



## CHAPTER 10

# Batching, Mixing, Transporting, and Handling Concrete

The specification, production, and delivery of concrete are achieved in different ways. The basic processes and common techniques are explained here. ASTM C 94 provides standard specifications for the manufacture and delivery of freshly mixed concrete. Standards of the Concrete Plant Manufacturers Bureau, Truck Mixer Manufacturers Bureau, and Volumetric Mixer Manufacturers Bureau can be found on the National Ready Mixed Concrete Association's website at <http://www.nrmca.org>.

Three options for ordering or specifying concrete are described in ASTM C 94:

1. Option A is performance based. It requires the purchaser to specify the compressive strength only, while the concrete producer selects the mixture proportions needed to obtain the required compressive strength.
2. Option B is prescription based. The purchaser specifies mixture proportions, including cement, water and admixture contents.
3. Option C is a mixed option. It requires the concrete producer to select the mix proportions with the minimum allowable cement content and compressive strength specified by the purchaser.

## BATCHING

Batching is the process of measuring concrete mix ingredients by either mass or volume and introducing them into the mixer. To produce concrete of uniform quality, the ingredients must be measured accurately for each batch. Most specifications require that batching be done by mass rather than by volume (ASTM C 94 or AASHTO M 157). Water and liquid admixtures can be measured accurately by either volume or mass. Volumetric batching (ASTM C 685 or AASHTO M 241) is used for concrete mixed in continuous mixers.

Specifications generally require that materials be measured for individual batches within the following

percentages of accuracy: cementitious material  $\pm 1\%$ , aggregates  $\pm 2\%$ , water  $\pm 1\%$ , and admixtures  $\pm 3\%$ .

Equipment should be capable of measuring quantities within these tolerances for the smallest batch regularly used as well as for larger batches (Fig. 10-1). The accuracy of scales and batching equipment should be checked periodically and adjusted when necessary.

Liquid chemical admixtures should be charged into the mixture as aqueous solutions. The volume of liquid, if significant, should be subtracted from the batched quantity of mixing water. Admixtures that cannot be added in solution can be either batched by mass or volume as directed by the manufacturer. Admixture dispensers should be checked frequently since errors in dispensing admixtures, particularly overdoses, can lead to serious problems in both fresh and hardened concrete.



**Fig. 10-1.** Control room for batching equipment in a typical ready mixed concrete plant. (69894)

## MIXING CONCRETE

All concrete should be mixed thoroughly until it is uniform in appearance, with all ingredients evenly distributed. Mixers should not be loaded above their rated capacities and should be operated at the mixing speed recommended by the manufacturer. Increased output should be obtained by using a larger mixer or additional mixers, rather than by speeding up or overloading the equipment on hand. If the blades of a mixer become worn or coated with hardened concrete, mixing action will be less efficient. These conditions should be corrected.

If concrete has been adequately mixed, samples taken from different portions of a batch will have essentially the same density, air content, slump, and coarse-aggregate content. Maximum allowable differences to evaluate mixing uniformity within a batch of ready mixed concrete are given in ASTM C 94 (AASHTO M 157).

Structural low-density concrete can be mixed the same way as normal-density concrete when the aggregates have less than 10% total absorption by mass or when the absorption is less than 2% by mass during the first hour after immersion in water. For aggregates not meeting these limits, mixing procedures are described in PCA (1986).

### Stationary Mixing

Concrete is sometimes mixed at the jobsite in a stationary mixer or a paving mixer (Fig. 10-2). Stationary mixers include both onsite mixers and central mixers in ready mix plants. They are available in sizes up to 9.0 m<sup>3</sup> (12 yd<sup>3</sup>) and can be of the tilting or nontilting type or the open-top revolving blade or paddle type. All types may be equipped with loading skips and some are equipped



Fig. 10-2. Concrete can be mixed at the jobsite in a stationary mixer. (58642)

with a swinging discharge chute. Many stationary mixers have timing devices, some of which can be set for a given mixing time and locked so that the batch cannot be discharged until the designated mixing time has elapsed.

Careful attention should be paid to the required mixing time. Many specifications require a minimum mixing time of one minute plus 15 seconds for every cubic meter (yard), unless mixer performance tests demonstrate that shorter periods are acceptable and will provide a uniform concrete mixture. Short mixing times can result in nonhomogenous mixtures, poor distribution of air voids (resulting in poor frost resistance), poor strength gain, and early stiffening problems. The mixing period should be measured from the time all cement and aggregates are in the mixer drum, provided all the water is added before one-fourth of the mixing time has elapsed (ACI 304R-00).

