred to a transit-mixer where the mixing is completed. Shrink-mixed concrete is used to increase the truck’s load capacity by reducing or “shrinking” the volume of the constituent parts.

The term “transit-mixed” describes ready-mixed concrete that is mixed completely in a truck mixer. This is sometimes referred to as “dry batching” and the previous two methods as “wet batching”.

Central-Mixed Concrete

A typical central-mixing plant will include either a revolving blade mixer or a revolving drum mixer. Aggregates are conveyed to storage bins above the weigh hopper. Cement is bulk-stored in a silo and water is metered into a storage tank adjacent to the stationary mixer. Batching is automatic and a 90-second mixing time is typical, although the specifications now permit a mixing time of 50 seconds (minimum) when directed by the engineer. The maximum mixing time allowed is 5 minutes.

Central-mixed concrete may be delivered in non-agitating “dump-crete” trucks. These trucks, which typically range from 4 to 8 cubic yards capacity, have special dump boxes with smooth sides and rounded corners to facilitate dumping of the concrete. Under the current specifications, when non-agitating equipment is used, discharge must be completed within 1 hour after mixing.

Truck agitators are used for longer hauls. As is the case with the dump-crete trucks, consistency of the mixed concrete must be correct because water may not be added unless the equipment is capable of revolving at mixing speed. Central-mixed concrete transported in truck agitators must be discharged within 90 minutes after the agitator is charged. A truck agitator is pictured in Figure 4-15.

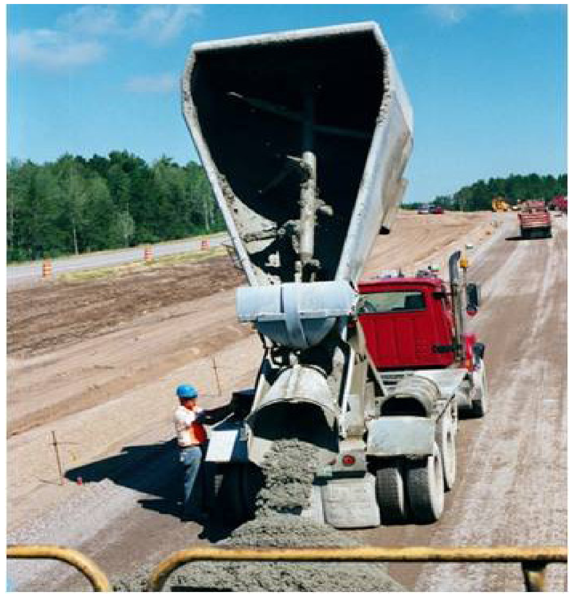


Figure 4-15. Truck Agitator.

Transit-Mixed Concrete

Many commercial concrete plants incorporate stationary mixers and thus by definition are central-mix plants. However, virtually without exception concrete for structure construction on State highway projects will be delivered to the work site in transit-mixing equipment, regardless of whether the technical description of the product is central-mixed, shrink-mixed or transit-mixed concrete. Accordingly, this discussion of transit-mixed concrete and transit-mixing equipment will be applicable to all structure concrete, including central-mixed concrete. Note also that the specifications provide that when concrete is partially mixed at a central plant (i.e., shrink-mixed concrete) all requirements for transit-mixed concrete will apply.

For discussion, a truck mixer (Figure 4-16) may be considered as three separate machines, each with a separate function to perform. First, it is a concrete mixer; second, it is an agitator-conveyor; and finally, it is a machine that can discharge its load either directly into the forms or into an intermediate conveyor such as a crane bucket or concrete pump hopper.

Figure 4-16. Truck Mixer.

The specifications require identification plates to be attached to truck mixers. These plates must show the truck's capacity as a mixer and, if applicable, as an agitator, along with mixing and agitating speeds, all as rated by the manufacturer. Mixing speed is generally not less than 6 revolutions per minute nor greater than 225 peripheral feet per minute; while agitating speed is usually between 2 and 4 revolutions per minute.

