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SANITARY AND INDUSTRIAL WASTEWATER COLLECTION-- PUMPING STATIONS AND FORCE MAINS

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SANITARY AND INDUSTRIAL WASTEWATER COLLECTION-
PUMPING STATIONS AND FORCE MAINS

*This manual supersedes TM 5-814-2 dated 1 September 1958.

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CHAPTER 1
GENERAL

1-1. Purpose and scope. This manual provides guidance, instructions and criteria for the design of sanitary and industrial wastewater pumping facilities at fixed Army and Air Force installations, and any applicable special projects. Facilities covered in this manual include pump and ejector stations required for (1) removal of sanitary and industrial wastes from remote or low lying areas of the installation which cannot be served hydraulically by gravity sewers, (2) controlled introduction and lifting of raw wastewater into the waste treatment plant, (3) transfer of recycled and bypassed flows throughout the plant, and (4) discharge of treated effluent. Pumping systems for the handling of sludge, grit and scum are presented in TM 5-814-3/AFM 88-11, Vol. 3. The design of a wastewater pumping station will typically include site improvements, structures, screening and flow monitoring devices, pumping units, pump drives, system controls and instrumentation, mechanical and electrical components, interior piping, underground force mains, valves and appurtenances.

1-2. Special wastes. Pumping systems for hazardous and explosive wastes, corrosive acids or alkalies, high temperature or other industrial type wastes, will generally require the selection of highly resistant pumps, valves and piping materials. Design of these systems will be in accordance with special criteria developed for the particular situation. Selection of materials for pumps, piping, valves and controls, etc., will be based on manufacturers' recommendations, product specifications, and any other appropriate design manuals or applicable criteria.

1-3. Pump stations alternatives

a. Gravity sewer system. Pumping stations and pneumatic ejectors will normally be required to remove wastes from areas which cannot be served hydraulically by gravity sewers. In certain situations however, a gravity sewer system can be utilized, but only at the expense of deep trench excavation, jacking, boring, tunneling, or construction of long sewer runs to avoid high terrain. In those cases, both wastewater pumping and gravity flow sewers will be technically feasible and capable of meeting service requirements. However, they may not be equivalent in economic terms. When it is not readily apparent which solution would be more economical, the decision to use one or the other will be based on a life cycle cost analysis. Initial capital and construction costs for pumps, ejectors, structures, force mains, etc., plus operation and maintenance costs, will be compared with the costs of deep trench excavation, or other special construction methods required for a gravity system. Generally, a gravity sewer system will be justified until its cost exceeds the cost of a pumped system by 10 percent. TM 5-814-8 contains criteria for economic evaluation of wastewater pumping. TM 5814-1/AFM 88-11, Vol. 1 provides criteria for engineering and design of sanitary and industrial wastewater collection systems.

b. Grinder pumps and vacuum systems. There may be areas so limited by high groundwater, subsurface rock, unstable soil or steep topography, that neither gravity sewers nor centralized pumping stations will be feasible. In these cases, the use of grinder pumps or vacuum systems will be investigated. See paragraph 1-4b of TM 5-814-1/AFM 88-11, Vol. 1. Design criteria for grinder pumps are contained in this manual.

CHAPTER 2
LOCATION OF PUMPING STATIONS

2-1. Service area. The requirement that an area be served by a wastewater pumping facility will in most cases be determined by topography. Building and grade elevations in the area generally will be too low for proper gravity drainage to an existing or proposed sewer system, or waste treatment facility. Thus, collection and pumping of wastes from these low lying areas will be necessary. In addition to topographic considerations, natural boundaries like waterways, rivers, streams, etc., and property lines of Federal, state and local jurisdictions, also play a role in determining the size and limits of service areas.

2-2. Site selection. The location of pumping facilities within a service area will be based primarily on topographic considerations and the need to provide for future development. Pump stations will be located so that all points within the intended service area can be drained adequately by gravity sewers. Any planned development within the service area, such as construction of new buildings or modifications to existing ones, or any projected shifts in population and/or workforce will be considered. This type of information is generally obtained from the installation master plans, or from personnel staffing requirements. It is a relatively simple matter to design a pumping station with capacity for future development by providing room for additional or larger pumps, motors, impellers, etc. However, the physical location of the station is more critical since it cannot be moved to accommodate new buildings or population increases. The following general guidelines for site selection and location of pumping stations will be used:

-Pumping facilities will not be constructed beneath buildings, streets, roadways, railroads, aircraft aprons or runways, or other major surface structures, to the maximum extent practical.

-Pump stations will not be located closer than 500 feet to buildings, or other facilities to be occupied by humans, unless adequate measures are provided for odor and gas control.

