Guide to Placing Concrete by Pumping Methods Guide to Placing Concrete by Pumping Methods

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Guide to Placing Concrete by Pumping Methods

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This guide discusses the use of pumps for transporting and placing concrete. Rigid and flexible pipelines, couplings and other accessories, and the various types of concrete pumps are discussed. The importance of proportioning a pumpable concrete mixture is emphasized with reference to sources for further direction on its design. Evaluation of trial mixtures to ensure pumpability and strength is encouraged. Of specific importance is a discussion on the use of lightweight aggregates. Methods to saturate these aggregates and provide a consistent moisture content are discussed.

Preconstruction planning for equipment placement and line routing are emphasized. Discussions on achieving a consistent mixture and its critical importance are also addressed.

Keywords: blockage; boundary layer; concrete pump; coupling; mixture design; pipeline; placing boom; preprimed; pumpability; reverse pumping; valve.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Pumping concrete through metal pipelines by piston pumps was introduced to the United States in Milwaukee, WI, in 1933 (Ball 1933). This concrete pump used mechanical linkages to operate, and usually pumped through pipelines 6 in. (150 mm) or larger in diameter.

Many new developments have since been made in the concrete pumping field. These include new and improved pumps, truck-mounted and stationary placing booms, and pipelines and hoses that withstand higher pumping pressures. Pumps are available with maximum theoretical output capacities of over 250 yd^3/h (190 m^3/h). As a result of these innovations, concrete placement by pumps has become one of the most widely used practices of the construction industry.

The construction industry recognizes that concrete pumping is useful when space for construction equipment is limited. Cranes and hoists are freed up and other crafts can work unhampered while pumping is in progress. Concrete pumps are designed to deliver the best combination of volume output and concrete line pressure possible.

How well the pump performs in an application depends on many factors, both internal and external to the equipment itself—for example, ambient temperature influences pump performance. Pipe diameter, pumping direction both for vertical and horizontal distance, and concrete mixture characteristics also have an effect.

As construction designs and projects become more sophisticated, such as requiring higher strength and greater durability, concrete mixture design today is more complex than what was traditionally placed (Putzmeister America, Inc 2010; American Concrete Pumping Association 2007, 2010, 2011b).

Pumpability is one consideration the contractor can request from the designer when specifying mixtures. Engineered mixtures, using special materials and processing, must consider design details including final strength, curing characteristics, site conditions such as underwater placement, material and handling expenses, flow characteristics, delivery/placement, and sustainability impacts. In cases where these features are in direct conflict, a compromise or alternate solution is necessary. Given the popularity and benefits of placement by pumping, it could become critical to a specific application that the components and proportions of a mixture be designed with consideration of pumpability.

There are many variables that could affect the successful pumping of a mixture in an application, including the specific requirements of a specific combination of materials, equipment components, and installation circumstances, of which several will be discussed in more detail in this guide.

This guide discusses concrete placement using the pumping method and how it affects the supplied concrete mixture when considering pumpability in mixture design, and with the goal to obtain optimum concrete pumping results.

1.2—Scope

This guide for concrete pumping discusses equipment use, proper mixtures for good pumpability, and field practices. References cited provide more detailed information on specific subjects. This guide does not address shotcreting or pumping of nonstructural insulating or cellular concrete.

CHAPTER 2—DEFINITIONS

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology", https://www.concrete.org/store/productdetail.aspx?ItemID=CT13. Definitions provided herein complement that source.

boundary layer—thin coating of mortar fraction that lines the inner pipeline wall during pumping.

degree of pumpability—the amount of resistance of a specific concrete mixture to being pumped through a delivery pipeline.

pumpability—capability of a specific concrete mixture to being pumped through a delivery pipeline.

relative movement—ability of concrete components to navigate small distances within the mixture and to position differently compared to the other components.

stable concrete—concrete mixture that resists the tendency to segregate.

CHAPTER 3—PUMPING CONCRETE

Pumped concrete moves as a cylinder riding on a thin lubricating film of grout or mortar on the inside diameter of the pipeline. Before pumping begins, the entire pipeline's interior diameter must be coated with either grout or a specialized commercial primer using the methods for 100 percent coating of the pipe walls as recommended by the manufacturer. Once concrete flow through the pipeline is established, the lubrication will be maintained as long as pumping continues with a properly proportioned and consistent mixture. A steady supply of pumpable concrete, defined as a mixture that is capable of being pumped through a hose or pipe, is necessary for satisfactory pumping (U.S. Bureau of Reclamation 1981). A pumpable concrete, such as conventional concrete, requires good quality control; that is, it is uniform, has properly graded aggregate, and its materials are uniformly batched and mixed thoroughly.

3.1—Mixture component distribution

3.1.1 *Boundary layer*—From the concrete pump's delivery cylinder to the point-of-placement end hose, effective and efficient concrete pumping depends on minimizing any drag caused by the inside wall of the delivery vessel. One suggestion is to have the inside wall continuously bordered by a boundary layer that gives the least resistance to movement as possible. At the start of each placement or "pour," to which it is sometimes referred, this boundary layer is achieved by priming the line with a thin film of grout or commercial primer. This coating provides a slicker surface with lower frictional resistance for the mixture to glide along than would a steel pipe or rubber hose.

To ensure that this low resistance-force action continues, the mixture should have enough mortar content to maintain a boundary layer between the body of mixture and the pipeline wall. This is similar to the need for a certain level of workability resulting from the mortar fraction when finishing concrete.

A boundary layer allows the concrete mass to move through the pipeline without the aggregates scraping the pipe wall. If scraping occurs, the contact friction causes resistance to pumping. The magnitude of the pumping resistance depends on the aggregate, pipe wall composition, and line pressure pushing the aggregate into the wall. This resistance is somewhat self-perpetuating because the line pressure increases the friction of the concrete being pumped, which in turn increases the amount of pressure in the line.

The boundary layer also increases the useful life of the pipeline. If the pipeline wall is not subjected to frictional scraping, it is more likely to remain coated and less likely to be worn down or damaged. This extends the amount of material that can be safely pumped through it before a replacement is needed.

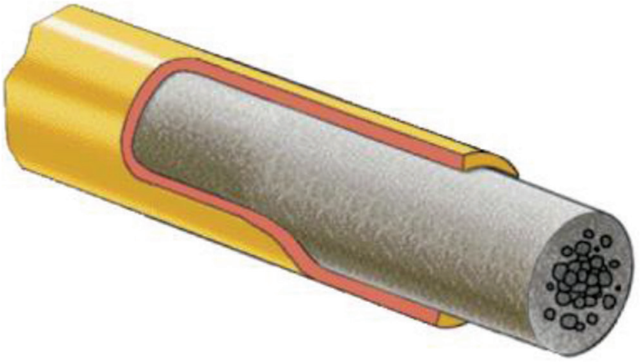
3.1.2 *Mortar content*—In addition to the need for a mortar-based boundary layer, the remaining concrete mass also requires a minimum amount of mortar to transport efficiently through the pipeline (Fig. 3.1.2). With a properly proportioned mortar content, the concrete mixture will:

a) Provide enough mortar fraction to suspend the aggregate during pumping, as well as facilitate finishing and strength development.

b) Quickly achieve a preferred arrangement with all components located in positions that best arranges them to both physical and electrostatic attraction/repulsion characteristics. This spatial arrangement remains intact unless it is forced to change to navigate pipeline elbows and reducers.

c) Create a shear-style flow. Because concrete pumping is not done completely through straight pipes of a constant diameter, the mixture requires a relative movement of components as it is transported through elbows and reducers. A mixture with a low barrier to movement or low viscosity will have the ability to change component locations more easily through this shear-style flow. The components near the pipe axis will flow faster than those closer to the pipeline wall. In a high-viscosity mixture, relative movement and component shifts are minimized, which could cause aggregate/wall abrasion and frictional resistance. The objective is to avoid working with a difficult mixture.

3.1.3 *Fiber reinforcement*—The addition of reinforcing fibers binds up the components in the pipeline into a preferred arrangement, effectively increasing the viscosity of the mixture. Their effect on pumpability is dependent on how much the fibers restrict component shifting, and how often they can penetrate the boundary layer and scrape the pipe wall.



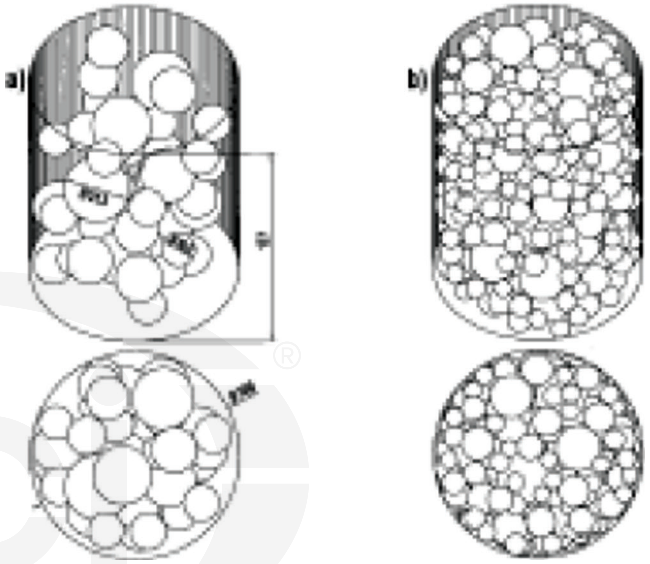


Fig. 3.1.2—Mixture component spatial arrangement.