Truck mixers must be equipped with electrically or mechanically actuated revolution counters. The truck mixer should be revolving as the materials are charged into the mixing drum. Some truck mixers have a charging speed. If so, the charging speed should be used; otherwise the batch should be received at mixing speed.

Although the specifications require concrete to be mixed at the rate of rotation designated as mixing speed by the manufacturer, there is no minimum revolution requirement. The specification requirement is that the number of revolutions at mixing speed be not less than recommended by the manufacturer, and not less than the number necessary to produce uniform concrete as determined by California Tests 533 and 529 (Standard Specifications Section 90-1.02G(4)).

When water is added after the concrete reaches the job site, the specifications require a minimum of 30 revolutions at mixing speed before the concrete is discharged.

In general, the total number of revolutions is not as important as the number of revolutions at the proper mixing speed. This is the case because manufacturers give a range of mixing speeds, typically from about 6 to 16 revolutions per minute. At a very slow mixing speed, inadequate mixing may occur even though the concrete has been mixed for the minimum number of revolutions recommended by the manufacturer. Experience shows that optimum mixing will occur at a mixing speed that is slightly slower than the recommended maximum speed.

Inadequate mixing can seldom be detected by a casual observation of the mixture. Thus where conditions are such that inadequate mixing may occur, consistency and uniformity tests should be performed. These tests will also reveal inadequate mixing from causes other than an insufficient number of drum revolutions, such as worn mixer blades and other mixer deficiencies.

When transit-mixing equipment is used as an agitator-conveyor, it is generally capable of carrying a greater load. (Keep in mind, however, that when carrying a load based on agitator capacity, the truck may not be used as a mixer.)

When agitating, the mixing drum must revolve continuously. Since agitator speeds are slow, it is not always possible to judge from a distance whether the drum is revolving at the proper speed, or even if it is revolving at all.

An almost universal shortcoming of both truck mixers and truck agitators is their tendency to segregate the mix so that the last portion contains an excess of coarse aggregate. Placement of concrete should be controlled so the latter part of the batch is discharged into a location where the excess coarse aggregate will not cause difficult . Locations immediately adjacent to forms, reinforcing steel, expansion joints and other critical points should be avoided, if possible.

In general, concrete must be discharged from truck mixers within 90 minutes, or before 250 drum revolutions, from the time cement is added to the mixture. Since either elapsed time or drum revolutions may govern the discharge, both must be checked. Under conditions contributing to rapid stiffening of the concrete or when the concrete temperature is ≥ 85°F, the engineer has the authority to reduce the 90-minute period.

For a long haul, such as might be required in a rural area, the time between batching and discharge has been extended by adding the cement, not at the batching plant, but at a point closer to the work. During the haul between the batch plant and the point at which the cement is added, the mixer should not be revolving, as this would subject the aggregate to unnecessary degradation.

Inspection of Mixing Equipment

Mixers should be inspected periodically to determine whether they are in satisfactory operating condition. Any hardened concrete or mortar which has accumulated on the mixer blades should be removed and the blades inspected. Mixer blades wear more quickly in the center and a dished blade indicates excessive wear. Most manufacturers recommend repairing or replacing mixer blades when any part or section is worn more than 2 or 3 cm below the original dimensions.

