ENGINEER MANUAL

EM 1110-3-164
April 1984

ENGINEERING AND DESIGN

WATER SUPPLY, WATER DISTRIBUTION

MOBILIZATION CONSTRUCTION

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314

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Engineering and Design
WATER SUPPLY, GENERAL DISTRIBUTION
Mobilization Construction

1. Purpose. This manual provides information for the design and construction of water distribution systems at U.S. Army mobilization installations.

2. Applicability. This manual is applicable to all field operating activities having mobilization construction responsibilities.

3. Discussion. Criteria and standards presented herein apply to construction considered crucial to a mobilization effort. These requirements may be altered when necessary to satisfy special conditions on the basis of good engineering practice consistent with the nature of the construction. Design and construction of mobilization facilities must be completed within 180 days from the date notice to proceed is given with the projected life expectancy of five years. Hence, rapid construction of a facility should be reflected in its design. Time-consuming methods and procedures, normally preferred over quicker methods for better quality, should be de-emphasized. Lesser grade materials should be substituted for higher grade materials when the lesser grade materials would provide satisfactory service and when use of higher grade materials would extend construction time. Work items not immediately necessary for the adequate functioning of the facility should be deferred until such time as they can be completed without delaying the mobilization effort.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
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DEPARTMENT OF THE ARMY
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CHAPTER 1

GENERAL

1-1. Purpose and scope. This manual prescribes the standards, methods and guidance to be used by personnel responsible for the design and construction of water distribution systems at Army mobilization installations.

1-2. Definitions. Definitions will be as defined in EM 1110-3-160.

1-3. System planning. The distribution system must provide water in sufficient quantities at adequate pressures for all intended purposes. In order to plan or design a water distribution system, the location or point of demand must be known or assumed, and the magnitude of each demand known or estimated; water demands may then be categorized by purpose as domestic, industrial, special, or fire protection. Criteria for determining water demands are presented in EM 1110-3-160. Criteria for water sources are presented in EM 1110-3-161. Criteria for sizing and locating water treatment plants are presented in EM 1110-3-162. Criteria for determining water storage facilities are presented in EM 1110-3-163. Sizing of the water treatment plant, water storage facilities, distribution pumps, or distribution mains is dependent on the size of the other parts of the system. It is not practical to size individual distribution mains without considering the other elements of the system. The effectiveness of any proposed combination of storage, pumping, and distribution works in meeting projected peak demands is best determined by hydraulic analyses of the system.

1-4. Cross connections.

a. Avoidance of cross connections. If fires are to be fought with both potable and nonpotable supplies, separate distribution systems should be used to deliver the two types of water to the required area. Hydrants or other connections for each system should be suitably identified to discourage improper use. Standby water reservoirs serving fire protection systems are sometimes filled from both potable and nonpotable supplies. If this is the case, the potable water should be discharged to the reservoir through an air break not less than 12 inches above the maximum water level of the reservoir. In a similar manner, where potable water is to be used as a gland seal on a pump handling nonpotable water, the gland seal water must be stored in a tank with an air gap between the end of the potable water supply line and the maximum water level possible in the tank. Special care must also be taken of such items as valve pits and water storage facilities to insure that surface water runoff cannot enter potable water systems. Other situations that can result in back-siphonage are flexible hose having one end immersed in nonpotable water and the other end connected to a potable water hose bib, potable water lines entering swimming pools without air gaps, lawn irrigation systems with sprinkler heads flush with the ground, and improper connections at vehicle wash racks.

b. Prevention of backflow. Devices for the prevention of backflow include air gaps, check valves, and reduced-pressure backflow preventers. Air gap distances should be at least twice the diameter of the water supply line. Check and double check valves for backflow prevention are not considered suitable and will not be used. Back-siphonage can be prevented with air gaps, atmospheric-type vacuum breakers, or pressure-type vacuum breakers.

CHAPTER 2

DISTRIBUTION SYSTEMS

2-1. Direct-pressure systems. A direct-pressure distribution system is one in which no elevated storage is provided, and the required distribution pressures are maintained only by pumping facilities. Direct-pressure distribution systems will be considered only where the use of special requirements will not permit the utilization of other systems. The pumping facilities in a direct-pressure system must have firm capacities equal to or greater than the peak demand rates exerted on the system. The firm capacity of a pumping facility is the total pumping capacity with the largest pump out of service. Direct-pressure systems could waste energy and should not normally be used in mobilization construction.

2-2. Gravity-pressure systems. A gravity-pressure distribution system, one in which elevated storage facilities are provided to maintain pressure levels, will be used at mobilization sites. The use of elevated storage facilities will reduce the size of pipes needed in the distribution system as well as the number and size of pumps needed for water distribution. Since partial supply can be maintained for a period of time even while distribution pumps are out of service, the provision of elevated storage also increases system reliability. In addition, gravity systems do not require the control features or special equipment for direct pressure or pneumatic systems.

2-3. Pneumatic systems.

a. Pneumatic water supply systems are used for boosting water from a low pressure source to a higher pressure, stabilizing a variable pressure supply within acceptable limits, and minimizing frequency of pump cycles. Hydropneumatic distribution systems are applicable where demands are less than 500 gpm.

b. The low pressure setting on the hydropneumatic tank is determined by distribution system requirements. The recommended minimum operating pressure is 30 psi. The high pressure setting on the hydropneumatic tank is dependent on the maximum allowable pressure in the distribution system. The recommended maximum operating pressure is 120 psi. For a specific application, the pressure variation in the tank is normally about 20 psi. The low water level (water level at the low pressure setting) must be high enough to provide a water seal. At the low water level, the water remaining in the tank should be at least 10 percent of the capacity of the tank. The high water level should be calculated to provide maximum possible efficiency. The pump(s) will be sized to deliver 125 percent of the calculated peak demand of the distribution system. The tank size will be sufficient for at least 10 minutes of pumping time at the rated capacity of the pump. The tank will be sized so that the pump cycles not less than 4 times per hour, or more than 10 times per hour, unless the pump motor horsepower rating exceeds 50, in which case the maximum number of cycles will be 6 per hour. Completely automatic hydropneumatic tank controls are available to maintain proper operating conditions (correct air-water volume ratios) during each pump cycle. An auxiliary air compressor-type air charging system will be used for tanks larger than 750 gallons and pressures higher than 75 psi. An air volume control valve operation will be used to maintain correct air-water volume ratios for all other applications.

2-4. Dual water supplies. Dual water supply systems consist of independent pipe networks supplying two grades of water to users. The higher quality water is used for domestic purposes such as drinking, cooking, dishwashing, laundry, cleaning, and bathing; the lower quality water may be used for toilet flushing, fire fighting, lawn and garden watering, and commercial or industrial uses not requiring high quality water. Dual water supply systems are not feasible except under unusual circumstances. A dual water supply might be utilized when the only available water supply is brackish and the cost of a dual system is less than the demineralization cost of all the water supplied to users, or when only a limited quantity of higher quality water is available, and it is more economical to construct a dual system than to implement the required treatment of the lower quality water. If a dual water supply system is established and the lower quality water use might result in human contact or ingestion (e.g., toilet flushing and lawn and garden watering), both water supplies must be disinfected.

2-5. Recycling used water. There are operations that generate effluent water that can be reused for the same operation after minimal treatment. This does not constitute a dual system. Examples of such effluents are laundry wastes, vehicle washrack waste water, and plating operations waste water. Recycling of such water should be practiced wherever feasible.

CHAPTER 3

DISTRIBUTION MAINS

3-1. Main sizes. Water distribution mains of various materials are readily available in sizes ranging from 6 to 48 inches inside diameter; large pipes up to 144 inches and greater can be specially made. Minimum diameter for distribution mains is 6 inches.

a. Domestic requirements. The system should be capable of delivering the peak domestic demand as described in EM 1110-3-160, plus any special requirements, at pressures not lower than 30 psi at ground elevation. The required daily demands should be determined by calculating the effective populations of various area to be served and applying the appropriate per capita water allowances (EM 1110-3-160).

b. Fire flows. The distribution system will be designed to deliver the necessary fire flow requirements, the required daily demand, and any industrial or special demands which cannot be reduced during a fire. When only hose streams are supplying the required fire flow streams, residual ground level water pressures at fire hydrants should be not less than 10 psi. If sprinkler systems are used, residual pressures adequate for proper operation of the sprinkler systems must be maintained. Specific guidance as to fire flows and pressure required for various structures and types of fire protection systems is given in EM 1110-3-166.

c. Friction losses. In computing head losses due to friction in a distribution system, the Hazen-Williams formula, equation 3-1, will be used.

$$V = 1.318\ CR^{0.63}S^{0.54} \qquad \text{(eq 3-1)}$$

or, $Q = 193.98\ CD^{2.63}S^{0.54}$ for circular pipe flowing full.

where:

V = the mean velocity of the flow, in fps.
Q = the discharge in gpm.
R = the hydraulic radius of the pipe in feet, i.e., the cross-sectional area of a flow divided by the wetted perimeter of the pipe. For a circular pipe flowing full, the hydraulic radius is equal to one-fourth the pipe diameter.
S = the friction head loss per unit length of pipe (feet per feet).
D = pipe diameter, in feet.
C = a roughness coefficient, values of which depend on the type and condition of pipe.

Unless otherwise determined, hydraulic analyses for mobilization will be made using a C value of 130.

d. Main size calculations. The velocity in distribution mains should be between 5 and 10 fps. A lower velocity indicates the pipe could be over-sized, leading to added pipe costs and sediment problems; a higher velocity implies added head loss adversely affecting flow capability and residual pressures. The velocity is determined by dividing the peak domestic flow by the cross-sectional area of the pipe selected. If the velocity falls within the given range, the pipe size is acceptable. Slight variations outside this range are permissible for situations peculiar to a particular design. The pipe diameter thus selected can be used in equation 3-1 to determine S. The total length of pipe is multiplied by S to give the total head loss for this pipe. This head loss is used to calculate the pressure drop along the pipe. The analysis is relatively simple for a single pipe. For more complex networks, procedures such as the Equivalent Pipe method, the Alternative Equivalent Pipe method, and the Hardy Cross method as demonstrated in appendix A, should be used.

e. Fire-hydrant branches. Fire-hydrant branches (from main to hydrant) should not be less than 6 inches in diameter and as short in length as possible, preferably not longer than 50 feet with a maximum of 300 feet.

3-2. Location of mains.

a. General. Mains should be located along streets in order to provide short hydrant branches and service connections. Mains should not be located under paved or heavily traveled areas and should be separated from other utilities to insure that the safety of potable water supplies will be maintained and that maintenance of a utility will cause a minimum of interference with other utilities.

b. Distribution system configuration. The configuration of the distribution system is determined primarily by size and location of water demands, street patterns, location of treatment and storage facilities, and topography. Two patterns of distribution main systems commonly used are the branching or dead end and gridiron patterns.

(1) Branching system. The branching system shown in figure 3-1(A), evolves if distribution mains are extended along streets as the service area expands. A branching system can be constructed faster and with less materials than the gridiron system but does not have its reliability. Dead ends in the distribution system are usually undesirable and should be avoided to the extent possible. Fittings and plugs should be provided where possible so that branched systems can be converted to looped systems as the need arises during the service period.