3.2—Disruptions to flow

3.2.1 *Turbulence makers*—Pipeline components can interfere with the orderly flow of mixture, which can both increase pressure needed to pump at the desired volume output and decrease the useful life of the pipeline. Because these disruptive sources can be found to some degree between the delivery cylinder and delivery pipeline, if a difficult mixture makes it through the first 20 ft (6.1 m) of a delivery system, it has a greater chance of success from a pumpability standpoint.

3.2.1.1 *Elbows*—The mixture has a momentum during pumping that tends to carry the aggregate away from the center of the pipeline and toward the outside wall of an elbow. In addition, due to the increased surface area at the outside radius, there is typically a decrease in the boundary layer thickness at the outside radius and an increase in the boundary layer at the inside radius. Depending on the conditions and mixture, the aggregate could then temporarily pierce through the boundary layer and contact the inner wall, causing it to either scrape the wall or twist enough to leverage other aggregates into piercing the boundary layer.

3.2.1.2 *Reducers*—

a) **Material cylinders:** Pulling concrete into material cylinders requires slow speeds because it is sucking in at very low pressure and should avoid sucking in air; inefficient delivery and compressible air can cause dangerous hose whip at the boom tip. For slow-speed, high-volume output, and cylinders short enough to fit on the truck, a larger diameter is needed.

b) **Pipeline:** A smaller diameter is equal to higher pressures, so use the largest diameter practical. A diameter of 5 in. (125 mm) is the most common on truck mounts, and 4 in. (100 mm) or smaller on lay-down pipelines due to handling of heavy/filled pipe sections. Reducing near the end creates a backpressure of concrete in line and, thus, a more even flow that does not increase pressure too much. Transition from 8 in./11 in. (200 mm/280 mm) material cylinder down to 5 in. (125 mm) pipeline is completed immediately: 1) close to the source of hydraulic power; and 2) with practical ease of supporting component filled with concrete, as the delivery pipeline uses components that reduce the diameter of the concrete. Because the area of the pipe cross section decreases rapidly with restriction in diameter, the material is being forced to move faster to transport the same rate of output. This increases the shear frictional forces and the pressure-related friction caused by aggregate penetrating through the boundary layer. The net result is a much higher required pumping pressure, localized component wear, and the greatest potential for a pipeline blockage.

Because the mortar fraction of a mixture in transit is constant, the percentage of a pipe's cross section that makes up the boundary layer has to be constant. In the smaller-diameter pipe, this means the thickness of the boundary layer has to decrease relative to the larger-diameter pipes preceding it.

3.2.1.3 *Gaps, dents, and edges*—If any feature exists within the delivery system, such as a hopper transition valve, it will interrupt the continuous inner wall, the flow of the boundary layer will be disturbed, and destructive turbulence will occur. Gaps at pipeline connections, dents in pipes, and exposed edges due to mismatches in pipe diameter all create turbulence that will increase resistance to flow, which in turn increases pumping power requirements, which will eventually result in the rapid removal of line component material at or near that point.

3.2.2 *Breakdowns and blockages*—Concrete pumping is only possible if the pipeline remains blockage-free and the mixture remains stable (nonsegregating). Take the following actions, proactively, to avoid problems in pumping:

a) The mixture must be designed, created, and delivered with the proper components and proportions.

b) The pipeline must be properly prepared (primed) prior to pumping.

c) The delivery pipeline should always be watertight (leakproof) to avoid a loss of water or paste. Leaking clamps disturb the boundary layer, allow water and paste to escape, and result in an encrustation ring inside the clamp. With this, the ring can no longer be removed by normal cleaning procedures and will prevent proper priming at the next job site, where blockages are likely to occur.

d) The mixture cannot be subjected to significant sources of vibration, especially the mounting of a vibrator to the hopper body.

e) Extended-length idle times or old batches should be avoided.

CHAPTER 4—PUMPING EQUIPMENT AND COMPONENTS

4.1—Piston pumps

The most common concrete pumps consist of a receiving hopper, two concrete pumping cylinders, and a valving system (4.2) to alternately direct the flow of concrete into the pumping cylinders and, from there, into the pipeline (Fig. 4.1). One concrete cylinder receives concrete from the receiving hopper while the other discharges into the pipeline to provide a relatively constant flow of concrete through the pipeline to the placing area. Pistons in the concrete cylinders create a vacuum to draw in concrete on the intake stroke and mechanically push it into the pipeline on the discharge stroke. These pistons are driven by a hydraulic system that alternately directs the primary hydraulic oil flow to the actively-pumping cylinder. This can be achieved using either closed- or open-loop designs, and hydraulic or electronic switching. A closed-loop electronic-switching system is capable of improved fuel efficiency, minimized heating of the hydraulic fluid, and faster switch actuation. Primary power is provided by diesel, gasoline, or electric motors. The cost of concrete pumps, their maximum pumping capacity, and their pressure applied to the concrete can vary greatly. Components are sized to provide the desired volume output and concrete pressure into the pipeline. Receiving hoppers vary in size to match the volume output capacity of the pump, and are usually equipped with agitators that assist in mixture uniformity, giving the mixture an initial push toward the intake cylinders.

These units are rated for a maximum theoretical volume output in yd^3/h (m^3/h) based on the diameter and length of concrete cylinders multiplied by the maximum available frequency of pumping strokes. They are also rated for a maximum pipeline pressure capability that is dependent on the hydraulic system and power source used.

4.2—Valve types

4.2.1 *Hydraulically-powered directional valves (Fig. 4.1)*—Although valve configurations can vary, all of them are operated hydraulically and control the flow of material between material cylinders and the pipeline. They can crush or displace aggregate that becomes trapped in the valve area. The maximum size aggregate (MSA) that can be pumped by these units is controlled by the diameter of the concrete passages within the pump and the diameter of the pipeline into which the concrete is being pumped (5.2.1). In nearly all applications, the pump outlet port is larger in diameter and less restrictive than the smaller pipeline at the point of place-

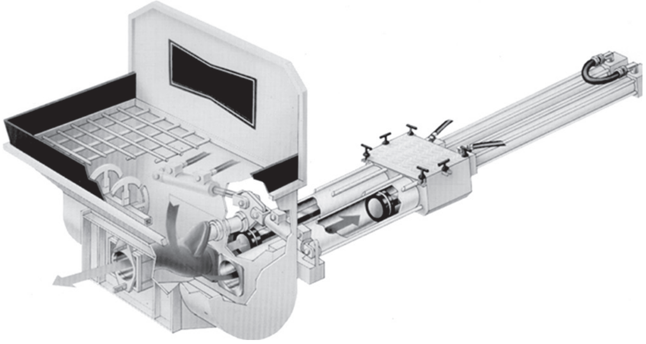


Fig. 4.1—Piston pump and powered valve.

ment. Piston pumps with hydraulic powered valves perform nearly all concrete pumping operations worldwide, handling the broadest possible range of concrete mixtures that can be pumped.

4.2.2 *Ball valve concrete pumps (Fig. 4.2.2)*—This type of pump uses steel balls and mating seats to control the flow of concrete from the hopper into the pumping cylinder and out of the pumping cylinder into the pipeline. The ball is forced into its seat by the concrete being pumped and has limited ability to displace or break aggregate that could be trapped in the valve area. Failure of the ball to seat will result in loss of pumping efficiency. These units are limited to pumping concrete with smaller than 1/2 in. (12.5 mm) MSA. Because they are limited to small aggregate and lower volume outputs, they are frequently used for small-scale grouting and can pump through pipeline or hose as small as 2 in. (50 mm) in diameter.

4.3—Trailer pumps

Trailer-mounted pumps (Fig. 4.3) are available with a wide range of output and pressure capabilities to match the wide range of applications in which they are used. Their use spans from small sidewalks to nearly 2000 ft (610 m) tall skyscrapers, or anywhere horizontal or vertical pipeline can be fixed into place. Once located on the job site, they are self-contained units that generate their own pumping power and weigh up to 24,000 lb (11,000 kg). They do, however, require another support vehicle for transportation between sites, cleanout water supply, and storage of delivery system components such as hose, pipe, and clamp.

4.4—Truck-mounted concrete pumps

4.4.1 *City pumps (Fig. 4.4.1)*—Some applications are best served with the concrete pump mounted on a truck. The power source for pumping can be from the chassis engine or a dedicated separate engine. The intent of this machine style is to combine a trailer-mounted unit with its supporting truck for efficiency and the ability to fit onto congested job sites that cannot support two vehicles. This model also supplies the most flexibility and is the most frequent user of both rod side (high output) or piston side (high pressure) hydraulic cylinder configurations.

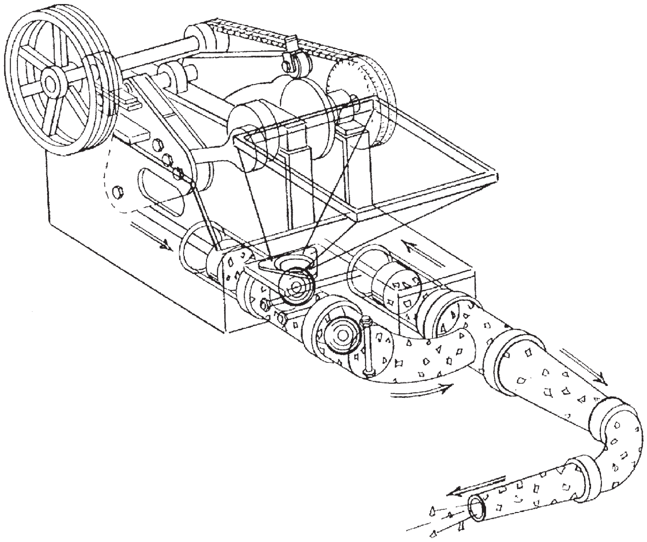


Fig. 4.2.2—Ball valve pump schematic.

