Pumping concrete: line pressure and equipment choice

How to figure the best combination for smooth, efficient operation

The first step in planning a concrete pumping system is to determine the capacity and pressure requirements of the system. To move concrete of a given slump through a pipeline of a particular length and diameter at a given rate of flow, a specific line pressure will be required. In general, the larger the inside diameter of a pipeline, the less pressure required to move a given quantity of concrete through the line at a given rate. Line pressure requirements also depend on pipeline layout. The length of straight and horizontal pipeline, the vertical rise, the number and severity of bends, the amount of flexible hose used in the line—each has an effect on pressure needed to move the concrete. But these are generalizations, not guidelines. So let's take a closer look at each of the major factors that affect pipeline pressure: pumping rate, line diameter, horizontal distance, vertical distance, configuration (including reducing sections) and slump.

Much pumping today is done with truck-mounted boom pumps with 5-inch lines. These can frequently be located where no more than about 20 feet of additional line is needed. Under these circumstances pumps soon get a feel for what pumping rates can be achieved readily with their equipment under a variety of conditions. On larger or more complicated jobs, however, the pump may discharge directly into long lines, or extensive line may be added at the end of the boom. Then it is useful to know how to estimate what pressures will be needed for a given pumping rate—or what rate can be expected at a given line pressure.

Diameter of line

While a larger inside pipeline diameter cuts down on the pressure needed, it also has one enormous drawback: the larger the line, the more labor, blocking and bracing it will require. With regular weight concrete, a 5-inch pipeline is generally considered a practical maximum without losing the advantage of maneuverability of the pipeline system. In heavy construction, contractors may use 6-, 7- or even 8-inch line because they know that harsh, low-slump mixes require a greater ratio of cross-sectional area to surface in the pipeline.

ACI 304.2R-71, “Placing Concrete by Pumping Methods,” recommends that the maximum size aggregate be no more than one-third the inside diameter of the delivery system. It is, however, difficult to pump any 4-inch-slump concrete a substantial distance through a 4-inch line using 1-inch top-size coarse aggregate—and almost impossible if it is lightweight aggregate that has not been thoroughly water-saturated by pretreatment.

Length of line

Pipeline length directly affects the line pressure requirement because of the friction between the concrete and the internal pipeline wall. That is why the smooth interior surface of steel pipe is highly desirable.

Although pipeline length would appear to be a fixed requirement for each job, careful planning will always offer ways of varying it. The first consideration is the location of the pump. The convenience of easy access for truck mixers must be weighed against the desirability of locating the pump closer to the point of placement to reduce pumping distance and thereby lower line pressures. When a job seems to require an excessive distance between the pump and the farthest point of placement, the contractor should consider using two lines and two pumps—the end of the first pipeline feeding into the hopper of the second pump. Two relatively short pumping systems, each operating at optimum line pressure, will work more dependably than a single system that is
too long and operating at excessive line pressures.

Pipeline layout

Pipeline layout affects the pressure required to pump concrete. When a change in direction occurs in a pipeline, there is increased resistance to movement of the concrete. For the least line resistance, the pipeline should contain a minimum number of bends.

Line resistance also increases where there is a decrease in cross-sectional area anywhere in the pumping system. For example, going from a 7-inch-diameter piston cylinder to a 5-inch delivery line reduces cross-sectional area almost 50 percent. This causes a large increase in line resistance and pressure. That is why experts recommend using lines of the same diameter throughout a pumping system.

Where it is absolutely necessary to reduce line size, reducers should be as long as possible to facilitate reshaping of the concrete to the smaller dimension and thus reduce pumping pressure. It takes far more energy to pump concrete through a reducer 4 feet long than one 8 feet long. Also, the greater the percentage of coarse aggregate in the mix, the more particle interference is apt to develop because of line reduction.

Slump of concrete

Under normal job conditions, the slump of concrete varies to some degree from one load to the next as a result of standard tolerances in crushing and screening equipment, batching equipment and mixers, and normal variation in operating procedures. These random variations will occasionally combine to produce a load of concrete considerably less pumpable.

ACI 304 indicates that the most practical slumps for pumping range from 2 to 6 inches. In higher slump mixes, aggregate tends to separate from the mortar and paste and may cause blocking of the pump lines. Concrete can be pumped only at pressures below the pressure at which this segregation, or pressure bleeding, occurs. And, as a practical matter, the total pressure required by any pipeline should be kept well below this maximum.

Figure 2. CONCRETE PUMP PERFORMANCE ESTIMATOR. Calculations based on pumpable mix designs containing 55 percent minus-1-inch gravel aggregate. For mixes containing crushed aggregate, increase line pressure by 12 percent. Note that pumping distance is a weighted value which is the sum of total line length plus vertical distance plus length of hose. (Figure courtesy of Challenge-Cook Brothers Inc.)
Optimum pressure

Whenever pumping is stopped, it requires a higher pressure to start the material moving again. If the concrete pump is being operated continually at higher-than-optimum line pressure there is no reserve pressure to restart the operation. The optimum pressure is a pressure level which the pump can sustain without unduly increased maintenance costs. Optimum line pressures mean dependable pump performance. High line pressures cause more wear and tear on all parts of the pumping system, including the pump, lines and hoses.

Remember that line pressures are not the same as the pump rating pressures supplied by the pump manufacturer. The pump rating pressure is often called the “piston face pressure,” “piston head pressure,” or “pressure on the face of the concrete.” (These are values that the pump manufacturer calculates. In piston pumps the values are calculated from the pressure in the hydraulic lines of the pump and the ratios of the areas of the hydraulic and concrete piston faces.) In piston pumps some of this pressure will be lost by the time the concrete has been constricted and moved through the exit line from the pump. Figure 1 shows schematically how to measure the line pressure on any job.