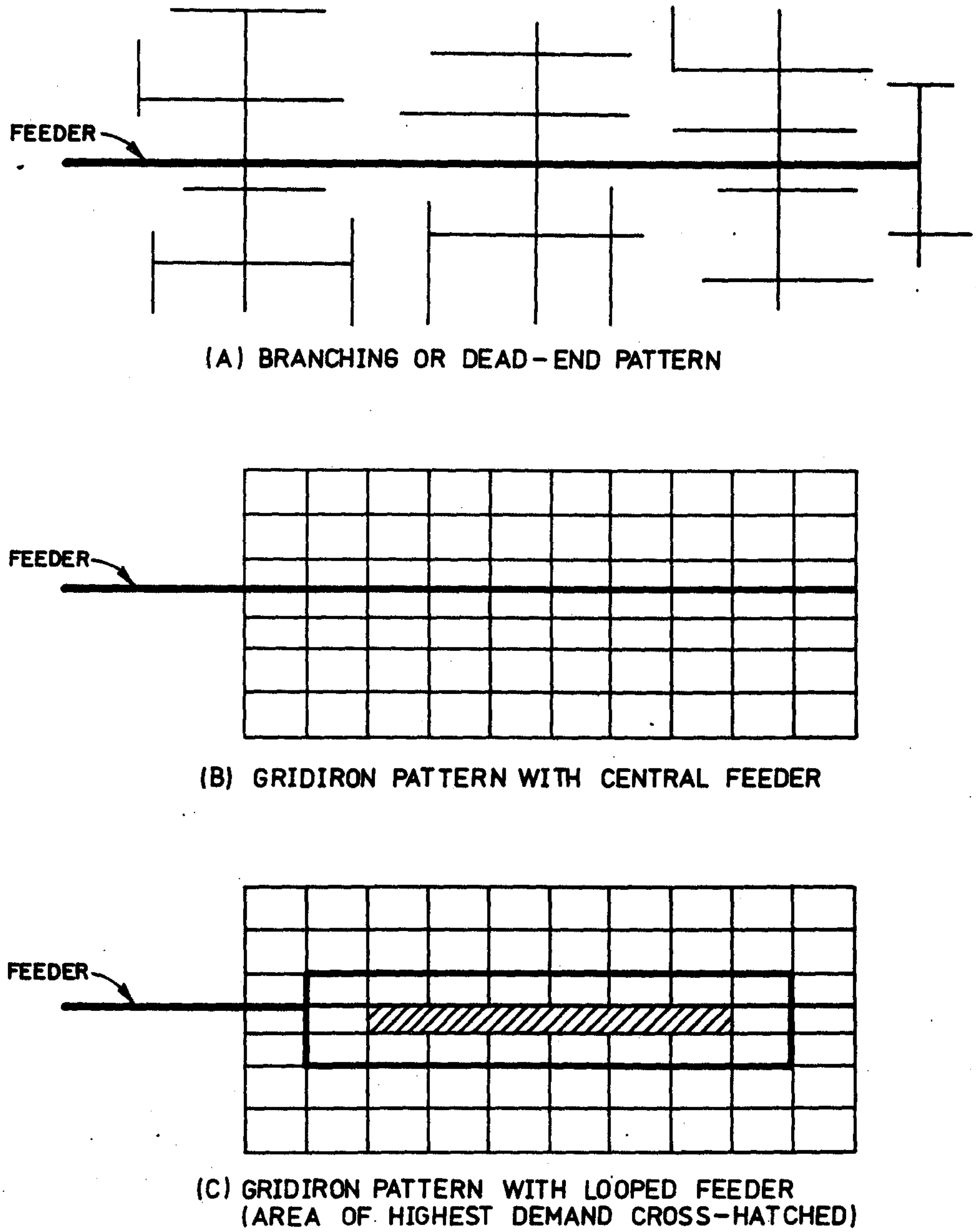

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FIGURE 3-1. WATER DISTRIBUTION SYSTEM PATTERNS

(2) Gridiron system. The second distribution configuration is the gridiron pattern shown in figure 3-1(B) and (C). The gridiron system has the hydraulic advantage of delivering water to any location from more than one direction, thereby avoiding dead ends. The use of a gridiron looped feeder system is preferable to the use of a gridiron pattern with a central feeder system because the looped feeder supplies water to the area of greatest demand from at least two directions. A looped feeder system is to be used for distribution systems whenever practicable. Although it is advantageous to have all water users located within a grid system, it is often impractical to do so. Water is generally delivered to a remote water user, or a small group of users, by a single distribution main. Therefore, the majority of the water users are served within a gridiron system, while the outlying water users are served by mains branching away from the gridiron system. Branching mains should be avoided to the extent possible.

c. Horizontal separation between water mains and sewers. Water mains should be laid horizontally, a minimum of 10 feet, from any point of existing or proposed sewer or drain line. Water mains and sewers must not be installed in the same trench. If any conditions prevent a horizontal separation of 10 feet, a minimum horizontal spacing of 6 feet can be allowed, but the bottom of the water main must be at least 12 inches above the top of the sewer. Where water mains and sewers follow the same roadway, they will be installed on opposite sides of the roadway, if practicable.

d. Water main sewer crossings. Where water pipes and sewers must cross, the sewer will have no joint within 3 feet of the water main unless the sewer is encased in concrete for a distance of at least 10 feet each side of the crossing. If special conditions dictate that a water main be laid under a gravity-flow sewer, the sewer pipe should be fully encased in concrete for a distance of 10 feet each side of the crossing, or should be made of pressure pipe with no joint located within 3 feet horizontally of the water main, as measured perpendicular to the water main. Pressure sewer pipe should always cross beneath water pipe, and a minimum vertical distance of 2 feet between the bottom of water pipe and the top of pressure sewer pipe should be maintained. The sewer must be adequately supported to prevent settling.

e. Protection in airfield pavement areas. Water mains should not be located under airfield pavement areas if other locations are available. Special protection of the mains is required when alternative locations are not available and it is necessary to locate water mains under pavement areas on which aircraft move under their own power. The amount of protection needed is dependent upon the importance of maintaining a supply of water to the area served by the main and on the availability of emergency water supplies to the affected area. The degrees of protection should be considered as follows:

(1) Minimum protection. The water main must be enclosed in a vented, open-end, outer conduit from which the main can be removed for repairs or replacement. The outer conduit must have sufficient strength to support all foreseeable loadings.

(2) Intermediate protection. Intermediate protection requires the water service to be carried under the airfield pavement by dual waterlines enclosed in an outer conduit or, preferably, in separate conduits.

(3) Maximum protection. Where more than one utility crosses the airfield pavement and individual crossings would be more expensive than a combined crossing, the utilities will be enclosed in a utility tunnel of sufficient size for in-place repairs. Special precautions must be taken in the placement and protection of individual utility lines within the tunnel to insure that failure of one utility does not affect the service of the others. Special protection of mains is not required where the mains are located beneath pavement areas that are not normally subject to the movement of aircraft under their own power, such as hangar access aprons on which aircraft would be towed.

CHAPTER 4

PRESSURES IN DISTRIBUTION SYSTEMS

4-1. General. Water distribution systems should be designed to maintain operating pressures within the system in accordance with EM 1110-3-160. Pressures at critical points in the system must be checked for anticipated periods of high draft (peak demand, fire fighting, etc.) to insure that required residual pressures are maintained. Critical points include usage points on high ground or points remote from elevated storage or pumping facilities. These pressures are calculated based on the lowest allowable water level in elevated storage or on the head produced (at high flowrates) by pumps employed in the system. Areas of potential high pressures must be checked to insure that maximum permissible pressures are not exceeded. These pressures include residual as well as static pressures and are calculated based on the highest possible water level in elevated storage or on the head produced (at low flow rates) by pumps employed in the system. Areas of excessively high or low pressures require that the system be divided into multiple pressure levels.

4-2. Multiple levels. Where multiple-level systems are required, it is desirable to establish the lines of separation so that the pressures in each system will approach the optimum range outlined in EM 1110-3-160. Three or more levels will not be used unless distribution pressures in a large area of the two-level system fall below 30 psi or exceed 100 psi. In all circumstances, fire flows must be adequate.

4-3. Pressure-reducing valves. Pressure-reducing valves will be required in areas of the distribution system that have pressures in excess of 100 psi. The pressure-reducing valves may be installed on the mains serving these areas or on the individual building services lines in high-pressure areas. If pressure-reducing valves are to be installed on individual service lines, the preferred location is adjacent to, and upstream from, the water meter for each building or immediately inside the building being served. In some cases, it may be necessary to install pressure-reducing valves only on lines to certain plumbing or heating units which are adversely affected by excessive pressures.

4-4. Pressure-relief valves. Pressure-relief valves should be installed in all systems which might be subjected to greater than allowable pressures. In systems with 100 psi pumps, the pressure-relief valves should be set to discharge at 120 psi; pressures greater than 120 psi may be experienced for brief periods during testing or operation of these pumps. All pumps driven by variable speed motors or engines will be provided with relief valves, and if the shutoff pressure of any pump exceeds 120 psi, the pressure-relief valves should be installed and set at approximately 120 psi.

4-5. Water hammer. Consideration of water hammer must be given to the system especially in low-lying areas subject to high flow rates and surge pressures. The occurrence and severity of water hammer can be reduced through the use of slow-closing valves, pressure-release valves, surge tanks, and air chambers.

CHAPTER 5

DISTRIBUTION SYSTEM EQUIPMENT

5-1. Valves. The types of valves most frequently used in water distribution are gate, butterfly, ball, plug, globe, and check valves. Valves of the 150 psi class should be the minimum pressure class considered. Applications of the various types of valves and the standards to be used for these valves are given in table 5-1. All valves should have the direction to open shown on their operators.

Table 5-1. Valve Applications

Type	Applications	Sizes to be Used (diameter, inches)
Gate	Sectionalizing distribution mains. Isolating fire-hydrant branches.	3 or larger
Butterfly, rubber seated	Mains with water pressures less than 150 psi	3 or larger
Ball	Applications involving throttling or frequent operation. Water service lines.	6 or less*
Plug	Applications involving throttling or frequent operation. Water service lines.	6 or less
Globe	Throttling operations. Water service lines.	2 or less

*Ball valves larger than 6 inches may be used if gate valves or butterfly valves are not available.

a. Gate valves. Gate valves may have either a single solid wedge gate or double disc. Solid wedge gates are satisfactory in sizes up to 6 inches, but double disc gates should be used for larger sizes. Because of the excessive wear and leakage of the gates and seats which may result, gate valves should not be used where frequent operation is required. If gate valves are left open for long periods, debris may accumulate in the seat and prevent complete closure, but if left closed for long periods, deposits may prevent opening. Gate valves should be operated periodically to break loose any deposits which might have formed. Large gate valves should be geared to make operation easier.

b. Butterfly valves. The advantages of butterfly valves include easy operation, small space requirement, low cost, minimum maintenance, low head loss, driptight shutoff, suitability for throttling, and reliability. A disadvantage is that main cleaning and lining equipment cannot be used in lines containing butterfly valves without removing the valves. Mechanical valve operators will be designed to restrict the rate of closure so that water hammer will not occur in the system on which the valve is installed.

c. Ball valves. Ball valves have the advantage of ease of operation, reliability, durability, and capability of withstanding high pressures, but they are usually expensive.

d. Plug valves. Lubricated and eccentric plug valves are the types of plug valves commonly used. Lubricated plug valves normally have a cylindrical or tapered plug, intersecting the flow, with a rectangular port opening. Round ports can be obtained in the smaller sizes. Specially formulated greases are used both for lubrication and sealing of lubricated plug valves. When operated periodically, these valves are relatively easy to operate and provide a tight shutoff, but the plugs may freeze if not operated for a long period of time. Plug valves are especially good for high pressure applications. Eccentric plug valves are preferable to lubricated plug valves because of greater ease of operation and reduced maintenance requirements; eccentric plug valves are also less prone to freeze. Ball and plug valves will not be used on buried pipelines, except when installed in a valve pit. The basic application for the eccentric plug valves is normally on small service lines.

e. Globe valves. Globe valves are particularly well suited to throttling operations, and most plumbing fixtures are normally equipped with these valves. Small globe valves normally have rubber discs and metal seats to provide driptight shutoff, but special discs and seats are available for more severe conditions and may be used on water service lines 2 inches or less in diameter.

f. Check valves. Any valve used to prevent the reversal of flow is considered a check valve. Most check valves are equipped with plugs or hinged discs which close flow openings when flow is reversed. Rapid and complete valve closing is often insured by the addition of special weights or springs to the plugs or discs. A newer type of check valve has spring-loaded, wafer-style, semicircular plates mounted on a vertical pivot through a flow reversal. This wafer-style check valve has the disadvantage of producing relatively high head losses and of showing excessive wear under some operating conditions.

g. Air release and vacuum relief valves. Air release valves are required to evacuate air from the main at high points in the line when it is filled with water and to allow the discharge of air accumulated under pressure. Excess air allowed to accumulate at high points creates a resistance to flow, and an increase in pumping power requirements results. Vacuum relief valves are needed to permit air to enter a line when it is being emptied of water or subjected to vacuum. Special valves are available to perform either or both of these functions. Air release and vacuum relief valves should be installed at high points in the line or where a long line changes slope.

h. Valve location.

(1) Shutoff valves. The purpose of installing shutoff valves in water mains at various locations within the distribution system is to allow sections of the system to be taken out of service for repairs or maintenance without significantly curtailing service over large areas. Valves should be installed at intervals not greater than 5,000 feet in long supply lines and 2,400 feet in main distribution loops or feeders. All branch mains connecting to feeder mains or feeder loops should be valved as closely to the feeders as practicable so that the branch mains can be taken out of service without interrupting the supply to other locations. In the areas of greatest water demand, or where the dependability of the distribution system is particularly important, maximum valve spacings of 1,000 feet may be appropriate. At intersections of distribution mains, the number of valves required will normally be one less than the number of radiating mains; the one valve will be omitted from the line which principally supplies flow to the intersection. Valves are not usually installed on branches serving fire hydrants on Army installations. As far as practicable, shutoff valves should be installed in standardized locations (e.g., the northeast corner of intersections or a certain distance from the centerline of streets) so they can easily be found in emergencies. For large shutoff valves (approximately 30-inch diameter and larger), it may be necessary to surround the valve operator or entire valve with a vault to allow for repair or replacement. In important installations and for deep pipe cover, pipe entrance access manholes should be provided so that valve internal parts can be serviced. If valve vaults or access manholes are not provided, all buried valves, regardless of size, should be installed with special valve boxes over the operating nut in order to permit operation from ground level by the insertion of a special long wrench into the box.

(2) Blowoff valves. Blowoff valves or fire hydrants should be installed at the ends of dead-end mains to allow periodic flushing of the mains. However, if time and materials become critically short, these valves may be deleted. Primary feeder mains and larger distribution mains should have a blowoff valve in each valved section which should be installed at low points in the mains where the flushing water can be readily discharged to natural drainage channels. Blowoff valves should be designed so that operation will not result in erosion. Special care must be taken to eliminate the possibility of contaminated water entering the distribution system through blowoff valves which have not been tightly closed.