Fig. 4.3—Trailer-mounted pump.

Fig. 4.4.1—Truck-mounted city pump.

4.4.2 *Concrete boom pumps (Fig. 4.4.2)*—Some applications are not effectively able to fix a delivery line to the ground or a building and rely on a multiple-arm articulating boom to support the pipeline. These booms vary in size and are typically rated by their vertical reach in feet (meters) of up to approximately 230 ft (70 m). Their range of motion is best described as a nearly-spherical dome that extends in

Fig. 4.4.2—Truck-mounted boom pump.

all directions from the truck to the maximum reach. These booms are also capable of reaching below grade into an excavation site for foundation work. Most boom pumps receive their pumping power from the truck engine with a special gearbox. A few of them use a tractor/trailer arrangement where the trailer contains the pumping equipment, as well as a dedicated engine.

4.5—Separate placing booms

Separate placing booms (Fig. 4.5) are designed to be removed from the truck and mounted on a special pedestal located within the placement area. This boom and pedestal combination is then designed to be used in high-rise, remote, or barge-mounted placement applications, where it is often mounted on top of tower sections in either a free-standing, wall-supported, or inside (building) of self-climbing configuration.

4.6—Specialized equipment

Concrete pumps and placing booms have been developed to mount on concrete trucks. These units are capable of placing the concrete mixed and transported in the truck that carries them, and can also receive concrete from other concrete trucks to complete a placement. These units usually have the pumping capacities of small trailer pumps (Fig. 4.6(a)). Concrete pumps have also been mounted on volumetric-measuring continuous-mixing (VMCM) units that are also known as mobile mixers. Power to operate the pump is usually derived from the chassis engine (Fig. 4.6(b)).

4.7—Pipeline and accessories

Most concrete placed by pumping methods is pumped through rigid steel tubing or heavy-duty flexible hose called pipelines. Connections between segments should use coupling devices that are rated to meet or exceed the pipeline pressure and provide a secure, sealed joint. If these requirements are met, the ability to permit rapid assembly and disassembly of components at any joint is beneficial. Various special-use accessories are available to customize delivery line setups to fulfill numerous concrete placing requirements. Accessories include elbows of varying degree and radius, valves (shutoff and diversion type), reducers, brackets, fabric and wire-reinforced hose, and cleanout elements (Fig. 4.7). Careful handling of the pipeline during assembly, cleaning, and dismantling will aid in lowering line resistance by preventing the formation of rough surfaces, dents in pipeline sections, and crevices in couplings.

Pipeline surface irregularity or roughness, diameter variations, and directional changes disturb the smooth flow of pumped concrete (American Concrete Pumping Association 2008). This results in increased pressure requirements to push concrete through the pipeline and an increased wear rate at those locations. Exposing long lengths of pipeline to direct sunlight or extreme hot or cold temperatures can adversely affect the temperature of the concrete being pumped. The pipeline should be shielded from these conditions as necessary.

Vertical lines require 10 to 15 percent of the vertical height as the starting point for horizontal line length, which helps provide a stable base for the direction changes and line movements (von Ekardstein 1983). It is common to use 3 vertical lines to 1 horizontal.

4.7.1 *System pressure capacity*—Increases in concrete pump volume and pressure have greatly increased the importance of using a suitable pipeline system to achieve satisfactory results. All components of the system must be able to handle the maximum internal pressure that the concrete pump being used is capable of producing with an adequate safety factor. Pipeline components are generally rated according to both working pressure and ultimate or burst pressure. The ratio of the burst pressure to working pressure constitutes the safety factor. A minimum safety

Fig. 4.5—Separate placing boom.

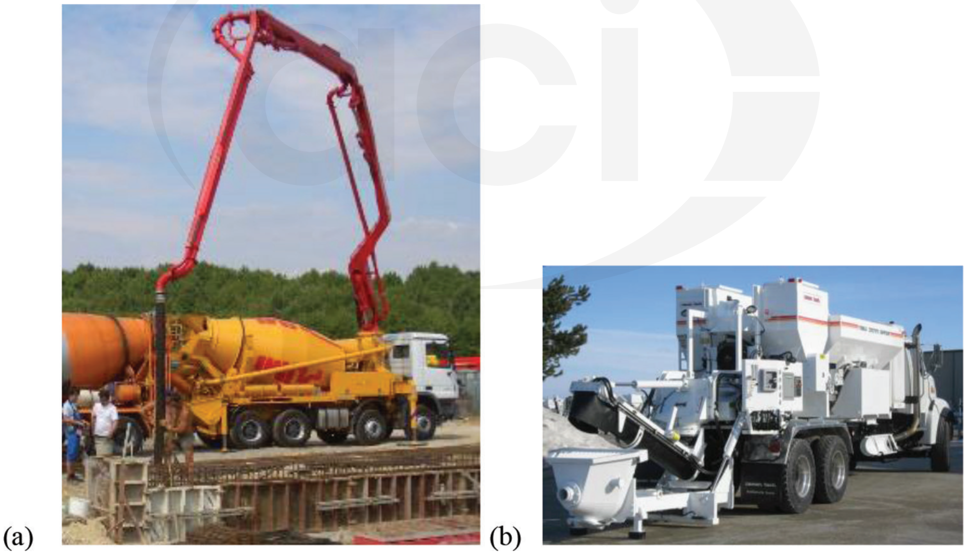


Fig. 4.6—Rotating drum and volumetric-measuring continuous-mixing (VMCM) units with pump. (Photos courtesy of: (a) Putzmeister; and (b) Cemen Tech.)

factor of 2:1 is recommended. Special usage or conditions could require a higher degree of safety. The burst pressure, and subsequently the safety factor, decreases as the pipeline wears from the abrasiveness of the concrete. The rate of wear varies greatly. Hard aggregate such as crushed granite is more abrasive than a softer aggregate like limestone. In addition to physical characteristics of the concrete, wear is also affected by the yardage conveyed, material velocity, pumping pressure, and geometry of the system (Crepas 1991; Tobin 1972).

Hardening processes and pipe wall configurations have been developed to decrease the wear rate and increase the component life. If a significant hardness level and affected depth are achieved in the wall with which the concrete comes in contact, the pipeline life can be increased by a multiple of 5 or more. This resistance to wear can be found in both single and twin wall pipes. The latter separates the wear resistance and pressure resistance functions into two distinctly different pipe layers, each designed for that specific purpose.

4.7.2 *Rigid placing line: straight sections, bends, and elbows*—Straight sections of pipeline are made of welded or seamless steel tubing, most commonly 10 ft (3 m) in length. The most common inside diameters are 4 and 5 in. (100 and 125 mm), with the majority of systems in the 5 in. (125 mm)

Fig. 4.7—Pipeline and accessories.

size, as these are the largest that can be handled by workers. Both rigid pipeline sections and accessory components are available in a variety of wall thicknesses, from 11 gauge to 0.50 in. (3.05 to 12.7 mm), and wear-resistance levels. Choosing the proper combination for pressure and total volume requirements is of prime importance. Aluminum pipeline cannot be used in concrete pumping because aluminum particles produced by abrasion react with the cement causing excessive air voids (Newlon and Ozol 1969).

Because pipelines are frequently routed around or through obstructions, elbows are available in many degrees and curvatures. The distance in which the curvature occurs is referred to as the center line radius (CLR). Whenever a choice is available, a longer radius elbow provides less resistance to flow. As the concrete travels around a bend, flow accelerates at the outer wall and the mortar boundary layer becomes thinner, allowing some aggregate to contact the wall face (3.2.1.1). This contact causes a greater wear rate at the outer wall. For this reason, most elbows are manufactured with a thicker outer wall. Heat treatment of elbows also improves longevity.

4.7.3 *System connection*—Concrete pipeline components can be assembled in any order, then disassembled and reconfigured in a different manner. To achieve this flexibility, each delivery line component requires the use of connecting ends or collars, a coupling, and a gasket.

4.7.3.1 *Couplings*—Couplings consist of two halves that are either bolted together or hinged at one end (Fig. 4.7.3.1). Hinged-type couplings typically use a cam-lever closure handle. This snap or quick-release coupling provides the benefit of the most rapid assembly and disassembly of a placing system. Snap couplings should always have a

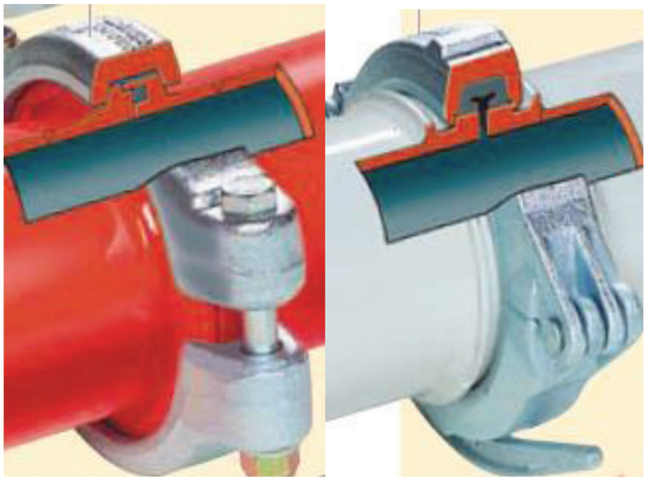


Fig. 4.7.3.1—Pipeline connection types (photo courtesy of Esser Pipe Technology).

closed-position lock pin that prevents inadvertent or accidental opening of the coupling due to vibration or mechanical interference. Bolted-type couplings provide a stronger, more secure connection joint than a snap coupling. This type of coupling is recommended for vertical standpipe, line locations subject to high internal pressures, or locations where the coupling will be pulled around obstructions.