How to determine proper line pressure

Figure 2 is a pump performance estimator. The variables described earlier can be established and programmed into this estimator; then the proper line pressure for a specific job can be determined. The estimator is planned mainly for use with pumps without booms or with booms running into a supplemental line.

Examples in the case histories below show how to use the estimator. First it should be explained how to compute what is called pumping distance. Take the total distance from the pump to the point of placement. Then take the length of hose and vertical line included in this figure and add it again to the total. This process of weighting the vertical runs and hoses two-to-one over the horizontal runs is done because of the greater pressure necessary to overcome extra resistance and friction. For this reason, elbow sections and rubber distribution hose should be used as sparingly as possible.

To use the estimator it will also be necessary to know the pumping rate. The desired pumping rate—or rate of flow of concrete from the discharge hose—depends primarily on the design of the structure and the size of the workforce available. A large monolithic pour may require an extremely rapid rate of placement, while on another job the rate of flow may be limited by forming and stripping requirements. Each job will have its own characteristics that dictate optimum pumping rate.

Obviously, the faster the pumping rate, the greater the requirement for line pressure. For a given length and diameter of pipe, it takes about twice the pressure to move 80 cubic yards per hour through the line as to move 40 cubic yards per hour. The pumping rate, therefore, affects the distance concrete can be pumped. If the rate is considered as a fixed factor rather than a variable for a given job, it is likely to determine not only the rated capacity of the pump to be used, but the number of pumps and pipelines as well.

Thus you can start with the pumping rate or end with it, depending on which factors are fixed and which are variable in your concrete pumping plan. Either way, the estimator can establish the combination of factors to (1) achieve a given rate, or (2) plot constant factors to determine a possible rate. Let’s look at some examples to see how the estimator works:

Case history 1

A pumping contractor selected the line pressure of 200 psi because he felt it would be necessary for his job. Since 4-inch slump concrete was specified, he drew a line on the estimator from the 200-psi point to a point intersecting the 4-inch slump line (follow dotted line in Figure 2).

The job called for placement of a slab on the fifth floor of a high-rise structure. The pump was to be 50 feet from the base, and a vertical run of 50 feet was needed to get the concrete to the fifth floor. To cover the farthest corners of the deck would require 100 feet of slickline and 25 feet of distribution hose. The total distance, therefore, would be 225 feet.

To this total are added the length of vertical runs (50 feet) and the length of hose (25 feet) to get a total weighted pumping distance of 300 feet. The next step is to draw a line across the estimator from the previous intersection on the slump line to the 300-foot line in the pumping-distance quadrant of the estimator.

The contractor chose 4-inch-diameter pipe so he then extended the line on the estimator from the 300-foot distance up to the 4-inch-diameter line. Then to find the pumping rate possible under these conditions, he extended the line straight across from the point where it had intersected the 4-inch line to the pumping-rate axis, and found that the rate would be 30 cubic yards per hour.

Using the same job conditions, he might have begun with a desired production rate of 30 cubic yards per hour and proceeded clockwise through the three quadrants of the estimator to find that a 200-psi line pressure would be required.

Case history 2

Another contractor required a consistent and rather quick placement schedule and so decided he needed a pumping rate of 50 cubic yards per hour to meet that schedule. Specifications called for a 5-inch slump concrete to be placed on the third-level roof deck of a parking structure.

The pump was to be 100 feet from the base. A vertical run of 25 feet was required; to cover the farthest corners of the deck it took 100 feet of slickline and 25 feet of dis-
distribution hose. To this total was added the length of hose plus the vertical distance for a weighted pumping distance of 300 feet.

The pumping contractor chose a 4-inch distribution line for his trial calculation. Starting in the upper right-hand quarter of the estimator, and proceeding clockwise, he drew a line from 50 cubic yards per hour across to the 4-inch line size, then vertically to the 300-foot line in the pumping-distance quadrant, and then across to the 5-inch slump line. From this intersection, he drew a line vertically until it intersected the line-pressure axis, where he found that a 240-psi line pressure would be required.

Since this pressure would be marginal for continuous operation with the available equipment, it was decided to look for variations that might be considered to limit the operating line pressure to the optimum performance range.

Alternate A: By extending access roads for truck mixers, it would be possible to put the concrete pump 50 feet closer to the structure, thus reducing the effective pumping distance to 250 feet. By plotting this new factor into the estimator, the required line pressure could be reduced to 190 psi, which is within the optimum performance range.

Alternate B: If the pumping distance could not be reduced, consideration could be given to increasing the distribution line diameter, even though the sections are more difficult to handle because of increased weight. However, by increasing the line size to 5 inches and plotting this new factor on the estimator, line pressure could be reduced to 150 psi.

Alternate C: If neither of the above had been possible, a lower rate of placement might have been considered. If, for example, a pumping rate of 40 cubic yards per hour were economically acceptable, the resulting line pressure—with all other variables remaining the same—would be 190 psi.

Alternate D: In general, a higher slump concrete can be pumped at lower line pressure. Although altering the mix design should generally be avoided, if the slump in the above example could be increased to 5 1/2 inches, the line pressure would be 190 psi. (The increase in slump might perhaps require an increase in cement content to maintain the same water-cement ratio established by the mix designer.)

Conclusions

In practice, the estimator can be used to determine the effect of changing the variable conditions on a given job. The examples given illustrate various possible ways that might be used to achieve an optimum pumping operation.

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