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Wastewater Technology Fact Sheet
Sewers, Force Main

DESCRIPTION

Force mains are pipelines that convey wastewater under pressure from the discharge side of a pump or pneumatic ejector to a discharge point. Pumps or compressors located in a lift station provide the energy for wastewater conveyance in force mains. The key elements of force mains are:

1. Pipe.
2. Valves.
3. Pressure surge control devices.
4. Force main cleaning system.

Force mains are constructed from various materials and come in a wide range of diameters. Wastewater quality governs the selection of the most suitable pipe material. Operating pressure and corrosion resistance also impact the choice. Pipeline size and wall thickness are determined by wastewater flow, operating pressure, and trench conditions.

Common Modifications

Force mains may be aerated or the wastewater chlorinated at the pump station to prevent odors and excessive corrosion. Pressure surge control devices are installed to reduce pipeline pressure below a safe operating pressure during lift station start-up and shut-off. Typically, automatically operated valves (cone or ball type) control pressure surges at the pump discharge or pressure surge tanks. Normally, force main cleaning includes running a manufactured "pigging" device through the line and long force mains are typically equipped with "pig" insertion and retrieval stations. In most cases, insertion facilities are located within the lift station and the pig removal station is at the discharge point of the force main. Several launching and retrieval stations are usually provided in long force mains to facilitate cleaning of the pipeline.

APPLICABILITY

Force mains are used to convey wastewater from a lower to higher elevation, particularly where the elevation of the source is not sufficient for gravity flow and/or the use of gravity conveyance will result in excessive excavation depths and high sewer pipeline construction costs.

Ductile iron and polyvinyl chloride (PVC) are the most frequently used materials for wastewater force mains. Ductile iron pipe has particular advantages in wastewater collection systems due to its high strength and high flow capacity with greater than nominal inside diameters and tight joints. For special corrosive conditions and extremely high flow characteristics, polyethylene-lined ductile iron pipe and fittings are widely used.

Cast iron pipe with glass lining is available in standard pipe sizes, with most joints in lengths up to 6.1 meters (20 feet). Corrosion-resistant plastic lined piping systems are used for certain waste carrying applications. Polyethylene-lined ductile iron pipe and fittings known as "poly-bond-lined" pipe is widely used for force mains conveying highly corrosive industrial or municipal wastewater.

The types of thermoplastic pipe materials used for force main service are PVC, acrylonitrile-butadiene-styrene (ABS), and polyethylene (PE).

The corrosion resistance, light weight, and low hydraulic friction characteristics of these materials offer certain advantages for different force main applications, including resistance to microbial attack. Typically, PVC pipes are available in standard diameters of 100 to 900 mm (4 to 36 inches) and their laying lengths normally range from 3 to 6 meters (10 to 20 feet). The use of composite material pipes, such as fiberglass reinforced mortar pipe ("truss pipe"), is increasing in the construction of force mains. A truss pipe is constructed on concentric ABS cylinders with annular space filled with cement. Pipe fabricated of fiberglass reinforced epoxy resin is almost as strong as steel, as well as corrosion and abrasion resistant.

Certain types of asbestos-cement pipe are applicable in construction of wastewater force mains. The advantage of asbestos-cement pipes in sewer applications is their low hydraulic friction. These pipes are relatively lightweight, allowing long laying lengths in long lines. Asbestos-cement pipes are also highly corrosion resistant. At one time it was thought that many asbestos containing products (including asbestos-cement pipe) would be banned by the Environmental Protection Agency. However, a court ruling overturned this ban and this pipe is available and still used for wastewater force main applications (Sanks, 1998).

Force mains are very reliable when they are properly designed and maintained. In general, force main reliability and useful life are comparable to that of gravity sewer lines, but pipeline reliability may be compromised by excessive pressure surges, corrosion, or lack of routine maintenance.

ADVANTAGES AND DISADVANTAGES

Advantages

Use of force mains can significantly reduce the size and depth of sewer lines and decrease the overall costs of sewer system construction. Typically, when gravity sewers are installed in trenches deeper than 6.1 meters (20 feet), the cost of sewer line installation increases significantly because more complex and costly excavation equipment and trench shoring techniques are required. Usually, the diameter of pressurized force mains is one to two sizes smaller than the diameter of gravity sewer lines conveying the same flow, allowing significant pipeline cost reduction. Force main installation is simple because of shallower pipeline trenches and reduced quantity of earthwork. Installation of force mains is not dependent on site specific topographic conditions and is not impacted by available terrain slope, which typically limits gravity wastewater conveyance.

Disadvantages

While construction of force mains is less expensive than gravity sewer lines for the same flow, force main wastewater conveyance requires the construction and operation of one or more lift stations. Wastewater pumping and use of force mains could be eliminated or reduced by selecting alternative sewer routes, consolidating a proposed lift station with an existing lift station, or extending a gravity sewer using directional drilling or other state-of-the art deep excavation methods.