-Pumping stations at wastewater treatment facilities will normally be located adjacent to, or in connection with, other plant elements as required for proper functioning of the treatment systems.

-The location of pumping stations will be made with proper consideration given to the availability of required utilities such as electric power, potable water, fire protection, gas, steam and telephone service.

2-3. Building and site requirements

a. Floor and building elevations. The invert elevations of incoming sewers will determine the depths of underground portions (substructure) of the pumping station. It is common practice to set the maximum liquid level in the wet well equal to the 80-90 percent flow depth of the lowest incoming sewer. Subsurface and soil conditions at the site will dictate the structural design, excavation depths, and top of footing elevations required for the foundation. Surface conditions such as adjacent buildings and site grading will determine the elevations of floors above ground (superstructure), except that the elevation of the ground floor will be set above the maximum expected flood level.

b. Architectural and landscaping. For pumping stations located in built-up areas, the architectural exterior of the buildings should be made similar to, or compatible with, surrounding buildings. When the station is located in a remote area, building appearance is not important, but the possibility of future development in the vicinity will be considered. Pump stations and facilities will be provided with fencing where necessary to prevent vandalism, and to protect people from hazardous contact with electrical transformers and switching equipment. Landscaping should be considered in built-up areas, and will be required in residential communities. Where stations must be constructed in close proximity to residences or other quarters, buffer zones of planted shrubbery should be provided for noise reduction.

c. Access. All pump stations will be readily accessible from an improved road. For stations that are not enclosed, access will be provided for direct maintenance from a truck equipped with hoist attachments. For enclosed stations, provisions will be included in the structure to facilitate access for repair, and to provide a means for removal and loading of equipment onto a truck.

CHAPTER 3
TYPE AND CAPACITY OF PUMPING STATIONS

3-1. Required pumping capacity. Proper selection of the number and capacity of pumping units is dependent upon the quantity and variation of wastewater flows to be handled. Except as indicated below for small stations, pumping units will be selected to handle the normal daily range of wastewater flows generated in the service area. The number and capacity of pumps provided will be sufficient to discharge the minimum, average, peak daily and extreme peak flowrates as calculated in TM 5-814-1/AFM 88-11, Vol. 1. Pumping capacity will be adequate to discharge the peak flowrates with the largest pump out of service. Pumps utilized for treatment plant processes, recycling and bypassing of flows, etc., will be based on criteria developed in TM 5-8143/AFM 88-11, Vol. 3. Consideration will be given to future conditions which may occur during the life of the station. Normally, where future development and population increases are projected for the area, pumps will be designed for initial conditions only, and the station will be provided adequate room for expansion of pumping capacity at a later date. Expansion of pumping capacity can be accomplished with the installation of additional pumping units, larger pumps, impellers, drive units, adjustable or variable speed drives. However, some situations may warrant provision of capacity for future increases initially, for economic or other reasons. Each case will be analyzed individually.

a. Small stations. Pumping stations required for small remote areas which generate extreme peak flowrates of less than 700 gpm, and where the possibility of future expansion is unlikely, and grinder pump installations serving three or more buildings, will be provided with two identical pumping units. Each pumping unit will be of the constant speed type, and will be capable of discharging the extreme peak wastewater flowrate. The station will be designed to alternate between zero discharge and peak discharge. This arrangement will provide 100 percent standby capacity to allow for necessary maintenance and repairs. Pneumatic ejector stations will be provided with duplex ejectors each sized for the extreme peak flowrate.

b. Large stations. Pumping stations serving large areas of the installation, and especially stations where the entire wastewater flow or major portions thereof must be pumped to the treatment facility, will be designed so far as practicable to operate on a continuous basis. The rate of pumpage must change in increments as the inflow to the station varies. This mode of operation will normally require two or more wastewater pumps of the constant or variable speed type, operating in single or multiple pump combinations, as required to match the incoming flowrates.

3-2. Type of construction. A classification of pumping stations by capacity and the method of construction normally utilized for that capacity is provided in Table 3-1. Factory assembled pumping stations, commonly referred to as package type stations, are manufactured in standard sizes and are shipped from the factory in modules with all equipment and components mounted, installed, and ready for connection. These type stations will be suitable for low flows, and where the need to protect pumps from clogging is minimal. Conventional field erected pumping stations are designed for a particular location and to meet specific requirements. Field constructed stations will be used where the quantity of flow or its variation, or both, exceeds the capacity of available factory assembled stations, or where site conditions require the use of special designs or construction methods.

Table 3-1. Classification of pumping stations.

