Most standard construction mixes can be pumped with little or no modification. However, several factors affect the pumpability of the concrete mix, and job factors, such as aggregates available, conveying line size, and pumping equipment to be used, must be considered when designing a concrete mix for pumping.

PROPERTIES OF FRESH CONCRETE

Concrete contains cement, water, fine aggregate or sand and coarse aggregate, usually gravel or crushed stone. Admixtures such as air-entraining agents, fly ash or water-reducing agents may also be added. How the fresh concrete behaves depends on properties and proportions of the materials used. Some of the factors that affect pumpability are:

- Slump—The slump test measures the ability of a concrete to flow. Higher-slump concretes that are still cohesive flow more readily and are easier to pump. However, excessively high slump concrete can separate and cause plugs in the pump or in the line. To obtain a higher slump, more water can be added to the mix. Adding water to increase the slump will also decrease concrete strength if no additional cement is added. An alternative method to increase slump is to add a water reducing admixture. However, you must maintain adequate free water in the mix to transmit the energy of the pump to the concrete, and you must maintain adequate cement content to provide sufficient mortar for lubrication in the pipeline. The addition of a water reducing agent accompanied by a reduction in cement and water can produce a mix that is difficult to pump.

  NOTE: *When slump tests are to be made on a pumped concrete job, the specifications (usually ASTM C-94 or ACI 301) will state where the slump test is to be taken—at the pump hopper or at the end of the pipe-*

line. The concrete is subjected to pressure in the line, and may lose slump and air entrainment, especially if the aggregates are absorptive. A concrete mix could have a 6-inch (150-mm) slump at the hopper but only a 3-inch (75-mm) slump after it is discharged from the line.

- Trowelability—A concrete that is easy to finish will generally also be easier to pump. Trowelability or finishability is affected primarily by the amount of fine sand, cement and other fines such as fly ash in the mix. Up to a point, the more fines and the higher the mortar volume, the lower the line pressure will be if slump is held constant.

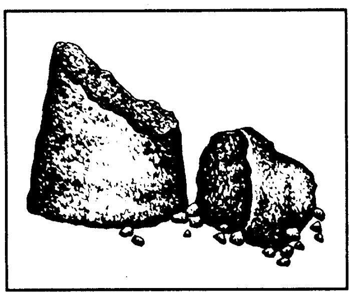

Figure 2-1. If a part of the concrete used in a slump test shears off or falls away, the concrete is probably not pumpable.

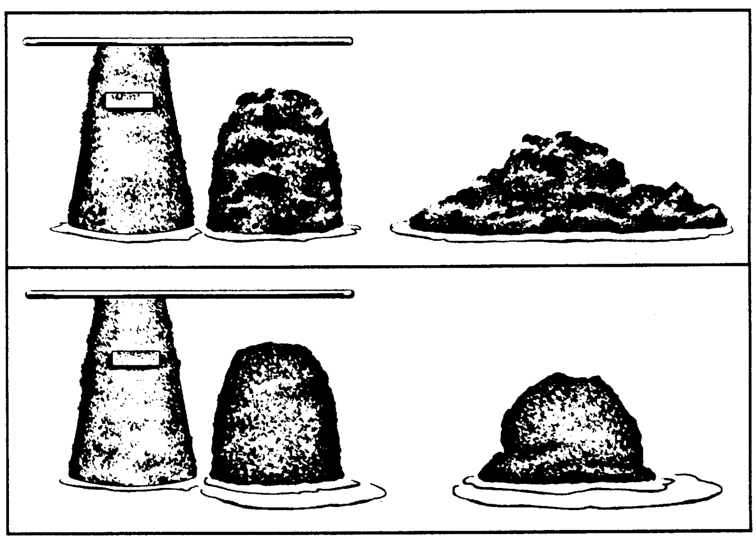

Figure 2-2. Tap the side of a slump specimen with the tamping rod. A harsh mix (top drawing) will crumble. A mix with adequate cohesion (bottom drawing) will hold together.

- Segregation—Segregation is separation of coarse aggregate from mortar or separation of cement paste from aggregate in freshly mixed concrete. Mixes that segregate easily will be harder to pump.
- Harshness—Harsh concrete mixes do not have sufficient mortar to ade-

quately coat the surface of the aggregate and to fill the voids between the aggregate. Because of this they lack cohesion. They are more likely to segregate and, are more difficult to finish or pump than mixes with sufficient mortar. If, in a slump test, the slumped concrete breaks off (Figure 2-1) or falls apart when lightly tapped with the tamping rod (Figure 2-2), the mix lacks cohesion and probably won't be pumpable.