The dissolved oxygen content of the wastewater is often depleted in the wet-well of the lift station, and its subsequent passage through the force main results in the discharge of septic wastewater, which not only lacks oxygen but often contains sulfides. Frequent cleaning and maintenance of force mains is required to remove solids and grease buildup and minimize corrosion due to the high concentration of sulfides.

Pressure surges are abrupt increases in operating pressure in force mains which typically occur during pump start-up and shut-off. Pressure surges may have negative effects on force main integrity but can be reduced by proper pump station and pipeline design.

DESIGN CRITERIA

Force main design is typically integrated with lift station design. The major factors to consider in analyzing force main materials and hydraulics include the design formula for sizing the pipe, friction losses, pressure surges, and maintenance. The Hazen-Williams formula is recommended for the design of force mains. This formula includes a roughness coefficient C, which accounts for pipeline hydraulic friction characteristics. The roughness coefficient varies with pipe material, size, and age.

Force Main Pipe Materials

Selection criteria for force main pipe materials include:

1. Wastewater quantity, quality, and pressure.

2. Pipe properties, such as strength, ease of handling, and corrosion resistance.

3. Availability of appropriate sizes, wall thickness, and fittings.

4. Hydraulic friction characteristics

5. Cost.

Ductile iron pipe offers strength, stiffness, ductility, and a range of sizes and thicknesses and is the typical choice for high-pressure and exposed piping. Plastic pipe is most widely used in short force mains and smaller diameters. Table 1 lists the types of pipe recommended for use in a force main system and suggested applications.

Velocity

Force mains from the lift station are typically designed for velocities between 0.6 to 2.4 meters per second (2 to 8 feet per second). Such velocities are normally based on the most economical pipe diameters and typical available heads. For shorter force mains (less than 610 meters or 2,000 feet) and low lift requirements (less than 9.1 meters or 30 feet), the recommended design force main velocity range is 1.8 to 2.7 meters per second (6 to 9 feet per second). This higher design velocity allows the use of smaller pipe, reducing construction costs. Higher velocity also increases pipeline friction loss by more than 50 percent, resulting in increased energy costs. To reduce the velocity, a reducer pipe or a pipe valve can be used. Reducer pipes are often used because of the costly nature of pipe valves. These reducer pipes, which are larger in diameter, help to disperse the flow, therefore reducing the velocity.

The maximum force main velocity at peak conditions is recommended not to exceed 3 meters per second (10 feet per second). Table 2 provides examples of force main capacities at various pipeline sizes, materials, and velocities. The flow volumes may vary depending on the pipe material used.

TABLE 1 CHARACTERISTICS OF COMMON FORCE MAIN PIPE MATERIALS

Material	Application	Key Advantages	Key Disadvantages
Cast or Ductile Iron, Cement Lined	High pressure Available sizes of 4-54 inches	Good resistance to pressure surges	More expensive than concrete and fiberglass
Steel, Cement Lined	High pressure All pipe sizes	Excellent resistance to pressure surges	More expensive than concrete and fiberglass
Asbestos Cement	Moderate pressure For 36-inch + pipe sizes	No corrosion Slow grease buildup	Relatively brittle
Fiberglass Reinforced Epoxy Pipe	Moderate pressure For up to 36-inch pipe sizes	No corrosion Slow grease buildup	350 psi max pressure
Plastic	Low pressure For up to 36-inch pipe sizes	No corrosion Slow grease buildup	Suitable for small pipe sizes and low pressure only

Source: Sanks, 1998.

TABLE 2 FORCE MAIN CAPACITY

Diameter (inches)	Velocity = 2 fps gpm	Velocity = 2 fps lps	Velocity = 4 fps gpm	Velocity = 4 fps lps	Velocity = 6 fps gpm	Velocity = 6 fps lps
6	176	11	362	22	528	33
8	313	20	626	40	626	60
10	490	31	980	62	1,470	93
18	1,585	100	3,170	200	4,755	300
24	2,819	178	5,638	356	8,457	534
36	6,342	400	12,684	800	19,026	1,200

Source: Metcalf and Eddy, 1981.

Vertical Alignment

Force mains should be designed so that they are always full and pressure in the pipe is greater than 69 kiloPascals (10 pounds per square inch) to prevent the release of gases. Low and high points in the vertical alignment should be avoided; considerable effort and expense are justified to maintain an uphill slope from the lift station to the discharge point. High points in force mains trap air, which reduces available pipe area, causes non-uniform flow, and creates the potential for sulfide corrosion. Gas relief and vacuum valves are often installed if high points in the alignment of force mains cannot be avoided, while blowoffs are installed at low points.