4.7.3.2 *Gaskets*—Several gasket configurations are available and are designed to match the application. Examples are clamp-type and swivel couplings. The coupling connections require a gasket sealing ring to hold the required pressure and to prevent mortar leakage. Loss of mortar reduces the lubricating film on the pipeline surface and may result in a pipeline blockage. This could also cause encrustation, which is where a hard ring of deposited material forms inside the joint. If this is not removed, it will cause problems in cleanout, initial priming, and pumping (3.2.1.3).

4.7.3.3 *End configurations*—The connecting ends or collars are produced with mating surfaces to accommodate the coupling devices. Several styles of matched ends and couplings are used in concrete pumping (Fig. 4.7.3.1).

4.7.3.3.1 *Raised-end, welded-on*—This end incorporates a raised section profile of a set width and shoulder diameter that the coupling engages. Because material is added to the outer diameter of the tubing, these joints can withstand pressures exceeding 2000 psi (14 MPa). They can also withstand considerable stress from external bending forces. Raised-end systems are the most commonly used type. There are several different styles. One style may not be compatible with another, so they should not be intermixed without proof of compatibility.

4.7.3.3.2 *Tongue-and-groove*—This style uses a male and a female flange with the sealing ring positioned between the two end faces. This configuration can handle the highest line pressures and is generally used near the pump. A disadvantage of this arrangement is that the tube assembly can be oriented in only one configuration. In addition, it is difficult to remove a section of placing line, and proper cleaning of the female end groove can be tedious.

4.7.3.3.3 *Grooved*—Note that past practices have allowed a grooved connection. In this style, shallow grooves are cut into the tubing or a separate weld-on end. The end, or collar, typically has the same outer diameter as the tube itself. Because grooved-end systems over 3 in. (75 mm) are not able to withstand the pressures generated by most concrete piston pumps, they cannot be used with pumps capable of exceeding their 500 psi (35 bar) working pressure limit.

4.8—Flexible system hose types and applications

Rubber hose is frequently used at the end of a placement system. The flexibility of the hose allows workers to place concrete exactly where it is needed. This hose is specifically designed and manufactured to meet the rigorous demands of placing concrete. Abrasive material is pumped through it under high pulsating pressures while the outside covering is subject to friction, rough handling, and abuse on the job site. Concrete pumping hose is divided into two classifications: single-ended hose, and double-ended hose.

4.8.1 *Single-ended hose*—Single-ended hose is used at the end of a placing boom (end hose) or placing line (discharge hose). The boom end hose can be supplied in a continuous inner diameter or as a reducing diameter. The latter is used in applications that try to balance the output flow.

4.8.2 *Double-ended hose*—Double-ended hose has identical coupling connections on each end of the hose and is intended for connecting other line components. Specifically, this hose is used to accommodate the movement required between segments of pipeline, such as the transition from land-based to floating pipeline. This type of hose should never be used as a boom end hose due to its extra potential for bodily harm by the steel coupling in the event of a hose whipping.

There are multiple methods and materials used for manufacturing a concrete pumping hose. Reinforcements of fabric, cable, and wire can be combined with different assembly patterns. The hose burst and working pressures will also need to meet the pressure ratings of the machine used, which is usually 2:1 and 1:1, respectively (ASME B30.27), and are determined by the quantity, type, and strength of the reinforcement (piles). Some end hoses are also specially designed to resist or eliminate hose whipping.

Notes regarding pumping pressure:

a) Approximately three times more pressure is required to pump concrete through a given length of flexible hose than is needed to pump through the same length of steel line.

b) Pumping pressure could cause a curved or bent hose to straighten, resulting in injuries from such movement. Sharp bends must be avoided.

4.9—Concrete placing system accessories

4.9.1 *Valves (Fig. 4.9.1)*—Several types of valves are currently manufactured for concrete pipelines. Manually or hydraulically operated valves are available for three basic functions of shutoff, diversion, and discharge. Manufacturers' recommendations for appropriate location and pressure limitations should be followed.

Fig. 4.9.1—Shutoff and diversion valves.

4.9.1.1 *Shutoff*—This type of valve stops the flow of concrete within the placing system. These valves are useful for holding a head of concrete in a vertical standpipe and come in a wide range of internal pressure ratings. All these valves restrict the flow of concrete by the insertion of a blocking member in the valve body.

4.9.1.2 *Diversion*—This type of valve can divert or split concrete into more than one placing line. A swing tube-type diversion valve rotates the discharge between two or more outlet ports. Diversion valves are commonly used in concrete tunnel lining work where more than one pipeline may be placed within the form.

4.9.1.3 *Discharge*—A discharge valve allows concrete to be placed at desired locations along the pipeline. These may be set up in a series to accomplish specific location pours. Concrete drops from these valves instead of being forced out under pressure. Pipes with hoppers resembling "tremies" used for underwater concrete placement are often used in conjunction with discharge valves to control placement (Fig. 4.9.1.3).

Fig. 4.9.1.3—Hoppers resembling "tremies" used for underwater concrete placement.

4.9.2 *Reducers*—Reducers are tapered sections of rigid placing line used to make a transition between different system diameters. Reducers are commonly used between the pump discharge and the placing line. Additionally, reducers are commonly used to convert from the rigid placing system to a smaller and more flexible placing hose. Reducers should have high wear resistance and be able to withstand the pressure requirements.

The concrete has to move faster through a smaller line than through a large one to deliver the same volume in a given period of time. This increase in velocity causes a significant increase in the wear rate at the reducer. Reducers should be made of the heaviest wall material practical, be as long and as gradual as practical, have smooth interior surfaces, and have inlet and outlet diameters that match the connecting line.

4.9.3 *Support brackets and restraints*—A variety of pipeline support brackets and system-restraining products are currently available. Movement of the pipeline creates high stresses on the couplings and reduces pumping performance. Better and safer pumping performance can be achieved when the system is secured or restrained to minimize movement. The appropriate brackets should be easy and quick to use and be adjustable to adapt to variable job-site conditions.

Safety chains or slings are used in placing operations where system components are to be suspended over work areas. Reducers and hoses at the tip of placing booms are prime examples.

4.9.4 *System cleanout elements*—To help achieve maximum component life and avoidance of pipeline blockages, safe and thorough cleanout of the pipeline is necessary at the end of each placement or at any time a lengthy delay in pumping operation occurs. A concrete pumping pipeline is cleaned by propelling a sponge ball, or rubber go-devil, through the line, either with air or reverse pumping.

4.9.4.1 *Reverse pumping*—The safest way to clean out a system is to change the direction of pumping and suck the concrete back through the pipeline and into the hopper. Alternative methods exist, but this is typically done by wetting a sponge ball, placing it into the end/discharge hose, and reverse pumping. Disposal of the waste concrete will depend on the equipment and site conditions, but under-hopper or drive-up waste receptacles are now available for this purpose. Arrangements for disposal of this residual concrete should be made before pumping begins. Long pipelines and high-rise applications may be impractical for reverse pumping clean out.

4.9.4.2 *Compressed air*—This method has unique risks because compressed air in the pipeline will remain in the system until it is safely relieved, even after the air supply is turned off. This residual pressure can propel the cleanout device with an explosive and violent force, or cause an unsecured system to whip if it is not properly relieved. Opening any coupling in a pipeline under air pressure could result in injury or death. Components are available specifically for this purpose, including cleanout balls of various diameters and materials, go-devils, devil catchers, and air and water valve caps (Concrete Construction Staff 1992). The cleanout operation must be performed under the supervision of a trained and qualified operator.

CHAPTER 5—PUMPABLE CONCRETE

5.1—Basic considerations

Concrete pumping is well established in most areas and applications for which concrete producers can regularly supply a mixture that will pump without incident. Like all construction processes, concrete pumping is affected by the capability of the pumping equipment; design, control, and the consistency of all ingredients in the mixture; batching and mixing operations; and knowledge and experience of the personnel involved. Concrete pumping equipment has reached a point of dependability and capability where highly-pumpable mixtures are able to match the placement needs of nearly any given application.

However, a growing number of applications now require a more sophisticated mixture than what has been traditionally placed. Pumpability is only one of a few feature considerations the designer will need to use when specifying the mixture. Engineered mixtures should also take into consideration such design details as the final strength, curing characteristics, site conditions such as underwater placement, material and handling expenses, flow characteristics, and sustainability impacts. In some cases, these features could be in direct conflict and a compromise or alternative solution should be made.

The extent to which attention is given to the components and their proportions in a mixture design for a specific application depends on capabilities of the pump, and is relative to application details, including height, distance, and volume output, for the concrete that is to be pumped.

The principles of proportioning are not thoroughly covered in this document. Instead, refer to Kosmatka and Wilson (2011) for more information. This chapter discusses the characteristics of coarse and fine normalweight and lightweight aggregates, water, cement, and admixtures as they relate to pumpability of concrete. Once a mixture is proved to be pumpable, a consistent repetition of all factors ensures smooth operation.

5.2—Normalweight aggregate

Consistency in grading promotes consistency in the pumpability of any mixture. Thus, aggregate gradings should be closely monitored and blends adjusted if necessary, to assure uniformity in the combined aggregate gradation.