Range Class/Type	Recommended Capacity Gallons Per Minute
Factory Assembled (Package Type)	
Pneumatic Ejectors	30-200
Wet Pit Submersible Pumps	100-500
Dry Pit Pumps	100-2,000
Conventional Field Erected	
Small	300-1,500
Intermediate	1,500-10,000
Large	over 10,000

Note: Package type, dry pit pump stations in the capacities shown are generally available off-the-shelf. However, station capacities up to 5,000 gallons per minute can be obtained by special order.

CHAPTER 4
WASTEWATER PUMPING EQUIPMENT

4-1. WASTEWATER PUMPS

a Centrifugal pumps. The centrifugal pump is the predominate type of wastewater pump used. These pumps are available in three variations, radial flow, mixed flow, and axial flow. Centrifugal pumps will not be used in capacities of less than 100 gallons per minute.

(1) Radial flow pumps. The radial flow centrifugal pump is the major type used for pumping raw wastes. In a radial flow pump, the fluid enters the impeller axially and is discharged at right angles to the shaft. Two types of radial flow pumps are available, single suction and double suction. In a single-end suction pump, fluid enters the impeller from one side. The shaft does not extend into the suction passage, and because of this, rags and trash do not clog the pump. The single-end suction pump will be suitable for handling untreated wastewater. For a double suction pump, fluid enters the impeller from both sides, however the shaft extends into the suction passage, thereby limiting its use to handling only clear water. Radial flow centrifugal pumps are available in discharge sizes of 2 to 20 inches. However, pumps with a capacity to pass 3-inch minimum solids will be required. The recommended capacity range for these pumps is 100 to 20,000 gpm. Pumps are available in discharge heads of 25 to 200 feet total dynamic head (TDH). Peak design efficiency ranges from 60 percent for smaller pumps to 85 percent for larger pumps. Radial flow pumps are suitable for either wet well or dry well applications. They can be installed with horizontal or vertical shafting, however, vertical shaft pumps require considerably less space.

(2) Mixed flow pumps. The mixed flow centrifugal pump is an intermediate design between the radial flow type and the axial flow type, and has operating characteristics of both. The mixed flow pump is designed with wide unobstructed passages, and is therefore suitable for handling wastewater or clear water. Mixed flow centrifugal pumps are available in 8-inch through 84-inch discharge sizes. The recommended capacity range for these pumps is 1,000 to 80,000 gpm. Pumps are available to operate at 10 to 60 feet TDH. Peak design efficiency depends on the size and characteristics of the individual pump, but generally ranges from 80 to 90 percent. The mixed flow centrifugal pump is normally used only in dry well applications, with either horizontal or vertical shafting configuration.

(3) Axial flow pumps. Axial flow centrifugal pumps will not be used to pump raw untreated wastewater. This pump is designed primarily for clear water service and for wet well installations. The pump is furnished with vertical shaft having a bottom suction, with the propeller mounted near the bottom of the shaft and enclosed in a bowl. The propeller is totally submerged and can be clogged by large solids, rags or trash. Therefore, this pump will only be used for clear well applications. Axial flow centrifugal pumps are available in 8-inch through 72-inch discharge sizes. The recommended capacity range for these pumps is 500 to 100,000 gpm. Pumps are available to operate from 1 to 40 feet TDH.

(4) Pump construction. Centrifugal wastewater pumps will normally be constructed of cast iron with bronze or stainless steel trim, and with either cast iron or bronze impellers. When operating' ill wastewater containing substantial quantities of grit, impellers made of bronze, cast steel or stainless steel will be required. Enclosed impellers will be specified for wastewater pumps required to pass solids. Pump casings of the volute type will be used for pumping raw untreated wastes and wastewaters containing solids. Diffusion of turbine type casings may be utilized for effluent or clear water service at waste treatment facilities. Pump shafts will be high grade forged steel, and will be protected by renewable bronze or stainless steel sleeves where the shaft passes through the stuffing box. Stuffing boxes will utilize either packing glands or mechanical type seals.