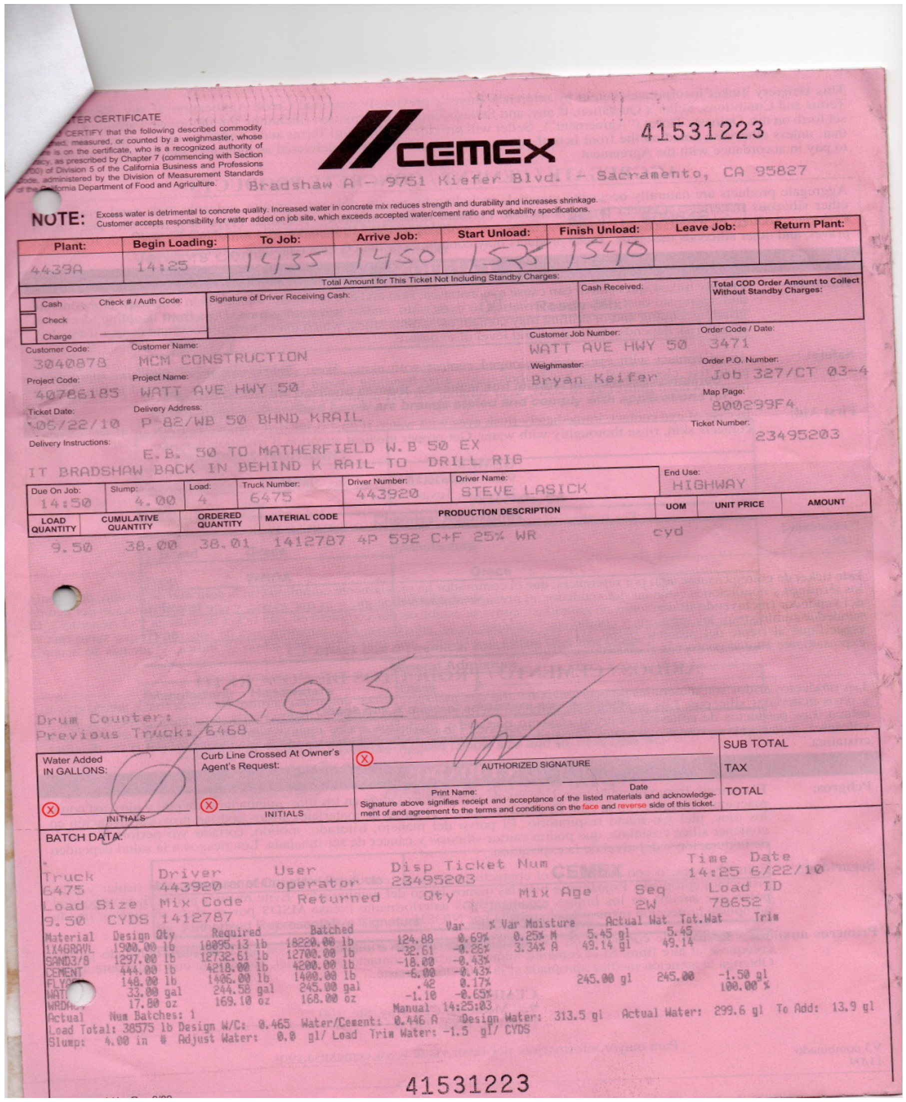
The interior of the mixer drum must be clean. Deposits of hardened concrete or mortar, which sometimes accumulate inside the drum and on the mixing blades, will reduce the effectiveness of the mixer and should be removed.

The water supply system should be inspected periodically for leaking valves and fittings. Truck mixers in particular should be checked to see that there is no leakage from the water tank into the mixing drum. Water metering equipment should be checked for accuracy by discharging into measured containers.

Transit-mixing equipment should be checked periodically to see that the revolution counters are functioning properly and that the required manufacturer's rating plate is affixed to the truck and is clean and clearly visible. The water measuring equipment should be inspected for leaks, and the accuracy of the gauge or meter verified by discharging a measured amount of water into a container of known volume.

Transporting Mixed Concrete

Specifications require that each load of concrete delivered to the job site be accompanied by a weighmaster certificate showing the mix identification number, a non-repeating load number, the date and time the material was batched, the total quantity of water added to the load for transit-mixed concrete, the revolution counter reading at the time the truck mixer is charged with cement, and actual scale weights in pounds for the ingredients batched. Figure 4-17 shows an example of a weighmaster certificate, often called a batch ticket.



ER CERTIFICATE

CERTIFY that the following described commodity ...ed, measured, or counted by a weighmaster, whose ...e is on the certificate, who is a recognized authority of ...cy, as prescribed by Chapter 7 (commencing with Section ...00) of Division 5 of the California Business and Professions ...ode, administered by the Division of Measurement Standards of the ...ornia Department of Food and Agriculture.