Under usual conditions, up to about 10% of the mixing water should be placed in the drum before the solid materials are added. Water then should be added uniformly with the solid materials, leaving about 10% to be added after all other materials are in the drum. When heated water is used in cold weather, this order of charging may require some modification to prevent possible rapid stiffening when hot water contacts the cement. In this case, addition of the cementitious materials should be delayed until most of the aggregate and water have intermingled in the drum. Where the mixer is charged directly from a batch plant, the materials should be added simultaneously at such rates that the charging time is about the same for all materials. If supplementary cementing materials are used, they should be added after the cement.

If retarding or water-reducing admixtures are used, they should be added in the same sequence in the charging cycle each time. If not, significant variations in the time of initial setting and percentage of entrained air may result. Addition of the admixture should be completed not later than one minute after addition of water to the cement has been completed or prior to the start of the last three-fourths of the mixing cycle, whichever occurs first. If two or more admixtures are used in the same batch of concrete, they should be added separately; this is intended to avoid any interaction that might interfere with the efficiency of any of the admixtures and adversely affect the concrete properties. In addition, the sequence in which they are added to the mix can be important too.

### Ready Mixed Concrete

Ready mixed concrete is proportioned and mixed off the project site and is delivered to the construction area in a freshly mixed and unhardened state. It can be manufactured by any of the following methods:



1. Central-mixed concrete is mixed completely in a stationary mixer (Fig. 10-3) and is delivered either in a truck agitator (Fig. 10-4 bottom), a truck mixer operating at agitating speed (Fig. 10-3), or a nonagitating truck (Fig. 10-4 top). Fig. 10-5 illustrates a central mix ready mix plant.
2. Shrink-mixed concrete is mixed partially in a stationary mixer and completed in a truck mixer.
3. Truck-mixed concrete is mixed completely in a truck mixer (Fig. 10-6).

ASTM C 94 (AASHTO M 157) notes that when a truck mixer is used for complete mixing, 70 to 100 revolutions of the drum or blades at the rate of rotation designated by the manufacturer as *mixing speed* are usually required to produce the specified uniformity of concrete. All revolutions after 100 should be at a rate of rotation designated by the manufacturer as *agitating speed*. Agitating speed is usually about 2 to 6 rpm, and mixing speed is generally about 6 to 18 rpm. Mixing at high speeds for long periods of time, about 1 or more hours, can result in concrete strength loss, temperature rise, excessive loss of entrained air, and accelerated slump loss.

When truck mixers are used, ASTM C 94 (AASHTO M 157) also limits the time between batching and complete discharge of the concrete at the job site; this time is  $1\frac{1}{2}$  hours or before the drum has revolved 300 times after introduction of water to the cement and aggregates or the cement to the aggregates. Mixers and agitators should always be operated within the limits for volume and speed of rotation designated by the equipment manufacturer.



Fig. 10-3. Central mixing in a stationary mixer of the tilting drum type with delivery by a truck mixer operating at agitating speed. (69926)



Fig 10-4. (top) Nonagitating trucks are used with central-mix batch plants where short hauls and quick concrete discharge allows the rapid placement of large volumes of concrete. (bottom) Truck agitators are also used with central-mix batch plants. Agitation mixing capabilities allow truck agitators to supply concrete to projects with slow rates of concrete placement and at distances greater than nonagitating trucks. (69897, 69898)