(5) Stuffing box seals. The stuffing box will be lubricated and sealed against leakage of wastewater (into the box) by grease, potable water, or another clear fluid. The lubricating and sealing sealing medium will be supplied to the stuffing box at a pressure of 5 to 10 psi greater than the pump shutoff head. Grease seals are usually provided by cartridges which are either spring loaded or pressurized by connections off the pump discharge. These arrangements generally do not maintain sufficient seal pressure on the stuffing box. However, they will be acceptable for low head pumps and where the wastewater contains little grit, as when pumping treated effluent. When pumping raw untreated wastes containing the usual quantities of grit, a potable water seal system with seal pump will be required if a potable water line is assessable within a reasonable distance. The Later seal system will be capable of supplying 3 gpm per pump minimum. The principal advantage of a water seal over a grease seal is the positive pressure maintained on the stuffing box by the seal pump, and small amount of water which flows from the stuffing box into the pump casing. Grit and other abrasive materials that may be in the wastewater are

thereby prevented from entering the stuffing box, thus reducing wear on the shaft and packing. The advantage of less frequent repairs to the shaft and less frequent repacking should be considered in relationship to the cost of providing the water line and other necessary facilities for the water seal. Where freezing of seal water is likely to occur, protective measures will be taken. There must not be, under any circumstances, a direct connection between wastewater pumps and the potable water system, nor any possibility of backflow of wastes into the potable water system. Air Force facilities will comply with AFM 85-21.

b. Screw pumps. The screw pump is classified as a positive displacement pump, and as such, maintains two distinct advantages over centrifugal pumps. It can pass large solids without clogging, and can operate over a wide range of flows with relatively good efficiencies. Screw pumps are normally available in capacities ranging from 150 to 50,000 gpm with a maximum lift of 30 feet. Because of its nonclog capabilities and wide pumping range, the screw pump is best suited for lifting raw untreated wastewater into the treatment facility, and for the pumping of treated effluent. Its use in sludge pumping is discussed in TM 5-814-3/AFM 88-11, Vol. 3. Also, when treatment plants are upgraded, screw pumps may be installed to overcome the additional head losses created by new treatment units, so that existing discharge facilities can be retained. Screw pumps are usually driven by a constant speed motor with gear reducer, and are inclined at angles of 30 to 38 degrees from the horizontal. In most instances, screw pumps will be installed outdoors with only the drive unit enclosed.

c. Pneumatic ejectors. Pneumatic ejector stations will generally be used only in remote areas where quantities of wastes are small, and where future increases in waste flows are projected to be minimal. A pneumatic ejector consists of a receiving tank, inlet and outlet check valves, air supply, and liquid level sensors. When the wastewater reaches a preset level in the receiver, air is forced in ejecting the wastewater. When the discharge cycle is complete, the air is shut off and wastewater flows through the inlet into the receiver. Generally, duplex ejectors operate on a 1-minute cycle, filling for 30 seconds and discharging for 30 seconds. Thus, each receiver tank will be equal in volume to 30 seconds of the extreme peak flowrate. Pneumatic ejector stations are available in capacities ranging from 30 to 200 gpm with recommended operating heads up to 60 feet TDH. A typical ejector installation will include duplex units with two compressors, receivers, level sensors, etc.

d Grinder pumps. Grinder pumps shred solids normally found in domestic wastewater, including rags, paper and plastic, into a slurry. The slurry can be pumped under low head through pressure sewers as small as 1¼ inches in diameter. Grinder pumps are for submersible installation, with a recommended operating range of 10 to 100 gpm. These pumps are available in discharge heads of 10 to 150 feet TDH. The peak design efficiency is generally very low. Grinder pumps will be used only to handle domestic type wastes from one or more individual buildings, and only in remote areas or areas where gravity sewers and centralized pumping facilities are not feasible (see paragraph 1-3b).

4-2. Pump drives

a Electric motors. As a general rule, electric motors will be provided as the primary drive unit in sanitary and industrial wastewater pumping stations. Small pump stations serving remote areas where electric power is not available, will usually require engine drives. The three types of electric motors most commonly used in wastewater pumping are (1) squirrel-cage induction, (2) wound-rotor induction, and (3) synchronous. Squirrel-cage induction motors will normally be selected for constant speed pump applications because of their simplicity, reliability and economy. They can also be used for variable speed operation when provided with the proper speed control. Synchronous motors may be more economical for large capacity, low rpm, constant speed pumps. Wound-rotor induction motors are most commonly used for pumps requiring variable speed operation. For a 60 cycle, alternating current power supply, the maximum synchronous motor speed allowed for wastewater pumps will be 1800 rpm (approximately 1770 rpm induction speed). The normal range of speeds is from 600 to 1200 rpm, with speeds below 450 rpm unusual at military installations. Lower speed pumps and motors are larger and more expensive, but generally are more reliable. The selection of electric motors will depend upon the type, size and location of the pumps, type of speed control used, and the power available at the site. Pump location will determine the type of motor enclosure. For dry pit pump installations, motor enclosures will normally be the open, drip proof type. Pumps installed outdoors, or in dirty or corrosive environments, will require totally enclosed motors. Submersible pumps will have motor enclosures which are watertight. Motors installed outdoors will have temperature ratings adjusted to suit ambient operating conditions. For pumps designed to operate on an intermittent basis, space heaters will be provided in motor housings to prevent condensation. Motors installed in wet wells will be explosion proof. Motor starting equipment will be selected in accordance with paragraph 7-3, and will be suitable for the type of motor required voltage. Motor starters will be designed for limiting the inrush current where shocks or disruptions to the electrical supply are likely to occur as a result of pump start-up. Where low starting inrush current is required for constant speed pumps, such as when using engine driven generator sets, wound-rotor motors will be considered as an alternative to squirrel-cage motors. The voltage required for operation of motors and other equipment will be determined in accordance with paragraph 7-3.