5-2. Fire hydrants.

a. Dry- and wet-barrel hydrants. The most common types of fire hydrants are the dry- and wet-barrel varieties. They are similar in configuration and operation, but in the dry-barrel hydrant, provision is made for draining water from the barrel after the hydrant is shut off. This is normally accomplished by gravity drainage through special drain outlets in the base or barrel of the fire hydrant. Wet-barrel hydrants can be used in areas where the temperature is always above freezing.

b. Safety hydrants. Barrel-type hydrants extending aboveground are available in models which can be damaged by automobiles or trucks without disturbing the main valve. These are the "safety" or "traffic" fire hydrants and should be used near heavily traveled roads or intersections where adequate protection of the hydrant cannot be provided.

c. Flush-top hydrants. In cases where the barrel-type aboveground hydrant would interfere with necessary traffic, a flush-top hydrant can be utilized. In this type of hydrant, the operating nut and hose nozzles are located in a cast-iron box below ground level. The top of the box has a horizontal lid which is flush with the adjacent ground surface. However, flush-top hydrants are more difficult to locate than barrel-type hydrants, especially in areas subject to heavy snows, and once located are awkward to uncover and put into operation. Barrel-type hydrants are preferable to flush-top hydrants. Hydrants of all types should have the direction to open shown on their operators.

d. Hydrant nozzles. Nozzles on fire hydrants are either 2-1/2 or 4-1/2 inches in diameter. The 2-1/2 inch nozzle is for direct connection to fire hoses and the 4-1/2 inch nozzle is for use with mobile fire pumper units. Unless unusual conditions dictate otherwise, hydrants with two fire hose nozzles and one pumper should be used. The outlet nozzles on most hydrants are located at 90-degree angles to each other. The pumper outlet should normally face the street or intersection, and the two fire hose nozzles should face opposite directions, 90 degrees from the pumper nozzle. Hydrants with either more or less than three nozzles should be alined so that the nozzles are readily accessible from the street.

e. Hydrant spacing.

(1) General. Hydrant distributions will conform to the standards shown in table 5-2 and as demonstrated in appendix B.

(2) Troop housing areas. The preferred location for fire hydrants in troop housing areas is at street intersections. Where additional hydrants are required because of the above hydrant distributions, these additional hydrants will normally be located

adjacent to streets approximately halfway between intersections. Each unit will have at least one hydrant within 300 feet and a second hydrant within 500 feet.

Table 5-2. Hydrant Distribution

Required Fire Flow, gpm	Average Area per Hydrant, square feet
1,000 or less	160,000
1,500	150,000
2,000	140,000
2,500	130,000
3,000	120,000
3,500	110,000
4,000	100,000
4,500	95,000
5,000	90,000
5,500	85,000
6,000	80,000
6,500	75,000
7,000	70,000
7,500	65,000
8,000	60,000
8,500	57,500
9,000	55,000
10,000	50,000
11,000	45,000
12,000	40,000

(3) Airfields. For airfield hangar areas, hydrants will be spaced approximately 300 feet apart and where economically feasible will be connected to the base distribution system and not to the special system serving deluge sprinkler systems in the hangars. At double cantilever hangar areas, hydrants will be connected only to the base water distribution system. For aircraft fueling, mass parking, servicing, and maintenance areas, the fire hydrants will be installed along the edge of aircraft parking and servicing aprons. Hydrants will be spaced approximately 300 feet apart, and hose will be provided in sufficient length so that every part of the apron may be reached by approximately 500 feet of hose. One or more hydrants will be located within 300 feet of all operational service points.

(4) Remote fuel storage areas. Army fuel storage facilities that are remotely located with relation to the public or post water systems will generally not have fire hydrant protection. However, where the facility is of a critical nature or is of a high strategic or monetary value that would justify some degree of fire protection and the materials are available, fire hydrants will be installed.

f. Hydrant location.

(1) Proper clearance should be maintained between hydrants and poles, buildings, or other obstructions so that hose lines can be readily attached and extended. Generally, hydrants will be located at least 50 feet from the buildings protected, and in no case will hydrants be located closer than 25 feet to a building except where building walls are blank fire walls.

(2) Street intersections are usually the best locations for fire hydrants because fire hoses can then be laid along any of the radiating streets. However, the likelihood of vehicular damage to hydrants is greatest at intersections, so the hydrants must be carefully located to reduce the possibility of damage. Hydrants should not be located less than 6 feet from the edge of a paved roadway surface, nor more than 7 feet. If hydrants are located more than 7 feet from the edge of the paved roadway surface and if the shoulders are such that the pumper cannot be placed within 7 feet of the hydrant, consideration may be given to stabilizing or surfacing a portion of wide shoulders adjacent to hydrants to permit the connection of the hydrant and pumper with a single 10-foot length of suction hose. In exceptional circumstances, it may not be practical to meet these criteria, and hydrants may be located to permit connection to the pumper using two lengths of suction hose (a distance not to exceed 16 feet).

(3) Hydrants should not be placed closer than 3 feet to any obstruction nor in front of any entranceways. The center of the lower outlet should not be less than 18 inches above the surrounding grade, and the operating nut should not be more than 4 feet above the surrounding grade.

(4) In aircraft fueling, mass parking, servicing, and maintenance areas, the tops of hydrants will not be higher than 24 inches above the ground with the center of lowest outlet not less than 18 inches above the ground. The pumper nozzle will face the nearest roadway.

g. Hydrant installation. Many problems of hydrant operation and maintenance can be avoided if the hydrant is properly installed. All hydrants should be installed on firm footings such as stone slabs or concrete bases to prevent settling and strains on line joints. Separation of the pipe joints in the elbow beneath the hydrant is sometimes a problem because of forces created by the water pressure across the joint through the elbow. This problem can be alleviated by placing thrust blocks between the elbow and supporting undisturbed soil or by tying the joint.

h. Hydrant markings. All hydrants at Army mobilization facilities will be marked in accordance with NFPA 291.

5-3. Water pipe materials. Water distribution pipes are available in a variety of materials. Those most commonly used, and most suitable for use at Army installations, are asbestos-cement, ductile iron, reinforced concrete, steel, and plastic. All water mains and service lines should be designed for a minimum normal internal working pressure of 150 psi plus appropriate allowances for water hammer. Internal working pressure as well as external stresses due to earthfill and superimposed loadings will be calculated in accordance with the applicable standards of the American Water Works Association for each kind of pipe.

a. Selection of materials. In selecting the material to be used for a particular application, the following items should be considered:

(1) Availability of the material and its ability to be delivered within the time frame allotted.

(2) Ability to withstand maximum anticipated internal pressures and external loads or the most severe combination thereof.

(3) Ease of installation. This involves the unit weight of the pipe, type of joints used, type of bedding required, and whether or not thrust blocking is required.

(4) Resistance to external and internal corrosion.

(5) Joint tightness.

(6) Durability.

(7) Ease of tapping for service connections.

(8) Cost.

b. Types of materials.

(1) Asbestos-cement pipe.

(a) This pipe is usually unaffected by aggressive soil conditions and is installed in many locations where unprotected ductile-iron or steel pipe would suffer excessive corrosion. Standard lengths of asbestos-cement pipe are 13 feet for pipe 8 inches or larger in diameter and either 10 or 13 feet for pipe 4 or 6 inches in diameter. The three classes of asbestos-cement pipe are: Class 100, Class 150, and Class 200 for pipe 4 inches through 16 inches and Class 30, Class 35, Class 40, etc. for pipe 18 inches through 42 inches. These refer to the maximum anticipated internal working pressure, not including sudden surges, to which the pipe is to be subjected. A factor of safety of 4.0 has been used in the design and manufacture of these pipes. They should theoretically be capable of withstanding internal bursting pressures of at least 400 psi (Class 100), 600 psi (Class 150), and 800 psi (Class 200). Techniques for evaluating both internal and external loads are given in AWWA C401. External loads include both weight of the backfill supported by the pipe and the weight of superimposed loads, static or dynamic, on the pipe. A factor of safety of 2.5 is used in designing for external loads. Asbestos-cement pipe is not readily available in sizes greater than 24 inches so its use should be restricted to smaller distribution lines.

(b) Asbestos-cement pipe is also grouped into two categories according to the percentage of uncombined calcium hydroxide in the pipe. Type I has no limit on the uncombined calcium hydroxide; Type II has 1.0 percent or less. Inasmuch as the uncombined calcium hydroxide may be leached from the walls of a pipe, thereby reducing the strength of the pipe, Type II pipe will be considered in all mobilization construction, but when supplies become short, an allowance for Type I should be made.

(c) Fittings and specials are not made of asbestos-cement for pressure pipe so other types of materials must be used. The recommended material is cast iron, but adapters must be used to make a correct fit. Information on the details for fittings and specials should be sought from the pipe manufacturer.

(d) Couplings for asbestos-cement pipe usually come with the pipe. They are of the slip-on variety and come with rubber gaskets. Curves and bends in this type water line can be made by deflecting the joints. However, joint deflection should not exceed manufacturer's recommendations.

(e) Installation of asbestos-cement pipe will be in accordance with the provisions of AWWA C603. Tapping of asbestos-cement pipe can be achieved by the following methods:

- Employing a special coupling with a brass insert. This is usually factory installed.

- Directly tapping the pipe, similar to ductile iron pipe.

- Strapping on a tapping saddle.

(2) Ductile iron pipe.

(a) Ductile iron pipe of equivalent thickness is stronger, tougher, and more durable than other kinds of water pipe. The prescribed method of determining the required thickness of ductile iron pipe is given in AWWA C150. Ductile iron is preferred in situations where some pipe deflection may occur, such as in earthquake-prone areas or in soil conditions where settling of the pipe may occur.

(b) Ductile-iron pipes are frequently lined with coal-tar enamel or cement mortar to reduce corrosion of interior surfaces. Cleaning and lining of corroded ductile-iron pipe can substantially reduce the head losses in the pipe; pipeline cleaning without lining is not permitted unless the line has been relegated to short term duty (less than 1 year) and will be abandoned.

(c) Fittings and specials for ductile-iron pipe must be suitable for the pressure ranges anticipated. The occurrence of water main failure is most probable at fittings' and specials' joints, so particular attention must be given to restraining them.

(d) Joints available for ductile iron pipe include the push-on, mechanical joint and flanged types. Push-on type joints are preferable in most situations because of ease of installation. Mechanical joints are desirable where a more positive type water seal is required. Flanged connections are usually employed in open areas such as meter pits or plants and are seldom used in buried areas.

(e) Methods for tapping ductile-iron pipe include integral tapping bosses, tapping saddles, direct bore and thread taps, and actual insertion of a tee into a water main. Methods are available which allow tapping under pressure with relative ease.

(3) Concrete pipe. Concrete pipe is strong, durable, corrosion-resistant, and has a smooth interior which allows high flow velocities with minimal head losses. Concrete pipe should be used for larger sized mains (greater than 24 inches) for cost-effectiveness, material savings, and relative ease of installation.

(a) The type of concrete pipe to be considered for mobilization work is prestressed concrete cylinder pipe. There are two types of prestressed concrete cylinder pipe available. They are the lined-cylinder type with concrete cast inside the steel cylinder, wire wrapped under tension around the steel cylinder, and a concrete or mortar covering over the wire and cylinder; and the embedded-cylinder type with the steel cylinder encased in concrete, wire wrapped on the outer concrete surface, and the wire covered with a coating of cement or mortar. Both types are characterized by high strength and relatively light weight as compared to other kinds of concrete pipe. The lined-cylinder type is used for pressures up to 250 psi and the embedded-cylinder type for pressures up to 350 psi. Diameters of the pipe range from 16 to 48 inches for the lined-cylinder type and from 24 to 144 inches for the embedded-cylinder type. The design and manufacture of both types of prestressed concrete cylinder pipes are covered in AWWA C301.

(b) Fittings and specials for concrete pipe include bends, tees, wyes, connections to valves, closures, curves, and pipes with outlets for air valves and blowoffs. Details of these items should be presented on the construction drawings to expedite fabrication.

(c) Joints for concrete pipe usually consist of two steel rings, one in the spigot end of one pipe section, the other in the bell end of another pipe section. The spigot ring has a seat which contains a rubber gasket. This gasket is compressed against the ring in the bell end when the two pipe sections are joined. Operating experience has shown that rubber-gasketed bell-and-spigot joints provide a long-lasting, watertight seal when proper installation procedures are followed. Subsequent coating of the joint with mortar insures watertightness.

(d) Tapping of concrete pipe without special equipment or expertise is more difficult than other types of pipe and it should not be used where multiple future tapping for building service may be required. If tapping of concrete pipe is anticipated, service connections should be built into the pipe at the factory or fabrication point.

(4) Steel pipe.

(a) The properties of steel pipe favoring its use are high strength, ability to yield or deflect under a load while still resisting the load, the capability of bending without breaking, and the ability to resist shock. Like ductile-iron, steel pipe is susceptible to corrosion if effective coatings and linings are not applied and maintained. Inasmuch as corrosion products do not adhere to steel pipe, they are continually sloughed off, thus allowing further corrosion. By contrast, corrosion products adhere to ductile-iron pipe and offer some protection against further corrosion. Steel pipe is generally available in diameters ranging to 144 inches and greater. Maximum allowable working pressures depend on pipe wall thicknesses and may be selected for the entire range of waterworks applications. In designing steel pipe to withstand internal pressures, a factor of safety of 2.0 is generally used; a factor of safety of 1.5 or 2.0 is recommended in designing for external loads. Steel pipe may be used for transmission lines and service lines with adequate protective coatings and linings and cathodic protection as determined necessary by site conditions. Steel pipe should not be used for distribution mains. The basics of steel pipe waterlines are covered in AWWA C200.

