

Placing Concrete by Pumping Methods

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This report describes pumps for transporting and placing concrete. Rigid and flexible pipelines are discussed and couplings and other accessories described. Recommendations for proportioning pumpable concrete suggest optimum gradation of aggregates; outline water, cement, and admixture requirements; and emphasize the need for evaluation of trial mixes for pumpability. The importance of saturating lightweight aggregates is stressed. Suggestions are given for layout of lines; for maintaining uniform delivery rate, as well as uniform quality of concrete at the end of the line; and for cleaning out pipelines.

This report does not cover shotcreting or pumping of nonstructural insulating or cellular concrete.

Keywords: admixtures; aggregate gradation; aggregates; cement content; coarse aggregates; concrete construction; concretes; conveying; couplings; fine aggregates; fineness modulus; lightweight aggregate concrete; lightweight aggregates; mix proportioning; pipeline; placing; placing boom; pozzolans; pumped concrete; pumps; quality control; water content.

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ACI defines pumped concrete as concrete that is transported through hose or pipe by means of a pump. Pumping concrete through metal pipelines by piston pumps was introduced in the United States in Milwaukee in 1933. This concrete pump used mechanical linkages to operate the pump and usually pumped through pipelines 6 in. 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 pipeline and hose that withstand higher pumping pressures. As a result of these innovations, concrete placement by pumps has become one of the most widely used practices of the construction industry.

Pumping may be used for most concrete construction, but is especially useful where space for construction equipment is limited. Concrete pumping frees hoists and cranes to deliver the other materials of construction concurrently with concrete placing. Also, other crafts can work unhampered by concrete operations.

A steady supply of pumpable concrete is necessary for satisfactory pumping.¹ A pumpable concrete, like conventional concrete, requires good quality control, i.e., uniform, properly graded aggregate, materials uniformly batched and mixed thoroughly.² Concrete pumps are available with maximum output capacities ranging from 15 to 250 yd³/hr.

Maximum volume output and maximum pressure on the concrete cannot be achieved simultaneously from most concrete pumps because this combination requires too much power. Each foot of vertical rise reduces the horizontal

pumping distance about 3 to 4 ft because three to four times more pressure is required per foot of vertical rise than is necessary per foot of horizontal movement.

Pumped concrete moves as a cylinder riding on a thin lubricant film of grout or mortar on the inside diameter of the pipeline.³⁻⁵ Before pumping begins, the pipeline interior diameter should be coated with grout. Depending on the nature of material used, this initial pipeline coating mixture may or may not be used in the concrete placement. 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.

CHAPTER 2—PUMPING EQUIPMENT**2.1—Piston pumps**

The most common concrete pumps consist of a receiving hopper, two concrete pumping cylinders, and a valving system to alternately direct the flow of concrete into the pumping cylinders and from them to the pipeline (**Fig. 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 hydraulic cylinders on most pumps, but may be driven mechanically. Primary power is provided by diesel, gasoline, or electric motors. The cost of concrete pumps and their maximum pumping capacity and pressure applied to the concrete vary greatly. Components are sized to provide the desired output, volume, and pressure on the concrete in the pipeline. The hydraulic pumps on most units are equipped with horsepower limiters that protect the power unit by destroking or reducing displacement to reduce the volume output of the hydraulic pump so it can provide the pressure required to move concrete at the maximum height or distance of the concrete pump's capability. Receiving hoppers vary in size to match the volume capacity of the pump and are usually equipped with agitators which prevent aggregate segregation and stacking in the hopper. The hopper de-



Fig. 1—Piston pump and powered valve pumping train

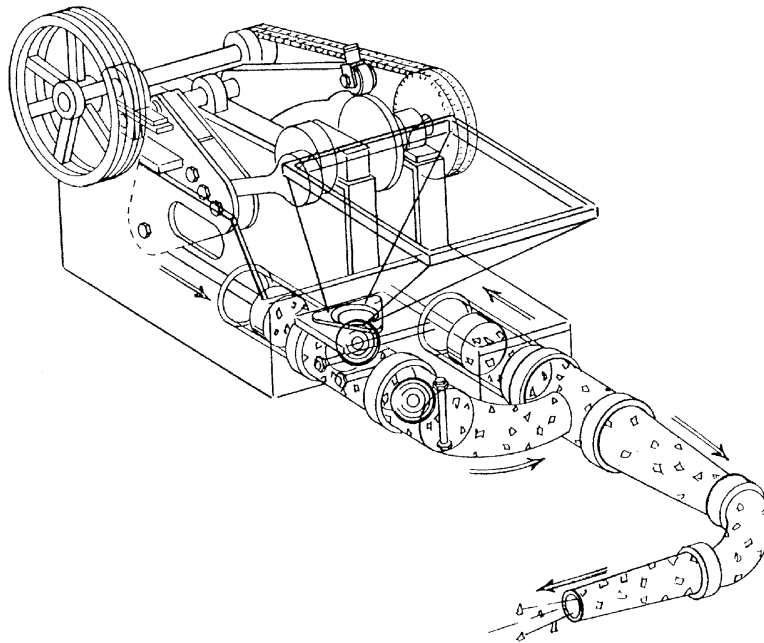


Fig. 2—Ball check pump schematic



Fig. 3—Ball check concrete pump

sign should maintain a head of concrete at the intake to the concrete cylinders.

2.2—Types of valves

2.2.1 Hydraulically powered valves—Pumps in this class use different types of valves, but all of them are operated hydraulically and have the ability to crush or displace aggregate which becomes trapped in the valve area. The size of the maximum size aggregate (MSA) which 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 concrete is being pumped (see [Section 4.2.1](#)). Most of these pumps have an outlet port 5 in. or larger in diameter and utilize reducers to reach smaller pipeline size as is necessary. [Fig. 1](#) is typical of these units.

The capacity of these pumps may vary from 20 to 250 yd³/hr. They handle the broadest possible range of concrete mixtures that can be pumped.

2.2.2 Ball-check concrete pumps—This type of pump utilizes 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 a very limited ability to displace or break aggregate which may be trapped in the valve area. Failure of the ball to seat results in loss of pumping efficiency ([Fig. 2](#)). These units are limited to pumping concrete with smaller than 1/2 in. MSA. The concrete pistons in these units are frequently mechanically driven although there are hydraulically powered units available. They are usually rated at 20 yd³/hr or less. Because they are



Fig. 4—Pump with hydraulically powered valve

limited to small aggregate and low volume, they are frequently used for grouting and may pump through pipeline or hose as small as 2 in. in diameter (Fig. 3).

2.3—Trailer pumps

2.3.1 General—Trailer-mounted pumps are available with a very wide range of capacities and pressures. These units are usually rated for maximum theoretical volume in yd^3/hr based on the diameter of the concrete cylinders and the length and frequency of the pumping strokes and the pressure applied to the concrete at the piston face. The most significant comparison factor is the horsepower available to pump concrete. The effect of horsepower limiters mentioned in Section 2.1 is most pronounced on general purpose and medium-duty trailer-mounted pumps because they use lower horsepower engines. Most trailer pumps are powered with diesel engines and fall into relatively standard horsepower ranges that are determined by the number of cylinders in the power unit and whether it is turbo-charged.

2.3.2 Small general purpose pumps—These trailer-mounted pumps are generally rated from about 20 to 35 yd^3/hr , are powered with up to 60 hp engines, and weigh up to 5000 lb. They may have either hydraulically powered or ball-check valves. They generally utilize 5- and 6-in.-diameter concrete cylinders and apply pressures up to about 750 psi on the concrete. They are capable of pumping up to 250 ft vertically or up to 1000 ft horizontally. They are most suitable for grouting masonry walls and placing concrete in floor slabs, footings, walls, columns, and decks where the limitations imposed by forming or finishing requirements limit the volume of concrete and the rate at which it can be placed (Fig. 4). Operators usually use the smallest possible pipeline di-

ameter (Section 4.2.1) for the grout or concrete being pumped — 2 in., 2 1/2 in., and 3 in. are the most popular sizes.

2.3.3 Medium duty pumps—These units have a capacity range from about 40 to 80 yd^3/hr , are powered with engines from 60 to 110 hp, and weigh from 5000 to 10,000 lb. They generally use 6-, 7-, or 8-in.-diameter concrete cylinders and are capable of applying pressures up to 900 psi on the concrete. This pressure allows them to pump up to 300 ft vertically or 1200 ft horizontally. They are used on larger volume concrete placements where the ability to place concrete more quickly justifies their higher cost of ownership and operation (Fig. 5). Operators generally use 4- or 5-in.-diameter pipelines.

2.3.4 Special application pumps—These trailer-mounted pumps place over 80 yd^3/hr , utilize engines with 110 hp and more, and weigh over 10,000 lb. They have a wide variety of pressure and volume capacities depending on the applications for which they are used. Typical applications are specialty projects like high-rise buildings and tunnel projects that require pumping long horizontal distances because of limited access (see Fig. 6). Pumps in this class have pumped concrete over 1400 ft vertically and over 4600 ft horizontally. Pipeline is selected to match the volume and pressure requirements of the project (Chapter 3).

2.4—Truck-mounted concrete pumps

2.4.1 Separate engine drive—Separate engine-driven concrete pumps mounted on trucks are used primarily for projects with capacity requirements where the horsepower required for pumping the concrete is considerably less than that required to move the vehicle over the road. Such pumps are frequently modified versions of the general purpose trailer pumps and have the same operating capacities.

2.4.2 Truck engine-driven pumps—These pumps have capacities ranging from about 100 to 200 yd^3/hr . They generally use 8- and 9-in.-diameter concrete cylinders and concrete pressures range from about 640 to 1250 psi. Many units have different ratings when pumping oil is applied to the rod side (high capacity) or to the piston side (high pressure) of the hydraulic pumping cylinder. With such wide variations in capacity, it is not possible to summarize maximum vertical and horizontal pumping distances. These pumps are generally used with placing booms and require a heavy-duty truck chassis to carry their combined weight. A larger engine is required for highway travel than is normally required for the pumping operation. The most economical combination in this case is to use the truck engine and a split shaft or power divider that can use the truck engine to power the running gear of the truck or to drive hydraulic pumps to provide pumping power. These units have receiving hoppers much larger than those on most trailer pumps to accommodate their higher pumping rates (Fig. 7). High-volume pumping requires that the receiving hopper have an effective agitator.

2.5—Placing booms

Placing booms support a 5-in.-diameter pipeline which receives the discharge from a concrete pump and places it in the forms. Booms have three or four articulating sections.