5.2.1 *Coarse normalweight aggregate*—The maximum size of angular coarse aggregate is limited to one-third of the smallest inside diameter of the pump or pipeline. Provisions should be made for the elimination of oversized particles in the concrete by finish screening (ACI 304R) or by careful selection of the coarse aggregate. While the grading of sizes of coarse aggregate should meet the requirements of ASTM C33/C33M, recognize that the range between the upper and lower limits of this standard is broader than what is recommended to produce a pumpable concrete. ASTM C33/C33M states that the ranges are, by necessity, very wide to accommodate nationwide conditions. In addition, ASTM C33/C33M specifies grading requirements based on nominal maximum-size aggregate (NMSA), which designates a size number down to the smallest sieve opening through which most of the aggregate will pass. Where a small-diameter pipeline is used, all coarse aggregate must pass the designated screen opening or line blockage will result. For example, 1 in. (25 mm) or less is recommended for 3 in. (75 mm) diameter pipeline, and all aggregate must pass that screen for successful pumping.

For optimum pumpability, ASTM C33/C33M states that:

"Designation of a size number (for coarse aggregate) to indicate a nominal size shall not restrict the person responsible for selecting proportions from combining two or more gradings of aggregate to obtain a desired grading, provided that the gradings are not otherwise restricted by the project specifier and the NMSA indicated is not exceeded."

This allows the addition of ASTM C33/C33M pea gravel gradings 8, 89, and 9A. Although size No. 9 is a fine aggregate, it is included as a coarse aggregate when combined with a size 8 material to create a size 89, which is a coarse aggregate. These materials fill major voids between coarse aggregate particles (Shilstone 1991) without excessive use of sand or cement.

The maximum size of the coarse aggregate has a significant effect on the volume or amount of coarse aggregate that can be efficiently used. The quantity of coarse aggregate must be substantially reduced as the NMSA is reduced because the greater surface area of the smaller-diameter aggregate for a given weight of coarse aggregate requires more paste to coat all surfaces. This decreases the amount of paste available to lubricate the pipeline wall and promote mixture flexibility inside the body of the concrete cylinder.

The shape of the coarse aggregate, whether angular or rounded, has an influence on the mixture proportions, although both shapes can be pumped satisfactorily. The angular pieces have a greater surface area per unit volume and a higher percentage of voids. This combination requires more mortar for the coating of each piece for pumpability.

5.2.2 *Fine normalweight aggregate*—Properties of the fine aggregate or sand play a more prominent role in the proportioning of pumpable mixtures than do those of the coarse aggregate. Together with cement and water, the fine aggregate in a pumpable mixture provides the mortar that both conveys the coarse aggregates in suspension and limits its motion to adjust to delivery line configuration changes.

The gradation of fine aggregate should conform to the requirements of ASTM C33/C33M. Experience has shown that for optimum pumpability, particular attention should be given to those portions passing the finer screen sizes (Anderson 1977). At least 15 to 30 percent should pass the No. 50 (300 mm) screen and 5 to 10 percent should pass the No. 100 (150 mm) screen. Fine aggregates that are deficient in either of these two sizes should be blended with selected fine sands, supplementary cementitious materials, or other materials to produce these desired percentages. Use of greater amounts of these finer fractions requires the use of additional water that may cause excessive shrinkage and be harmful to strength.

Higher values of fineness modulus indicate coarser materials, and lower values indicate finer materials. Pumpability of mixtures is generally improved with a decrease in the fineness modulus or, in other words, with the use of finer fine aggregate. Sands having a fineness modulus between 2.40 and 3.00 are generally satisfactory, although the fineness modulus alone, without stipulations about particle distribution, may not produce satisfactory results.

Fine aggregate for concrete may be obtained from natural deposits, or may be manufactured by crushing and grinding coarser materials to the desired sizes. The pumping characteristics of various sources of fine aggregate may vary, but it appears that the fineness modulus is a good indicator of the acceptability of either type.

5.3—Lightweight aggregate concrete

5.3.1 *Introduction*—Lightweight aggregate structural concrete has many economic applications and advantages in building construction. This material is particularly suited to multi-story construction, and the use of pumps for placement has become desirable in many instances. If it is a critical design parameter, the mixture proportions established for the job should take into consideration the possible slump loss that may occur during both transporting and pumping. This is especially true for lightweight concrete because the loss due to pumping is primarily from water absorption by the aggregate under pressure.

5.3.2 *Increasing moisture content*—The first step in preparing pumpable concrete with lightweight aggregate is to assure that the material is properly saturated (Michard 1992). Lightweight aggregates are generally porous materials with the capability of absorbing significant amounts of water. Allowances are made for this absorption in ACI 211.2. Absorption under atmospheric pressure may vary for different lightweight aggregate from 5 to 25 percent by weight. Under the pressures exerted by pumping, absorption may be considerably greater. If absorption is significantly increased during pumping, the loss of water from the mortar reduces fluid properties and pumpability of the concrete. Therefore, to pump lightweight concrete, it is necessary to both pretreat the aggregate and supply enough water in the mixture design to prevent excessive stiffening and loss of mortar available for the pumping operation. A more detailed discussion of methods of saturating lightweight aggregate is given in ACI 213R.

5.3.2.1 *Presoaking coarse and fine aggregate*—Presoaking of lightweight aggregate is critical and should receive serious attention regardless of whether it is coarse or fine aggregate. The characteristic rate of absorption and methods for achieving saturation using a presoaking operation are always different between the two, but it is extremely important for both that this be completed as described in ACI 213R.

5.3.2.2 *High-percentage saturation*—Vacuum saturation (Burgess 1969) and thermal saturation are processes described in ACI 213R. They produce a very high degree of saturation (sometimes called super-saturated) and are recommended whenever high pumping pressures are encountered or expected.

5.3.2.3 *Retention of moisture*—Lightweight aggregate saturated by sprinkling or presoaking should be used soon after achieving the desired level of saturation or maintained at a proper saturation until placement.

5.3.3 *Coarse and fine lightweight aggregate*—The grading of coarse lightweight aggregate should fall within the limits stated in ASTM C330/C330M. ACI 213R provides reasoning to select which gradations to use. Note that the lightweight aggregates could fluctuate in their unit weight. Such variations within limits are recognized and permitted by ASTM C330/C330M. These changes in unit weight could be due to the different expanding characteristics of the raw material during processing, changes in moisture content, changes in gradation, or a combination of all three. Adjustments in batch weights to compensate for these changes are imperative to maintain consistent absolute volumes of aggregate and proper yield (ACI 213R). Batching of lightweight coarse aggregate by volume, rather than by weight, is another established method used for maintaining consistency and volumetric yield.

Structural lightweight aggregates may have a coated or uncoated exterior surface, depending on the production method. They also may be either rounded-, cubical-, or angular-shaped pieces. Proper allowances may be made for shape and surface texture to handle any type of lightweight aggregate in a pump mixture using slight changes in the ratio of mortar to coarse aggregate.

In some localities, lightweight coarse aggregates larger than No. 4 (4.75 mm) are produced in two separate fractions. These two sizes should be combined, preferably at the batch plant, to produce a blended total coarse aggregate combination that satisfies ASTM C330/C330M gradation specifications. Uniformity of gradation should be carefully maintained from one batch to the next because fluctuations will affect the degree of pumpability.

5.4—Water and slump

In the history of concrete pumping, a traditional normal-weight concrete mixture (basic ingredients of cement, sand, coarse aggregate, and water, without admixtures and cementitious substitutes) has been dependent on water content for determining the slump value. This, in turn, has been the primary indicator of the mixture's pumpability, with a 2 to 6 in. (50 to 150 mm) slump range being the target, and has been used for estimating the equipment needed to meet a specific application (Fig. 5.4). To reach this slump range, the available water-cement ratio (*w*/*c*) would typically have a corresponding 0.4 to 0.6 baseline target range. Necessary adjustments can then be made for specific properties in the aggregate, its gradation, or both. Examples are water absorption in lightweight aggregate, aggregate size or shape, and the amount of fine aggregates used.