CEMEX

41531223

Bradshaw A - 9751 Kiefer Blvd. - Sacramento, CA 95827

NOTE: Excess water is detrimental to concrete quality. Increased water in concrete mix reduces strength and durability and increases shrinkage. Customer accepts responsibility for water added on job site, which exceeds accepted water/cement ratio and workability specifications.

Plant:	Begin Loading:	To Job:	Arrive Job:	Start Unload:	Finish Unload:	Leave Job:	Return Plant:
4439A	14:25	1435	1450	1525	1540		

Total Amount for This Ticket Not Including Standby Charges:

Cash / Check / Charge — Check # / Auth Code: — Signature of Driver Receiving Cash: — Cash Received: — Total COD Order Amount to Collect Without Standby Charges:

Customer Code: 3040878 — Customer Name: MCM CONSTRUCTION — Customer Job Number: WATT AVE HWY 50 — Order Code / Date: 3471

Project Code: 40786185 — Project Name: WATT AVE HWY 50 — Weighmaster: Bryan Keifer — Order P.O. Number: Job 327/CT 03-4

Ticket Date: 05/22/10 — Delivery Address: P 82/WB 50 BHND KRAIL — Map Page: 800299F4 — Ticket Number: 23495203

Delivery Instructions: E.B. 50 TO MATHERFIELD W.B 50 EX IT BRADSHAW BACK IN BEHIND K RAIL TO DRILL RIG

Due On Job:	Slump:	Load:	Truck Number:	Driver Number:	Driver Name:	End Use:
14:50	4.00	4	6475	443920	STEVE LASICK	HIGHWAY

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	MATERIAL CODE	PRODUCTION DESCRIPTION	UOM	UNIT PRICE	AMOUNT
9.50	38.00	38.01	1412787	4P 592 C+F 25% WR	cyd		

Drum Counter: 2.0.5

Previous Truck: 6468

Water Added IN GALLONS: — INITIALS

Curb Line Crossed At Owner's Agent's Request: — INITIALS

AUTHORIZED SIGNATURE — Print Name: — Date

Signature above signifies receipt and acceptance of the listed materials and acknowledgement of and agreement to the terms and conditions on the face and reverse side of this ticket.

SUB TOTAL / TAX / TOTAL

BATCH DATA:

Truck 6475 — Driver 443920 — User operator — Disp Ticket Num 23495203 — Time 14:25 — Date 6/22/10

Load Size 9.50 CYDS — Mix Code 1412787 — Returned — Qty — Mix Age — Seq 2W — Load ID 78652

Material	Design Qty	Required	Batched	Var	% Var	Moisture	Actual Wat	Tot.Wat	Trim
1X4GRAVL	1900.00 lb	18095.13 lb	18220.00 lb	124.88	0.69%	0.25% M	5.45 gl	5.45	
SAND3/8	1297.00 lb	12732.61 lb	12700.00 lb	-32.61	-0.26%	3.34% A	49.14 gl	49.14	
CEMENT	444.00 lb	4218.00 lb	4200.00 lb	-18.00	-0.43%				
FLY..	148.00 lb	1406.00 lb	1400.00 lb	-6.00	-0.43%				
WAT..	33.00 gal	244.58 gal	245.00 gal	.42	0.17%		245.00 gl	245.00	-1.50 gl
WRDH..	17.80 oz	169.10 oz	168.00 oz	-1.10	-0.65%				100.00 %

Actual Num Batches: 1 — Manual 14:25:03

Load Total: 38575 lb Design W/C: 0.465 Water/Cement: 0.446 A Design Water: 313.5 gl Actual Water: 299.6 gl To Add: 13.9 gl

Slump: 4.00 in @ Adjust Water: 0.0 gl/ Load Trim Water: -1.5 gl/ CYDS

41531223

Figure 4-17. Example of a Weighmaster Certificate.