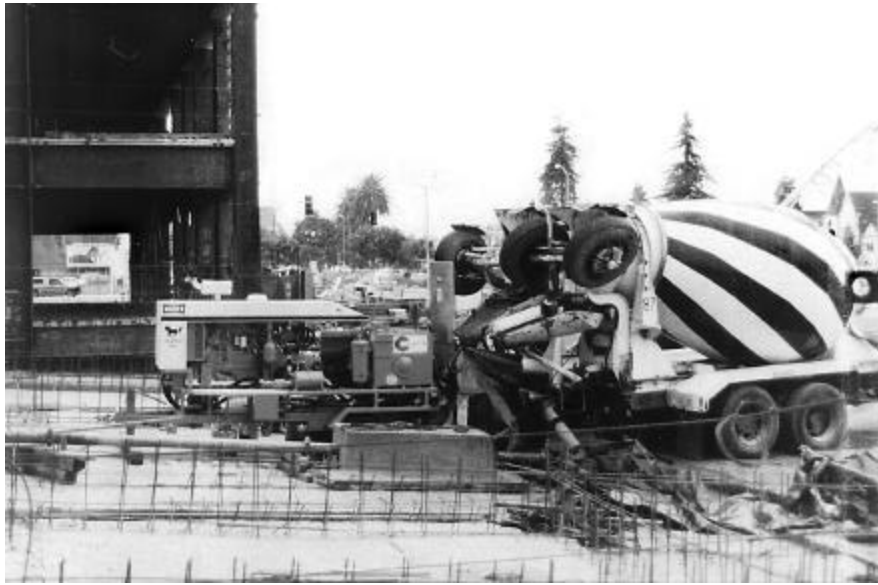


Fig. 5—Medium-duty trailer-mounted concrete pump



Fig. 6—Special application-type trailer-mounted concrete pump

The booms are mounted on a turret that rotates to enable the discharge of the pipeline to be located anywhere within a circle. One type of boom telescopes 17 ft. Most booms are permanently mounted to the trucks on which they are transported, along with the concrete pump. Some booms are designed to be removed from the truck and mounted on a pedestal that can be located in the placement area or supported on the floors of buildings under construction. There also are placing booms designed to be used only on a pedestal or to be mounted on tower cranes. Placing booms should never be used as a crane and must be inspected for structural integrity on a regular basis.⁶

2.6—Specialized equipment

Concrete pumps and placing booms have been developed that are mounted on ready-mixed 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 ready-mixed concrete trucks to complete a placement. These units usually have the capacities of small general purpose pumps ([Section 2.3.2](#)).

2.7—Safety

Concrete pumps are powerful machines that utilize high hydraulic oil pressures, concrete under high pressure, and compressed air for cleanup. Safe operating practices are a necessity for the protection of the pump operator, ready-mixed concrete drivers, and the workers placing and finishing the pumped concrete. The American Concrete Pumping Association has prepared a detailed *Safety Manual*⁷ for those who supervise or engage in concrete pumping.



Fig. 7—Truck engine-driven concrete pump

Table 1—Concrete placing line data

Pipe inside diameter	In.	2	3	4	5	6	7
Cross-sectional area (inside pipe)	in. ²	3.14	7.07	12.57	19.63	28.27	38.48
	ft ²	0.02	0.05	0.09	0.14	0.20	0.27
Volume of concrete per 100 ft of pipe	ft ³	2.18	4.91	8.73	13.64	19.63	26.73
	yd ³	0.08	0.18	0.32	0.51	0.73	0.99
Weight of concrete per 10-ft section of pipe	Lb	32.72	73.63	130.90	204.53	294.52	400.88
Pipe length per yd ³ of concrete	Ft	1237.59	550.04	309.40	198.01	137.51	101.03
Inside diameter		Wall		Weight, lb per ft			
				Line empty	Concrete only	1-ft section	10-ft section
In.	Gage	In.					
2	11	0.120		2.72	3.27	5.99	59.89
3	11	0.120		4.00	7.36	11.36	113.62
4	11	0.120		5.28	13.09	18.37	183.70
4	9	0.150		6.65	13.09	19.74	197.38
5	11	0.120		6.56	20.45	27.01	270.15
5	9	0.150		8.25	20.45	28.70	287.03
5	7	0.188		10.42	20.45	30.87	308.70
5	—	0.250		14.02	20.45	34.47	344.71
6	11	0.120		7.84	29.45	37.30	372.96
6	9	0.150		9.85	29.45	39.30	393.05
7	11	0.120		9.12	40.09	49.21	492.13

Note: All concrete weights based on 150 lb per ft³.

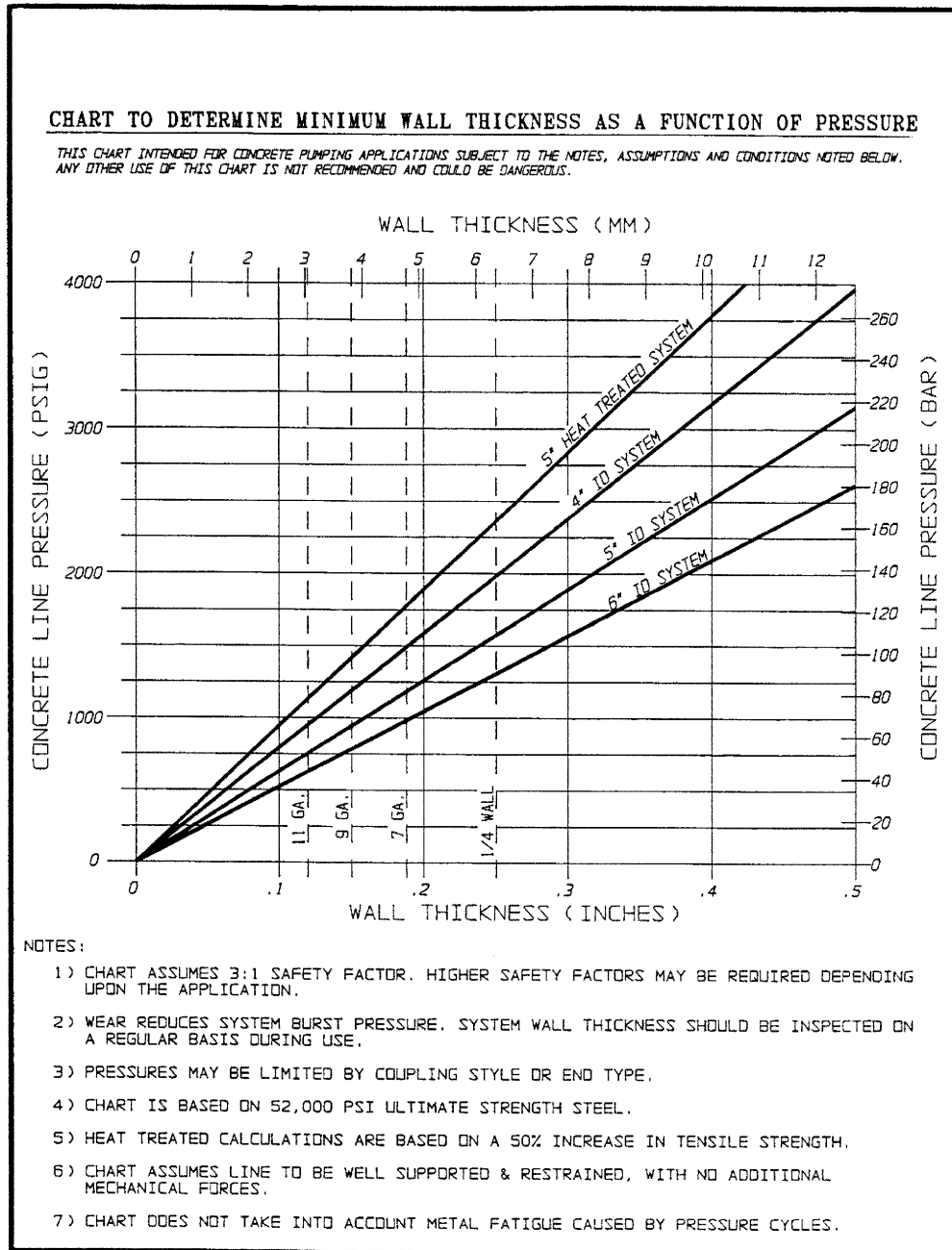
CHAPTER 3—PIPELINE AND ACCESSORIES

3.1—General description

Most concrete transported to the placement area by pumping methods is pumped through rigid steel tubing or heavy-duty flexible hose, both of which are called pipeline. Connections between segments should utilize coupling devices that permit rapid assembly and disassembly of components

at any joint and provide a secure, sealed joint. Various special use accessories are available to customize delivery line setups to fulfill numerous concrete placing requirements. Accessories include bends of varying degree and radius, valves (shut-off and diversion type), reducers, brackets, fabric and wire-reinforced hose, and cleanout elements. Careful handling of the pipeline during assembly, cleaning, and dis-

Table 2



mantling 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.⁷ This results in increased pressure required to push concrete through the pipeline and increased wear rate throughout the pump and pipeline. Exposing long lengths of pipeline to direct sunlight or extreme hot or cold temperatures may adversely affect the temperature of the concrete being pumped. The pipeline should be shielded from these conditions as necessary.

3.2—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 which 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 factor of 3:1 is recommended. Special usage or conditions may require a higher degree of safety. The burst pressure and subsequently the safety factor decreases as the pipeline wears due to the abrasiveness of the coarse and fine aggregate used in the concrete. The rate of wear varies greatly. Hard aggregate such as crushed granite is more abrasive

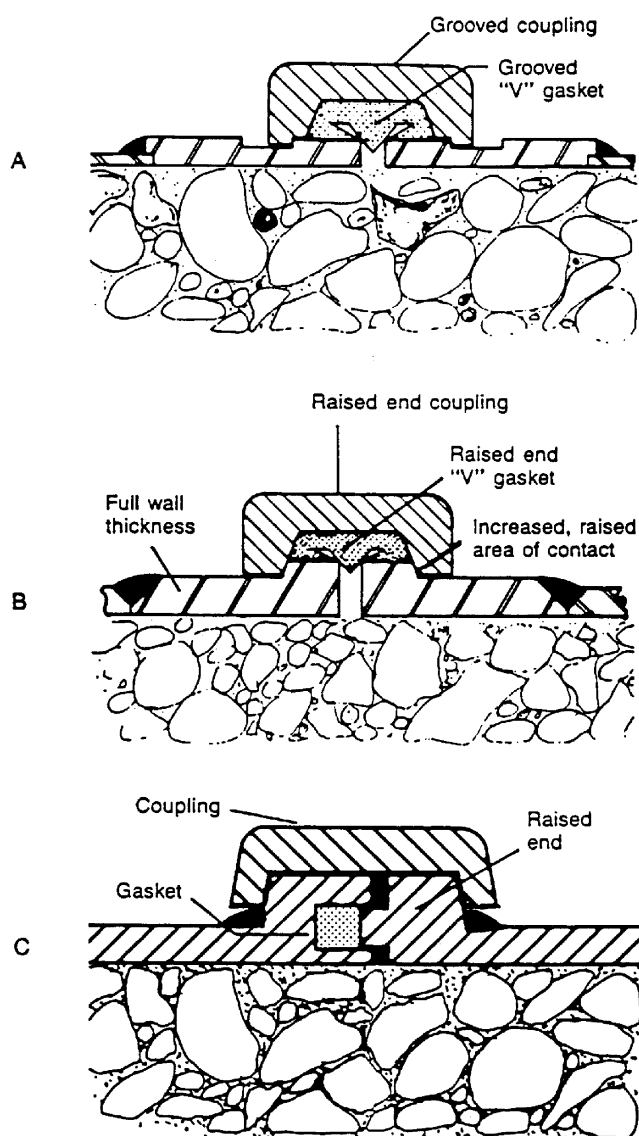


Fig. 8—Pipeline components are made with grooved (a) or raised (b) ends, shown in cross section here. Raised ends with tongue-and-groove flanges (c) are also available (courtesy ConForms, Cedarburg, Wi.)

than a softer aggregate such as limestone. In addition to the physical characteristics of the concrete, wear is also affected by the yardage conveyed, the material velocity, the pumping pressure, and the geometry of the system.^{8,9}

Hardening processes have been developed to increase the material strength of the steel tubing, and decrease the wear rate. Depending upon the chemistry and the process used, only the surface or the entire cross section of the tube may be hardened.