(b) Fittings and specials for pipe 3 inches and under may be flanged, screwed, or mechanically jointed (dresser-type coupling). All fittings and specials must be galvanized. Fittings and specials for larger sized steel pipe are not, in general, stock items. Therefore, these items must be specifically made for each project. Detailed information as to spatial limitations, size, pressure requirements, angles, etc., must be provided for fabrication.

(c) Several options are open to the designer for steel pipe joints. Steel pipe may be welded, flanged, or connected by a mechanical coupling. Threaded couplings are also available for pipe sizes 3 inches and under.

(d) Steel pipe may be tapped in a manner similar to ductile-iron pipe except that welding service connections or couplings onto steel pipe may be more advantageous on steel pipe than on ductile-iron pipe.

(5) Plastic pipe.

(a) Plastic pipe. Several different types of plastic have been used in the manufacture of water distribution pipes. The most commonly used plastic pipes include polyvinyl chloride pipe (PVC) and two closely related types: reinforced thermosetting-resin pipe (RTRP) and reinforced plastic mortar pipe (RPMP). These materials are described in this section.

(b) Other types of plastic pipes. Numerous other types of plastic pipes have been developed mainly to provide resistance to corrosive liquids. Thus, these materials are adequate for potable water and should be given consideration especially if supplies are readily available. Such materials include polymers of acrylonitrile, butadiene, and styrene (ABS); polyethylene (PE) and high-density polyethylene (HDPE); polybutylene (PB); and polypropylene (PP).

(c) The advantages and disadvantages of plastic pipe. The advantages of plastic pipe are that it has a very low resistance to flow, it is somewhat flexible and can deflect under earth or superimposed loadings, it does not corrode from electrical or microbial action, and it is relatively lightweight and easy to install. Disadvantages are that it suffers a permanent loss of tensile strength with time, and that the tensile strength of the pipe at any time is decreased by temperature increases. Plastic pipe also undergoes significant expansions and contractions with temperature changes, necessitating the use of gasket couplers. Tapping could be difficult - care must be exercised to prevent the pipe from splitting. Plastic pipe materials are vulnerable to heat and ultra-violet radiation so care must be taken during transportation and storage of these materials to insure that they neither deform under heat nor deteriorate in sunlight.

(d) PVC pipe. PVC pipe is used in sizes of 4 to 12 inches inside diameter for distribution lines. It is available in pressure classes of 100, 150, and 200 psi, which correspond to the maximum anticipated internal working pressure for the pipe. A factor of safety of approximately 3.0 is used in the design of PVC pipe for sustained internal pressures, and a factor of safety of 4.0 is used for sudden pressure surges. However, due to the loss of tensile strength with time, these factors of safety decrease correspondingly. Pipe conforming to AWWA C900 with elastomeric gasket bell and spigot joints in 4-inch diameter through 12-inch diameter size, is acceptable for transmission, distribution, and service lines. Transmission, distribution, and service lines less than 4-inch diameter will require Schedule 80 pipe with threaded joints or Schedule 40 pipe with elastomeric gasket bell joints.

(e) RTRP and RPMP. Reinforced thermosetting-resin pipe (RTRP) and reinforced plastic mortar pipe (RPMP) are products belonging to the glass-fiber-reinforced thermosetting-resin pressure pipe family. These pipes are usually unaffected by aggresive soil conditions and have excellent resistance to corrosivity found in the water carried by these pipes. Common laying lengths of RTRP and RPMP are 10, 20, 40, or 60 feet, although other lengths can be provided. Diameters vary from 1 inch to 144 inches. For water, the standard pressure classes of up to 250 psi are available. The plastic pipe described herein is available in two types depending on the method of manufacture: Type I is filament wound; Type II is centrifugally cast. RTRP is the same as RPMP except the RPMP contains aggregate in the base material whereas the RTRP does not. Four grades are available depending on the materials incorporated in the pipe.

- Grade 1 - RTRP epoxy
- Grade 2 - RTRP polyester
- Grade 3 - RPMP epoxy
- Grade 4 - RPMP polyester

The differing grades generate differing resistances to salts, chemicals, and chemical solvents but are not affected by potable water. Selection of a particular grade and type for potable water use should be based on material availability and delivery time.

(f) Fittings and specials for plastic pipe. Cast-fittings for plastic pipe may be made of iron or of the same material as the pipe. If cast-iron fittings are used, consideration must be given to the use of adapters whenever plastic pipe joints with cast-iron fittings.

(g) Joints and couplings for plastic pipe. Joints for plastic pipe may be threaded, solvent welded, or push-on type with elastomeric gaskets. Fiberglass pipe may be joined by overlapping the joint with material similar to the pipe material.

(h) Tapping plastic pipe. Plastic pipe requires more expertise for tapping, especially in cold weather, since this pipe has a greater tendency to crack over other types of pipe material. The piping manufacturer's recommendations should be followed for details on tapping before work is started on plastic pipe.

CHAPTER 6

SERVICE CONNECTIONS

6-1. Tapping of water lines.

a. Ductile-iron pipes. In most circumstances, ductile-iron pipe can be tapped for building service connections while under pressure; consequently, this type of pipe is well suited for applications where future tapping may be necessary.

b. Asbestos-cement lines. Asbestos-cement pipe can be tapped either wet or dry using standard waterworks equipment. The largest size corporation stop which can be tapped directly into asbestos-cement pipe is 1 inch. Larger outlet sizes up to 2 inches can be secured by using service clamps or bossed sleeves. Tapping sleeves and valves can be used for making taps larger than 2 inches in asbestos-cement pipe under pressure.

c. Concrete lines. New service connections on existing concrete pipelines can be made with or without interruption of service. Concrete pipe is more difficult to tap than other pipe materials; and the cost of pressure tapping the pipeline is considerably greater than incorporating outlets for future connections during pipe manufacture. Fittings are available for making threaded connections from 1/2 to 2 inches in diameter for the various types of concrete pressure pipe. Flanged outlet taps can be made under pressure for branch lines with diameters as large as one size smaller than that of the pipe to be tapped. Step by step procedures for small and large pressure connections are available in most manufacturer's literature.

d. Steel lines. Service connections to steel pipe can be readily made with commercially available equipment. This includes service connections both dry and with pipe under internal pressure. Small service connections consist of threaded couplings welded to the steel pipe surface and drilled through with standard drilling equipment. Large diameter service connections are normally made under pressure utilizing a flanged service outlet, a tapping valve, and a standard drilling machine. The service outlet may be either a bolted-in-place service saddle or a fabricated steel service saddle that is welded to the pipe.

e. Plastic lines. Plastic pipe can be direct tapped wet or dry, using standard waterworks equipment, for insertion of corporation stops. However, a special tool has been developed which will minimize PVC shavings and retain the coupon. The largest size corporation stop which can be tapped directly into the pipe is 1 inch. AWWA threads are recommended for all direct taps. Larger outlet sizes can be obtained by using service clamps, saddles, or bossed sleeves. Maximum outlet size recommended by these methods is 2 inches. Tapping sleeves and valves can be used for making large taps, under pressure, size to size, i.e., 8-inch outlet in 8-inch pipe, etc. Tapping sleeves should be assembled in accordance with the manufacturer's directions.

6-2. Service connection materials.

a. Copper. Copper has been the most widely used material for service piping due to its flexibility, ease of installation, corrosion-resistance, and its capability to withstand high pressures. Although the cost of copper pipe has risen rapidly in recent years, it is still well suited for service connection use. Copper is a strategic metal so its use for services should be limited to dire emergencies.

b. Plastic. Plastic pipe is frequently selected because of its relatively low cost and easy installation. The capabilities of plastic pipe to withstand maximum internal and external loadings and temperatures should be carefully examined before use.

c. Galvanized steel. Galvanized steel pipe has been used for service connnections for many years. The main advantage of galvanized steel pipe is its relatively low cost. However, since galvanized steel pipe is rigid and requires threading, it is not easily installed. Also, galvanized steel service connections may have relatively short lives if placed in soils in which corrosion is likely to occur. Galvanized steel pipe is generally not used for 2-inch or larger service connections.

d. Other materials. Ductile-iron and asbestos-cement pipes are not generally available in the small sizes required for most service connections but could be considered for service connections to large water users for which pipe sizes of 3 inches or larger are needed.

6-3. Sizes. The size of the service connection needed in any particular situation should be the minimum size through which water can flow at the maximum required rate without excessive velocity or head loss. A maximum velocity of 10 fps is commonly used. In general, head losses through service connections during maximum flows should be small enough to insure that a residual pressure of 25 psi is available for water distribution within the plumbing of each building. Head losses of 15 psi or greater through service connections are considered excessive, even if the 25-psi residual criterion can be met. Although 1/2-inch service connections can be used for facilities requiring very small flows, the minimum size for most installations should be 3/4 inch.

6-4. Installation. Service connections will be installed in as direct a path as possible from the distribution main to the building served and will enter the building on the side closest to the distribution main. Service connections will be installed below the frost depth. If the size and wall thickness of the main are adequate, smaller service lines may be connected to the main by direct drilling and tapping. This can be accomplished with special machines while maintaining water pressure in the main. Larger service connections (greater than 2 inch) may necessitate the installation of tees or special branch connections into distribution mains but may be made with the main under pressure with a tapping machine, tapping valve, and sleeve in most cases.

6-5. Service connections at airfields. Water-service connections are required for servicing aircraft at airfields. These connections will be located adjacent to the parking apron at nondispersed stations or adjacent to the servicing apron at dispersed stations.

CHAPTER 7

DISTRIBUTION SYSTEM DESIGN DETAILS

7-1. Minimum pipe cover. Minimum cover over pipes will be 2-1/2 feet in grassed areas, 3 feet under unpaved driveways or roadways, and 4 feet under railroad tracks. Where frost depths are greater than the above minimums, the cover should be at least equal to the frost depth, particularly for small lines which may not be flowing continuously. Where lines pass under railroads, pipes may be encased in concrete or enclosed in rigid conduit. Installation of pipelines and conduits under railroad main lines is usually accomplished by carefully controlled tunneling and jacking. For branch lines or lines used infrequently, open cut installation may be permitted by the railroad. Jacking or tunneling procedures are usually required if a pipeline is to be installed under a major roadway with no disruption of traffic.

7-2. Protection of items penetrating the frost zone. Water distribution equipment items penetrating the frost zone are sometimes subject to freezing if protective measures are not taken.

a. Air vent and vacuum relief valves. These items can be protected from freezing by installation in pits deep enough to place the valves below the frost zone.

b. Blowoff valves. Blowoff valves should be installed at depths below the frost zone. If terrain conditions permit, the drain line from a blowoff valve should go to a nearby low surface area to allow gravity drainage. The valve discharge must be piped to the atmosphere and provide drainage from the line to the outlet side of the valve. If gravity drainage cannot be provided, the blowoff valve should be provided a tee, with foot valve to prevent backflow, discharging into a dry well below the frost line.

c. Fire hydrants. Fire hydrants penetrating the frost zone will be of the dry-barrel variety (para 5-2). Free draining backfill will be placed around the barrel to prevent frost-heave due to moisture around the barrel in the frost zone.

d. Post indicator valves. Freezing should not be a problem with post indicator valves and valve boxes if they are constructed and maintained so that water does not collect in or around them.

7-3. Disinfection of water supply systems. New distribution mains and existing distribution piping affected by construction may be sources of water supply contamination. Therefore, disinfection of new and connecting work is required. The procedures set forth in AWWA C601 for disinfection must be followed.

7-4. External corrosion.

a. Corrosion of the external surfaces of cast-iron or steel pipes can, under some conditions, be a significant problem. Therefore, ductile-iron or steel pipelines placed in aggresive soils must be protected by coatings of coal-tar, polyethylene encasement or cement mortar. Cement mortar coatings may be applied by mechanical or pneumatic means.

b. The characteristics of the soil in which a pipe is placed affect the rates of corrosion, with the most corrosive soils being those having poor aeration and high values for acidity, electrical conductivity, dissolved solids, and moisture content. The relative potential for corrosion may be estimated by evaluating the degree of corrosion of pipelines or other metallic objects previously buried in that soil.

c. In locations where the soils are known to be very corrosive, it may be desirable to use cathodic protection systems as a supplement to (but not in place of) the above coatings.

d. Another method of avoiding corrosion of distribution mains is through the use of nonmetallic pipe materials such as asbestos-cement, reinforced concrete, or plastic.

7-5. Thrust blocking. Criteria for determining the magnitudes of thrusts and the relative need for thrust blocking or anchorage are given in appendix C.

7-6. Layout map. An up-to-date layout map, to a suitable scale, showing the entire distribution system involved in the design will be maintained.