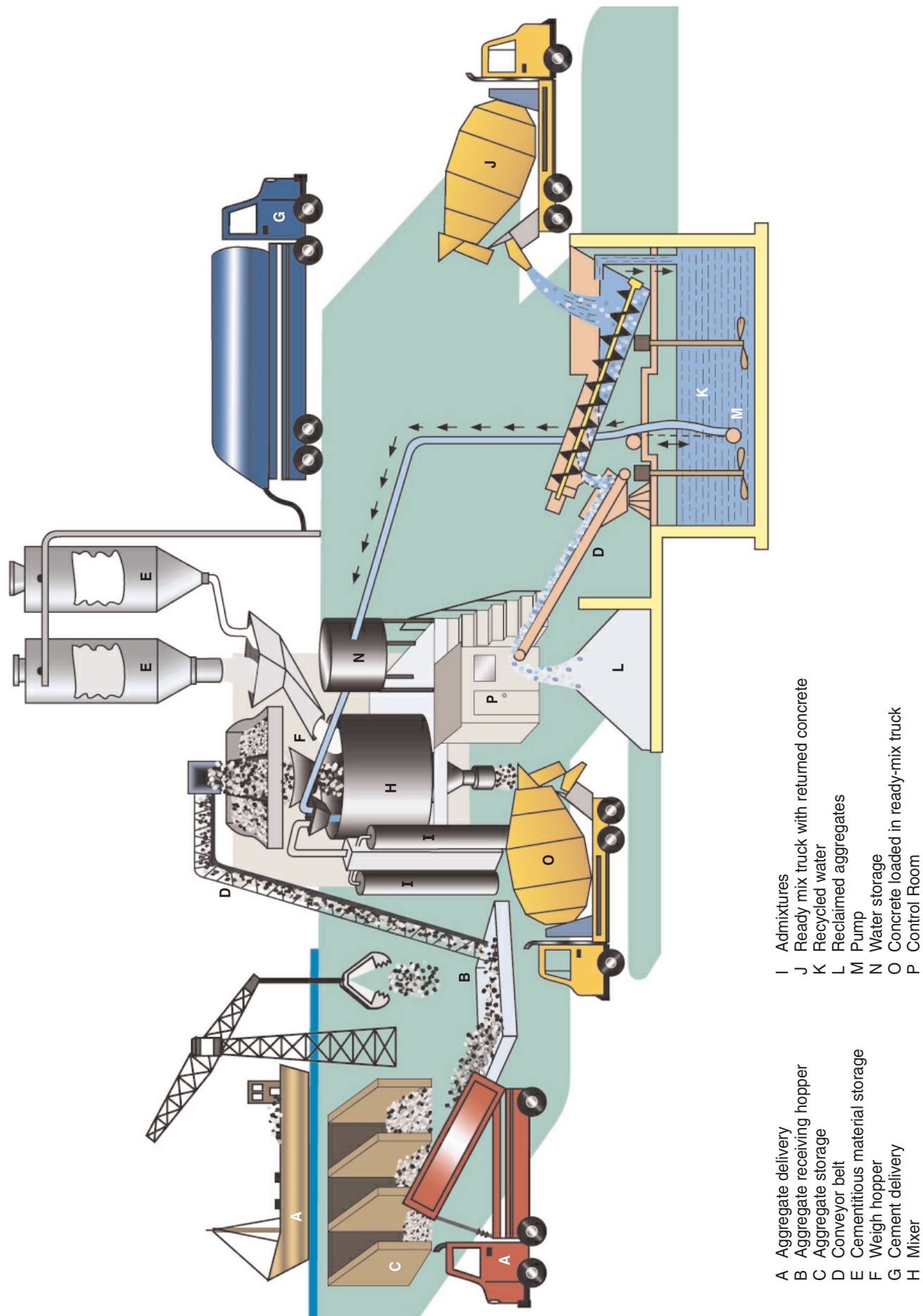


Fig. 10-5. Schematic of a ready mix plant.





Fig. 10-6. Truck-mixed concrete is mixed completely in a truck mixer. (1153)

### Mobile Batcher Mixed Concrete (Continuous Mixer)

Mobile volumetric mixers are special trucks (Fig. 10-7) that batch by volume and continuously mix concrete as the dry concrete ingredients, water, and admixtures are continuously fed into a mixing trough, typically an auger system. The concrete must conform to ASTM C 685 (AASHTO M 241) specifications and is proportioned and mixed at the jobsite in the quantities needed. The concrete mixture is also easily adjusted for project placement and weather conditions.