- Bleeding—Bleeding is movement of water to the top surface of concrete as heavier materials settle. This is caused by a poorly graded sand which does not properly fill all the voids, and allows the water to "bleed" through the very small open channels. Mixes that bleed excessively are difficult to pump. Even on jobs where the concrete isn't pumped the use of these mixes should be avoided because finishing will be delayed, flatwork surfaces will be less durable, secondary flooring such as tile may not adhere properly, and sand streaking will occur on vertical surfaces.

WHAT MAKES CONCRETE PUMPABLE?

Pumpable concrete can be pushed under pressure through a pipeline system that may include flexible hose as well as steel pipeline. In a pipeline, concrete moves in the form of a cylinder or slug separated from the pipeline wall by a lubricating layer of water, cement and fine sand, which is better described as mortar. The concrete mix must be such that the concrete slug can pass through reducers and go around bends in the line, which are normal pipeline setups that cause the aggregate in the mix to rearrange their position. For this to happen the mix must be dense, cohesive and have sufficient mortar. The mortar required depends on the size of line being used, on the efficiency of the valve on the concrete pump, and on the pressure available to push the concrete. The mortar required

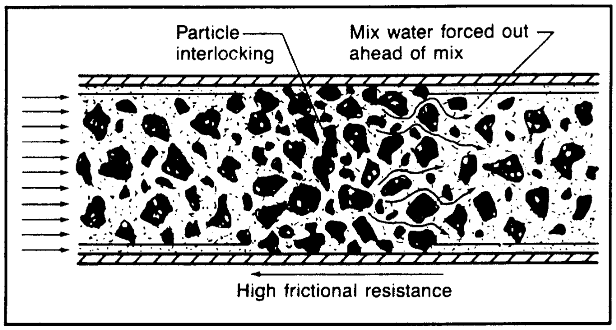

Figure 2-3. If pump pressure forces water out ahead of the mix a rock jam occurs. Friction between the aggregate and the pipe wall increases and the concrete stops moving.
DRAWING: AMERICAN CONCRETE INSTITUTE

varies from 52 percent by weight on a 5-inch (125-mm) high pressure pump to 57 percent by weight for a lower pressure pump using a 4-inch (100-mm) line. Cohesive mixes will deform as they go through bends or reducers. If the mix is harsh or lacks mortar and doesn't deform readily, particle interference and high friction will result and a blockage or plug will occur.

When concrete is pumped, free water in the mix transmits the pump pressure to the concrete slug. But if the spaces or voids between the aggregates are not filled with mortar, or the mortar is too thin and runny, the pump pressure can cause segregation forcing the water through the mix. When this happens, the lubricating layer is lost, the coarse particles interlock, friction between the particles and the pipeline increases and the concrete stops moving in the pipeline. To prevent this, the spaces between the aggregate particles must be filled with smaller aggregate particles so that the pressure at which segregation occurs is greater than the pressure needed to pump the concrete. Voids or spaces between aggregate particles are reduced in size by using a range of particle sizes from coarse to fine (proper gradation) and by using an adequate amount of cement and fine fines to create enough mortar to sufficiently coat all of the particle surfaces.

Concrete mixes that have *too many* fines may also be difficult to pump. Here, the problem isn't segregation. The mix is cohesive but friction between the concrete and the line may be so great that pump pressure isn't high enough to move the concrete. This type of pumping problem is more common with high strength concretes or with concretes containing a high proportion of very fine materials such as rock dust. These concretes are sticky and additional pressure is needed to overcome adhesion between the mortar and the pipe walls.

Increasing the amount of well-graded coarse aggregate in these mixes will help to reduce the fines content and improve pumpability. Use of a coarser sand is also recommended.

EFFECT OF AGGREGATE ON PUMPABILITY

The important properties of coarse aggregates that affect pumpability are maximum size, shape and surface texture, and most importantly, gradation of particle sizes present. If the porosity of the aggregate is exceptionally high, water absorption can also affect pumpability.

Maximum size of the coarse aggregate is considered when choosing line diameter. Generally speaking, the line diameter must be 3½ to 4 times greater than the maximum aggregate size. The hose size required is also affected by the coarseness of the mix and the angularity of the aggregate.