7-7. Design analysis. The design analysis will indicate the essential elements used in determining sizes and locations of mains, including:

- Projected populations and areas in which the populations are located

- Locations and magnitudes of special water demands

- Location and magnitude of fire demands

- Location and size of pump stations

- Storage input

- Water treatment plant or other input sources

APPENDIX A

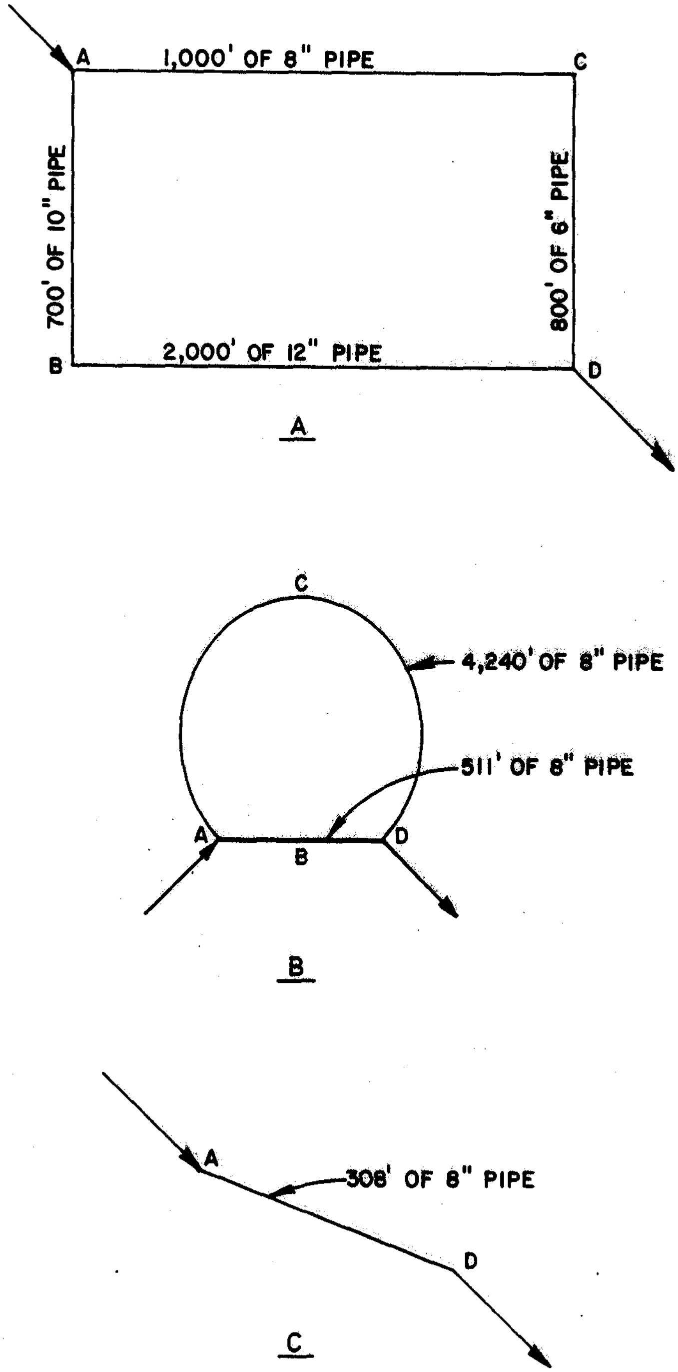
DISTRIBUTION SYSTEM HYDRAULIC ANALYSES

A-1. General. The sizing and location of mains, pump stations, and elevated storage facilites are dependent upon hydraulic analyses of the distribution system. The major techniques used in analysis of distribution networks are reduction into equivalent pipes and Hardy Cross analysis. For all but the very smallest systems, these analyses are best performed on computers.

A-2. Equivalent pipes. The "equivalent pipe" technique is a means of reducing a complex pipe network into a simpler configuration. It involves the substitution of one pipe of specific diameter and variable length or specific length and variable diameter for a series of different size pipes or several parallel pipes, as long as there are no inputs or withdrawals of water between the end points of the system. Application of the equivalent pipe method is best demonstrated by example. Referring to figure A-1, assume that the pipe network shown is to be converted to an equivalent 8-inch pipe. The following procedure should be used.

a. Series of different size pipes will be converted. An example is ACD and ABD in part (A) of figure A-1 being converted to equivalent 8-inch pipes. A flow rate will be assumed through each branch, the resulting loss of head calculated through the branch, and the length of 8-inch pipe substituted, which will give the same total loss of head through each branch. For example, assume that 200 gpm flows through branch ACD and 400 gpm through ABD. Using tables or nomographs based on the Hazen-Williams formula or the formula itself as given in equation 3-1, the loss of head through Section AC is 1.51 feet per 1,000 feet of pipe length (for this example, assume C = 100 for all pipes), so the total loss of head through pipe AC is (1.51/1,000) x 1,000 = 1.51 feet. Likewise, the loss of head through pipe CD at a flow of 200 gpm is 6.1 feet per 1,000 feet of pipe length, which gives a loss of head through CD of (6.1/1000) x 800 = 4.9 feet. Hence, the total loss of head through ACD is 6.4 feet. The length of 8-inch pipe which will have the same total loss of head at the same flow is 6.4 / (1.51/1000) = 4,240 feet. The two pipes of branch ACD can be replaced by 4,240 feet of 8-inch pipe. The total loss of head through ABD at a flow of 400 gpm is (1.83 x 700/1000) + (0.75 x 2,000/1,000) = 2.78 feet. At the same flow of 400 gpm, an 8-inch pipe has a loss of head of 5.44 feet per 1,000 feet of length, so the length of 8-inch pipe equivalent to section ABD is (2.78/5.44) x 1,000 = 511 feet. Part (B) of figure A-1 shows the configuration of the system after branches ACD and ABD have been converted to equivalent 8-inch pipes.

b. The 8-inch equivalent pipes for ACD and ABD will be converted into a single equivalent 8-inch pipe. Since it is known that water passing through ACD must have the same loss of head as water passing



U. S. Army Corps of Engineers

FIGURE A-1. EQUIVALENT PIPE NETWORKS

through ABD, a constant loss of head value can be assumed. For purposes of this example, a loss of head of 10 feet between A and D is arbitrarily chosen. At this total loss of head, the loss of head per 1,000 feet of length in ACD is 2.36 feet and in ABD is 19.6 feet. Referring again to the Hazen-Williams equation, it can be determined that the flows producing these losses of head are 255 gpm in ACD and 800 gpm in ABD. Thus, the total flow from A to D with a loss of head of 10 feet is 1,055 gpm. At this total flow, the loss of head through a single 8-inch pipe is 32.5 feet per 1,000 feet of length. For a total loss of head of 10 feet from A to D at a total flow of 1,055 gpm, a single 8-inch pipe would be (10/32.5) x 1,000 = 308 feet long. Part (C) of figure A-1 shows the single 8-inch pipe which is equivalent to section ABCD shown in part (A) of figure A-1.

A-3. Alternative equivalent pipe procedure. Several variations of the equivalent pipe procedure are possible. The following is an alternative procedure for converting the pipe network of figure A-1 to a single equivalent 8-inch pipe, assuming that C = 100 for all pipes.

a. Arbitrarily select a rate of flow to be passed through both branch ACD and branch ABD. For this example, a flow of 0.5 mgd is used.

b. Calculate the losses of head through branches ACD and ABD.

Pipe	Diameter (inches)	Loss of Head Per 1,000 feet	Length (feet)	Loss of Head (feet)
AC	8	4.18	1,000	4.18
CD	6	16.90	800	13.52
AB	10	1.41	700	0.99
BD	12	0.58	2,000	1.16

Loss of head through ACD = 4.18 feet + 13.52 feet = 17.70 feet
Loss of head through ABD = 0.987 feet + 1.16 feet = 2.147 feet

c. Adjust the flow in branch ABD for the same loss of head as in branch ACD. This can be done with the following equation.

$$\frac{Q_2}{Q_1} = \left(\frac{HL_2}{HL_1}\right)^{0.54}$$

where:

Q_1 = initial flow in pipe
Q_2 = final flow in pipe
HL_1 = initial friction loss of head through the pipe
HL_2 = final friction loss of head through the pipe

Thus:

$$Q_2 = Q_1\left(\frac{HL_2}{HL_1}\right)^{0.54} = 0.5 \times \left(\frac{17.7}{2.147}\right)^{0.54}$$

Q_2 = 1.56 mgd in ABD (loss of head = 17.7 feet)

d. Find the total rate of flow through branches ABD and ACD with a loss of head of 17.7 feet in both branches. The total flow is equal to 1.56 mgd + 0.5 mgd = 2.06 mgd.

e. Determine the length of 8-inch pipe which will have a loss of head of 17.7 feet at a rate of flow of 2.06 mgd. At this rate of flow in an 8-inch pipe, the loss of head is 57.3 feet per 1,000 feet of pipe length. The total equivalent pipe length is:

Length of equivalent 8-inch pipe = (17.7/57.3) x 1,000 = 309 feet.

A-4. Hardy Cross analysis. Equivalent pipe techniques can be used for finding flows or losses of head in simple systems, but more complex networks involving multiple withdrawal points and crossover pipes require different methods of solution. The Hardy Cross method is one means of network analysis by which accurate determination of rates of flow and losses of head through a system can be computed. It involves the application of corrections to assumed values of flow or head until the system is in hydraulic balance. If flows are to be balanced, the correction factor to be applied to network flows is found by solving:

$$\Delta Q = - \frac{\Sigma H}{n\,\Sigma(H/Q)}$$

where:

ΔQ = change in percentage of flow in a particular pipe
H = loss of head in that pipe, in feet
n = 1.85

In order to use the Hardy Cross method, the following guidelines must be observed.

a. The configuration of the pipe network to be analyzed must be known or estimated. This includes pipe lengths, pipe diameters, and coefficients of roughness.

b. The locations and magnitudes of inflows and outflows to and from the system must be known or estimated.

c. Flows in either a clockwise or counterclockwise direction may be considered positive, and those in the opposite direction will be negative. For example, if clockwise flows are assumed to be positive, counterclockwise flows will be negative. The same rule also applies for values of losses of head. Thus, the terms in the numerator of the above equation will always have the appropriate sign. The term in the denominator must always have a positive value because corresponding H and Q values have the same sign, therefore H/Q is always positive.

d. The sign of the calculated correction, ΔQ, must be observed when modifying the flows in a pipe loop. Pipes appearing in more than one loop are subject to the combined corrections for the loops in which they appear. An example of the Hardy Cross analysis is shown in figure A-2 and in table A-1. Figure A-2 gives the configuration of the pipe network and inflows and withdrawals (expressed in percent) from the network. The initial percentage of flow assumptions are shown in table A-2.

Table A-1. Computations for Hardy Cross Analysis.

Trial 1

Loop Number	Pipe Number	Pipe Diam. (inches)	Pipe Length (feet)	Initial Flow (percent)	Loss of Head (feet)	$\frac{H}{Q}$	$n\Sigma\frac{H}{Q}$	ΣH	ΔQ (percent)	Adjusted Flow (percent)
I	1	10	4,000	- 25.0	- 24.7	1.0			- 1.1	- 26.1
	2	20	8,000	+ 75.0	+ 12.9	0.2			- 1.1	+ 73.9
	3	8	4,000	+ 15.0	+ 28.4	1.9			- 1.9	+ 13.1
	4	8	8,000	- 5.0	- 7.4	1.5	8.4	9.2	- 2.0	- 7.0
II	4	8	8,000	+ 5.0	+ 7.4	1.5			+ 2.0	+ 7.0
	5	8	4,000	- 20.0	- 48.4	2.4			+ 0.9	- 19.1
	6	8	3,000	+ 17.5	+ 28.3	1.6			+ 0.9	+ 18.4
	7	10	9,000	+ 5.0	+ 2.8	0.6	11.2	- 9.9	+ 0.9	+ 5.9
III	3	8	4,000	- 15.0	- 28.4	1.9			+ 1.9	- 13.1
	8	16	8,000	+ 60.0	+ 25.3	0.4			+ 0.8	+ 60.8
	9	8	2,000	- 2.5	- 0.5	0.2			+ 0.8	- 1.7
	10	10	9,000	- 2.5	- 0.8	0.3	5.2	- 4.4	+ 0.8	- 1.7

Trial 2

Loop Number	Pipe Number	Pipe Diam. (inches)	Pipe Length (feet)	Initial Flow (percent)	Loss of Head (feet)	$\frac{H}{Q}$	$n\Sigma\frac{H}{Q}$	ΣH	ΔQ (percent)	Adjusted Flow (percent)
I	1	10	4,000	- 26.1	- 26.7	1.0			+ 0.7	- 25.4
	2	20	8,000	+ 73.9	+ 12.5	0.2			+ 0.7	+ 74.6
	3	8	4,000	+ 13.1	+ 22.0	1.7			+ 1.4	+ 14.5
	4	8	8,000	- 7.0	- 13.8	2.0	9.0	- 6.0	+ 1.0	- 6.0
II	4	8	8,000	+ 7.0	+ 13.8	2.0			- 1.0	+ 6.0
	5	8	4,000	- 19.1	- 44.5	2.3			- 0.3	- 19.5
	6	8	3,000	+ 18.4	+ 31.0	1.7			- 0.3	+ 18.0
	7	10	9,000	+ 5.9	+ 3.8	0.6	12.3	+ 4.1	- 0.3	+ 5.5
III	3	8	4,000	- 13.1	- 22.0	1.7			- 1.4	- 14.5
	8	16	8,000	+ 60.8	+ 25.9	0.4			- 0.7	+ 60.1
	9	8	2,000	- 1.7	- 0.2	0.1			- 0.7	- 2.4
	10	10	9,000	- 1.7	- 0.4	0.2	4.6	+ 3.3	- 0.7	- 2.4