### Remixing Concrete

Fresh concrete that is left to agitate in the mixer drum tends to stiffen before initial set develops. Such concrete may be used if upon remixing it becomes sufficiently plastic to be compacted in the forms. ASTM C 94 (AASHTO M 157) allows water to be added to remix the concrete when the truck arrives on the jobsite and the slump is less than specified providing the following conditions are met: (1) maximum allowable water-cement ratio is not exceeded as calculated including surface water on aggregates as well as batch water and water added on site; (2) maximum allowable slump is not exceeded; (3) maximum allowable mixing and agitating time (or drum revolutions) are not exceeded; and (4) concrete is remixed for a minimum of 30 revolutions at mixing speed or until the uniformity of the concrete is within the limits described in ASTM C 94 (AASHTO M 157). Water should not be added to a partial load. If early



Fig. 10-7. Mobile batcher measures materials by volume and continuously mixes concrete as the dry ingredients, water, and admixtures are fed into a mixing trough at the rear of the vehicle. (54087)

setting becomes a persistent problem, a retarder may be used to control early hydration, especially in high-cement-content mixes. Mixture adjustments at the jobsite for air entrainment, and the addition of other admixtures, is permitted, followed by sufficient mixing.

Indiscriminate addition of water to make concrete more fluid should not be allowed because this lowers the quality of concrete. The later addition of water and remixing to retemper the mixture can result in marked strength reduction.

## TRANSPORTING AND HANDLING CONCRETE

Good advanced planning can help choose the appropriate handling method for an application. Consider the following three occurrences that, should they occur during handling and placing, could seriously affect the quality of the finished work:

**Delays.** The objective in planning any work schedule is to produce the fastest work with the best labor force and the proper equipment for the work at hand. Machines for transporting and handling concrete are being improved all the time. The greatest productivity will be achieved if the work is planned to get the most out of personnel and equipment and if the equipment is selected to reduce the delay time during concrete placement.

**Early Stiffening and Drying Out.** Concrete begins to stiffen as soon as the cementitious materials and water are mixed, but the degree of stiffening that occurs in the first 30 minutes is not usually a problem; concrete that is kept agitated generally can be placed and compacted within 1½ hours after mixing unless hot concrete temperatures or

high cement contents speed up hydration excessively. Planning should eliminate or minimize any variables that would allow the concrete to stiffen to the extent that full consolidation is not achieved and finishing becomes difficult. Less time is available during conditions that hasten the stiffening process, such as hot and dry weather, use of accelerators, and use of heated concrete.

**Segregation.** Segregation is the tendency for coarse aggregate to separate from the sand-cement mortar. This results in part of the batch having too little coarse aggregate and the remainder having too much. The former is likely to shrink more and crack and have poor resistance

to abrasion. The latter may be too harsh for full consolidation and finishing and is a frequent cause of honeycombing. The method and equipment used to transport and handle the concrete must not result in segregation of the concrete materials.

## Methods and Equipment for Transporting and Handling Concrete

Table 10-1 summarizes the most common methods and equipment for moving concrete to the point where it is needed.

**Table 10-1. Methods and Equipment for Transporting and Handling Concrete**

Equipment	Type and range of work for which equipment is best suited	Advantages	Points to watch for
Belt conveyors	For conveying concrete horizontally or to a higher or lower level. Usually positioned between main discharge point and secondary discharge point.	Belt conveyors have adjustable reach, traveling diverter, and variable speed both forward and reverse. Can place large volumes of concrete quickly when access is limited.	End-discharge arrangements needed to prevent segregation and leave no mortar on return belt. In adverse weather (hot, windy) long reaches of belt need cover.
Belt conveyors mounted on truck mixers	For conveying concrete to a lower, horizontal, or higher level.	Conveying equipment arrives with the concrete. Adjustable reach and variable speed.	End-discharge arrangements needed to prevent segregation and leave no mortar on return belt.
Buckets	Used with cranes, cableways, and helicopters for construction of buildings and dams. Convey concrete directly from central discharge point to formwork or to secondary discharge point.	Enables full versatility of cranes, cableways, and helicopters to be exploited. Clean discharge. Wide range of capacities.	Select bucket capacity to conform to size of the concrete batch and capacity of placing equipment. Discharge should be controllable.
Chutes on truck mixers	For conveying concrete to a lower level, usually below ground level, on all types of concrete construction.	Low cost and easy to maneuver. No power required; gravity does most of the work.	Slopes should range between 1 to 2 and 1 to 3 and chutes must be adequately supported in all positions. End-discharge arrangements (downpipe) needed to prevent segregation.
Cranes and buckets	The right equipment for work above ground level.	Can handle concrete, reinforcing steel, formwork, and sundry items in bridges and concrete-framed buildings.	Has only one hook. Careful scheduling between trades and operations is needed to keep crane busy.
Dropchutes	Used for placing concrete in vertical forms of all kinds. Some chutes are one piece tubes made of flexible rubberized canvas or plastic, others are assembled from articulated metal cylinders (elephant trunks).	Dropchutes direct concrete into formwork and carry it to bottom of forms without segregation. Their use avoids spillage of grout and concrete on reinforcing steel and form sides, which is harmful when off-the-form surfaces are specified. They also will prevent segregation of coarse particles.	Dropchutes should have sufficiently large, splayed-top openings into which concrete can be discharged without spillage. The cross section of dropchute should be chosen to permit inserting into the formwork without interfering with reinforcing steel.
Mobile batcher mixers	Used for intermittent production of concrete at jobsite, or where only small quantities are required.	A combined materials transporter and mobile batching and mixing system for quick, precise proportioning of specified concrete. One-man operation.	Trouble-free operation requires good preventive maintenance program on equipment. Materials must be identical to those in original mix design.