3.3—Rigid placing line—Straight sections, bends, and elbows

Straight sections of pipeline are made of welded or seamless steel tubing, most commonly 10 ft in length. The most common diameters are 4 and 5 in., with the majority of systems in the 5 in. size (Tables 1 and 2). These sizes are the largest that can be handled by workers. Both rigid pipeline sections and accessory components are available in wall

thicknesses from 11 gage (0.120 in.) to 0.50 in. Choosing the proper wall thickness for the pressure and total volume requirements is of prime importance. Typically, the thicker the wall, the higher the pressure capacity and the longer the expected wear life of the pipeline. Aluminum pipeline should not be used in concrete pumping.¹⁰

Because pipeline must frequently be routed around or through obstructions, various tube bends and elbows are available in almost any degree of curvature desired. The distance in which the curvature occurs is referred to as the center line radius (CLR). Bends in a pipeline increase the resistance to concrete flow. Whenever a choice is possible, a longer radius elbow provides less resistance to flow. As the concrete travels around a bend, flow accelerates at the outer wall. This causes greater wear rate at the outer wall. For this reason some bends are manufactured with a heavier outer wall. Heat treatment of elbows also improves longevity.

3.4—System connection

Concrete pipeline components may be assembled in virtually 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.

3.4.1 Couplings—The coupling devices are made from malleable or ductile cast iron, and cast or forged steel. Couplings consist of two halves that are either bolted together or hinged at one end. Hinged-type couplings typically utilize a cam-lever closure handle. This snap or quick release coupling provides the benefit of the most rapid assembly and disassembly of placing system. Snap couplings should always have a 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.

3.4.2 Gaskets—The coupling connections require a gasket sealing ring to hold the required pressure and to prevent grout leakage. Loss of grout reduces the lubricating film on the pipeline surface and may result in a pipeline blockage.

3.4.3 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. 8).

a) Grooved—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. Grooved-end systems over 3 in. are not able to withstand the pressures generated by most concrete piston pumps and must not be used with pumps capable of exceeding their 500 psi working pressure limit.

b) Raised-end welded-on ends incorporate a raised section profile of a set width and shoulder diameter which the coupling engages. Since material is added to the outer diameter of the tubing, these joints can withstand pressures in excess of 2000 psi. 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 style and they should not be intermixed without proof of compatibility.

c) Tongue-and-groove—Basically a modified raised end, 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 way. In addition, it is difficult to remove a section of placing line and proper cleaning of the female end groove can be tedious.

3.5—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 jobsite.

Concrete pumping hose is divided into two classifications: hose intended for use at the end of a placing line (discharge hose), and hose used on a placing boom (boom hose). Discharge hose has a lower pressure rating. Boom hose typically connects rigid boom sections and must withstand high pressures. This type of hose is also used to accommodate movement required between segments of pipeline, such as the transition from land-based to floating pipeline.

The two basic types of concrete pumping hose are fabric-reinforced and wire-reinforced. The hose burst and working pressures are determined by the quantity, type, and strength of the reinforcement (piles).

In addition to the classification and working pressure, there are several other important hose selection considerations. They are:

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

b) Pumping pressure may cause a curved or bent hose to straighten. Injuries have resulted from such movement. Sharp bends must be avoided.

3.6—Concrete placing system accessories

3.6.1 Valves—Several types of valves are currently manufactured for concrete pipelines. Manually or hydraulically operated valves are available for three basic functions. Manufacturers recommendations for appropriate location and pressure limitations must be followed.

Shut-off—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. Shut-off valves may be of the “spade,” “gate,” or “pin” variety. All of these valves restrict the flow of concrete by the insertion of a blocking member in the valve body.

Diversion—This type of valve has the ability to divert or split concrete into more than one placing line. A diversion-

type “Y” valve incorporates a moveable paddle to direct concrete flow to one line while sealing off flow to the other line. The paddle is moved by an external lever. A swing tube-type of 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.

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 in lieu of being forced out under pressure. Tremies are often used in conjunction with discharge valves to control placement.

3.6.2 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 must have high wear resistance and be able to withstand the pressure requirements. Because changing the system diameter causes increased friction and wear, the reducer lengths should be as long and as gradual as practical.

Concrete must 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, have smooth interior surfaces, and have inlet and outlet diameters that match the connecting line.

3.6.3 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 jobsite 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.

3.6.4 System cleanout elements—To help achieve maximum component life, 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 with air or water pressure. The cleanout operation must be performed under the supervision of a trained and qualified operator.

The safest way to clean out a system is with water, but water is not always available, and may present a disposal problem. Air cleanout presents fewer operational problems, but compressed air in the pipeline will remain in the system even after the air supply is turned off, until it is safely relieved. This residual pressure can propel the cleanout device with an explosive and violent force or cause an unsecured system to

Table 3—Suggested weights per yd³ of rounded river gravel for concrete to be pumped

Type of sand	Coarse aggregate size				
	3/8 in., No. 4	1/2 in., No. 4	3/4 in., No. 4	1 in., No. 4	1 1/2 in., No. 4
Coarse F.M. 2.80 to 3.00	1010 to 1110	1250 to 1350	1510 to 1610	1640 to 1740	1760 to 1860
Medium F.M. 2.60 to 2.80	1060 to 1160	1300 to 1400	1560 to 1660	1690 to 1790	1810 to 1910
Fine F.M. 2.40 to 2.60	1110 to 1210	1350 to 1450	1610 to 1710	1740 to 1840	1860 to 1960

This table is derived from Committee 304 experience and is based on rounded river gravel having a dry loose unit weight of 96 pcf. Weights shown above may be increased or decreased in direct proportion to this unit weight to suit local conditions.

Table 4—Suggested weights per yd³ of crushed stone aggregate for concrete to be pumped

Type of sand	Coarse aggregate size				
	3/8 in., No. 4	1/2 in., No. 4	3/4 in., No. 4	1 in., No. 4	1 1/2 in., No. 4
Coarse F.M. 2.80 to 3.00	900 to 980	1100 to 1180	1330 to 1410	1450 to 1530	1570 to 1650
Medium F.M. 2.60 to 2.80	940 to 1020	1140 to 1220	1370 to 1450	1490 to 1570	1610 to 1690
Fine F.M. 2.40 to 2.60	980 to 1060	1180 to 1260	1410 to 1490	1530 to 1610	1650 to 1730

This table is derived from Committee 304 experience and is based on crushed stone aggregate having a dry loose unit weight of 85 pcf. Weights shown above may be increased or decreased in direct proportion to this unit weight to suit local conditions.

whip if it is not properly relieved. Opening any coupling in a pipeline under air pressure may result in injury or death.

Many items are manufactured to help enable safe system cleanout using either water or air under pressure. Components available include cleanout balls of various diameters and materials, “go-devils,” “devil catchers,” and air and water valve caps.¹¹

Arrangements for disposal of this residual concrete should be made before pumping begins.

CHAPTER 4—PROPORTIONING PUMPABLE CONCRETE

4.1—Basic considerations

Concrete pumping is so established in most areas that most ready-mixed concrete producers can supply a concrete mixture that will pump readily if they are informed of the concrete pump volume capacity and its pressure capability, pipeline diameter, and horizontal and vertical distance to be pumped.

Tables 3 and 4, which are based on field experience, suggest the weights of natural and crushed coarse aggregate to be used with fine aggregate, of various fineness moduli per cubic yard

of concrete. In many cases, this guideline is all that is required to provide a pumpable mix. The following information on proportioning is provided for use where a supplier of pumpable concrete is not readily available or to expedite identification of the mixture components causing a pumping problem with a mix which is expected to be pumpable.

The shape of the coarse aggregate, whether angular or rounded, has an influence on the mix proportions, although both shapes can be pumped satisfactorily. The angular pieces have a greater surface area per unit volume as compared to rounded pieces, and thus require more mortar to coat the surface for pumpability.

The extent to which attention must be given to the mortar (cement, sand, and water), and to the amounts and sizes of aggregates will depend on the capability of the pump to be used, and the height and/or distance the concrete is to be pumped. Dependability of concrete pumping is affected by the capability of the pumping equipment and the control and consistency of all the ingredients in the mixture, the batching and mixing operations, and the knowledge and experience of the personnel involved.

The principles of proportioning are covered elsewhere.¹²⁻¹⁵ Particular reference in this report is made to ACI 211.1 and ACI 211.2 covering the principles of proportioning for normal weight and for lightweight concrete. This chapter discusses the characteristics of coarse and fine normal weight 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 insures smooth operation.

4.2—Normal weight aggregate

4.2.1 Coarse normal weight aggregate—The maximum size of angular coarse aggregate is limited to one-third of the smallest inside diameter of the pump or pipeline. For well-rounded aggregate, the maximum size should be limited to two-fifths of these diameters. Provisions should be made for elimination of over-sized 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 C 33, it is important to recognize that the range between the upper and lower limits of this standard is broader than that the Committee recommends to produce a pumpable concrete. ASTM C 33 states that the ranges are by necessity very wide to accommodate nationwide conditions. In addition, ASTM C 33 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, 1/2 in. minus is recommended for 2-in.-diameter pipeline, and all aggregate must pass that screen for successful pumping.

An important addition to ASTM C 33 is the provision 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 grad-

ings 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 a pea gravel which is too coarse to be sand and too fine to be coarse aggregate. These materials fill major voids between coarse aggregate particles.¹⁶

This procedure allows combining and blending certain fractional sizes to produce aggregate suitable for pumping. Consistency in grading is essential to avoid variability in the pumpability of any mixture. Aggregate gradings must be closely monitored and blends adjusted, if necessary, to assure uniformity in the combined aggregate gradation.

The maximum size of the coarse aggregate has a significant effect on the volume or amount of coarse aggregate that may 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 and leaves insufficient paste to lubricate the pipeline.

4.2.2 Fine normal weight aggregate—The properties of the fine aggregate or sand play a much more prominent role in the proportioning of pumpable mixes than do those of the coarse aggregate. Together with the cement and water, the fine aggregate provides the mortar or fluid which conveys the coarse aggregates in suspension, thus rendering a mixture pumpable.

Tables 3 and 4 suggest a simplified approach to determine the amount of coarse aggregate for pump mixes depending on the fineness modulus of the fine aggregate. Table 3 should be used for rounded river gravel and Table 4 for crushed stone. This information is based on the values shown in Table 5 and incorporates the characteristic differences between rounded river gravel and crushed stone.

The gradation of fine aggregate should conform to the requirements of ASTM C 33. Experience has shown that particular attention should be given to those portions passing the finer screen sizes.¹ At least 15 to 30 percent should pass the No. 50 screen and 5 to 10 percent should pass the No. 100 screen. Fine aggregates that are deficient in either of these two sizes should be blended with selected fine sands, mineral admixtures, or other materials to produce these desired percentages. Use of greater than the preceding amount of these finer fractions requires the use of additional water that may cause excessive shrinkage and be harmful to strength.

The fineness modulus of fine aggregate meeting ASTM C 33 gradation specifications will fall between 2.30 and 3.10 with the median being 2.70. 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 provided the percentages passing the No. 50 and 100 sieves meet the previously stated requirements. The fineness modulus alone, without stipulations about particle distribution, may not produce satisfactory results. With the finer fine aggregate (lower values of fineness modulus), larger quantities

Table 5—Volume of coarse aggregate per unit of volume of concrete

Nominal maximum size of aggregate, in.	Volume of oven-dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli of fine aggregate			
	2.40	2.60	2.80	3.00
1/4	0.60	0.48	0.46	0.44
1/2	0.69	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1 1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

*Volumes based on aggregates in oven-dry-rodded conditions as described in ASTM C 29.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10 percent. For more workable concrete, see Section 6.1 6.1.