Pressure Surges

The possibility of sudden changes in pressure (pressure surges) in the force main due to starting and/or stopping pumps (or operation of valves appurtenant to a pump) must be considered during design. The duration of such pressure surges ranges between 2 to 15 seconds. Each surge is site specific and depends on pipeline profile, flow, change in velocity, inertia of the pumping equipment, valve characteristics, pipeline materials, and pipeline accessories. Critical surges may be caused by power failure. If pressure surge is a concern, the force main should be designed to withstand calculated maximum surge pressures.

Valves

Valves are installed to regulate wastewater flow and pressure in the force mains. Valves can be used to stop and start flow, control the flow rate, divert the flow, prevent backflow, and control and relieve the pressure. The number, type, and location of force main valves depends on the operating pressures and potential surge conditions in the pipeline. Although valves have a lot of benefits, the costliness of them prevents them from being used extensively.

PERFORMANCE

Force main performance is closely tied to the performance of the lift station to which it is connected. Pump-force main performance curves are used to define and compare the operating characteristics of a given pump or set of pumps along with the associated force main. They are also used to identify the best combination of performance characteristics under which the lift station-force main system will operate under typical conditions (flows and pressures). Properly designed pump-force main systems usually allow the lift station pumps to operate at 35 to 55 percent efficiency most of the time. Overall pump efficiency depends on the type of pumps, their control system, and the fluctuation of the influent wastewater flow.

OPERATION AND MAINTENANCE

The operation of force main-lift station systems is usually automated and does not require continuous on-site operator presence. However, annual force main route inspections are recommended to ensure normal functioning and to identify potential problems.

Special attention is given to the integrity of the force main surface and pipeline connections, unusual noise, vibration, pipe and pipe joint leakage and displacement, valving arrangement and leakage, lift station operation and performance, discharge pump rates and pump speed, and pump suction and discharge pressures. Depending on the overall performance of the lift station-force main system, the extent of grease build-up and the need for pipeline pigging are also assessed.

If there is an excessive increase in pump head and the headloss increase is caused by grease build-up, the pipeline is pigged. Corrosion is rarely a problem since pipes are primarily constructed of ductile iron or plastic, which are highly resistant to corrosion. Buildup can be removed by pigging the pipeline.

COSTS

Force main costs depend on many factors including:

1. Conveyed wastewater quantity and quality.
2. Force main length.
3. Operating pressure.
4. Soil properties and underground conditions.
5. Pipeline trench depth.
6. Appurtenances such as valves and blowoffs.
7. Community impacts.

These site and system specific factors must be examined and incorporated in the preparation of force main cost estimates.

Construction Costs

Unit force main construction costs are usually expressed in $ per linear foot of installed pipeline and costs typically include labor and the equipment and materials required for pipeline installation. Table 3 unit pipeline construction costs for ductile iron and plastic (PVC) pipes used for force main construction. These costs are base installation costs and do not include the following:

1. General contractor overhead and profit.
2. Engineering and construction management.
3. Land or right-of-way acquisition.
4. Legal, fiscal, and administrative costs.
5. Interest during construction.
6. Community impacts.

All unit pipeline costs are adjusted to 1999 dollars.

TABLE 3 CONSTRUCTION COSTS FOR DUCTILE IRON AND PLASTIC PIPES

Pipe Diameter (inches)	Ductile Iron Pipe ($/linear foot)	PVC Pressure Pipe ($/linear foot)
8	23	15
10	29	20
12	36	26
14	46	33
16	53	41
18	66	48
20	72	56
24	84	65
30	142	90
36	190	135

Source: James M. Montgomery Consulting Engineers, 1998.

Operation and Maintenance Costs

Force main operation and maintenance costs include labor and maintenance requirements. Typically, labor costs account for 85 to 95 percent of total operation and maintenance costs and are dependent on the force main length. The maintenance costs usually vary from \$7 to \$20/meter (\$2 to \$6/linear foot), depending on the size and number of appurtenances installed on the force main. An internal inspection using TV equipment can be completed, if visual inspection is not sufficient. TV inspection can be costly, ranging from \$1,000 to \$11,450 per mile with an average cost of \$4,600 per mile (WERF, 1997; Arbour and Kerri, 1997).

Table 4 summarizes force main construction costs from several projects, adjusted to 1999 dollars.

TABLE 4 FORCE MAIN CONSTRUCTION COSTS

Project/ Location	Force Main Average Capacity (mgd)	Construction Costs ($US/linear foot)
Compton, CA	8	70
Oceanside, CA	18	85
Eugene, OR	12	90
CMCWD I, CA	42	510
CMCWD II, CA	30	260
Goleta, CA	56	365
Gillette, WY	30	120

Source: James M. Montgomery Consulting Engineers, 1998.

REFERENCES

Other Related Fact Sheets

Sewers, Lift Stations
EPA 832-F-00-073
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Pipe Construction and Materials
EPA 832-F-00-068
September 2000

Sewer Cleaning and Inspection
EPA 832-F-99-031
September 1999

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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