**Table 10-1. Methods and Equipment for Transporting and Handling Concrete (Continued)**

<b>Equipment</b>	<b>Type and range of work for which equipment is best suited</b>	<b>Advantages</b>	<b>Points to watch for</b>
Nonagitating trucks	Used to transport concrete on short hauls over smooth roadways.	Capital cost of nonagitating equipment is lower than that of truck agitators or mixers.	Concrete slump should be limited. Possibility of segregation. Height is needed for high lift of truck body upon discharge.
Pneumatic guns (shotcrete)	Used where concrete is to be placed in difficult locations and where thin sections and large areas are needed.	Ideal for placing concrete in freeform shapes, for repairing structures, for protective coatings, thin linings, and building walls with one-sided forms.	Quality of work depends on skill of those using equipment. Only experienced nozzle men should be employed.
Pumps	Used to convey concrete directly from central discharge point at jobsite to formwork or to secondary discharge point.	Pipelines take up little space and can be readily extended. Delivers concrete in continuous stream. Pump can move concrete both vertically and horizontally. Truck-mounted pumps can be delivered when necessary to small or large projects. Tower-crane mounted pump booms provide continuous concrete for tall building construction.	Constant supply of freshly-mixed concrete is needed with average consistency and without any tendency to segregate. Care must be taken in operating pipeline to ensure an even flow and to clean out at conclusion of each operation. Pumping vertically, around bends, and through flexible hose will considerably reduce the maximum pumping distance.
Screw spreaders	Used for spreading concrete over large flat areas, such as in pavements and bridge decks.	With a screw spreader a batch of concrete discharged from a bucket or truck can be quickly spread over a wide area to a uniform depth. The spread concrete has good uniformity of compaction before vibration is used for final compaction.	Screw spreaders are normally used as part of a paving train. They should be used for spreading before vibration is applied.
Tremies	For placing concrete under-water.	Can be used to funnel concrete down through the water into the foundation or other part of the structure being cast.	Precautions are needed to ensure that the tremie discharge end is always buried in fresh concrete, so that a seal is preserved between water and concrete mass. Diameter should be 250 to 300 mm (10 to 12 in.) unless pressure is available. Concrete mixture needs more cement, 390 kg/m <sup>3</sup> (658 lb/yd <sup>3</sup> ), and greater slump, 150 to 230 mm (6 to 9 in.), because concrete must flow and consolidate without any vibration.
Truck agitators	Used to transport concrete for all uses in pavements, structures, and buildings. Haul distances must allow discharge of concrete within 1½ hours, but limit may be waived under certain circumstances.	Truck agitators usually operate from central mixing plants where quality concrete is produced under controlled conditions. Discharge from agitators is well controlled. There is uniformity and homogeneity of concrete on discharge.	Timing of deliveries should suit job organization. Concrete crew and equipment must be ready onsite to handle concrete.
Truck mixers	Used to transport concrete for uses in pavements, structures, and buildings. Haul distances must allow discharge of concrete within 1½ hours, but limit may be waived under certain circumstances.	No central mixing plant needed, only a batching plant, since concrete is completely mixed in truck mixer. Discharge is same as for truck agitator.	Timing of deliveries should suit job organization. Concrete crew and equipment must be ready onsite to handle concrete. Control of concrete quality is not as good as with central mixing.
Wheelbarrows and buggies	For short flat hauls on all types of onsite concrete construction, especially where accessibility to work area is restricted.	Very versatile and therefore ideal inside and on jobsites where placing conditions are constantly changing.	Slow and labor intensive.