When using mixes with 1- to 1½-inch (25- to 37-mm) rock, it is recommended that you use a 5-inch (125-mm) line. A 4-inch (100-mm) line is suitable for mixes using ¾- to 1- inch (19- to 25-mm) aggregate and a 3-inch (75-mm) line should be used when placing ¾-inch (19-mm) and smaller aggregates. As the hose gets smaller, the mortar requirement increases. A 3-inch (75-mm) hose will require a mix containing approximately 58 percent mortar while a 2-inch (50-mm) hose will require approximately 60 percent mortar.

Shape and surface texture of coarse aggregate have an effect on mix proportions although concretes with angular or rounded and rough or

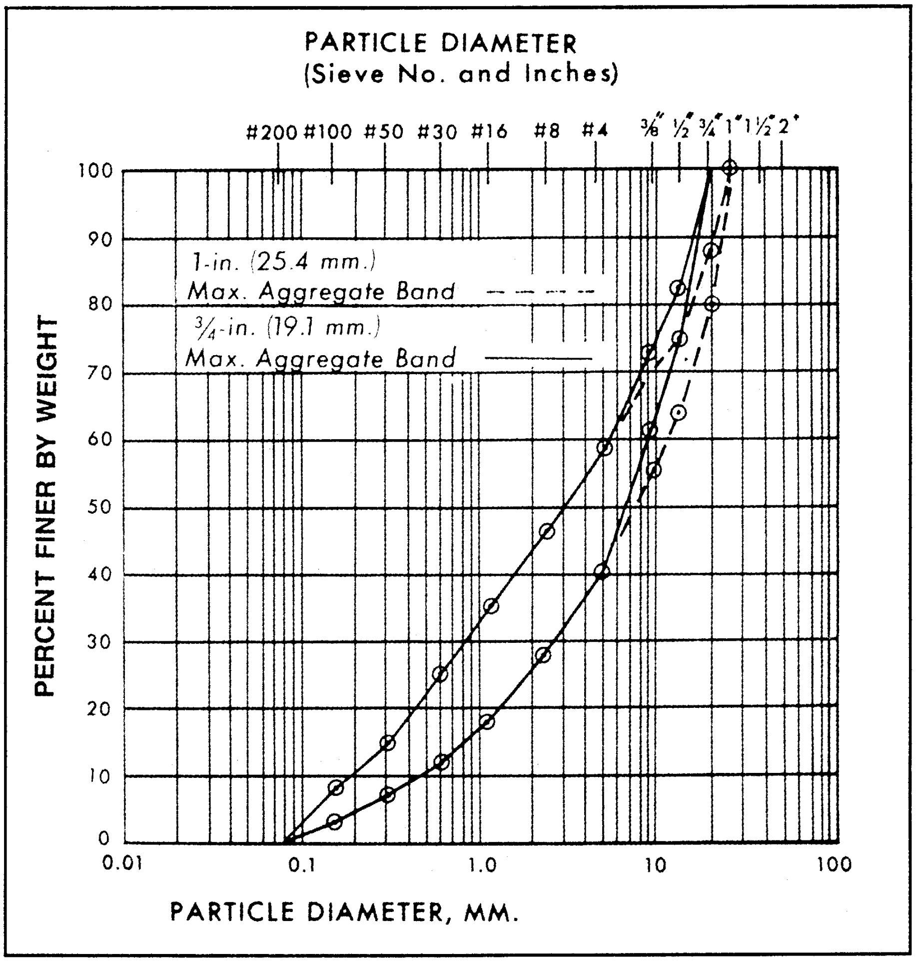

Figure 2-4. Recommended combined aggregate gradation for normal weight aggregates.
GRAPH: AMERICAN CONCRETE INSTITUTE

smooth particles can be pumped satisfactorily. Concretes made with angular, rough particles usually have to have a higher mortar content to be pumpable.