The batch ticket is an indispensable tool in the quality assurance effort. Each ticket is to be collected and initialed at the job site. The following information can be assessed: Verify that the mix number on the ticket matches the mix number that was approved for the current concrete placement operation; in this example, Mix no. 1412787. The mix number may not be specific to your contract so verify that your project has been identified on the ticket; in this example, Watt Ave HWY 50. Verify that the date is accurate; in this example, batched

06-22-10. The Standard Specifications require that the concrete be discharged within 90 minutes of being batched. The time of batching is shown on the ticket; in this example, Time Batched 14:25. Weighmaster certificate and weighmaster Bryan Keifer are shown as required by the Standard Specifications. The Truck #6475 is shown on the ticket and this should be verified to be certain that the batch ticket represents the contents contained in the truck. The batch tickets are filed in the job files so notes can be placed on the ticket with the inspector's initials. The number on the drums revolution counter should be recorded on the ticket. In this case 205 revolutions were recorded. Batch weights and moisture content of the aggregates, 3.34% for sand and 0.25% for coarse aggregate, are reported. The batch weights can be compared to the weights required by the mix design and the moisture content can be used to verify the reported water in the batch.

No water in excess of that in the approved mix design can be incorporated into the concrete. If a contractor requests to add water at the job site a review of the ticket is required to evaluate if there is a balance of water that can be added without exceeding the amount contemplated by the approved mix design. If any water is added it should be noted on the ticket and initialed by the inspector. If a sample has been taken from the batch and tests performed on that sample this too can be noted on the ticket.

Time or Amount of Mixing

Although thorough mixing is essential to the production of high quality concrete, prolonged mixing beyond that necessary to produce a uniform mixture should be avoided. If a uniform, workable concrete mixture can be obtained at a given number of drum revolutions, there is no benefit to be gained by additional mixing.

Prolonged mixing, even at agitating speeds, is objectionable for several reasons. First, mixing results in a grinding action that causes degradation of aggregate particles, and this in turn increases the amount of very fine material in the mix.

Second, mixing produces friction, which raises the concrete temperature. Both of these factors reduce plasticity, which increases the amount of water needed to maintain a given consistency.

Tests by the Portland Cement Association indicate that for an average concrete (medium strong aggregate and initial concrete temperature of 70°F) the slump decreased from 13 cm to 6 cm over a 1 hour period. The slump loss was attributed to aggregate degradation, to heat generation due to friction, and to cement hydration during the mixing period. An even greater slump loss would be expected with softer aggregate, higher initial concrete temperature, and/or a longer mixing time.

Finally, for air-entrained mixes, prolonged mixing can cause a significant reduction in air content. (See Chapter 9 of this manual for a discussion of this phenomenon.)

On-Site Mixing

The specifications permit the use of paving and stationary mixers to produce structure concrete at the job site. Such mixers may be of the revolving drum or revolving blade type, may be tilting or non-tilting, and may or may not be equipped with loading skips and movable discharge chutes.

When used for structure concrete, the required mixing time for both paving and stationary mixers is greater than or equal to 90 seconds and less than 5 minutes.

In multiple-drum mixers, the transfer time between drums is counted as part of the required mixing time.

Paving and stationary mixers must be equipped with an automatic timing device, which can be set and locked. The timing device and discharge mechanism must be interlocked so that during normal operation no part of the batch will be discharged until the specified mixing time has elapsed.

References

Portland Cement Association. “*Concrete Inspection Procedures*.” John Wiley & Sons, Inc., 1975.

Portland Cement Association. “*Principles of Quality Concrete*.” John Wiley & Sons, Inc., 1975.

Kosmatka, Steven H. and William C. Panarese. “*Design and Control of Concrete Mixtures*.” Thirteenth Edition. Portland Cement Association, 1988.

Mindess, Sidney and J. Francis Young. “*Concrete*.” Prentice-Hall, Inc., 1981.

Dobrowolski, Joseph A. and Joseph J. Waddell. “*Concrete Construction Handbook*.” Third Edition. McGraw-Hill, Inc., 1993.

Staff of Research and Education Association. “*Handbook of Concrete Technology and Masonry Construction*.” Research and Education Association, 1981.

ACI Committee 304. “*Guide for Measuring, Mixing, Transporting, and Placing Concrete, ACI 304R-00*.” American Concrete Institute, 2000.

ACI Committee 305. “*Hot Weather Concreting*.”