There have been few, if any, major changes in the principles of conveying concrete during the last 75 years. What has changed is the technology that led to development of better machinery to do the work more efficiently. The wheelbarrow and buggy, although still used, have advanced to become the power buggy (Fig. 10-8); the bucket hauled over a pulley wheel has become the bucket and crane (Fig. 10-9); and the horse-drawn wagon is now the ready mixed concrete truck (Figs. 10-10 and 10-11).



**Fig. 10-8. Versatile power buggy can move all types of concrete over short distances. (54088)**



**Fig. 10-9. Concrete is easily lifted to its final location by bucket and crane. (69687)**



**Fig. 10-10. Ready mixed concrete can often be placed in its final location by direct chute discharge from a truck mixer. (54955)**



**Fig. 10-11. In comparison to conventional rear-discharge trucks, front-discharge truck mixers provide the driver with more mobility and control for direct discharge into place. (70006)**

Years ago concrete was placed in reinforced concrete buildings by means of a tower and long chutes. This was a guyed tower centrally placed on the site with a hopper at the top to which concrete was hauled by winch. A series of chutes suspended from the tower allowed the concrete to flow by gravity directly to the point required. As concrete-framed buildings became taller, the need to hoist reinforcement and formwork as well as concrete to higher levels led to the development of the tower crane—a familiar sight on the building skyline today (Fig. 10-12). It is fast and versatile, but the fact that it has only one hook must be considered when planning a job.

The conveyor belt is old in concept and much changed over the years (Fig. 10-13). Recently, truck-mixer-mounted conveyor belts have come into use (Fig. 10-14). The pneumatic process for shotcreting was patented in 1911 and is





Fig. 10-12. The tower crane and bucket can easily handle concrete for tall-building construction. (69969)



Fig. 10-13. The conveyor belt is an efficient, portable method of handling concrete. A dropchute prevents concrete from segregating as it leaves the belt; a scraper prevents loss of mortar. Conveyor belts can be operated in series and on extendable booms of hydraulic cranes. (69896)



Fig. 10-14. A conveyor belt mounted on a truck mixer places concrete up to about 12 meters (40 feet) without the need for additional handling equipment. (53852)

literally unchanged (see Chapter 18). The first mechanical concrete pump was developed and used in the 1930s and the hydraulic pump was developed in the 1950s. The advanced mobile pump with hydraulic placing boom (Fig. 10-15) is probably the single most important innovation in concrete handling equipment. It is economical to use in placing both large and small quantities of concrete, depending on jobsite conditions. For small to medium size projects, a combination of truck mixer and boom pump can be used to transport and place concrete. The screw spreader (Fig. 10-16) has been very effective in placing and distributing concrete for pavements. Screw spreaders can place a uniform depth of concrete quickly and efficiently.



Fig. 10-15. (top) A truck-mounted pump and boom can conveniently move concrete vertically or horizontally to the desired location. (bottom) View of concrete discharging from flexible hose connected to rigid pipeline leading from the pump. Rigid pipe is used in pump booms and in pipelines to move concrete over relatively long distances. Up to 8 m (25 ft) of flexible hose may be attached to the end of a rigid line to increase placement mobility. (69968, 69966)



**Fig. 10-16. The screw spreader quickly spreads concrete over a wide area to a uniform depth. Screw spreaders are used primarily in pavement construction. (69895)**

See Panarese (1987) for extensive information on methods to transport and handle concrete.

## Choosing the Best Method

The first thing to look at is the type of job, its physical size, the total amount of concrete to be placed, and the time schedule. Studying the job details further will tell how much of the work is below, at, or above ground level. This aids in choosing the concrete handling equipment necessary for placing concrete at the required levels.

Concrete must be moved from the mixer to the point of placement as rapidly as possible without segregation or loss of ingredients. The transporting and handling equipment must have the capacity to move sufficient concrete so that cold joints are eliminated.

## Work At and Below Ground Level

The largest volumes of concrete in a typical job usually are either below or at ground level and therefore can be placed by methods different from those employed on the superstructure. Concrete work below ground can vary enormously—from filling large-diameter bored piles or massive mat foundations to the intricate work involved in basement and subbasement walls. A crane can be used to handle formwork, reinforcing steel, and concrete. However, the crane may be fully employed erecting formwork and reinforcing steel in advance of the concrete, and other methods of handling the concrete may have to be used to place the largest volume in the least time.