Grading of coarse aggregate used in concrete pumping can be the same as for concrete to be placed by other methods. Coarse aggregate grading requirements published by the American Society for Testing and Materials (ASTM) are shown in Table 2-1. For best pumpability the coarse aggregate should fall in the center of the gradation specifications as shown in Figure 2-4. This helps reduce the number of voids and reduces the requirement for mortar. A mix with an excess of large particles will have

TABLE 2-1. GRADING REQUIREMENTS FOR COARSE AGGREGATES (ASTM C 33)

	Size No. 467 1½ in. to No. 4	Size No. 57 1 in. to No. 4	Size No. 67 ¾ in. to No. 4	Size No. 7 ½ in. to No. 4
SIEVE SIZE	**PERCENT PASSING**			
2-in.	100	100	100	100
1½-in.	95 to 100	100	100	100
1-in.	—	95 to 100	100	100
¾-in.	35 to 70	—	90 to 100	100
½-in.	—	25 to 60	—	90 to 100
⅜-in.	10 to 30	—	20 to 55	40 to 70
No. 4	0 to 5	0 to 10	0 to 10	0 to 15
No. 8	—	0 to 5	0 to 5	0 to 5

large voids to fill with mortar, and will have particle interference, whereas a mix containing mostly small particles needs more mortar to coat all of the additional surface area. A mix with too much small aggregate can be made to pump by adding large rock, such as 1- or 1½-inch (25- or 37-mm), as long as the system diameter meets the requirements previously stated.

Porosity of the coarse aggregate can affect pumpability if a significant amount of mix water is absorbed by the aggregate during pumping. When absorption causes problems, one solution is to thoroughly wet down the aggregate stockpiles before batching the concrete. For lightweight aggre-

TABLE 2-2. GRADING REQUIREMENTS FOR FINE AGGREGATES (ASTM C 33)

SIEVE SIZE	PERCENT PASSING
⅜-in.	100
No. 4	95 to 100
No. 8	80 to 100
No. 16	50 to 85
No. 30	25 to 60
No. 50	10 to 30
No. 100	2 to 10

gates, soak the stockpiles for at least 3 days before using the aggregate in concrete.

Fine aggregate properties have a greater effect on pumpability than do coarse aggregate properties. Grading is most critical and of particular importance is the portion of the fine aggregate that passes a No. 50 sieve. Fine aggregate grading requirements given in ASTM C 33, Standard Specifications for Concrete Aggregates, are shown in Table 2-2. Tighter limits may be necessary when concrete is to be placed by pumping; ACI Committee 304 recommends that 15 to 30 percent of the sand pass the No. 50 sieve and that 5 to 10 percent pass the No. 100 sieve. Low-cement-content concretes made with coarser sands bleed more and are harder to pump. Adding more sand to these mixes won't help pumpability.

If available sands are deficient in the finer sizes they can be blended with selected finer sands or an admixture such as fly ash or stone dust can be added to make up the deficiency in fines.

Too many fines can also cause problems. Finer materials have more surface area that has to be coated with the cement-water paste. So if there is too much fine sand or stone dust in a mix, more water will be needed to get the required slump. This extra water has several harmful effects:

- It reduces strength.

- It increases shrinkage.
- It makes concrete less watertight.
- It may cause dusting of floors.

As mentioned earlier, mixes with too much fine material may also develop excessive friction in the pipeline. For this reason, high strength concretes that have high cement contents may pump better when coarser sands are used.

LIGHTWEIGHT AGGREGATE CONCRETES FOR PUMPING

Lightweight aggregate concretes are frequently pumped. The lightweight aggregates absorb considerably more water than hardrock (normal weight) aggregates and under pressure in a pumpline this absorption is even greater. When line pressure forces mixing water into the aggregate pores, the resulting slump loss makes concrete pumping more difficult and sometimes impossible.

Pumping lightweight concrete requires presoaking of the aggregate, and the use of a 5-inch (125-mm) pipeline to reduce pressure. When bidding lightweight jobs the contractor must take these factors into consideration.

Two very effective methods for presoaking aggregates are sometimes used at lightweight aggregate production plants. One uses a vacuum tank in which aggregate voids are filled with water. The other uses immersion of heated aggregate in water during the production process to fill the voids. Aggregates treated by either process reportedly respond to pumping in much the same way as normal-weight aggregates. Aggregates treated by either of these methods cost more than dry aggregates but are less likely to cause pumping problems. During cold weather, when sprinkling the stockpiles may cause them to freeze, use of vacuum or thermally saturated aggregates is particularly advantageous.

However, most areas of the country do not have these methods available, and more conventional presoaking methods must be utilized. Presoaking of the aggregates can be accomplished by sprinkling the stockpiles for several days prior to batching. A 72-hour minimum soaking period is recommended and longer periods are desirable. The aggregate pile needs to be turned over with an end loader 2 or 3 times per day to ensure uniform presoaking.