See ASTM C 136 for calculation of fineness modulus.

of coarse aggregate may be used, as shown in Table 5. (Fig. 9 shows the same information as a graph.) ACI 211.1, Section 6.3.6.1 states for more workable concrete, which is sometimes required when placement is by pump, it may be desirable to reduce the estimated coarse aggregate content determined by Table 5 up to 10 percent. However, caution must be exercised to assure the resulting slump, water-cement or water-cementitious materials ratio, and strength properties of the concrete meet applicable project specification requirements. This reduction provides a safety margin for variations in fine aggregate gradation and reduces pumping pressures. Under conditions of good materials control and uncomplicated line systems, this reduction may not be required. It should also be emphasized that for uniformity, the fineness modulus of the fine aggregate should not vary more than 0.20 from the average value used in proportioning.

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. More or less of any particular particle size than ASTM C 33 permits for fine aggregate should be avoided. Small quantities of materials such as crusher dust, wash pit sediment, fly ash, and beach or dune sand are often useful in correcting deficiencies in the finer sizes. Experience indicates that combining materials from separate sources often brings excellent results. The use of as little as 5 percent river sand may render crushed rock sand pumpable. In the same way, small additions of rock fines may improve the pumpability of natural sands, particularly where dredging has washed out the finer sizes. Additions of as little as 25 lb/yd³ can create a noticeable improvement in pumpability of a mixture.

Table 5 is suggested as a guide to determine the amounts of coarse aggregate to be combined with fine aggregate of different fineness modulus values.

As a guide in selecting suitable fine aggregate, the solid-line curves in Fig. 10 and 11 are suggested. In Fig. 10, the percentage passing each screen size is shown together with

**Bulk Volume of Coarse Aggregate
as a Fraction of Total Concrete Volume
Data from Table 6.3.6 ACI 211.1-91**

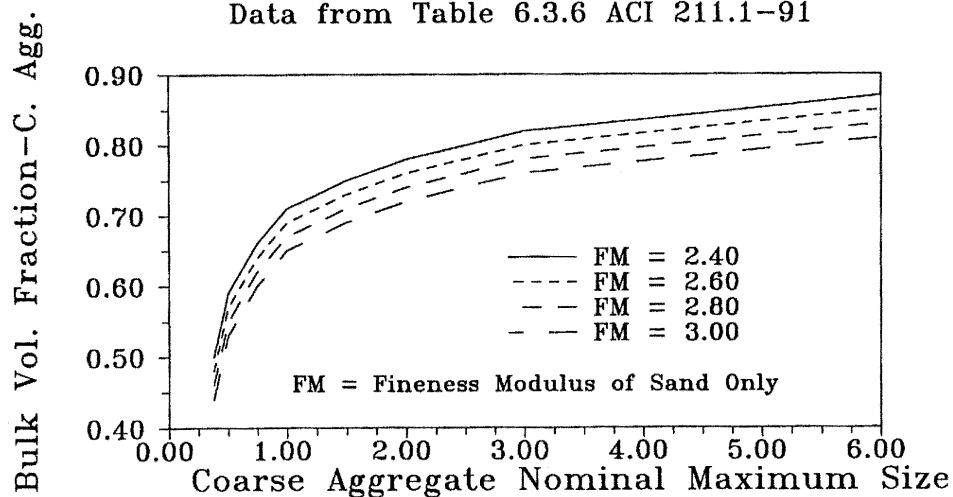


Fig 9—Bulk volume of coarse aggregate as fraction of total concrete volume data from Table 6.3.6, ACI 211.1-91

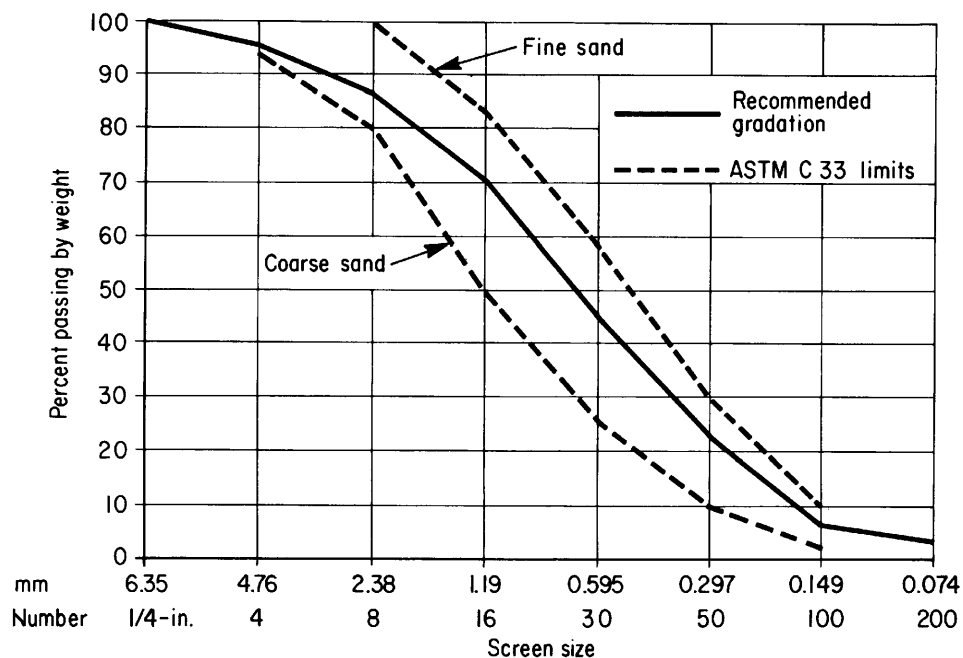


Fig. 10—Recommended normal weight fine aggregate gradation (percent passing)

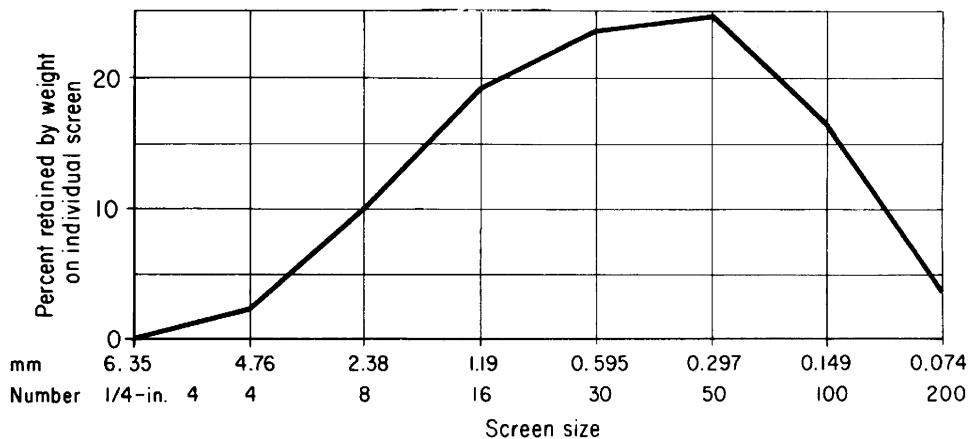


Fig. 11—Recommended normal weight fine aggregate gradation (individual percent retained)

Combined normal weight aggregate analysis

Step 1. Determine total weight of all aggregates.

Wt. coarse aggregate (lbs.) (CA) _____ A
 Wt. fine aggregate (lbs.) (FA) _____ B
 Wt. other fine materials:
 Blend aggregates _____
 Cement over 470 lbs. _____
 Total other aggregate lbs. (OA) _____ C
 Weight of total aggregate (TA) _____ D

Step 2. Determine adjustment factor for CA, FA & OA percentages.

CA wt. - TA wt. [A - D] = _____ CA factor
 FA wt. - TA wt. [B - D] = _____ FA factor
 OA wt. - TA wt. [C - D] = _____ OA factor

Step 3. Determine weighted percent of aggregate passing each screen.

Material	% Passing			Col. A	Col. B	Col. C	A+B+C
Size	%CA	%FA	%OA	%CA x CA Factor	%FA x FA Factor	%OA x OA Factor	Cum % Passing
2							
1 1/2							
1							
3/4							
1/2							
3/8							
#4							
#8							
#16							
#30							
#50							
#100							

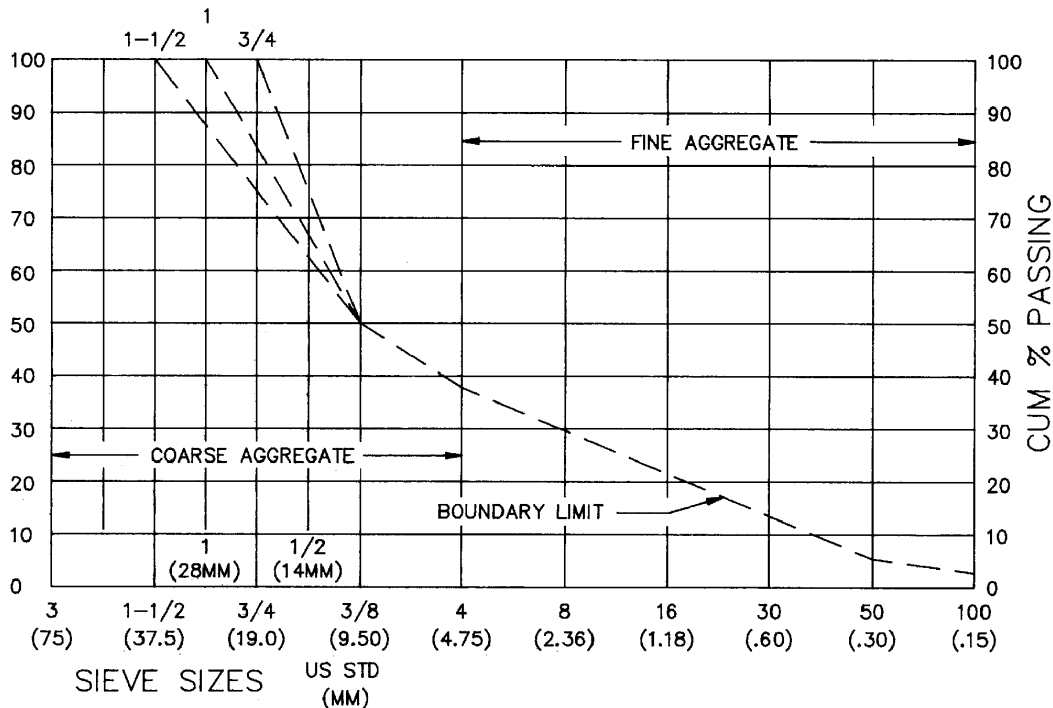


Fig. 12—Analysis worksheet (courtesy Morgen Manufacturing Co., Yankton, SD)

ASTM limits, while in Fig. 11 the individual percent retained on each screen is shown. Both solid curves represent identical data. Although in practice it may be impossible to duplicate this recommended fine aggregate gradation exactly, fine aggregates having a gradation closer to the upper limit (fine) are more desirable for pumping than those near the lower limit (coarse). The fineness modulus of this composite material is 2.68; the gradation meets ASTM C 33 specifications and produces a smooth curve, and the percentages passing the No. 50 and No. 100 screens are well within the limits prescribed previously.