Trial 3

Loop Number	Pipe Number	Pipe Diam. (inches)	Pipe Length (feet)	Initial Flow (percent)	Loss of Head (feet)	$\frac{H}{Q}$	$n\Sigma\frac{H}{Q}$	ΣH	ΔQ (percent)	Adjusted Flow (percent)
I	1	10	4,000	- 25.4	- 25.4	1.0			- 0.4	- 25.8
	2	20	8,000	+ 74.6	+ 12.8	0.2			- 0.4	+ 74.2
	3	8	4,000	+ 14.5	+ 26.5	1.8			- 0.9	+ 13.6
	4	8	8,000	- 6.0	- 10.3	1.7	8.8	3.5	- 0.6	- 6.6
II	4	8	8,000	+ 6.0	+ 10.3	1.7			+ 0.6	+ 6.6
	5	8	4,000	- 19.5	- 45.9	2.4			+ 0.2	- 19.3
	6	8	3,000	+ 18.0	+ 30.0	1.7			+ 0.2	+ 18.2
	7	10	9,000	+ 5.5	+ 3.4	0.6	11.8	- 2.2	+ 0.2	+ 5.7
III	3	8	4,000	- 14.5	- 26.5	1.8			+ 0.9	- 13.6
	8	16	8,000	+ 60.1	+ 25.4	0.4			+ 0.5	+ 60.6
	9	8	2,000	- 2.4	- 0.5	0.2			+ 0.5	- 1.9
	10	10	9,000	- 2.4	- 0.7	0.3	5.1	- 2.3	+ 0.5	- 1.9

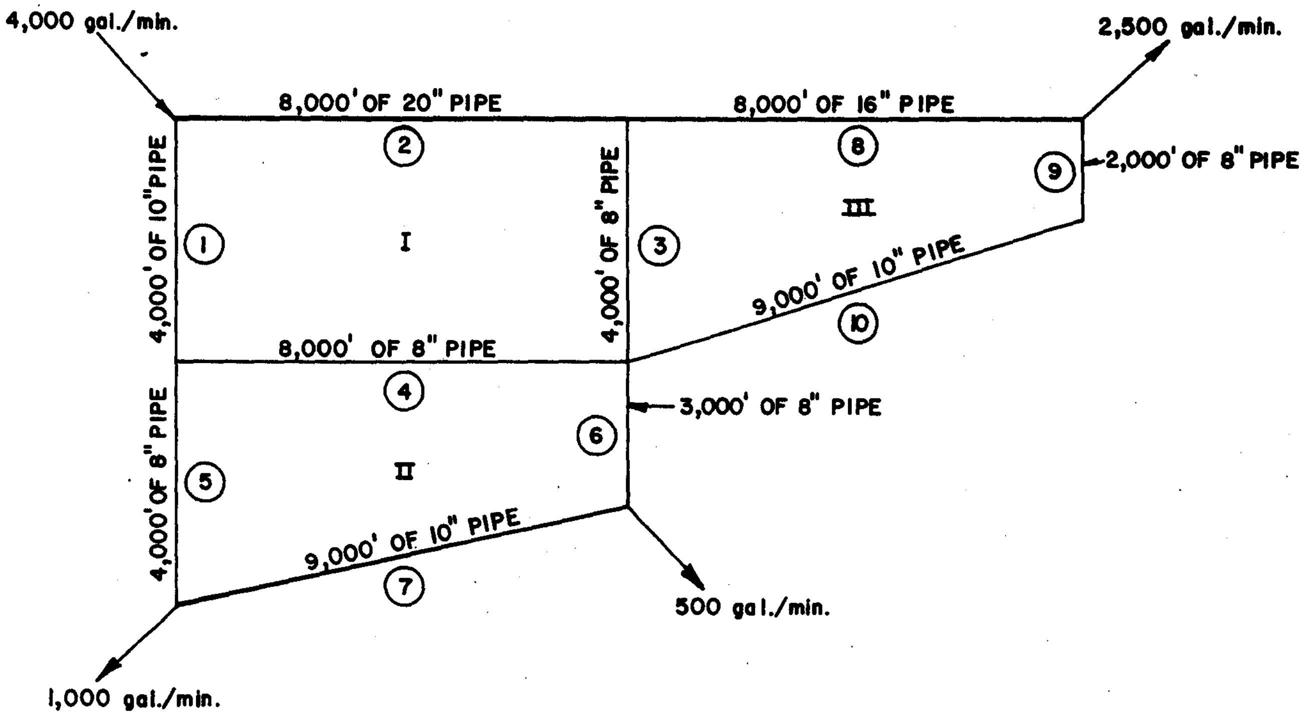


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FIGURE A-2. EXAMPLE PIPE NETWORK FOR HARDY CROSS ANALYSIS

Table A-2. Initial Flow Assumptions

Pipe number	Flow (Percent)	Direction of flow
1	-25	Counterclockwise
2	75	Clockwise
3	15	Clockwise (Loop I)
4	-5	Counterclockwise (Loop I)
5	- 20	Counterclockwise
6	17.5	Clockwise
7	5.0	Clockwise
8	60	Clockwise
9	- 2.5	Counterclockwise
10	- 2.5	Counterclockwise

The computational procedure used in determining the actual flows is shown in table A-1. All pipes are assumed to have a roughness coefficient of 130; final flow percents and values are shown in table A-3.

Table A-3. Final Flow Values

Pipe number	Flow (percent)	Flow (gpm)	Direction of flow
1	25.8	1,033	Counterclockwise
2	74.2	2,967	Clockwise
3	13.6	544	Clockwise (Loop I)
4	6.6	263	Counterclockwise (Loop I)
5	19.3	771	Counterclockwise
6	18.2	730	Clockwise
7	5.7	224	Clockwise
8	60.6	2,423	Clockwise
9	1.9	77	Counterclockwise
10	1.9	77	Counterclockwise

A-5. Other methods of hydraulic analysis. Other hydraulic analysis techniques may be used if appropriate. Such techniques may include, but are not limited to, Newton-Raphson network analysis and network simulation with analog computers.

APPENDIX B

FIRE HYDRANT LAYOUT, SPACING, AND TESTING CALCULATIONS

B-1. General. The locations and spacings of fire hydrants are a function of the facilities to be protected. These facilities dictate the required fire flow (found in EM 1110-3-166) which specifies the area to be covered by each hydrant (table 5-2). The fire protection aspect of the distribution system must be analyzed to insure that adequate fire flows at required residual pressures are maintained for the duration of a possible fire.

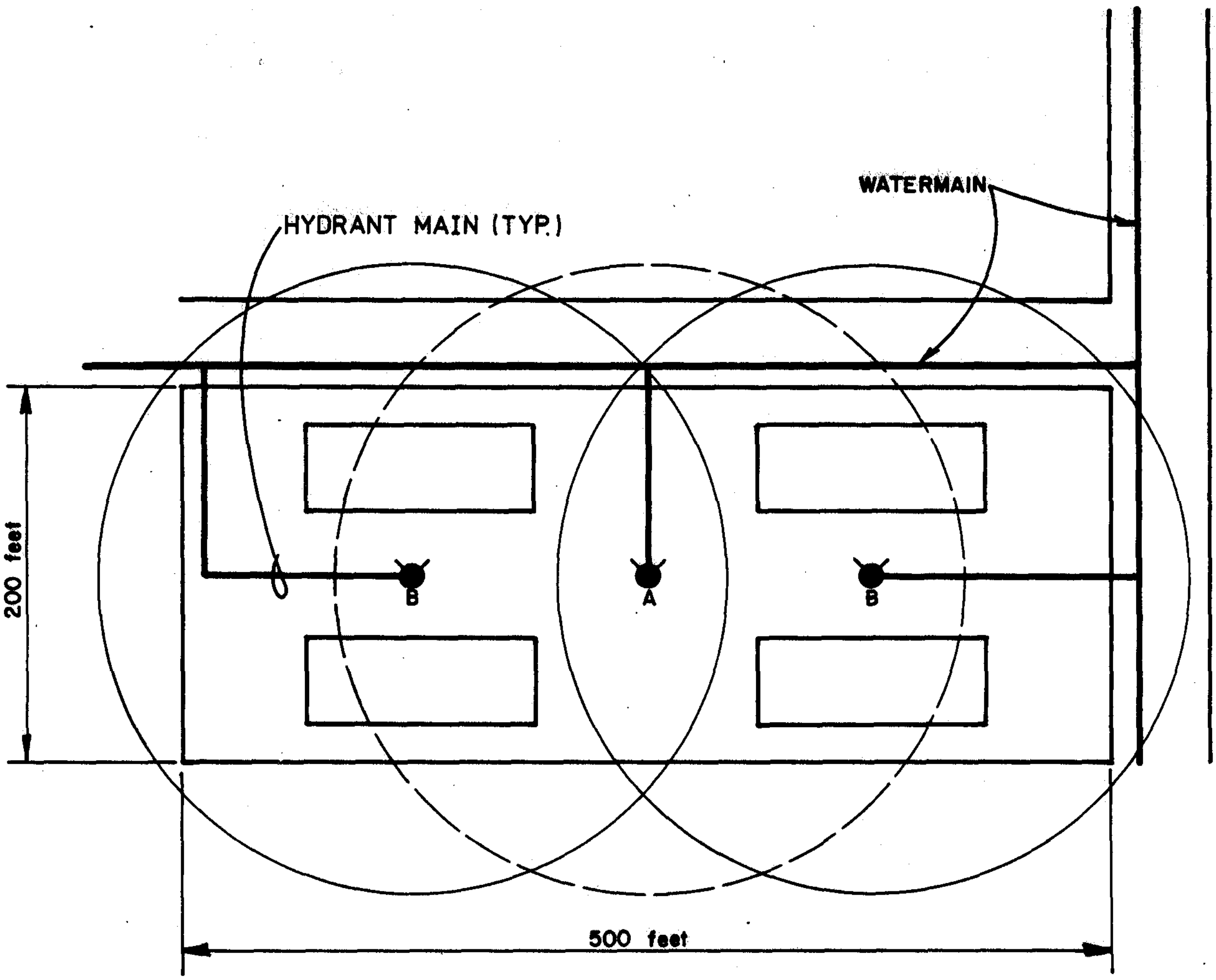
B-2. Hydrant layout and spacing. Figure B-1 illustrates an example for laying out fire hydrants in an industrial area. The four buildings shown require a fire flow of 5,000 gpm. They are enclosed in an area measuring 200 feet by 500 feet or 100,000 square feet. From table 5-2, 90,000 square feet is the area coverage for the 5,000 gpm flow. The number of hydrants required is 100,000 square feet divided by 90,000 square feet per hydrant which equals 1.1 hydrants. One hydrant (located at point A) would seem feasible, but its coverage (designated by the dashed circle) would not be sufficient to cover the buildings completely. Therefore, two hydrants would be required. These two hydrants would be located at points designated by B. These points can be moved to shorten hydrant mains or allow for clearance from the buildings or roads, but the coverage area (shown by circles) should totally encompass the buildings. In this example, the radius of the circles is calculated by using the average area per hydrant, in this case, A = 90,000 square feet.

$$\text{i.e.,} \quad r = \sqrt{\frac{A}{\pi}} = 169 \text{ feet.}$$

Figure B-2 illustrates an example for laying out fire hydrants in a troop housing area. The quarters shown require a fire flow of 1,000 gpm. Each residence must have a fire hydrant within 300 feet and a second hydrant within 500 feet. From the diagram, it can be seen from the dashed circles, that these requirements are met. From table 5-2, 160,000 square feet is the area coverage for the 1,000 gpm flow. A circle corresponding to this area would have a radius of:

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{160{,}000}{\pi}} = 226 \text{ feet}$$

All residences must fall within the area thus scribed by one of these circles. This is the case as shown in figure B-2 by the solid circles. Figure B-3 illustrates an example for laying out fire hydrants in a remote area. The facility shown is a warehouse requiring 12,000 gpm fire protection. The warehouse has 15,900 square feet with the configuration as shown. One hydrant can cover 40,000 square feet as indicated in table 5-2, but consideration must be given to where the