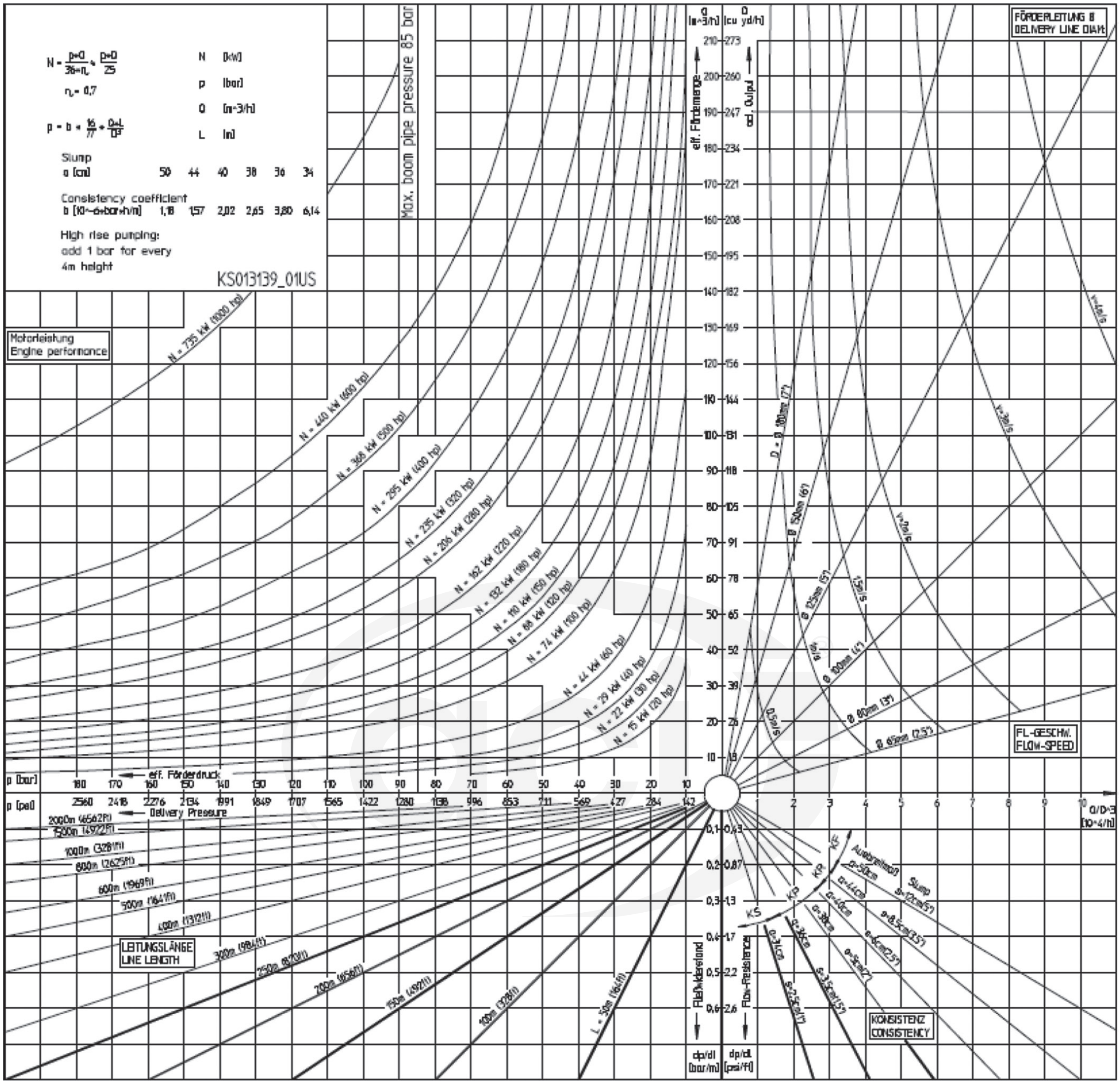


Fig. 5.4—Pressure-volume nomograph (courtesy of Putzmeister).

In the traditional mixture, the slump range was an indicator of how well the mortar paste would perform relative to the pumping concepts described in Chapter 3. Beyond any strength and shrinkage implications, too high of a slump would indicate that the mortar paste could be too thin and, therefore, have a high risk of not properly suspending the aggregate in the pipeline and simply washing over it. At the opposite range, a low slump would indicate that there might not be enough fluidity to coat the aggregate, provide limited relative aggregate movement, and create a sufficient boundary layer at the pipeline wall for efficient/effective pumping.

Concrete mixture design has seen increased regular usage of highly advanced admixtures and cementitious/pozzolanic materials that are focused on delivering the specific desired result needed for the application. Mixture variations are commonplace due to the large array of factors for which they are designed to achieve in terms of compressive strength, curing time, freezing-and-thawing resistance, creation and placement costs, durability, permeability, workability, pumpability, shrinkage, environmental conditions (that is, ambient temperature and underwater placement), transportation time, and flow characteristics for hopper-to-cylinder movement and difficult point-of-placement geometries.

It is possible to begin with a basic traditional mixture and adjust the recipe such that the slump is greatly increased without causing an equal change in the pumpability of the mixture. Because slump would no longer be a relevant indicator of the pumpability for these mixtures, it would no longer be useful in the application of estimating, as seen in Fig. 5.4.

For example, it is a common perception that concrete pumping is responsible for large decreases in slump. Rules of thumb have been developed for how much slump loss can be expected without necessarily understanding what is causing the loss. There are, however, several reasons why the slump of concrete might change between initial mixing and final placement. They include:

a) Variations in the setting time of cement due to the physical or chemical properties

b) Amount of time spent in transport, waiting for downloading, and pumping

c) Variations in ambient air temperature or concrete mixture temperature during mixing and pumping

d) Variations in the temperature of cement, water, and aggregates prior to mixing

e) Influence of all admixtures continuously interacting with other components in varying conditions

f) Variations in the water requirements and absorptive capacities of the aggregates

g) Water added or lost (environment, improper addition, non-watertight pumping system)

h) Potential loss of entrapped air in the pipeline or at placement

Because job-site personnel cannot readily determine the exact cause of a loss of slump, they should not add water to a mixture in an effort to meet a slump specification or improve pumpability. This is especially true with misguided attempts to add water to the concrete pump's hopper. The agitator paddles are not designed to be an effective mixer, and nearly all the additional water would likely result in undesirable voids in the cured concrete. If slump at placement is critical, changes should instead be made by reviewing the mixture design and improving the quality control within batching, mixing, or transporting.

5.5—Cementitious materials

Determination of the cementitious materials content for a pumpable mixture follows many of the same basic principles used for any concrete. The use of extra quantities of cementitious materials as the only solution to the correction of pumping difficulties is shortsighted and uneconomical. It is far more desirable, as well as economical, to first correct any deficiencies in the aggregate gradation, especially in the fine aggregate fraction. With well-graded coarse and fine aggregates, properly combined, the cement factors for pump mixtures will closely parallel those used in other concrete. This is explained in further detail in ACI 211.1.

The substitution of portland cement using other cementitious materials such as fly ash, silica fume, and slag cement, have differing effects on the pumpability of the resultant mixture. In general terms, fly ash improves pumpability (smooth/spherical shape), silica fume consumes available water that may be needed for pumping, and slag cement's effects are source and production-method dependent.

5.6—Admixtures

5.6.1 *General*—Any admixture that increases workability will usually improve pumpability. The type of admixture and the advantages gained from its use in concrete to be pumped will depend on the characteristics of the pump mixture. When an admixture is selected for use as an aid in concrete pumping, it can provide additional lubrication or reduce segregation.

Admixtures used to improve pumpability are generally classified as:

a) Normal- and high-range water-reducing admixtures

b) Supplementary cementitious materials

It is beyond the scope of this report to discuss all types of concrete admixtures. Refer to ACI 212.3R for a general discussion of them.

5.6.2 *Normal- and high-range water-reducing admixtures*—The primary benefit derived from water-reducing admixtures is the reduction in water requirement at a constant slump or a decrease in viscosity at a constant *w/c*. Some water reducers are designed to have no apparent effect on setting time, and others to achieve varying degrees of acceleration or retardation in the setting rate of the mixture. When used as directed, most water-reducing admixtures increase pumpability of the concrete mixture.

High-range water-reducing admixtures can be effective in increasing the pumpability of concrete. They are, however, effective for only a limited time. Concrete that depends on high-range water-reducing admixtures for pumpability will have to be discharged from the pipeline before any reduction in slump occurs. These admixtures should be included in the trial mixture program if their use is proposed. Compatibility of the mixture ingredients should be closely watched.

5.6.3 *Finely divided mineral additives*—These finely divided mineral admixtures are classified into three types:

1. **Relatively chemically inert material:** This type includes such materials as ground limestone and quartz, and hydrated lime.

2. **Cementitious materials:** This type includes natural cement, fly ash (ASTM C618), slag cement (ASTM C989/C989M), hydraulic lime (ASTM C141/C141M), and blended cements Type IS (ASTM C595/C595M).

3. **Pozzolans:** Examples of pozzolanic materials are Class C and F fly ash (ASTM C618), diatomaceous earth, volcanic glass, some heat-treated shales or clays, and silica fume (ASTM C1240).

Many of these materials have particle sizes as small or smaller than portland cement. Some have a beneficial strength effect on the concrete mixture and can be used to enhance pumpability due to their spherical particle shape and smooth, dense surface texture.

In concrete mixtures deficient in fines, the addition of a finely divided mineral admixture generally improves workability and pumpability.

5.7—Fiber reinforcement

Both steel and synthetic fiber-reinforced concrete can be pumped. While the proper addition of steel or synthetic fibers can affect viscosity and flow characteristics, most of them do not have an overwhelming adverse effect on the pumpability of the concrete to which they are added. The fiber manufacturer's literature and ACI 544.1R should be consulted to ensure proper application of fiber-concrete systems. A reinforcing fiber for concrete should comply with ASTM C1116/C1116M.

5.8—Trial mixtures and pumpability testing

Where prior experience or a mixture analysis does not provide satisfactory assurance that the planned mixture proportions will provide the required physical characteristics and pump satisfactorily in the appropriate style and size pump, trial mixtures intended for pumping should be prepared and tested. The highest possible fineness modulus of fine aggregate should be used in test mixtures rather than the average fineness modulus to ensure worst-case scenario performance during pumping.

Testing pumpability of the trial mixture involves the production of a sizeable quantity of the mixture and pumping it under predetermined conditions. For optimum results, the tests should include the equipment, pressures, and placing rate anticipated for completed work. If testing is not possible due to risk of failure, a scaled-down version using less distance or decreased volume output is an option, as long as the main variables are controlled.

This test is usually performed at a construction site as part of a more routine initial placement. Taking the final pumping application as a guide, the variables required in 5.9 should be duplicated. Specifically, the mixture should be pumped using a known delivery system (pipe diameter and total horizontal and vertical lengths) at a specific volume output setting. The resultant hydraulic pressure needed in the equipment to do the work can be equated to a resultant pipeline pressure. Using Fig. 5.4, the equivalent characteristic slump (consistency) can be deduced for that specific mixture. Several different volume settings should be tested in this same manner to get an average consistency value. This value can then be used in the estimating process in 5.9 to match the equipment (horsepower, pressure, and volume output capabilities) to the application.