b Internal combustion engines. Internal combustion (I.C.) engines will be used primarily at large pumping stations where electric motors are the primary drive units, and where emergency standby facilities are required. Conditions which dictate the use of fixed, standby power at wastewater pumping stations are outlined in paragraph 7-4. I.C. engines will be required for small pump stations in remote locations where no electric power source exists. At large wastewater treatment plants where abundant digester gas is produced, it will generally be more feasible to use I.C. engines which are fueled by the waste gas. I.C. engines may be arranged to drive horizontal pumps by direct or belt connections, or they may drive vertical pumps through a right angle gear drive with an electric motor as the primary drive unit (dual drive). It is more common however, and will be the general rule at large pump stations, to provide fixed emergency generator sets powered by I.C. engines. Generators produce electric power not only for pumps, but also for auxiliary equipment such as heaters, lights, alarms, etc., and for critical pump control systems. The types of internal combustion engines normally used include (1) diesel, (2) gasoline, (3) natural gas, primarily digester gas, and (4) dual-fuel diesel. The use of gasoline engines for anything except small, remotely located pumping stations is not recommended due to the hazards associated with fuel handling and storage. Dual-fuel diesel engines fire a mixture of diesel oil and natural gas, with a minimum of 10 percent diesel fuel required to ignite the mixture. Propane is usually provided as a backup fuel for gas and dual-fuel diesel units. The selection of I.C. engines will be coordinated with the installation's Facility Engineer to insure that adequate operation and maintenance can be made available.

4-3. Drive mechanisms

a Direct drive. Direct drive, with the shaft of the drive unit directly connected to the pump shaft, is the most common configuration. This connection can be either close-coupled or flexible-coupled. When using a close-coupled connection, the pump is mounted directly on the drive shaft. This is the normal arrangement for a vertical pump driven by an electric motor. A horizontal pump will usually have a flexible connection, with the engine mounted adjacent to the pump. A vertical motor mounted above, and at a distance from a vertical pump, will be connected to the pump with one or more lengths of flexible shafting. Direct drive offers the most efficient operation because no power is lost between the drive unit and the pump.

b Belt drive. Belt drives may be utilized if the pump speed is different from those available with standard drive units, or if speed adjustment is required. Speed adjustment is accomplished by changing pulley or sheave ratios. Belt drives used with horizontal pumps require more floor space than a direct drive unit. There is power loss through the belt, which results in lower efficiency, and belt wear increases maintenance requirements. Belt drives will be used only when it is not possible to choose single speed equipment to cover service conditions, or where pump speed adjustments may be required, but variable speed operation is not.

c Right angle drive. Right angle drives will be used on vertical pumps being driven by horizontal engines. If the engine serves as emergency standby, a combination gear box will be installed on the angle drive to allow operation of the pump by the primary drive unit, which is normally an electric motor. A clutch or disconnect coupling disengages the right angle gear when the motor drives the pump. When the engine drives the pump, the clutch is engaged and the motor rotates freely. In case of a power failure the engine is automatically started, and after reaching partial operating speed is engaged to drive the pump.

4-4. Pump speed controls

a Mode of operation. Wastewater pumps will be designed to operate in one of the following modes: (1) constant speed, (2) adjustable speed, or (3) variable speed. The type of speed control system will be selected accordingly. As indicated in paragraph 4-2a, the type of speed control required will influence the type of electric motor to be used.

(1) Constant speed. Constant speed drive is the simplest, most reliable, and most economical mode of operation, and will be suitable for the majority of wastewater pumping applications at military installations. However, where there is a need to match pumping rates with the incoming wastewater flowrates, a variable speed drive will usually be more appropriate.

(2) Adjustable speed. By changing pulley or sprocket ratios on a belt driven pump, the speeds can be adjusted to accommodate several constant speed pumping rates. This type of system will be used mainly in sludge pumping, but can be a good alternative

to variable speed control in wastewater pumping when speed adjustment is not required too often. Where automatic operation is needed pulleys or sheaves can be positioned through the use of pneumatic, hydraulic or electric devices.