SCALE: 1 INCH = 100 FEET

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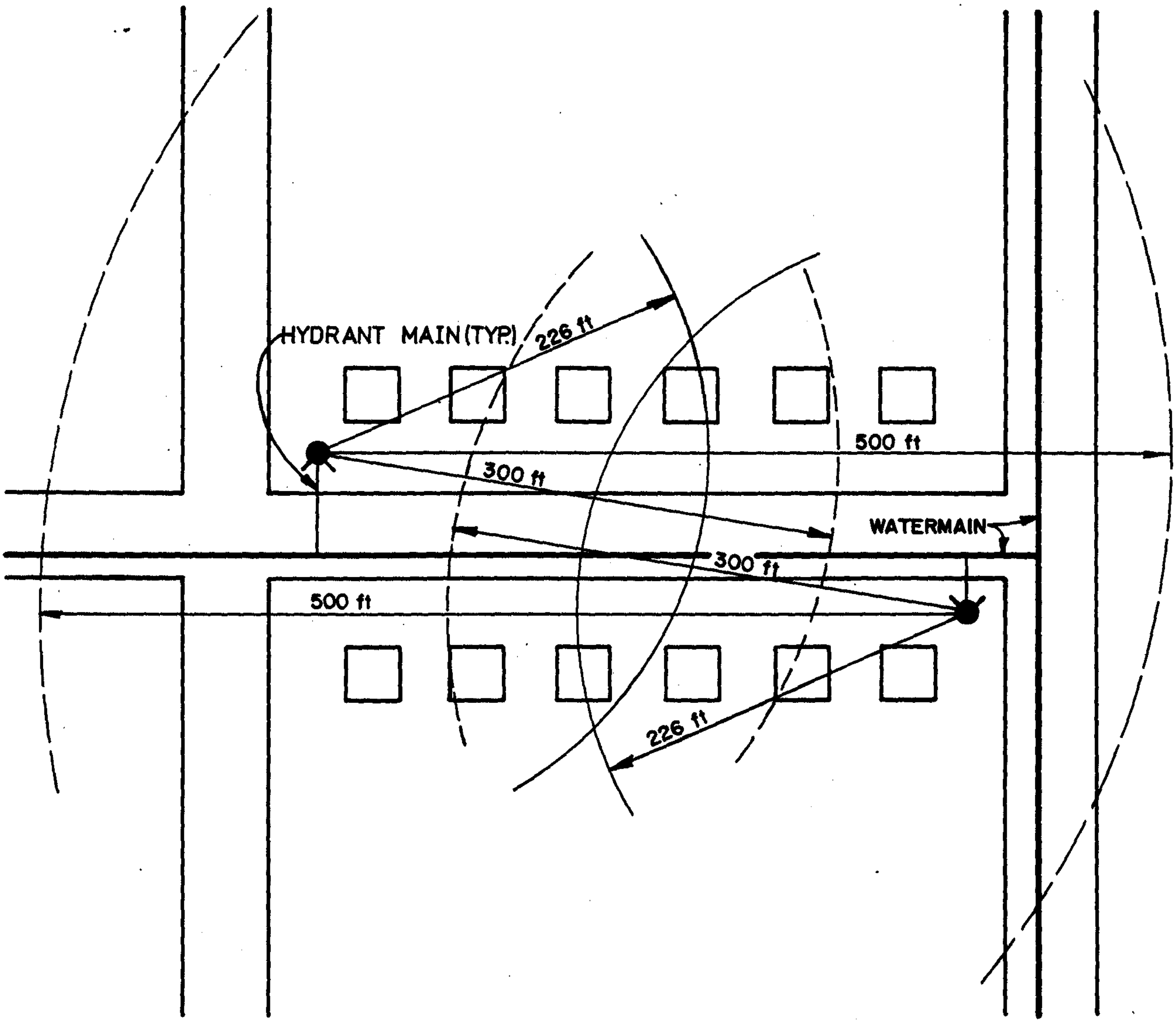
FIGURE B-1. FIRE HYDRANT LAYOUT FOR AN INDUSTRIAL AREA



SCALE: 1 INCH = 100 FEET

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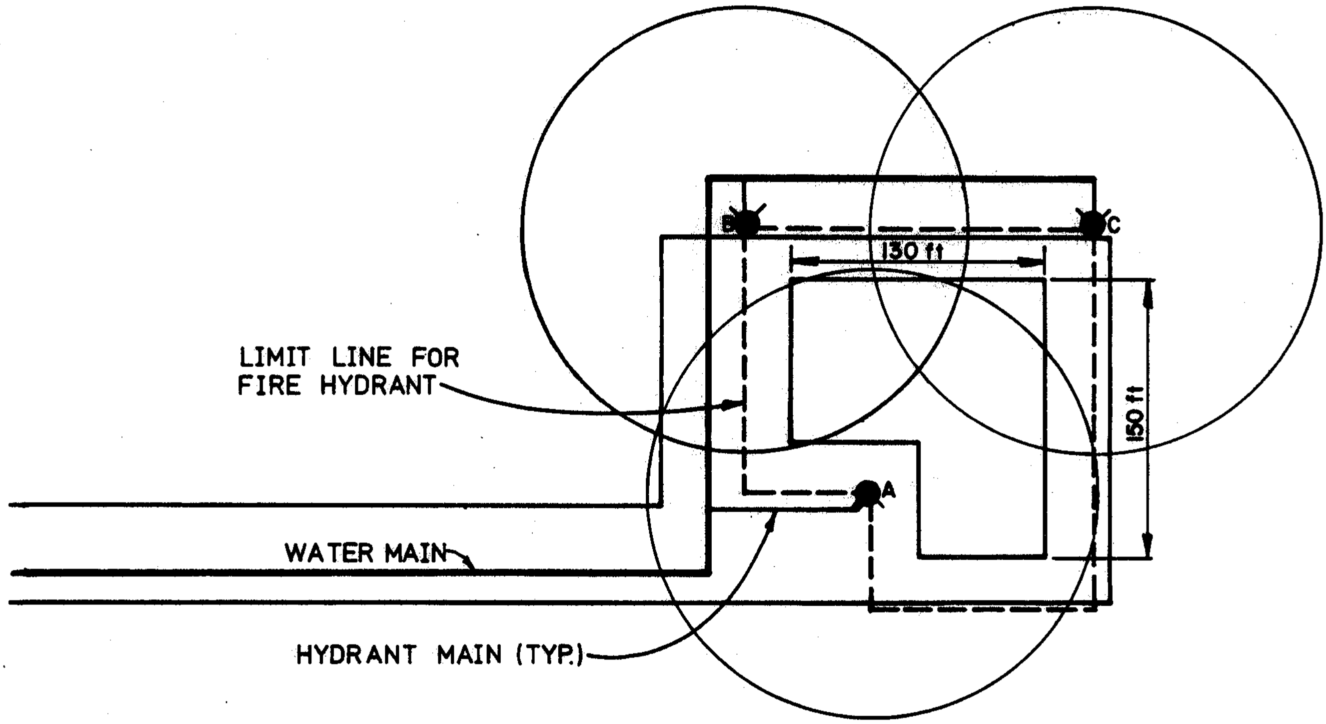
FIGURE B-2. FIRE HYDRANT LAYOUT FOR A TROOP HOUSING AREA



SCALE: 1 INCH = 100 FEET

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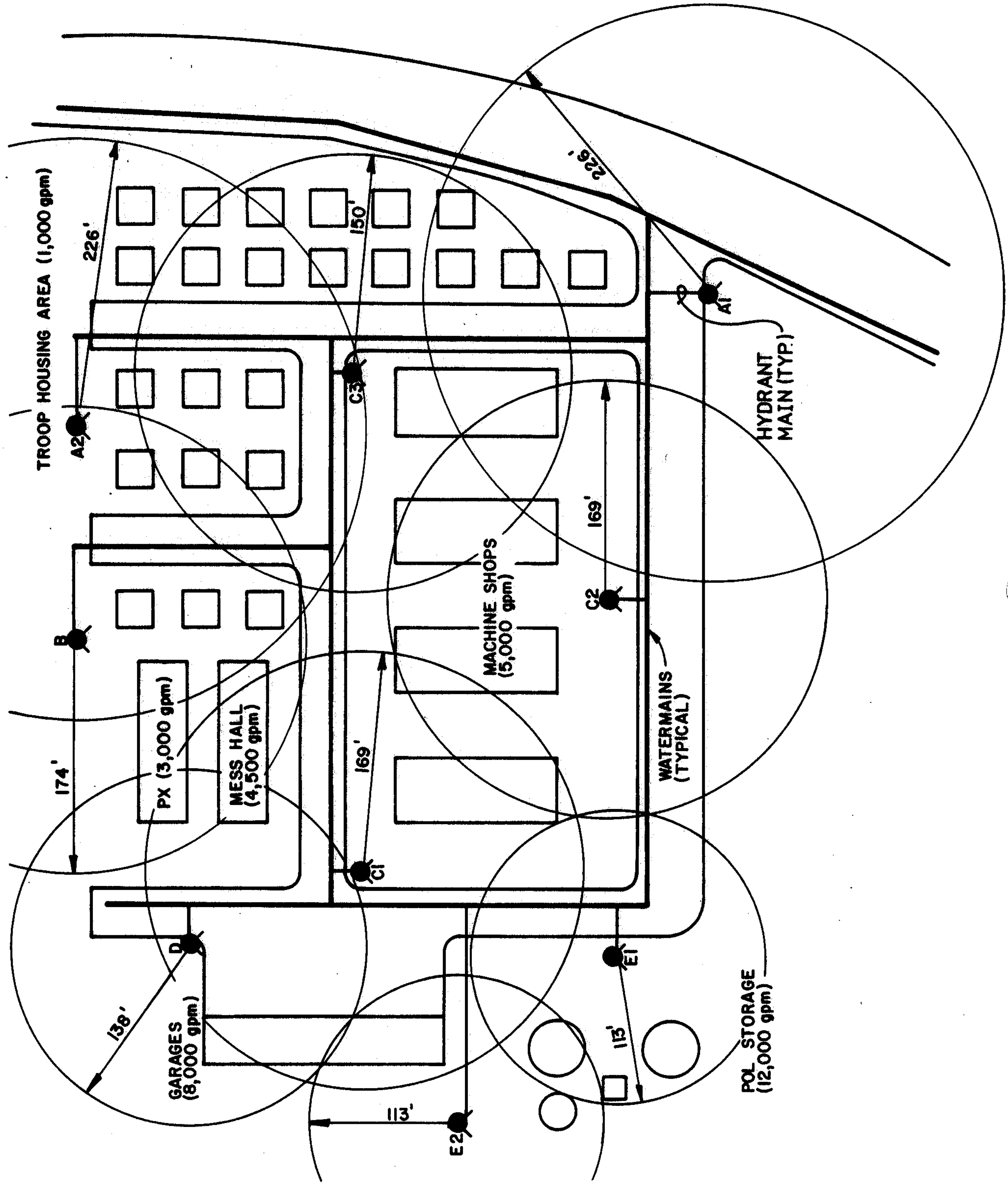
FIGURE B-3. FIRE HYDRANT LAYOUT FOR A REMOTE FACILITY hydrants must be placed. A minimum 25 feet clearance must be kept from the building, demonstrated by the dashed lines. A circle with area of 40,000 square feet would have a radius of 113 feet. Hydrants must be placed so that circles scribed by this radius encompass the entire warehouse. Given these constraints, three fire hydrants at the locations A, B, and C shown in figure B-2 must be provided. These points can be adjusted slightly to clear traffic and roadways, but the coverage area for each hydrant should totally encompass the building the hydrant is protecting. Figure B-4 illustrates an example for laying out fire hydrants in a combined industrial and troop housing area. The fire flows required would be determined from EM 1110-3-166, but for example purposes, are assumed as follows:

Facility	Required fire flow (gpm)	Coverage area per hydrant (feet)	Radius of coverage circle (feet)
Troop housing	1,000	160,000	226
P-X	3,000	120,000	195
Mess hall	4,500	95,000	174
Machine shops	5,000	90,000	169
Garages	8,000	60,000	138
P.O.L.	12,000	40,000	113

The coverage area per hydrant figures are from table 5-2 and the radii of coverage circles have been calculated in the same manner as in the previous examples. In the diagram, the circles represent the coverage areas for each particular fire demand. The radii vary since the coverage areas decrease with the increasing fire demand. The circle related to a particular demand must encompass the structures creating this fire demand. An exception would be when another circle of higher demand already covers the building or structure in question. For example, hydrant B, designed to protect the Mess Hall, also protects the P-X. The P-X has a lesser fire demand than the Mess Hall. Therefore, a hydrant explicitly for the P-X is unnecessary. Similarly, a portion of the garages is protected by hydrant E-2. Hydrants A-1 and A-2 protect the troop housing area, hydrants C-1, C-2, and C-3 protect the machine shop area; hydrant D protects the remainder of the garage area, and hydrants E-1 and E-2 protect the P.O.L. area. The layout plan of fire hydrants is optimal when all buildings and structures are covered and when the overlaps among the various circles are minimized. The minimization of the overlap area would tend to reduce the number of redundant fire hydrants. There are several restraints or restrictions which must be taken into consideration. All hydrants must be kept a minimum of 25 feet, preferably 50 feet, from the facility it is to protect. There must be one fire hydrant within 300 feet and another within 500 feet of any particular barracks or living quarters. Hydrant mains should be kept as short as possible. The layout presented is not the only possible solution; other configurations are possible. Sound



SCALE: 1 INCH = 100 FEET

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FIGURE B-4. FIRE HYDRANT LAYOUT FOR COMBINED INDUSTRIAL AND HOUSING AREAS judgment and actual field conditions must be applied for a proper layout design.