4.2.3 Combined normal weight aggregates—The combined coarse and fine aggregate occupies about 67 to 77 percent of the mixture volume. For gradation purposes the fine and coarse aggregate should be considered as one — even though fine and coarse aggregate are usually proportioned separately.¹⁶

Fig. 12 is an analysis worksheet for evaluating the pumpability of a concrete mixture by combining the fine and coarse aggregate with NMSA from 3/4 in. to 1-1/2 in. The worksheet makes provision for additional coarse and fine aggregate that may be added to a mixture to improve the overall gradation and recognizes possible overlap of some coarse and fine aggregate components.

If a mixture that is known to be pumpable is evaluated and graphed first as shown, the curve representing its proportions provides a useful “boundary line” for determining the pumpability of the questionable mixture. If that mixture has a curve running in a zigzag fashion or has one or more values falling below the “boundary line,” the mixture is borderline for pumping and may not be pumpable by all types of concrete pumps described in Chapter 2. Those pumps with powered valves, higher pressure on the concrete, and the most gradual and smallest reduction from concrete tube diameter can pump the most difficult mixtures. However, a borderline mixture may be pumpable in less capable pumps if some optimum characteristics or changes in combined gradation compensate for those that are deficient. The concrete pump inherently measures batch uniformity by adversely reacting to decreasing pumpability. Slight changes in composition of a borderline mixture that result in it not being pumpable can result in expensive pump downtime from pipeline blockage. For purposes of this analysis, any cement in excess of 470 lb/yd³ should be considered as material passing the No. 50 or No. 100 sieve.¹⁷

4.3—Lightweight aggregate concrete

4.3.1 Introduction—Lightweight aggregate structural concrete has many economic applications and advantages in building construction. This material is particularly suited to multistory construction, and the use of pumps for placing it has become desirable in many instances.

Tables 6 and 7, which are based on field experience, suggest the volumes of prewetted or super-saturated lightweight aggregate to be used with fine aggregate, of various fineness moduli, per cubic yard of lightweight concrete. They distinguish between prewetted and super-saturated material (see 4.3.2.3). In many cases, this guideline is all that is required

to provide a pumpable mixture. The following information on saturating and proportioning lightweight aggregate is provided for use when a supplier of pumpable lightweight concrete is not readily available, or to expedite identification of the cause of any problem in pumping lightweight concrete.

4.3.2 Increasing moisture content of lightweight aggregate—The first step in preparing pumpable concrete with lightweight aggregate is to assure that the material is properly saturated.¹⁸ 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 its fluid properties and the pumpability of the concrete. Therefore, to pump lightweight concrete it is necessary to pretreat the aggregate to prevent excessive stiffening resulting from water being absorbed during the pumping operation.

Inadequately saturated aggregate results in pipeline blockage. Handling and mixing of unsaturated lightweight aggregate is undesirable. A more detailed discussion of methods of saturating lightweight aggregate is given in ACI 304.5R.

4.3.2.1 Coarse aggregate—The total amount of water absorbed by lightweight coarse aggregate soaked or sprinkled at atmospheric pressure increases with time, but the rate of absorption of some lightweight aggregate is very rapid at first and later tapers off. Lightweight coarse aggregate for pumping may be presoaked in stockpiles or bunkers prior to use in concrete. Generally, a minimum of 3 to 5 days of sprinkling is recommended to reach a level of moisture content to promote successful pumping.¹⁸ However, the actual time required should be based on appropriate tests on, or experience with, the particular aggregate being used. Presoaking may be accomplished by suitable sprinkling for penetration to the full depth of the material. Sprinkling should be temporarily discontinued when free water appears at the base of the material. Sprinkling should be resumed and repeated to provide additional water for additional absorption. The moisture content of the presoaked material should exceed the average 24 hr absorption as measured by ASTM C 127. To achieve uniform slump control, free water should be allowed to drain away before using the aggregate in concrete.

The mixture proportions established for the job should take into consideration possible slump loss which may occur during both transporting and pumping. Generally, the slump of the concrete going into the pump must be increased and the coarse aggregate content must be reduced, sometimes by as much as one-third of the quantity normally used in lightweight concrete. Table 8 indicates the volume of oven-dry, loose coarse aggregate which is generally used per cubic yard of concrete with different fineness moduli of fine aggregate. Table 6 contains similar information for prewetted material and gives a workable range in these quantities. More fine aggregate may be required and sometimes it is also nec-

essary to use finer fine aggregate, air-entraining admixtures, water-reducing admixtures, and/or pozzolans to further improve pumpability.

4.3.2.2 Fine aggregate—Presoaking of lightweight fine aggregate should receive as much attention as the coarse lightweight materials. If the fine materials are soaked in a stockpile or bunker, it is more difficult for the water to penetrate through the mass to the total depth of the material. However, each individual grain or particle, when it comes in contact with water, will attain its absorption per unit of volume at a much faster rate than coarse pieces. Presoaking helps to prevent segregation of sizes, but oversoaking may wash out the extremely fine particles which are critically needed. Presoaking of lightweight fines is occasionally accomplished in the mixer drum with about two-thirds of the total mixing water before adding other ingredients. Presoaking by this method is accomplished in approximately 5 min. Presoaked fine lightweight aggregate will probably introduce some surface moisture to the mixture along with the absorbed water. Proper allowances for this surface water must be made to control the slump of the concrete. However, the total water, that is, the surface water and the absorbed water, should be determined prior to batching by weight to insure that the proper absolute volume of fine aggregate is introduced into the concrete (ASTM C 128).

4.3.2.3 High percentage saturation—Vacuum saturation¹⁹ 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. The suggested volumes of coarse lightweight aggregates used with this degree of saturation are shown in Table 7.

4.3.2.4 Retention of moisture—Lightweight aggregate saturated by sprinkling or presoaking should be used soon after achieving the desired level of saturation. In contrast, lightweight aggregate treated with the vacuum or thermal saturation process may be stockpiled for over 90 days without significant loss of moisture. Concrete made from saturated lightweight aggregate should be allowed to cure for several weeks before it is subjected to freezing and thawing cycles.

4.3.3 Coarse lightweight aggregate—The gradation of coarse lightweight aggregate should fall within the limits stated in ASTM C 330. Most lightweight aggregate producers will have either 1/2 or 3/4 in. nominal maximum sizes, or both, available. The aggregate producer should be consulted for suggestions and recommendations on all aspects of proportioning. It is important to mention that the lightweight aggregates may fluctuate in their unit weight. Such variations within limits are recognized and permitted by ASTM C 330. These changes in unit weight may 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 is imperative to maintain consistent absolute volumes of aggregate and proper yield. Batching of lightweight coarse aggregate by volume rather than by weight is another well established method used for maintaining consistency and volumetric yield (ACI 304.5R).

Table 6—Suggested volumes (ft³) of prewetted lightweight aggregate per yd³ of concrete to be pumped

Type of fine aggregate	Coarse lightweight size, range		
	3/8 in., No. 4	1/2 in., No. 4	3/4 in., No. 4
Coarse F.M. 2.80 to 3.00	7.9 to 8.7	9.3 to 10.5	11.8 to 12.6
Medium F.M. 2.60 to 2.80	8.3 to 9.1	10.2 to 11.0	12.2 to 13.0
Fine F.M. 2.40 to 2.60	8.7 to 9.5	10.6 to 11.4	12.5 to 13.4

Values shown in this table are in loose ft³ of prewetted lightweight aggregate per yd³ of concrete. They may be applied to both crushed or coated particles. Total weight is obtained by multiplying these figures times the unit weight in lb per ft³ for the particular aggregate being used. This data is derived from Committee 304 experience.

*Suggestions apply only to relatively low pump pressures in 4-in. pipelines. The sum of the vertical lift in ft plus one-third the total length of the distribution line should preferably be less than 150 ft.

Table 7—Suggested volumes (ft³) of super-saturated lightweight aggregate per yd³ of concrete to be pumped

Type of fine aggregate	Coarse lightweight size, range		
	3/8 in., No. 4	1/2 in., No. 4	3/4 in., No. 4
Coarse F.M. 2.80 to 3.00	10.6 to 11.5	13.0 to 14.0	15.7 to 16.7
Medium F.M. 2.60 to 2.80	11.1 to 12.1	13.5 to 14.5	16.2 to 17.2
Fine F.M. 2.40 to 2.60	11.6 to 12.6	14.0 to 15.0	16.7 to 17.7

Values shown in this table are in loose ft³ of saturated lightweight aggregate per yd³ of concrete. They may be applied to both crushed or coated particles. Total weight is obtained by multiplying these figures times the unit weight in lb per ft³ for the particular lightweight aggregate being used. This data is derived from Committee 304 experience.

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. In any case, proper allowances may be made for shape and surface texture to handle any type of lightweight aggregate in a pump mixture. These allowances are made by slight changes in the ratio of mortar to coarse aggregate.

In some localities, lightweight coarse aggregates larger than the No. 4 screen (3/16 in.) 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 C 330 gradation specifications. Uniformity of gradation should be carefully maintained from one batch to the next, since fluctuations will affect the degree of pumpability.

4.3.4 Fine lightweight aggregate—The gradation of fine lightweight aggregate should also fall within the limits shown in ASTM C 330. In addition, it is imperative to pay specific attention to the very fine fractions. From 20 to 35 percent should pass the No. 50 screen and 10 to 20 percent should pass the No. 100 screen. If the lightweight fine aggregate is deficient in these sizes, some aggregate supplement or mineral admixture, such as pozzolan, fly ash, or rock dust in

Table 8—Volume of coarse lightweight aggregate per unit of volume of concrete

Maximum size of aggregate, in.	Volume of oven-dry loose coarse aggregates* per unit volume of concrete for different fineness moduli of sand			
	2.40	2.60	2.80	3.00
1/4	0.58	0.56	0.54	0.52
1/2	0.67	0.65	0.63	0.61
3/4	0.74	0.72	0.70	0.68

*Volumes based on aggregates in oven-dry loose conditions, as described in ASTM C 29 for Unit Weight of Aggregate.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For more workable concrete, such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10 percent.

Table 9—Comparison of fineness modulus by weight and volume for typical lightweight aggregate

Sieve size no.	Opening, in.	Percent retained, weight	Cumulative percent retained, weight	Bulk specific gravity, SSD basis	Percent retained, volume	Cumulative percent retained, volume
4	0.187	0	0	—	0	0
8	0.0937	22	22	1.55	26	26
16	0.0469	24	46	1.78	25	51
30	0.0234	19	65	1.90	19	70
50	0.0117	14	79	2.01	13	83
100	0.0059	12	91	2.16	10	93
Pan		9	100	2.40	7	100

Fineness modulus by weight = 3.03; fineness modulus by volume = 3.23.

approximately the amount of the deficiency, will improve pumpability.

In some instances it may be possible to blend lightweight fine aggregate with natural sands. This practice may entail some dual considerations. Replacing lightweight fines with natural sands may improve the overall gradation of these combined fine aggregates, but it may also adversely increase the weight of the finished concrete mixture. Adverse weight effects, however, might be minimized by the use of relatively small amounts of very fine natural sands if this combination results in improved gradation. Although the pumpability of a mixture may be enhanced by the addition of minus 50 to minus 200 mesh fractions in the fine aggregate, it should also be remembered that too great an increase in these very fine sizes will require greater amounts of mixing water which reduce the strength and increase the drying shrinkage.

The fineness modulus of the lightweight fine aggregate requires some further comments in addition to those previously stated on the fineness modulus for natural sand. These comments are taken from ACI 211.2.