(3) Variable speed. Variable speed operation will usually be required at large pumping stations where the entire wastewater flow, or major portions thereof, must be pumped to the treatment facility, and where it is desired to match the incoming flowrates in order to maintain a smooth, continuous flow into the plant. Pumping stations will normally require more pumps under a constant speed system than one utilizing variable speeds. Also, the size of the wet well can be reduced greatly when pumps operate on a continuous basis. Variable speed operation is less efficient than constant speed when pumping at reduced rates, however friction losses and thus power costs are generally less for the smaller flows.

b Speed control systems. The selection and design of the speed control system will be coordinated closely with the selection of the pump and drive units. The simplest system which allows pumps to accomplish the required hydraulic effects will be chosen for design. Factors to be considered in selecting a system include cost, efficiency, reliability, structural requirements, ease of operation and degree of maintenance necessary. The last two items are critical at military installations where adequate personnel cannot always be provided. Pumping stations will normally be designed for automatic on/off operation of the pumping units, with manual override by pushbutton or selector switch.

(1) Constant and adjustable speed. Most automatic constant speed and adjustable speed systems will operate from level signals. Pumps are turned on as the liquid level in the wet well rises, and are turned off when it falls. Pumping systems utilized in treatment plant processes are sometimes controlled by flow or pressure sensors. Level detection systems in standard use include the following:

(a) Float switches. The simplest type of switch consists of a float attached to a rod or tape, and suspended in the wet well. The float rod opens or closes a switch, depending on the rise or fall of the float riding on the liquid level. The float may also be suspended in a tube or cage. These units usually require frequent maintenance as grease, scum and debris in the wastewater build up on the equipment. Another type of float control incorporates a mercury switch encapsulated in a corrosion resistant ball, and suspended by cable in the wet well. This unit is not dependent upon the smooth, vertical movement of a rod, and thus is not subject to the maintenance problems described above.

(b) Bubbler tube. One of the most commonly used systems employs a bubbler tube which is suspended in the wet well and is fed by compressed air. The backpressure on the open end of the tube is sensed by pressure switches, and then transduced to a voltage or current signal. These signals are transmitted to a controller which operates the pumps. This system has no moving parts in contact with the wastewater, and requires very little maintenance. The constant flow of compressed air keeps the tube free of solids accumulations.

(c) Electrodes. A series of electrodes are mounted at different elevations so that when the liquid level rises and contacts an electrode, an electric circuit is energized. Electrodes are used primarily in pneumatic ejectors where the compressed air serves to keep the electrodes clean. They will not normally be used in wet wells due to frequent fouling by grease and waste debris.

(d) Sonic meters. A sonic meter measures the distance from the liquid level to the meter. They are difficult to install free of obstructions, and must be isolated from stray electrical or acoustic signals.

(e) Capacitances tubes and pressure diaphram sensors. These types of controls will not normally be used due to fouling by the wastes.

(2) Variable speed. A bubbler system will in most cases be employed to control the operation of automatic variable speed pumps. In these systems, the backpressure from the bubbler tube is transduced to a pneumatic or electronic signal for use in on/off and variable speed control of the pumps. On/ off controls are usually provided by pressure or electronic switches. Variable speed control devices consist of (1) magnetic (eddy current) clutches, (2) liquid clutches, (3) variable voltage controls, (4) variable frequency controls, and (5) wound-rotor motor controls. Magnetic and liquid clutches have been available for many years as controllers for variable speed pumps. These older methods are inefficient in that the slip losses which developed are lost as heat. The recent development of solid state electronics has led to the introduction of newer methods of variable speed control suitable for both squirrel-cage and wound-rotor induction motors. The variable voltage and variable frequency controls are suitable for use with squirrel-cage motors. Variable frequency drives are possible in efficiencies up to 95 percent, and are available in sizes up to 250 hp. However, variable voltage units are inefficient and are not recommended. Wound-rotor motor controls come in five categories, (1) fixed step resistors, (2) liquid rheostats, (3) reactance/resistance controllers, (4) electronic rheostats, and (5) regenerative secondary controls. Of these, the regenerative secondary

control offers the best efficiency, while the other units are considerably less efficient and require more maintenance. In general, variable speed control devices are more expensive, less efficient, and require a higher degree of maintenance than constant speed controls.