APPENDIX C

THRUST BLOCKING

C-1. Magnitudes of thrusts. Thrusts on pipelines with unrestrained joints occur wherever a branch outlet or a change of alinement exists. Thrust forces can be large and may cause the movement and rupture of an inadequately anchored distribution main with unrestrained joints. If the lengths of pipe are joined by tension joints, such as welded joints in a steel pipeline and lugged joints in concrete and cast-iron pipelines, other forms of anchorage are not usually required. The determination of whether or not a given section of pipeline needs thrust blocks or other means of anchorage should be made by a qualified engineer. All thrust anchorages will be designed for a safety factor of not less than 1.50 under maximum pressure loading. The magnitude of hydrostatic thrust may be determined by the following equation:

Thrust at bend: $T_A = 2\pi r^2 p \sin \Delta/2$

where:

T = thrust in pounds
r = radius of pipe joint in inches
p = water pressure in lb/in^2
Δ = bend deflection angle

Thrust at dead end or branch: $T_E = \pi r^2 p$; where T_E is thrust in pounds. Nomographs for the determination of thrusts are given in figures C-1 and C-2. The insets on these figures illustrate how the nomographs are to be used. For example, if the water in a 16-inch pipe is at a pressure of 100 psi, the thrust at a dead end on this pipe is 20.1 kips (a kip is equal to 1,000 pounds). This is obtained by drawing a straight line from the 100-psi value on the "P" column to the 16-inch value on the "D" column. This line crosses the "T_E" column at the resultant value of the end thrust. If this same pipe made a 45-degree bend, the thrust at the bend is determined by drawing a straight line from the 20.1-kip value on the "T_E" column to the 45-degree value on the "Δ" column. The point at which this line intersects the "T_A" column, 15.4 kips, is the value of the thrust at the bend. Detailed thrust block design can be obtained from the CIPRA Handbook of Ductile Iron Pipe Cast Iron Pipe.

C-2. Anchorage of horizontal thrusts.

a. Bends which do not require anchorage. Small horizontal bends formed by deflection of pipe joints, or by beveling pipe joints, often do not require anchorage against thrust. The maximum deflection angle which does not require some form of anchorage is given by the following equation:

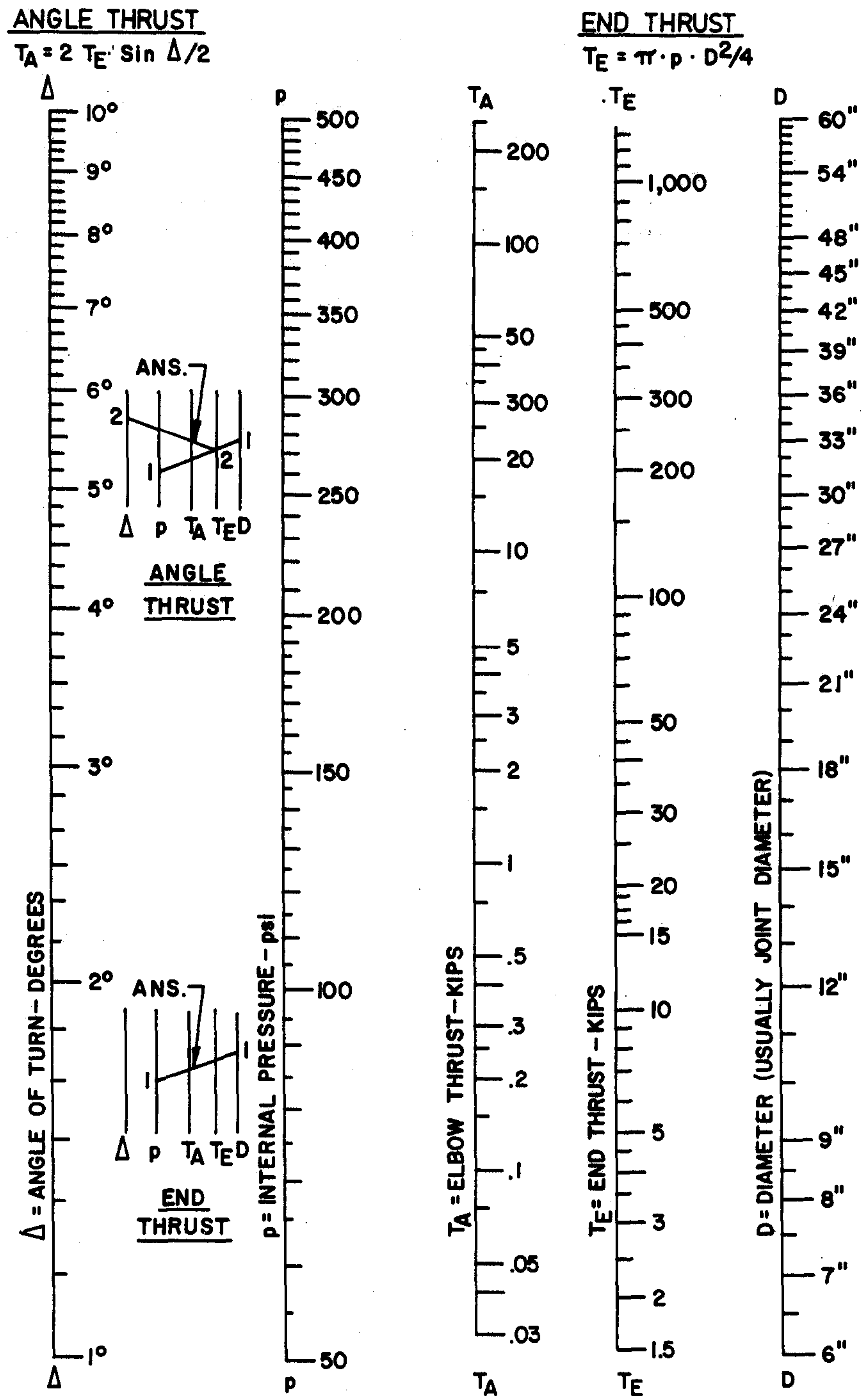

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FIGURE C-1. THRUSTS AT BENDS (LESS THAN 10 DEGREES) AND ENDS

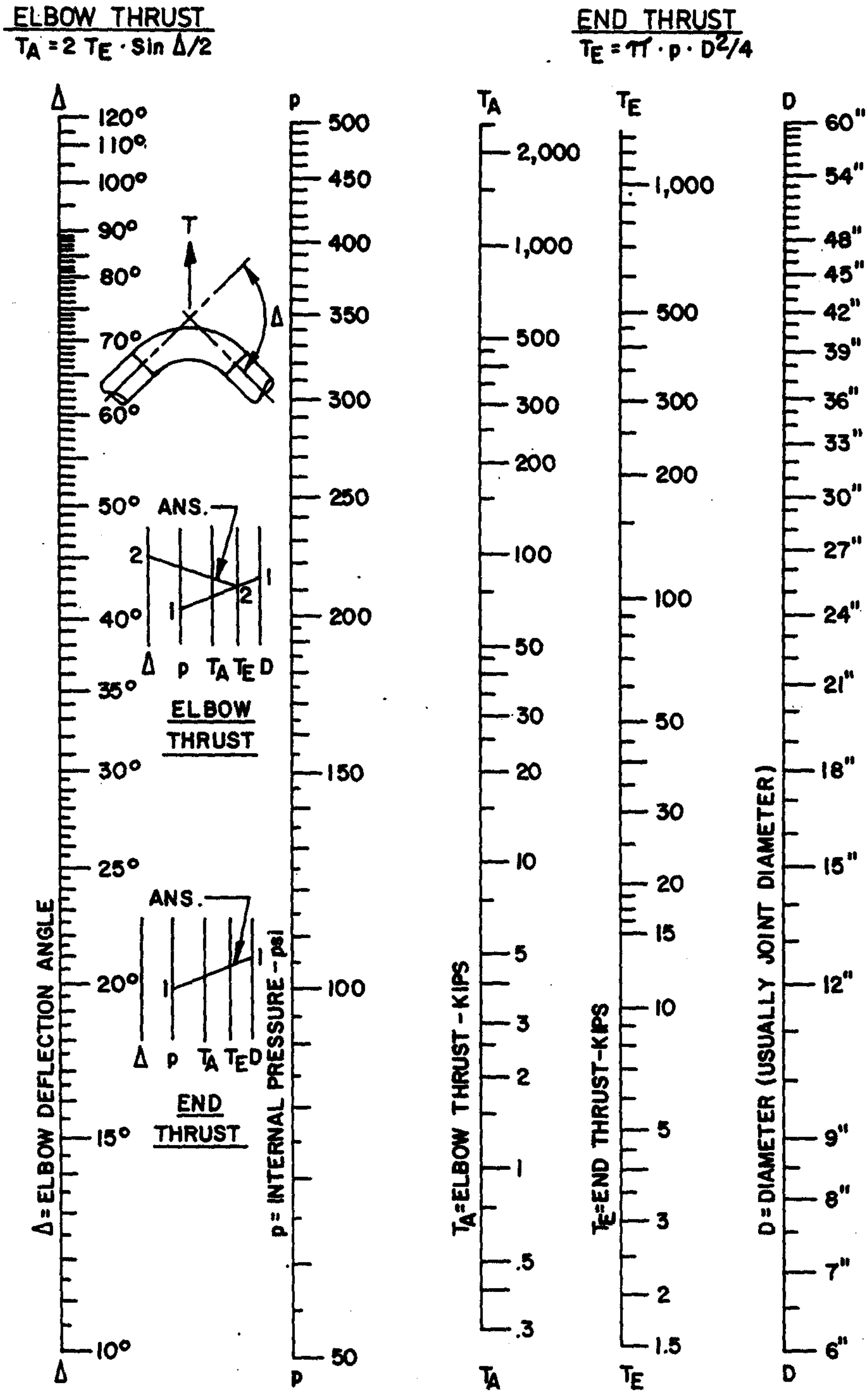

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FIGURE C-2. THRUSTS AT BENDS (GREATER THAN 10 DEGREES) AND ENDS

$$\Delta = 2 \tan^{-1} \frac{Wf}{(2\pi r^2 p)}$$

where:

Δ = maximum deflection angle
W = the combined weight of each pipe adjacent to the bend, the water in the pipe, and the soil over the pipe
f = the coefficient of friction between the pipe and the soil beneath

b. Types of anchorage. Either thrust blocks or frictional thrust anchorage may be used for bends requiring thrust anchorage. Blocks for horizontal thrusts must be poured against firm, undisturbed soil, and the bearing surface should be as nearly vertical as possible. In designing friction thrust anchorages, credit may be taken for the combined weight of the pipe, water in the pipe, and soil above the pipe in calculating the length of tied pipe necessary to develop frictional resistance to counteract the thrust.

C-3. Anchorage of vertical thrusts.

a. Bends which do not require anchorage. The maximum vertical deflection angle not requring some form of anchorage is given by the following equation:

$$\Delta = 2 \tan^{-1} \frac{(w \cos \theta)}{2\pi r^2 p}$$

where, assuming that water is flowing from pipe "a" to pipe "b":

Δ = the angle of deflection of the centerline of pipe "b" from the centerline of pipe "a"
θ = the angle of deflection of pipe "a" from the horizontal

In addition, the beam strength of the pipe must be adequate to safely carry the assumed loads; if it is not, the thrust at the bend should be anchored with a concrete reaction block.

b. Anchorage with reaction blocks. Bends larger than those determined by the above formula can be anchored by a reaction block poured around the bend or poured below and strapped around the bend.

C-4. Anchorage at valves and reducers. Provisions should be made to anchor longitudinal thrust against a closed valve, unless it can be absorbed by compression along the pipeline. Anchorage is normally not required for buried valves on concrete pipelines or on steel pipelines with welded joints, unless the valve is at or near the end of a buried concrete pipeline. Pipelines having joints which do not absorb compressive thrusts, such as some types of rubber-gasketed joints, should be supplied with some form of anchorage for valves and reducers. Suitable forms of anchorage include thrust collars poured around the pipe adjacent to the valve with the anchored pipe tied to the valve, or anchorage of the valve to the structural valve vault in which it might be enclosed.

APPENDIX D

REFERENCES

Government Publications.

Department of the Army.

EM 1110-3-160	Water Supply, General Considerations.
EM 1110-3-161	Water Supply, Water Sources.
EM 1110-3-162	Water Supply, Water Treatment.
EM 1110-3-163	Water Supply, Water Storage.
EM 1110-3-166	Water Supply, Fire Protection.

Nongovernment Publications.

American Water Works Association (AWWA), 6666 West Quincy Avenue, Denver, CO 80235

C150-76	American National Standard for the Thickness Design of Ductile Iron Pipe.
C200-80	Steel Water Pipe 6 Inches and Larger.
C301-79	Pre-stressed Concrete Pressure Pipe, Steel, Cylinder Type, for Water and Other Liquids.
C401-77	Selection of Asbestos-Cement Water Pipe.
C601-81	Disinfecting Water Mains.
C603-78	Installation of Asbestos-Cement Water Pipe.
C900-81	Polyvinyl Chloride (PVC) Pressure Pipe, 4 inch through 12 inch, for Water.

Cast Iron Pipe Research Association (CIPRA), 1301 West 22nd Street, Oak Brook, IL 60521

Handbook Ductile Iron Pipe, Cast Iron Pipe, 1978 (5th ed.)

National Fire Protection Association (NFPA), Batterymarch Park, Quincy, MA 02269

No. 291-77	Fire Flow Testing and Marking of Hydrants.