When the concrete is batched, it should be batched at the maximum specified slump as water will continue to be absorbed into the aggregate during mixing and transportation.

The saturated lightweight material can be weighed before batching to determine if it is sufficiently presoaked. Different aggregates have different specific gravities, but once you determine the minimum acceptable weight of the saturated material, it is fairly easy to determine when it is sufficiently saturated.

On lightweight pumping jobs, a maximum permissible unit weight may be specified. Before the job starts, the point at which unit weight tests will be run should be established. Water absorbed by the aggregates during pumping can increase the unit weight by as much as 2 pounds per cubic foot (32 kg/m^3). Tests run at the pump hopper might indicate a unit weight of 115 pcf (1870 kg/m^3) while tests at the end of the line could yield a unit weight of 117 pcf (1900 kg/m^3). To avoid disputes about compliance with specifications, the concrete producer needs to know in advance where the tests will be made.

Designing a mix for pumping lightweight concrete is the same as designing a mix with stone concrete, but it must be designed by volume as opposed to weight. You must maintain a sufficient quantity of natural sand to provide sufficient mortar for pumpability. Mixes with lightweight fines, and mixes weighing less than 115 pcf (1870 kg/m^3) are generally not pumpable.

ADMIXTURES FOR PUMPED CONCRETE

Admixtures are commonly used in most concrete, regardless of how the concrete is to be placed. However, many of the admixtures will affect pumpability as described below.

Air-entraining admixtures incorporate a large number of very small bubbles in the concrete. The main reason for putting entrained air in the mix is to improve resistance to deterioration caused by freezing and thawing. However, up to a point, the air also increases pumpability because of improved plasticity, less bleeding and less segregation. Especially with crushed aggregates, too little air increases line friction and makes start-ups after pumping delays more difficult. About 3 to 5 percent air by volume of the concrete is the best amount for pumping purposes. Too much air, in excess of 7 to 8 percent, can decrease pumping efficiency by absorbing some of the pump stroke energy as the air compresses.

Water-reducing admixtures can be used to increase slump without adding water. Or they can be used to reduce the amount of water needed to get a desired slump. High-range water reducers or superplasticizers can increase the slump of a concrete by as much as 6 inches (150 mm) without increasing the chance that segregation will occur. They have been used successfully on many pump jobs, especially for high-rise construction. However, water reducers will not by themselves make an unpumpable concrete pumpable.

Fly ash is a fine material which can be added to concrete either as an admixture or as a partial cement replacement. The additional fines reduce the void content of the solid materials and make the mix more pumpable. Because of their smooth surface and rounded shape, fly ash particles also reduce bleeding and internal friction without increasing the water required to keep the slump constant. Fly ash may make concrete set more slowly; this can delay finishing and increase the time period during which vertical forms must withstand maximum form pressures. Don't use more than 120 pounds (55 kg) of fly ash per cubic yard if the concrete is to be pumped.

Pumping aids are admixtures with the sole function of improving pumpability. They do this by making the water in the concrete thicker or more viscous. This makes the water less likely to be forced out of the concrete under pressure.

Accelerators are added to concrete to make it set and gain strength faster. If accelerators are used in pumped concrete, delays are a problem to be avoided because the concrete may lose slump faster or even set up in the lines. Accelerators are **not** antifreeze agents. If pumping lines are exposed to freezing temperatures, the concrete will freeze regardless of whether an accelerator has been added to it. Calcium chloride is the most commonly used and the least expensive accelerator. However, many specifications prohibit the use of calcium chloride in concrete because it increases the chance that reinforcing steel will corrode.

Retarders make concrete set more slowly. They may help the pumping operation under hot weather conditions, when very long pipelines are used or when the placing rate is very slow.

MIX DESIGNS FOR PUMPABLE CONCRETE

Selection of concrete mix proportions is not usually the pumping contractor's responsibility. There are several good sources of information for those interested in learning more about mix design and these are listed at the end of the chapter. There are also computer programs and portable hand-held computers available for use in selecting proportions for concrete that is to be pumped. Regardless of the mix design method used, trial mixes of concrete intended for pumping should first be prepared and tested in a laboratory. Tests and observations will indicate whether the slump, cohesiveness, finishability and strength are acceptable.

Even if it looks good in the laboratory, pumpability of the proposed mix for more complex projects should preferably be verified with a full-scale pumping test under field conditions. There's no worse place to find out that a mix won't pump than on a jobsite with fifteen laborers and finishers standing around waiting for the concrete.