CHAPTER 5
PUMPING SYSTEM DESIGN

5-1. Force main hydraulics

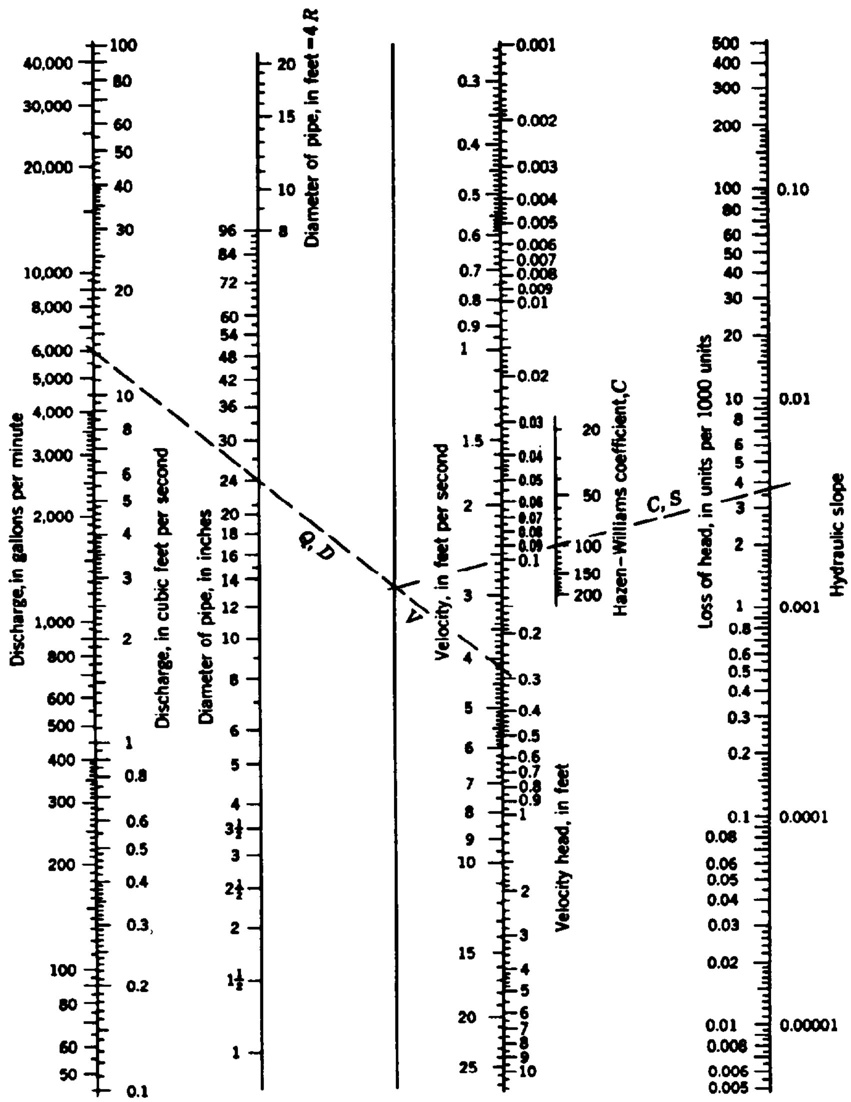
a. General. The pipeline which receives wastewater from a pumping station, and conveys it to the point of discharge, is called a force main. Force mains will be designed as pressure pipe, and must be adequate in strength to withstand an internal operating pressure equal to the pump discharge head, plus an allowance for transient pressures caused by water hammer. The internal operating pressure is maximum at the pumping station, and is reduced by friction to atmospheric, or near atmospheric, at the point of force main discharge. The primary consideration in the hydraulic design of force mains is to select a pipe size which will provide the required minimum velocities without creating excessive energy losses due to pipe friction. The most economical size of force main should be determined on the basis of power costs required for pumping, and capital investment costs of piping and equipment. In practice however, the size is usually governed by the need to maintain minimum velocities at low flows to prevent deposition of solids, and to develop sufficient velocity at least once a day to resuspend any solids which may have settled in the line. However, regardless of pipe sizes required for minimum velocities, the minimum diameters to be used are 1Y4-inch for pressure sewers at grinder pump installations, 4-inch for force mains serving small pump stations and pneumatic ejectors, and 6-inch for all other force mains.

b Design formula and chart. Force mains will be designed hydraulically with the use of the Hazen-Williams formula as follows:

$$V = 1.32\, C\, R^{0.63}\, S^{0.54}$$

where
V = velocity in feet per second
C = coefficient of pipe roughness
R = hydraulic radius in feet, and
S = slope of energy grade line in feet per foot

(1) Roughness coefficient. Values of C to be used in the formula range from 100 for older force mains which have been in service a number of years (usually over 10), to 140 for force mains which are newly constructed. Some manufacturers of plastic and asbestos-cement pipe report C values as high as 150. However, due to uncertainties in design and construction, plus a desire to provide a margin of safety, C values greater than 140 will not normally be permitted. At some installations, force mains may be very old (40 to 50 years) and in extremely bad condition, with offset joints broken pipe, or materials encrusted on pipe walls. For these cases, lower C values may be justified. However, values lower than 80 will not be allowed unless verified by flow and pressure tests. A solution to the Hazen-Williams formula is given in figure 5-1.