For normal weight aggregate the bulk specific gravities of fractions retained on the different sieve sizes are nearly equal. Percentages retained on each size indicated by weight, therefore, give a true indication also of percentages by volume. However, the bulk specific gravity of the various size fractions of lightweight aggregate increases as the particle size decreases. Some coarse aggregate particles may float on water, whereas material passing the No. 100 sieve may have a specific gravity approaching that of normal weight fine aggregate. It is the volume occupied by each size fraction, and

not the weight of material retained on each sieve, that determines the void content and required paste content, to provide workability of the concrete. Percentages retained on each sieve, and fineness modulus by weight and by volume, are computed for comparison in the example of Table 9.

The fineness modulus of 3.23 by volume in the example indicates a considerably coarser grading than that normally associated with the fineness modulus of 3.03 by weight. Therefore, the lightweight aggregate tends to require a larger percentage of material retained on the finer sieve sizes, on a weight basis, than does normal weight aggregate, to provide an equal size distribution by volume.

Since it is impractical to calculate the fineness modulus of lightweight fines on a volume basis, it is suggested that it be figured on a weight basis similar to normal weight fine aggregate. If an arbitrary allowance of 0.20 difference in fineness modulus is made between normal weight and lightweight fines, the suggested range of fineness modulus for lightweight becomes 2.20 to 2.80 as compared to the previously stated values of 2.40 to 3.00 for normal weight fine aggregate. Experience to date does not indicate the need for any greater accuracy. If natural sand is blended with the lightweight fines, the combined fineness modulus calculated on a weight basis should also fall within the limits of 2.20 to 2.80.

4.3.5 Combined lightweight aggregates—The proportioning of coarse and fine aggregates to produce pumpable lightweight concrete should rely on the recommendations and experience of the aggregate producer. In many areas, only a limited selection of materials may be available and it may be necessary to import other supplemental products to achieve the best results. For example, a pozzolanic material or fly ash might be successfully used as a fine aggregate supplement, and in other cases lightweight mixtures are proportioned with 100 percent normal weight fine aggregate. Pozzolanic materials in the small amounts generally used for gradation beneficiation have no significant effect on the unit weight of the concrete.

Tables 6 and 7 are suggested as a guide for the amount of coarse lightweight aggregate that might be selected for trial mixtures in lightweight concrete when atmospherically soaked or super-saturated aggregate is used. The values for fineness modulus shown in Table 9 are intended for the combination of all fine aggregates including natural sands or mineral supplements if they are used. Differences in particle shape, gradation, surface characteristics, void contents, and degree of presoaking may each have an influence on the optimum volume of coarse aggregate for a particular mortar. It is emphasized that these values are suggestions based on experience only and might easily vary as much as 10 percent above or below those shown for particular local conditions, as well as for specific pumps.

4.4—Water and slump

4.4.1 General—Water requirements and slump control for pumpable normal weight concrete mixtures are interrelated and extremely important considerations. The amount of water used in a mixture will influence the strength and durabil-

ity (for a given amount of cement) and will also affect the slump or workability.

4.4.2 Water—The mixing water requirements vary for different maximum sizes of aggregate, as well as for different slumps. A table showing the approximate quantity of water for different conditions is given in ACI 211.1 for both non-air-entrained and air-entrained concrete. It should be emphasized that these values are only approximate and may require some changes due to the amount or fineness of the fine aggregate or quantity of admixtures, additives, cement replacements, or other special materials being used in the concrete, as well as the concrete and air temperature and the time interval from initial mixing to the slump measurement.

For lightweight concrete, the total water requirements will be different than for normal weight mixtures. This is due to differences in the absorptive properties of the aggregate. If the total water in a lightweight mixture is divided into two segments, that is, into “free” water and “absorbed” water, it simplifies the considerations. The “free” water will establish the slump and have a direct bearing on the water-cementitious material relationship. The absorbed water, however, will be contained within the lightweight particles and will not change their displaced volume in the mixture. Also, the absorbed water will not directly affect the quality of the paste. The requirements for “free” water in lightweight concrete are approximately the same as for a similar mixture of normal weight concrete. The absorbed water, as mentioned previously, will vary, and to minimize these variations, saturating the lightweight aggregate has been emphasized. Additional absorption due to pump pressures will be discussed under slump control.

4.4.3 Slump control—To establish the optimum slump resulting from water content for a pump mixture and to maintain control of that particular slump through the course of a job are both extremely important factors. Experience indicates that slumps from 2 to 6 in. are most suitable for pumping. In mixtures with higher slump, the aggregate will separate from the mortar and paste and may cause pipeline blockage. Overly wet mixtures also exhibit excessive bleeding, loss of entrained air, and increased shrinkage. It is much more important to obtain a truly “plastic” mixture through proper proportioning than to try to overcome deficiencies by adding more water. However, slumps above 6 in. obtained through the use of superplasticizers are usually pumped without difficulty.

There are several reasons why the slump of concrete may change between initial mixing and final placement. Some of these are variations in the setting time of cement due to physical or chemical properties; variations in ambient air temperature or concrete mixture temperature during mixing and pumping; variations in the temperature of cement, water, and aggregates; the influence of admixtures such as accelerators and air-entraining admixtures; and variations in the water requirements and absorptive capacities of both normal weight and lightweight aggregates.

If additional absorption in lightweight concrete does occur during truck mixing time, the mixture should be brought to the specified slump by the addition of extra water to offset

that which was absorbed. This practice will not detract from the intended strength since the original proportions were predicated on “free,” not “absorbed,” water to produce the desired strength at that slump. If a slump loss takes place in lightweight mixtures between the pump and end of the discharge hose, this may be due to further aggregate absorption under pressure caused by insufficient saturation of the lightweight aggregate, too much coarse aggregate for a pumpable mixture, high pumping pressures, or a combination of these. If the slump at the end of the discharge hose can be maintained within specification limitations, it may be satisfactory for the concrete to enter the pump at a higher slump to compensate for slump loss, if, as previously stated, the change is due simply to aggregate absorption.

4.5—Cementitious materials

The determination of the cementitious materials content for a normal weight pump mixture follows the same basic principles used for any concrete. The specific water-cement ratio may be established on the basis of exposure conditions, strength requirements, or minimum cement factor, whichever governs. This is explained in ACI 211.1. Because of the slightly higher ranges in slump and the previously discussed ratios of fine to coarse aggregates, pump mixtures may require an increase in the amount of cement used.

The cementitious materials contents for pumpable lightweight concretes follow the general principles discussed in ACI 211.2 for lightweight concrete. It is recommended that the lightweight aggregate producer be consulted on cementitious materials content requirements for his particular material to meet the necessary strengths. It should be recognized that pumpable lightweight mixtures which use higher ratios of fine to coarse aggregates or higher slump may require an upward adjustment in cement contents.

In establishing the cement content for normal weight or lightweight trial mixtures, it is well to remember the need for overstrength proportioning in the laboratory to provide for field variations. A complete discussion of the subject of evaluation of concrete compressive strength may be found in ACI 214.

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.

4.6—Admixtures

4.6.1 General—Any admixture that increases workability in both normal weight and lightweight concretes will usually improve pumpability. The choice of 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 may provide additional lubrication, reduce segregation, and decrease bleeding.

Admixtures used to improve pumpability are generally classified as:

1. Water-reducing and high-range water-reducing admixtures
2. Air-entraining admixtures
3. Finely divided mineral admixtures

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 all types being used.

4.6.2 Normal and high-range water-reducing admixtures—The primary benefit to be derived from water-reducing admixtures is the reduction in water requirement at a constant slump or an increase in slump at a constant water-cement ratio. Some may be designed to have no apparent effect on setting time, others to achieve varying degrees of acceleration or retardation in the rate of setting of the mixture. In some instances, the chemicals that provide water reduction also may entrain air. Most water-reducing admixtures increase the pumpability of the concrete mixture. Frequently, the gain in compressive strength at all ages is greater than the water reduction might indicate.

High-range water-reducing admixtures (superplasticizers) may be effective in increasing the pumpability of concrete. However, they are effective for only a limited time. Concrete that depends on superplasticizers for pumpability must be discharged from the pipeline before any reduction in slump occurs. It is recommended that these admixtures be included in the trial mixture program if their use is proposed. Compatibility of the mixture ingredients should be closely watched, as rapid and significant loss of air content has been experienced with some high-range water-reducing admixtures.

4.6.3 Air-entraining admixtures—Air-entraining admixtures (AEA) may materially alter the properties of both freshly mixed and hardened concrete. Air-entrained concrete is considerably more cohesive and workable than nonair-entrained concrete. It can be pumped with less coarse aggregate segregation and there is less tendency for the concrete to bleed. Start-up after shut-down with the pipeline full is generally easier with air-entrained concrete than with nonair-entrained concrete due to reduced bleeding. Bleeding sometimes results in a loss of lubrication, which tends to cause pipeline blockage.

AEA should meet the requirements of ASTM C 260.

ACI 201.2R recommends air content limits based on nominal maximum size aggregate and required durability. For all concrete, including that which is pumped, these limits should be obtained at the point of placement in the structure.

Increased awareness of the need to incorporate entrained air in concrete to minimize freezing and thawing damage to concrete in structures has coincided with increased use of concrete pumps to place this concrete and development of longer placing booms. This has resulted in considerable research and testing, which has established that the AEA effectiveness in stabilizing a good air bubble system depends on many factors. The more important factors are the compatibility of the AEA and other admixtures, as well as the order in which they are introduced into the batch, the mix proportions and aggregate gradation, mixing equipment and procedures,

mixture temperatures, and slump. AEA effectiveness, and therefore the resulting dosage of AEA, also depends on the cement fineness, cement factor and water content, and on the chemistry of cement and water, as well as that of other chemical and mineral admixtures used in the concrete.

The ability to entrain air is strongly affected by carbon. Carbon from fly ash or other cementitious materials can greatly increase the amount of AEA needed to achieve a specific air content. Carbon can also affect the stability of air in concrete.

Aggregates, with increased amounts of sand in the #30 to #50 sieve range, are important for improving bubble stability. Changes to the sand batch weight or gradation can change the total air content.²⁰ Refer to ACI 212.3R, [Chapter 2](#), for additional information on AEA.