Possibly the concrete can be chuted directly from the truck mixer to the point needed. Chutes should be metal or metal lined. They must not slope greater than 1 vertical to 2 horizontal or less than 1 vertical to 3 horizontal. Long

chutes, over 6 meters (20 ft), or those not meeting slope standards must discharge into a hopper before distribution to point of need.

Alternatively, a concrete pump can move the concrete to its final position (Fig. 10-15). Pumps must be of adequate capacity and capable of moving concrete without segregation. The loss of slump caused by pressure that forces mix water into the aggregates as the mix travels from pump hopper to discharge at the end of the pipeline must be minimal—not greater than 50 mm (2 in). The air content generally should not be reduced by more than 2 percentage points during pumping. Air loss greater than this may be caused by a boom configuration that allows the concrete to fall excessively. In view of this, specifications for both slump and air content should be met at the discharge end of the pump. Pipelines must not be made of aluminum or aluminum alloys to avoid excessive entrainment of air; aluminum reacts with cement alkali hydroxides to form hydrogen gas which can result in serious reduction in concrete strength.

Belt conveyors are very useful for work near ground level. Since placing concrete below ground is frequently a matter of horizontal movement assisted by gravity, lightweight portable conveyors can be used for high output at relatively low cost.

## Work Above Ground Level

Conveyor belt, crane and bucket, hoist, pump, or the ultimate sky-hook, the helicopter, can be used for lifting concrete to locations above ground level (Fig. 10-17). The tower crane (Fig. 10-12) and pumping boom (Fig. 10-18) are the right tools for tall buildings. The volume of concrete needed per floor as well as boom placement and length affect the use of a pump; large volumes minimize pipeline movement in relation to output.

The specifications and performance of transporting and handling equipment are being continuously improved. The best results and lowest costs will be realized if the work is planned to get the most out of the equipment and if the equipment is flexibly employed to reduce total job cost. Any method is expensive if it does not get the job done. Panarese (1987) is very helpful in deciding which method to use based on capacity and range information for various methods and equipment.





**Fig. 10-17.** For work aboveground or at inaccessible sites, a concrete bucket can be lifted by helicopter. (Source: Paschal)



**Fig. 10-18.** A pump boom mounted on a mast and located near the center of a structure can frequently reach all points of placement. It is especially applicable to tall buildings where tower cranes cannot be tied up with placing concrete. Concrete is supplied to the boom through a pipeline from a ground-level pump. Concrete can be pumped hundreds of meters (feet) vertically with these pumping methods. (49935)

## REFERENCES

ACI Committee 304, *Guide for Measuring, Mixing, Transporting, and Placing Concrete*, ACI 304R-00, ACI Committee 304 Report, American Concrete Institute, Farmington Hills, Michigan, 2000.

ACI Committee 304, *Placing Concrete by Pumping Methods*, ACI 304.2R-96, ACI Committee 304 Report, American Concrete Institute, Farmington Hills, Michigan, 1996.

ACI Committee 304, *Placing Concrete with Belt Conveyors*, ACI 304.4R-95, ACI Committee 304 Report, American Concrete Institute, Farmington Hills, Michigan, 1995.

ACI Committee 301, *Specifications for Structural Concrete*, ACI 301-99, ACI Committee 301 Report, American Concrete Institute, Farmington Hills, Michigan, 1999.

Haney, James T., and Meyers, Rodney A., *Ready Mixed Concrete—Plant and Truck Mixer Operations and Quality Control*, NRMCA Publication No. 172, National Ready Mixed Concrete Association, Silver Spring, Maryland, May 1985.

Panarese, William C., *Transporting and Handling Concrete*, IS178, Portland Cement Association, 1987.

PCA, *Concrete for Small Jobs*, IS174, Portland Cement Association, [http://www.portcement.org/pdf\\_files/IS174.pdf](http://www.portcement.org/pdf_files/IS174.pdf), 1988.

PCA, *Structural Lightweight Concrete*, IS032, Portland Cement Association, [http://www.portcement.org/pdf\\_files/IS032.pdf](http://www.portcement.org/pdf_files/IS032.pdf), 1986.