Note that the easiest and least-risky configuration for this testing would include all horizontal pumping through steel pipe. Using conversion factors of 3 ft (1 m) rubber hose and approximately 10 ft (3 m) steel pipe, the results from this less-strenuous pump test can be extrapolated if the application includes the extensive use of vertical pipes or rubber hoses. An accurate reading of the hydraulic pressure is important, as is as the actual volume output as calculated using actual cylinder strokes per minute.

5.9—Estimating performance

To estimate compatibility of the mixture design and pumping equipment with the requirements of the application, nomographs have been created, as shown in Fig. 5.4. The specific variables included in this estimation process are:

a) Delivery line diameter
b) Required volume output
c) Consistency of the mixture (traditionally equal to slump)
d) Pumping distance equivalent*
e) Available engine performance
f) Delivery line pressure

To use the nomograph, many variables need to be specified. This scenario is then used to predict the value of the remaining variable(s) to determine if they meet the needed criteria. For example, if the equipment (available horsepower, available line pressure, pipe diameter, and pipe distances) and consistency are known, the nomograph can be used to determine the expected volume output capability at the point of placement.

This nomograph has limitations, as it is based on all other potential variables, such as quality control of the mixture and site and equipment conditions; ideal conditions; and values held as expected at the job site. The values are subject to interpretation of the chart intersection values at each point. Finally, the slump value shown on the graph is only relevant for the traditional basic mixtures.

As noted previously, the use of special admixtures can greatly modify the slump without an equal effect on pumpability. Therefore, the nomograph should reflect the consistency of the mixture differently than with the measurement of slump. The use of rheometers to measure the viscosity has been suggested as one alternative. However, the direct correlation with pumpability and the ability of the rheometers to give meaningful readings in high-viscosity mixtures have yet to be fully developed or made commercially available for use on most job sites.

Until these predictive tools are perfected, if a mixture/application/equipment combination appears to be close to what has historically been considered pumpable, it is strongly recommended that trial runs be performed as described in 5.8. Preparation for problems is a much better strategy than facing costly on-site downtime and personnel-intensive line cleanout.

CHAPTER 6—FIELD PRACTICES

6.1—General

The wide variety of concrete pumps and job-site applications has resulted in the development of field practices that are specifically appropriate to the pump's capability and the type of project on which it is being used. Preplanning for concrete pumping is essential for successful placements, with increasing detail and coordination required as the size of the placement and the project increases. At a minimum, the preplanning and preparation should involve the following:

a) Notifying the concrete supplier that the concrete will be pumped and confirmation that the appropriate provisions have been made to produce and provide, at the rate and in the quantity needed, concrete properly proportioned for pumping that also complies with all project specifications or other requirements. A continuous supply of concrete is required because if the pumping is stopped for any appreciable time, concrete in the line could stiffen, making it difficult to begin pumping again.

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*Vertical pumping adds one bar per 13 ft (4 m), one elbow = 3 ft (1 m) straight distance (von Ekardstein 1983), 3 ft (1 m) of rubber hose = 10 ft (3 m) of pipe distance (American Concrete Pumping Association 2011a).

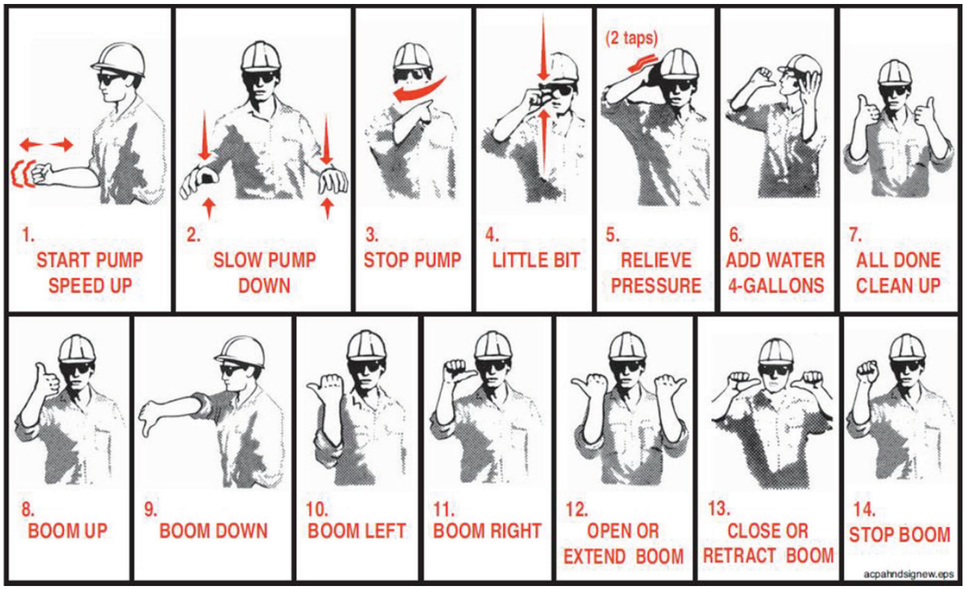

Fig. 6.1—American Concrete Pumping Association (ACPA) standard hand signals (courtesy of ACPA).

b) Establishing the distance concrete will be pumped (horizontal, elevation, and decline) and the maximum rate of placing required, followed by the pumping estimation described in 5.9, so that the proper equipment will be supplied.

c) Establishing a time that the pump will be ready for setup and placement, as well as the provision for any required pipeline. This includes agreements on the supply of pipeline materials and arrangements for the required labor to locate and assemble them.

d) Agreement between all parties involved—that is, pump operator, job supervisor, and placement crew—as to the placement sequence, total volume to be placed, safe-setup pump location as near to the placing area as practical, existence of any potential hazards such as power lines, supply of ground support timbers as required for the soil conditions, and required access to allow a minimum of two concrete trucks to discharge into the pump-receiving hopper at the same time. Two concrete trucks should be positioned to discharge into the pump-receiving hopper to maintain a constant flow of concrete to the pump and to enable blending of the last concrete discharged from the first concrete truck, which frequently has a higher percentage of coarse aggregate, with concrete from the second concrete truck.

e) Agreement on who is responsible for providing material to prime the pipeline and where that priming material will be placed.

f) Provision for clearing and cleaning the pump and pipeline when the placement is completed. Sometimes, the best arrangement is to design the placing system so concrete remaining in the pump hopper and pipeline can be discharged into a concrete truck. In other cases, a disposable or designated dumping container can be made available.

g) Familiarity with standard hand signals as shown in Fig. 6.1 by the pump operator and placing crew. When visual signals are not practical, telephone or radio communication should be provided. A method for communication between the mixer driver and pump operator should also be available. Examples are an audible horn or emergency stop button.

h) Awareness by the mixer operators of the hopper-filling method required to avoid introducing air into the pumping pipeline. Pump operators and finishing crews should be aware of what to do if air pockets are suspected to avoid injuries due to hose whipping.

i) Care taken not to segregate the mixture when placing concrete. Drop height from the discharge hose should be limited by the job-site conditions, type of structure, amount and spacing of reinforcing bar, and other job-specific obstacles.

6.2—Pipeline concrete placement

In pipeline placement, the limiting factor is the ability to spread the concrete as needed at the end of the pipeline. Generally, this is done by laborers using a rubber hose at the end of a rigid placing line (Fig. 6.2a). Manually operated placing booms are also available for horizontal spreading (Fig. 6.2b). Trailer-mounted concrete pumps are typically selected with the engine horsepower, concrete pressure, and output capacity appropriate for the project (5.9). The pump should be located as near the placing area as is possible and concrete placing should commence at the point most distant from the pump. This allows the entire pipeline to be grouted before concrete placing begins. As placement proceeds, rigid pipeline sections are removed to shorten the pipeline, and the rubber hose or placing boom is reconnected to the shortened steel pipeline. Concrete from the removed sections is used in the placement. These sections should then be cleaned outside the placement area. When placement is completed, the remaining pipeline can be disassembled and individual pieces drained of concrete and rinsed with water. Where a long section is involved, concrete remaining in the pipeline can be pushed out with water or air pressure. If air is used, take extreme care in regulating the air supply and pressure; a catcher should be installed at the point of discharge to prevent the go-devil from being ejected as a dangerous projectile. A provision will have to be made to relieve air pressure in the event of a pipeline blockage (4.9.4).

The weight of concrete in the pipeline becomes significant when pumping concrete up or down a substantial distance (over 50 ft [15 m]); this type of placing should only be done under the supervision of an experienced and knowledgeable professional.

6.3—Powered boom placement

6.3.1 *General*—A powered placing boom's discharge can be positioned at almost any point within the radius of the boom and at elevations achieved with the boom from near-vertical up or down to horizontal. Figure 6.3.1 shows the discharge range of a four-section 125 ft (38 m) boom. Most booms are rated according to the maximum elevation they can reach when truck-mounted, and they range in size from 50 to over 225 ft (15 to over 69 m). The horizontal reach is usually 10 to 12 ft (3 to 3.7 m) shorter, as shown in Fig. 6.3.1. Boom functions are operated by hydraulic cylinders and usually have provision for remote control from the placement area. Generally, a short discharge hose is attached to the pipeline at the tip of the boom and is used by a designated hose man to direct the concrete to where it is needed. Boom placement greatly reduces the number of laborers needed to get pumped concrete in place.