AEA stabilize bubbles created and trapped in the mixing process. The smallest air bubbles are most effective in preventing freezing and thawing damage. Larger or coarse bubbles are 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.²⁰

Twenty-four tests of the air content of concrete from six successive truckloads of concrete showed that the variation in truck to truck air content was frequently greater than the variation due to different methods of handling the concrete. Later tests on this fresh concrete after pumping, conveying, and free fall showed reduced air content. After pumping, the remaining air bubbles were smaller than the average bubble sizes before pumping. However, the air void spacing factor, which is often used as an index to frost resistance, was not significantly altered by pumping. The actual freezing and thawing resistance did not correlate with air content. In one ASTM C 666 test, the concrete that lost the most air in pumping turned out to have the lowest total air content and the highest durability factor.²¹

It is not unusual for concrete to lose 1.0 to 1.5 percent of air as a result of handling by any conventional means. Dropping concrete vertically from a bucket or through a tremie or elephant trunk, or the vertical dropping of concrete in a pipeline of a concrete pump, can reduce air content by up to 1.5 percent.²²

As a result of pumping, the total air content of air-entrained concrete has been observed to increase, decrease, or to remain unaffected.²² Others report it is normal to find 0.5 to 1.0 percent loss in air content at the discharge of a concrete pump.²³

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

Pumping pressure is reduced by designing a pumpable concrete mixture, with particular attention to optimizing the combined aggregate gradation to reduce either harshness or over-sanding, and to reduce the amount of water required to maintain workability. Pressure is also reduced by selecting the appropriate pump and pipeline for the task. “Free fall”

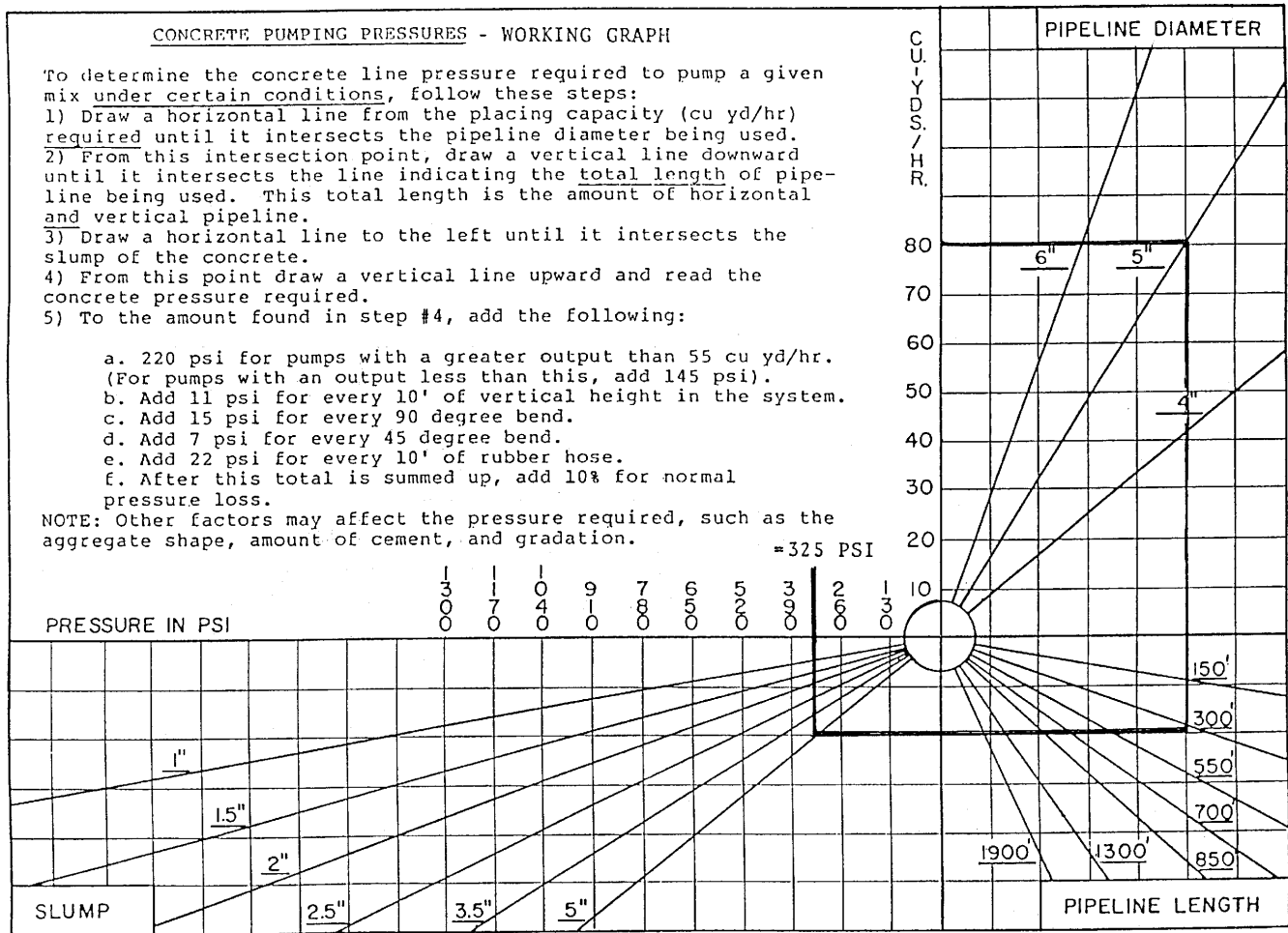


Fig. 13—Pressure volume chart (courtesy Morgen Manufacturing Co., Yankton, SD)

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. Curving the discharge hose supported by the boom or otherwise creating a back pressure to keep a full pipeline, reduce free fall, and slow the rate of depressurization have also been found to be useful. It has also been shown that a pumping rate that keeps the line full on the descending side avoids breakup of the flow followed by free fall.

In those cases in which air loss has been observed in the field, such change has not necessarily implied a reduction in the frost resistance of the concrete. When air has been lost under low pressure, free fall conditions, the loss has predominantly been in the larger air voids with negligible impact on freezing and thawing durability.^{22,24}

As specified in ASTM C 172, for project-specific air content changes, a correlation test may be conducted by sampling concrete entering the hopper and that discharged at the end of the pipeline. Tests by the National Ready-Mixed Concrete Association determined that a significant proportion of entrained air could be lost when a slug of concrete was allowed to slide down the 5-in.-diameter pipeline on long truck booms under its own weight.²³ This article recommends methods to prevent air loss and precautions to be taken.

Higher air content does not necessarily mean better concrete quality. Frost resistance in any concrete depends on more than the characteristics of the air void system. Porosity, permeability, tensile strength, degree of saturation, curing history, and rate of freezing also have an effect.²⁴

4.6.4 Mineral admixtures—Finely divided mineral admixtures may be classified into three types:

1. Relatively chemically inert material. This type includes such materials as ground limestone, ground quartz, and hydrated lime.
2. Cementitious materials. This type includes natural cement, ground-granulated blast furnace slag, hydraulic lime (ASTM C 141), and slag cements (ASTM C 595).
3. Pozzolans. Examples of pozzolanic materials are Class C and F fly ash, diatomaceous earth, volcanic glass, some heat-treated shales or clays (ASTM C 618), and silica fume (ASTM C 1240).

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 work-

ability and pumpability, reduces rate and amount of bleeding, and increases strength. The effect on strength depends on the type of mineral admixture used, conditions under which the concrete is cured, and the amount of admixture used.

4.7—Fiber reinforcement

Both steel and synthetic fiber reinforced concrete can be pumped. While the addition of steel or synthetic fibers can affect viscosity and flow characteristics, most of them do not have an adverse effect on the pumpability of the concrete to which they are added. However, the fiber manufacturer's literature should be consulted to insure proper application of fiber-concrete systems. See ACI 544.1R.

A reinforcing fiber for concrete should comply with ASTM C 1116 and documentation relative to ASTM C 1018.

4.8—Trial mixes

Where prior experience or the mixture analysis in [Section 4.2.3](#) 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 in a laboratory in accordance with applicable ASTM standards for their physical properties. There is no accepted test for pumpability, so the materials to be used must be selected in accordance with the guidelines provided in [Chapter 4](#). It is suggested that the highest possible fineness modulus of fine aggregate be used rather than the average fineness modulus to insure consistent performance during pumping. As indicated previously, if additional pumpability is required, ACI 211.1 permits a 10 percent reduction in coarse aggregate quantities. Experience with local aggregates and concrete mixtures and their uniformity should be considered in selecting a concrete to be pumped.

For lightweight concrete, it is strongly suggested that the lightweight aggregate supplier be consulted not only for the materials properties but also for recommendations on mixture proportions for pumping. It may also be advisable to confer with the ready-mixed concrete supplier to determine if storage and batching facilities are adequate to properly blend and saturate the materials.

4.9—Testing for pumpability

Testing pumpability of the trial mix involves production of a sizeable quantity of the mixture and pumping it under conditions involving the pressures and placing rate anticipated for the work to be done. This test is performed at a construction site usually as part of a more routine initial placement. It is suggested this can be done with a minimum of trouble and expense if an alternative method of placement is provided to complete placing the required volume of concrete if difficulty is encountered in pumping the trial mixture. The pressure and horsepower needed for the test can be estimated from [Fig. 13](#).

CHAPTER 5—FIELD PRACTICES

5.1—General

The wide variety of concrete pumps discussed in [Chapter 2](#) has resulted in the development of different field practices appropriate to the pump 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) Notification to the concrete supplier that the concrete is to 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.

b) Establish the distance concrete is to be pumped (horizontal, elevation, and decline) and the maximum rate of placing required so the proper size and capacity pump will be supplied.

c) Establish the time the pump is to be ready for setup and provision for any required pipeline including supply of the material and arrangements for the required labor to assemble it.

d) Agreement between the pump operator and the placement crew as to the placement sequence, total volume to be placed, pump location as near the placing area as practical, and required access to allow two ready-mixed concrete trucks to discharge into the pump receiving hopper at the same time. Two ready-mix trucks should be positioned to discharge into the pump receiving hopper to maintain constant flow of concrete to the pump and to enable blending of the last concrete discharged from the first ready-mix truck, which frequently has a higher percentage of coarse aggregate larger sizes, with concrete from the second ready-mix truck.

e) Agreement on who is responsible for providing material to grout the pipeline.

f) Provision for clearing and cleaning the pump and pipeline when the placement is completed. Frequently the best arrangement is to arrange the placing system so concrete remaining in the pump hopper and pipeline can be discharged into a ready-mix truck.

A continuous supply of concrete is required because if the pumping is stopped for any appreciable time, concrete in the line may stiffen and it may be difficult to start pumping again.

g) The pump operator and placing crew should be familiar with standard hand signals as shown in [Fig. 14](#). When visual signals are not practical, telephone or radio communication should be provided.

5.2—Pipeline concrete placement

Any trailer or truck-mounted concrete pump can be used for pipeline concrete placement. It is important to select the pump with the engine horsepower and concrete pressure and capacity appropriate for the project ([Fig. 13](#)). The limiting factor in using this method is the ability to spread the con-

A.C.P.A. HAND SIGNALS

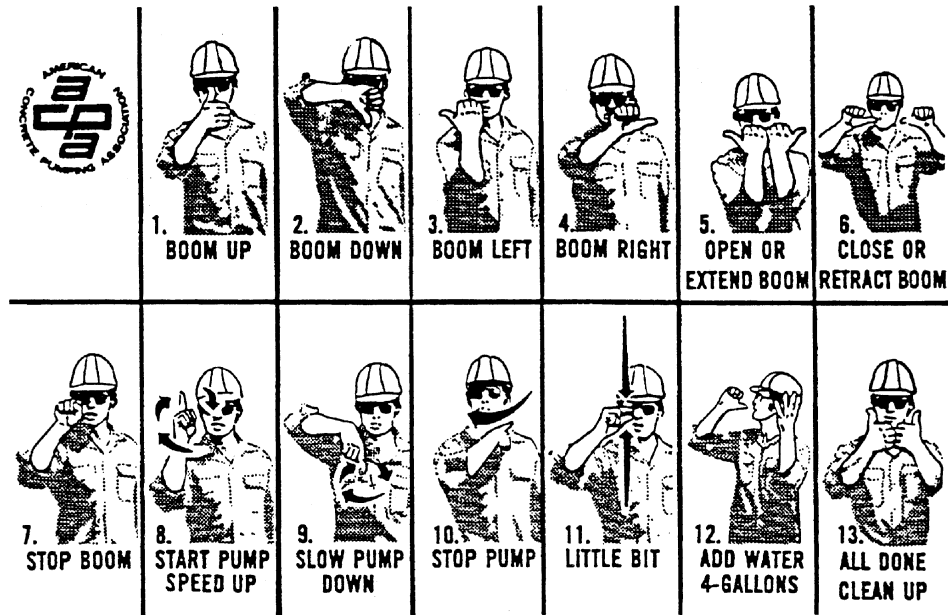


Fig. 14—ACPA hand signals. Note any addition of water to concrete must be in accordance with Section 4.4.3 (courtesy the American Concrete Pumping Association, Galena, OH)

crete 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. 15). Manually operated placing booms are available for horizontal spreading. 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 the 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. The concrete from the removed sections is used in the placement. These sections should then be cleaned outside the placement area. When the 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 may be pushed out with water or air pressure. If air is used, extreme care must be taken in regulating the air supply and pressure and a catcher must be installed at the discharge point on the pipeline to prevent the “go-devil” from being ejected as a dangerous projectile. Provision must be made to relieve air pressure in the event of a pipeline blockage (Section 3.6.4).