Testing a concrete mix for pumpability involves duplicating anticipated job conditions. The batching and truck mixing should be the same, the same pump and operator should be present and the pumpline layout should be similar to ones that will be used on the actual job. Making the effort to do this is worth the time and money. A job-proved mix prevents a lot of headaches and problems, especially on the first few pours for a project.

EFFECT OF CHANGES IN MIX PROPORTIONS

Uniform concrete from batch to batch is essential to a smooth-running pump operation. If concrete properties change frequently during a pour the pumping characteristics are also likely to change. The pump operator must recognize changes in the mix that could affect pumpability. The following general observations about pump mixes may help the pump operator to make judgments about the effect of mix changes on pumpability.

- Enough mortar (sand plus cement plus water) is needed in the concrete to ensure good pumpability. If pumping has been progressing satisfactorily on a job and the mix changes to a rocky or harsh appearance, pumping problems may develop.
- A sufficient amount of fines (cement, fly ash, fine sand or stone dust) is needed to ensure good pumpability. Increased bleeding is one good indicator that there aren't enough fines in the concrete. Mixes that are already starting to bleed in the pump hopper aren't likely to pump well.
- A high enough slump is needed to ensure good pumpability. If the mix doesn't have enough water in it and is too stiff it may not feed properly into the pumping cylinder and will not be as pumpable. Adding water at the jobsite is usually permitted but care should be taken not to add too much. Water should be added in increments of one gallon per cubic yard (5 liters/m^3) until the correct slump is reached. The concrete must be thoroughly mixed after water is added.
- If the slump is too high, concrete pumpability may decrease. Although some concretes containing superplasticizers may pump well at slumps as high as 8 or 9 inches (200 or 225 mm), concretes without admixtures at slumps greater than 6 inches (150 mm) are very likely to segregate in the pumpline and create rock jams.
- On lightweight pumping jobs, if the slump hasn't changed at the hopper but the concrete being discharged becomes drier, excessive absorption of water is probably the problem. Check with the plant to see if they're using aggregate from a dry part of the stockpile. Periodic unit

weight checks on the coarse aggregate by the concrete producer can help him to detect changes in aggregate moisture content. He can then make needed adjustments in mix proportions.

One of the operator's best tools for evaluating the concrete is his pump. The pump gauges and even the sound of the pump will indicate variations in pressure required to move each batch. Changes in material composition, aggregate gradation and mixing efficiency can all cause the variations; erratic changes in line pressure for a pump in good repair indicate quality control problems with the concrete.

EFFECT OF WEATHER EXTREMES

Hot and cold weather concreting using pumps presents some special problems. In hot weather, concrete sets faster. If delays are anticipated, slow or intermittent pumping is necessary even if it means wasting some concrete. A little wasted concrete is much preferable to risking a blockage that requires disassembling and cleaning to free the line. It's also very important to have tight joints in the pumpline so that no grout leaks out. Under extremely hot conditions it may be necessary to wrap the lines in wet burlap so that they are cooled by evaporation.

In cold weather the main danger is freezing of the concrete in exposed lines. Often this can be avoided by running the vertical line and as much of the horizontal line as possible inside the heated enclosure where concrete is being placed. Line exposed to the cold can be wrapped with insulation to retain heat and reduce the effect of wind chill. Remember that accelerators won't prevent concrete from freezing in the lines.

DON'T SAVE PENNIES AND LOSE DOLLARS

Although some concretes are harder to pump than others, the difficulty can often be traced to a correctable cause and taken care of early in the job.

- If the aggregate size is too big for the line size used, changing to a larger diameter line, perhaps from 4-inch to 5-inch (100-mm to 125-mm) line, may solve the problem.
- If there aren't enough fines in the concrete, adding cement, blow sand or fly ash may help.
- If the mix is bleeding too much and jams in the line because of this, a different sand, more cement, entrained air or fly ash may cut down on the bleeding and eliminate the blockage problem.
- If the mix is being pumped at too high a slump, changes can be made at the batch plant or water additions at the jobsite can be stopped.

The important thing to do is identify the problem and then act. More cement may increase the cost of the concrete and a larger diameter pipe may increase the cost of the line system. But a few dollars spent in advance to accommodate pumped concrete requirements will often deliver consistent savings in manpower and equipment costs throughout the life of the project.

REFERENCE SOURCES FOR INFORMATION ON CONCRETE MIX DESIGN

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