Fig. 6.2a—Material placement with flexible hose at end of rigid pipeline.

The pump operator must avoid hazardous proximity or contact with power lines under all circumstances. This means maintaining a 20 ft (6 m) clearance while accounting for movement of the wires by wind force (American Concrete Pumping Association 2008). The placing boom, the concrete being pumped, and all parts of the pump and concrete truck are conductors of electricity. Anyone touching any of them is at risk of electrocution.

Concrete placing and boom movement have to be directed or controlled from the placement area. Boom placing requires frequent relocation of the placing hose. This is usually done by an operator who controls both pumping and boom movement using a remote control. If the pump and boom operator are not stationed at the pump, it is desirable to have a laborer direct movement of the concrete trucks to the pump hopper charging location to ensure a constant flow of concrete into the hopper and stop the pumping if concrete is not available.

Fig. 6.2b—Rotary distributor placing booms.

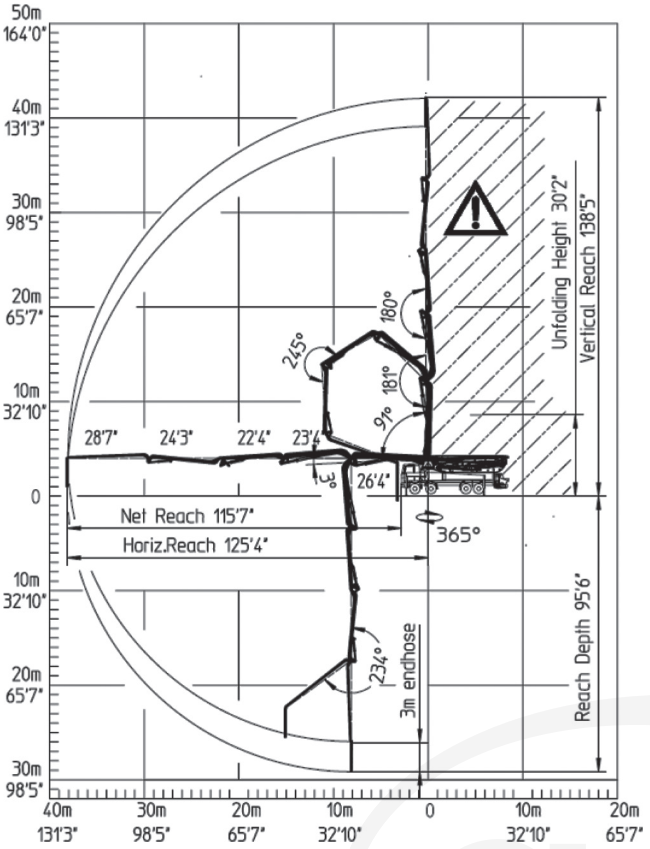

Fig. 6.3.1—Placing boom range diagram (courtesy of Putzmeister).

6.3.2 *Truck-mounted booms*—Truck-mounted concrete pumps and placing booms have the greatest flexibility because they have the mobility of the truck and the reach of the boom. These units move to and about the project like a truck and can quickly set up for placement. Boom stability for cantilevered reach is provided by an outrigger system and the unit weight. The area in which the pump is located must provide stable support for the outrigger feet, pump truck chassis, and concrete trucks. Generally, large pads are required under the outrigger feet to evenly distribute the concrete pump's leveraged forces into the ground. The outriggers also serve to level the boom pedestal to within the industry standard 3 degrees (ASME B30.27). Generally, these units use the truck engine to power the concrete pump and boom, so there is adequate power for pumping high capacities at medium pressures.

6.3.3 *Separate placing booms*—When the distance from the closest point accessible to concrete trucks exceeds the reach of truck-mounted placing booms, placing booms may be mounted on pedestals located in or adjacent to the placement area (Fig. 4.5). The functions of these booms are powered by separate diesel or electric power packs; concrete is brought from the concrete pump to the boom by a pipeline. For this type of operation, it is essential to have a good system of communication among the boom operator, pump operator, and placing crew.

6.4—Equipment and operational safety

Like many pieces of construction equipment, concrete pumps are powerful machines that require professional operators and the use of safe procedures in and around them. These safe operating practices are a necessity for the protection of the pump operator, concrete truck drivers, and the workers placing and finishing the pumped concrete. The concrete pumping industry has adopted the standardized hand signals shown in Fig. 6.1 (AMSE B30.27; American Concrete Pumping Association 2008).

6.5—Reduction in air content

It is not unusual for concrete to lose up to 1.5 percent of air as a result of handling by any conventional means. This includes dropping concrete vertically from a bucket, through a tremie or elephant trunk, or through the pipeline of a concrete pump (Hover 1993b; National Ready Mixed Concrete Association 1992).

In cases where air loss has been observed in the field, such change was not necessarily implied a reduction in the frost resistance of the concrete. When air has been lost under low-pressure freefall conditions, the loss has predominantly been in the larger air voids with negligible impact on freezing and thawing resistance (Hover 1993b,c). Higher air content does not necessarily mean better concrete quality. Frost resistance in any concrete depends less on total air content and more on the characteristics of the air void system. Porosity, permeability, tensile strength, degree of saturation, curing history, and rate of freezing also have an effect (Hover 1993c).

Tests have shown that variation in truck-to-truck air content was frequently greater than the variation due to different methods of handling concrete. After pumping, the remaining air bubbles were smaller than the average bubble sizes before pumping and the air void spacing factor, which is often used as an index to frost resistance, was not significantly altered. The actual freezing-and-thawing resistance did not correlate with air content. In one ASTM C666/C666M test, the concrete that lost the most air in pumping had the lowest total air content and the highest durability factor (Hover 1995).

Air-entraining admixtures stabilize bubbles created and trapped in the mixing process. The smallest air bubbles are most effective in preventing freezing-and-thawing damage. Larger bubbles are the least stable and the most likely to be lost during handling. They make limited contribution to frost resistance but may be recorded as a significant decrease in total air content when they are lost (Hover 1993a).

In general, the influence of pumping on air-entrained concrete is minimized by maintaining the lowest possible pumping pressure, minimizing freefall within a vertically descending pipeline, and reducing impact by directing discharge from the hose into previously placed concrete.

Pumping pressure is reduced by designing a pumpable concrete mixture as described previously. Pressure is also reduced by selecting the appropriate pump and pipeline for the task. Freefall and impact are reduced by planning the placement and pump location to avoid putting the boom in the A-frame configuration, and by laying a length of the placing hose flat at the point of discharge. In addition, the height of discharge from the end hose should be minimized, with a maximum of 3 ft (1 m). Curving the discharge hose or otherwise creating a back pressure to keep a full pipeline on descending sections have also been found to be useful, although they should be used with extreme caution and with slower output rates to avoid rapid hose whipping accidents.

CHAPTER 7—FIELD CONTROL

Quality concrete in the field is the ultimate objective. Pumped concrete does not require any compromise in quality. However, a high level of quality control for assurance of concrete uniformity should be maintained.

The locations at which samples for testing the concrete are taken are extremely important. Sampling, according to ASTM C94/C94M, is for the acceptability of the ready mixed concrete. The quality of the concrete being placed in the structure can only be measured at the placement end of the pipeline. If critical, sampling at both the truck discharge and point of final placement should be employed to determine if any changes in the slump, air content, and other significant mixture characteristics occur. When sampling at the end of the placement line, great care must be taken to ensure that the sample is representative of the concrete being placed. Changing the rate of placing, the boom configuration, or both, can result in varying or misleading test results. Concrete must not be allowed to freefall into the tester's container. Cylinders must be stored away from sources of vibration. The handling of the sample must not result in changes in concrete properties.

Pumpable concrete has been successfully produced by volumetric-measuring continuous-mixing (VMCM) equipment meeting ASTM C685/C685M and operated in accordance with ACI 304.6R. This type of equipment can provide a continuous supply of concrete to the pump if raw materials have been stockpiled at the job site, and allows for almost immediate adjustment of the mixture with little or no waste. Because the concrete is measured and mixed right at the pump, it is unnecessary to consider the possible detrimental effects of aged concrete.

Concrete has been pumped successfully during both hot and cold weather. Precautions could be necessary to provide adequate protection during extreme conditions (ACI 305R; ACI 306R).

The need for control and consistency of every operation has been emphasized throughout this report. ACI SP-2 gives a detailed outline of points to check in concrete construction.

CHAPTER 8—REFERENCES

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ACI 211.2-98(04)—Standard Practice for Selecting Proportions for Structural Lightweight Concrete

ACI 212.3R-10—Report on Chemical Admixtures for Concrete

ACI 213R-14—Guide for Structural Lightweight-Aggregate Concrete

ACI 304R-00(09)—Guide for Measuring, Mixing, Transporting, and Placing Concrete

ACI 304.6R-09—Guide for Use of Volumetric-Measuring and Continuous-Mixing Concrete Equipment

ACI 305R-10—Guide to Hot Weather Concreting

ACI 306R-16—Guide to Cold Weather Concreting

ACI 544.1R-96(09)—Report on Fiber Reinforced Concrete

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ASTM C141/C141M-14—Standard Specification for Hydrated Hydraulic Lime for Structural Purposes

ASTM C330/C330M-17—Standard Specification for Lightweight Aggregates for Structural Concrete

ASTM C595/C595M-17—Standard Specification for Blended Hydraulic Cements

ASTM C618-15—Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete

ASTM C666/C666M-15—Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

ASTM C685/C685M-14—Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing

ASTM C989/C989M-16—Standard Specification for Slag Cement for Use in Concrete and Mortars

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