The weight of the concrete in the pipeline becomes very significant when pumping concrete up or down a substantial distance (over 50 ft) and this should only be done under the supervision of a person experienced and knowledgeable in this type of placing.

5.3—Powered boom placement

5.3.1 Powered placing booms—Powered placing booms are described in Section 2.5. Their discharge may be positioned at almost any point within the radius of the boom and at elevations achieved with the boom from near-vertical up



Fig. 15—Spreading concrete with flexible hose at the end of a rigid pipeline

or down to horizontal. Fig. 16 shows the discharge range of a four-section 120-ft boom. Most booms are rated according to the maximum elevation they can reach and range in size from 72 to 175 ft. The horizontal reach is usually 10 to 12 ft shorter, as shown in Fig. 16. Boom functions are operated by hydraulic cylinders or motors 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 laborers to direct the concrete to where it is needed. Boom placement greatly reduces the number of laborers needed to get pumped concrete in place.

The pump operator must avoid hazardous proximity or contact with power lines under all circumstances. This means maintaining a 17-ft clearance while taking into account the movement of the wires by wind force. The placing boom, the concrete being pumped, and all parts of the pump

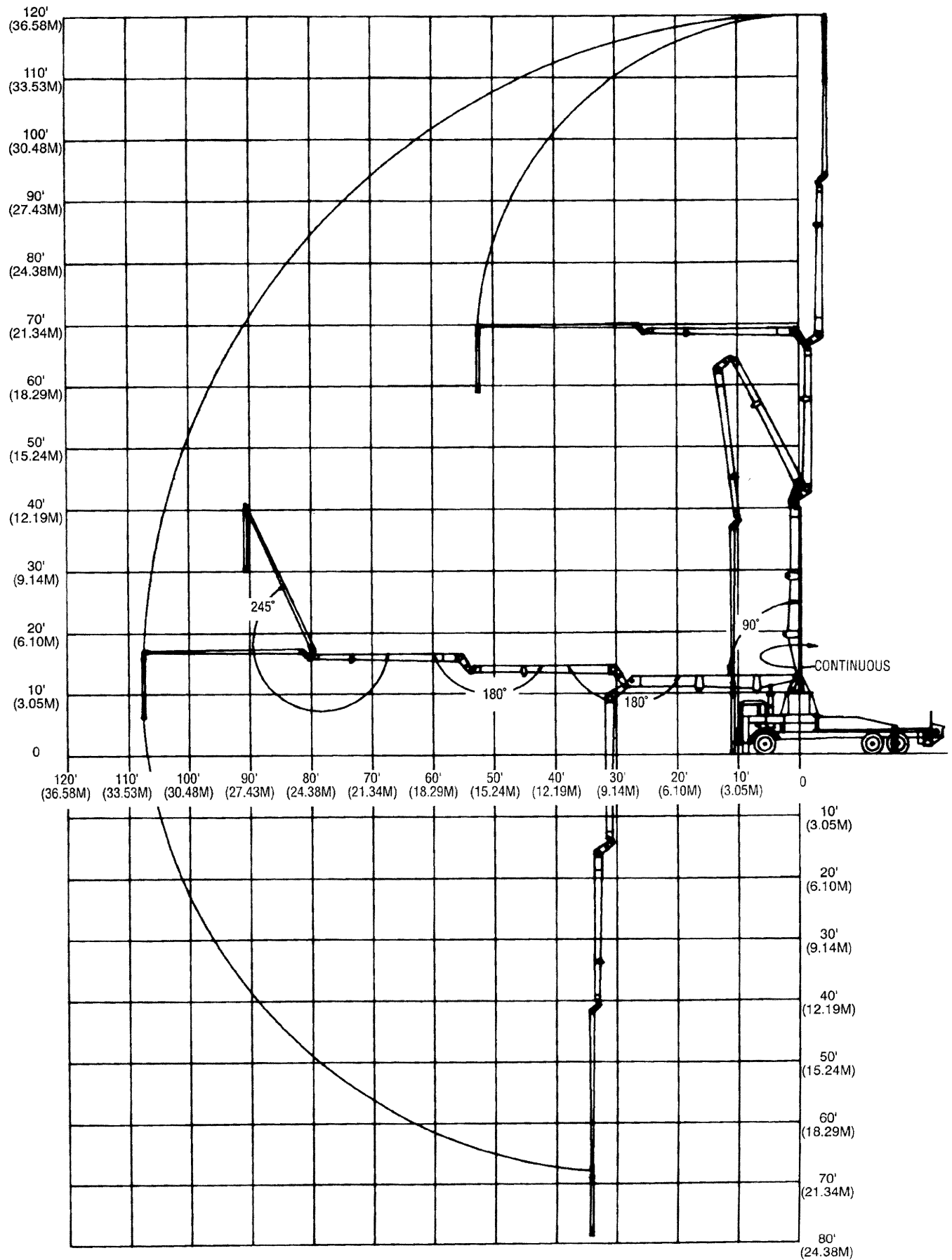


Fig. 16—Placing boom capability chart (courtesy Morgen Manufacturing Co., Yankton, SD)



Fig. 17—Truck-mounted concrete pump with powered placing boom



Fig. 18—Powered placing boom mounted on pedestal remote from concrete pump

and ready-mix truck are conductors of electricity. Anyone touching any of them is at risk.

Concrete placing and boom movement must 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. Especially with long boom pumps, if the pump and boom operator are not stationed at his pump, it is desirable to have a laborer direct the movement of the ready-mix trucks to the pump hopper charging location to assure a constant flow of concrete into the hopper and stop the pumping if concrete is not available.

5.3.2 Truck-mounted booms—Truck-mounted concrete pumps and placing booms have the greatest flexibility because they have the mobility of the truck plus the reach of the boom. These units move to and about the project like a truck and have the ability to set up for placement very quickly. Boom stability for cantilevered reach is provided by an outrigger system. The area in which the pump is located must provide stable support for the outrigger feet as well as pump truck chassis and ready-mix trucks. Generally, large pads are required under the outrigger feet to distribute the weight applied to them. The outriggers also serve to level the boom pedestal. Generally, these units utilize the truck engine to

power the concrete pump and boom so there is adequate power for pumping high capacities, generally from 100 to 200 yd³/hr (Fig. 17), at medium pressures.

5.3.3 Remote pedestal booms—When the distance from the closest point accessible to ready-mixed 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. 18). The functions of these booms are powered by separate diesel or electric power packs and 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, the pump operator, and the placing crew.

CHAPTER 6—FIELD CONTROL

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

The locations at which samples for testing the concrete are taken is extremely important. Sampling, according to ASTM C 94, is for the acceptability of the ready-mixed concrete. However, the quality of the concrete being placed in the structure can only be measured at the placement end of the pipeline. Where appropriate, 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 assure that the sample is representative of the concrete going into the placement. Changing the rate of placing and/or the boom configuration can result in erroneous test results. Concrete must not be allowed to free fall into the tester's container. The handling of the sample must not result in changes in concrete properties.

Concrete has been pumped successfully during both hot and cold weather. Precautions may be necessary to provide adequate protection during extreme conditions. The placing crew and inspector should always be alert to any segregation of concrete as discharged from the pipeline, particularly if it is caused to flow. It may be necessary under these conditions to modify or change the placing practice to eliminate or minimize such segregation.

The need for control and consistency of every operation has been emphasized throughout this report. ACI 311.1R gives a detailed outline of points to check in concrete construction. Good materials and good equipment in the hands of competent and knowledgeable people will always produce good results. This is particularly true for pumped concrete.

CHAPTER 7—REFERENCE

7.1—Recommended references

The documents of the various standards-producing organization referred to in this document follow with their serial designation.

American Concrete Institute

- 201.2R Guide to Durable Concrete
- 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
- 211.2 Standard Practice for Selecting Proportions for Structural Lightweight Concrete
- 212.3 R Chemical Admixtures for Concrete
- 213R Guide for Structural Lightweight Concrete
- 214 Recommended Practice for Evaluation of Strength Test Results of Concrete
- 304R Guide for Measuring, Mixing, Transporting, and Placing Concrete
- 304.5R Batching, Mixing, and Job Control of Lightweight Concrete
- 311.1R ACI Manual of Concrete Inspection, SP-2
- 544.1 R State-of-the-Art Report on Fiber Reinforced Concrete

ASTM

- C 29 Test Method for Unit Weight and Voids in Aggregate
- C 33 Specification for Concrete Aggregates
- C 94 Specification for Ready-Mixed Concrete
- C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate
- C 128 Test Method for Specific Gravity and Absorption of Fine Aggregate
- C 141 Specification for Hydraulic Hydrated Lime for Structural Purposes
- C 172 Method of Sampling Freshly Mixed Concrete
- C 260 Specification for Air-Entraining Admixtures for Concrete
- C 330 Specification for Lightweight Aggregates for Structural Concrete
- C 595 Specification for Blended Hydraulic Cements
- C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
- C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing
- C 1018 Test Method for Flexural Toughness and First-Crack Strength of Fiber Reinforced Concrete
- C 1116 Specifications for Fiber Reinforced Concrete and Shotcrete
- C 1240 Specification for Silica Fume for Use in Hydraulic Cement Concrete and Mortar

The preceding publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, Mich. 48333-9094

ASTM
100 Barr Harbor Dr.
West Conshohocken, Pa. 19428-2959

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Table A1.1—Conversion factors, in.-lb to SI units*

Quantity	In.-lb unit	SI [†] unit	Conversion factor, ratio: in.-lb/SI
Length	Inch (in.)	Millimeter (mm)	25.40
	Foot (ft)	Meter (m)	0.3048
Volume	Cu ft (ft ³)	Cu m (m ³)	0.02832
	Cu yd (yd ³)	Cu m (m ³)	0.7646
Mass	Pound (lb)	Kilogram (kg)	0.4536
Stress	Pounds per square in. (psi)	Megapascal (MPa)	6.895 × 10
Density	Pounds per cubic ft (lb/ft ³)	Kilograms per cubic meter (kg/m ³)	16.02
	Pounds per cubic yard (lb/yd ³)	Kilograms per cubic meter (kg/m ³)	0.5933
Temperature	Degrees Fahrenheit (F)	Degrees Celsius (C)	†

*Names and abbreviations of measurement units are given in the in.-lb system as used in the body of this report and in the SI metric system, along with multipliers for converting the former to the latter. From ASTM E 380.

†Système International d'Unités + C = (F - 32) / 1.8.

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Profiles in Concrete Pumping, Page, K. M.
Pumping for Slurry Walls.
Repair of Red Rock Dam, Tallard, G. R.
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APPENDIX 1—METRIC (SI) SYSTEM ADAPTATION

A1.1 Procedures outlined in this report have been presented using inch-pound units of measurement. The principles are equally applicable in the SI system with proper adaptation of units. **Table A1.1** gives relevant conversion factors.