can be made. If the initial and design flows differ considerably, it may be necessary to build a smaller force main initially and to install a second one at some later date.

Force mains are generally 200 mm (8 in) or larger in diameter. In some cases, 150-mm (6-in) pipe may be used for small pumping stations with short force mains, and 100-mm (4-in) pipe may be used for small ejector stations.

Energy losses in force mains. As discussed in Chap. 8, the system head-capacity curve is a plot of the total dynamic head (static lift plus the kinetic energy losses) versus the corresponding flowrates. Friction losses in force mains usually are determined by using the Hazen-Williams equation. The following C values are recommended for design conditions.

C = 100 for unlined cast-iron and ductile-iron pipes.
C = 120 for cement-lined cast-iron and ductile-iron pipes, reinforced-concrete pressure pipe; prestressed concrete cyclinder pipe; asbestos-cement pressure pipe; steel pipe, 500 mm (20 in) or larger, with bituminous or cement-mortar lining; and various types of plastic pipe.

Friction losses may also be calculated by using the Darcy-Weisbach equation with the appropriate f values (see Chap. 2).

Minor losses caused by valves and fittings and losses at entrances and exits may be calculated by the use of data presented in Appendix C. These minor losses plus the friction losses are the kinetic-energy losses in the force main.

In many cases, a pump that will operate satisfactorily in accordance with the system head-capacity curve for the design year may cavitate when first placed into operation. Cavitation occurs because the energy losses in the new force main are less than those calculated for the design year. Therefore, system head-capacity curves should be developed for both old pipe (design year) and new pipe (initial year). For new ductile-iron pipe and concrete pipe, a C value of 140 is recommended; for new plastic pipes, C values of 150 or higher should be used.

Force main velocities. Velocity criteria for force mains are derived from observations that solids do not settle out at a velocity of 0.6 m/s (2.0 ft/s) or greater. Solids do settle at lower velocities or when the pump is stopped, and a velocity of 1.1 m/s (3.5 ft/s) or greater is required to resuspend the deposited solids.

For small-size or medium-size pumping stations serving only part of a sewered area where flow may be pumped intermittently at any rate up to the maximum, the desirable force main velocities range from 1.1 to 1.5 m/s (3.5 to 5 ft/s). A small station would have only two pumps, one of which would be a standby, and these would discharge at the maximum rate or not at all. For pumping stations that operate intermittently, solids in the wastewater remaining in the line when the pump stops will settle out. A velocity of 1.1 m/s (3.5 ft/s) is desirable to ensure that these deposited solids are resuspended.

In a small station with two pumps, it should be possible to operate both pumps together, even though only one is needed for design-year conditions. If the flows are too small to warrant a 1.1 m/s (3.5 ft/s) design velocity, pumps can be selected to produce a 1.1 m/s minimum velocity with both pumps operating. In such a station, both pumps should be operated together by manual control once a week for a sufficient length of time to flush out the line.

Larger pumping stations of this type may have three of four pumps, all of the same size, one of which is a standby. For a station with three pumps, force main velocities of about 0.9 and 1.5 m/s (3.0 and 5.0 ft/s) might be selected with one and two pumps in operation, respectively. With stations having four pumps, force main velocities of about 0.7, 1.2, and 1.7 m/s (2.25, 4.0, and 5.5 ft/s) might be selected with one, two, and three pumps in operation, respectively. These velocities allow for a reduction in pump capacity because of greater friction losses at increased flows.

The pump capacities required to maintain velocities of 0.6 and 1.1 m/s (2.0 and 3.5 ft/s) in 150- to 300-mm (6- to 12-in) force mains are shown in Table 9-6.

Force main design usually becomes more complicated for pumping stations serving all or a major part of a sewered area where it is required to pump continuously at or close to the incoming flowrate. These pumping stations may have several sizes of pumps, some of which may be constant- or multiple-speed units and some variable-speed units. These pumps must operate continuously and must be sized so that, by operating either singly or in combination, they can pump at continuously varying flowrates ranging from initial minimum to design peak.

The range in discharge and velocity to provide for the flowrates shown in Table 9-6 may be on the order of 7 or 8 to 1. If the maximum velocity in the force main is set at 1.8 m/s (6 ft/s), the initial minimum flow would produce a velocity of only 0.22 to 0.26 m/s (0.7 to 0.9 ft/s) in the force main. For continuous pumping, one pump would have to be sized for this flow. Because these are not self-cleaning velocities, there will be some solids deposition, but this can be accepted for the following reasons:

1. At minimum flow, the solids and grit content of wastewater is lowest, and it is the grit that may settle out.
2. At daily peak flows, the pumping rate is 1.5 to 2.0 times the daily average, resulting in velocities that flush out any material which has settled out during minimum flow.
3. The alternative solution of two force mains is more expensive and operationally undesirable, and should be avoided if at all possible.
4. Pumping stations and force mains designed on this basis have worked satisfactorily.

Other Design Considerations

After the size of the force main has been determined, a number of other design details must be resolved to ensure that the force main can operate successfully.