Source: Design and Construction of Sanitary and Storm Sewers WPCF Manual of Practice No. 9 by Water Pollution Control Federation, 1970, p. 83.

Figure 5-1. Chart for Hazen-Williams formula.

(2) Velocity. Velocity criteria for force mains are based on the fact that suspended organic solids do not settle out at a velocity of 2.0 foot per second or greater. Solids will settle at velocities less than 1.0 fps and when wastewater pumps are idle. However, a velocity of 2.5 to 3.5 fps is generally adequate to resuspend and flush the solids from the line. Force mains serving small pump stations, which are designed to operate on an intermittant basis, will be sized to provide a minimum velocity of 3.5 fps at the peak discharge rate. For small stations having flows too low to warrant a minimum velocity of 3.5 fps with one pump operating, the design may call for both pumps to be operated manually once a week for a sufficient period of time to flush out the line. Larger stations having three or more pumping units, which operate a major portion of the time, will require minimum force main velocities ranging from 2.0 fps with one pump operating, to 5.0 fps with several pumps operating. In these cases, it is only required

that a minimum velocity of 2.5 to 3.5 fps be provided once or twice daily. Large pumping stations which serve the entire installation or major portions thereof, and which are designed to pump continuously, will usually have a greater number of pumps operating over a wider range of flowrates. Since the pumping range may vary from 7 or 8 to 1, it will generally be sufficient to design for velocities of 0.5 up to 7.0 or 8.0 fps. Maximum velocity is set at 10.0 fps.

(3) Slope. The value of S in the formula is equivalent to the kinetic energy loss due to pipe friction divided by the length of conduit, or $S = H_f/L$. Minor energy losses from fittings and valves will be converted to equivalent lengths of conduit for use in the formula. Conversion tables for fittings and valves can be found in standard hydraulics textbooks. The total kinetic energy loss in a force main will be computed by multiplying the slope of the energy grade line by the total length of conduit including equivalent lengths, or $H_f = S \times L$.

5-2. Pump analysis and selection

a. Total dynamic head. The head in feet against which a pump must work when wastewater is being discharged is termed the total dynamic head (TDH). The two primary components of TDH in wastewater applications are the static discharge head and the kinetic losses due to pipe friction. Velocity and pressure heads are also present, but are usually insignificant. The TDH will be calculated with the use of the Bernoulli energy equation which can be written as follows:

$$TDH = (P_d/W + V^2_d/2g + Z_d) - (P_8/W + V^2_8/2g + Z_8) + H_f$$

where

P_d, P_8 = gage pressures in pounds per square foot

V_d, V_8 = velocities in feet per second

Z_d, Z_8 = static elevations in feet

H_f = kinetic energy loss from pipe friction, fittings, and valves, as calculated in paragraph 5-1b (3).

w = specific weight of fluid in pounds per cubic foot, and

g = acceleration due to gravity 32.2 ft/sec^2)

All head terms are in feet. Subscripts d and 8 represent force main discharge and pump suction, respectively. In order to determine hydraulic conditions at the pump suction, it will be necessary to write an energy equation from the liquid level in the wet well to the pump suction nozzle.

b. System head-capacity curve. To determine the head required of a pump, or group of pumps, that would discharge at various flowrates into a force main system, a head-capacity curve must be prepared. This curve is a graphic representation of the total dynamic head, and will be constructed by plotting the TDH over a range of flowrates from zero to the maximum expected value. Friction losses can be expected to increase with time, thus affecting the capacity of the pumping units and their operation. Therefore, system curves well reflect the maximum and minimum friction losses to be expected during the lifetime of the pumping units, as well as high and low wet well levels. The typical set of system curves will generally consist of two curves using a Hazen-Williams coefficient of C = 100 (one for maximum and one for minimum static head), and two curves using a Hazen-Williams co-efficient of C = 140 (for maximum and minimum static head). These coefficients represent the extremes normally found in wastewater applications.

c. Pump head-capacity curve. The head that a particular pump can produce at various flowrates is established in pump tests conducted by the pump manufacturer. The results of these tests are plotted on a graph to form the pump characteristic curve. Along with the discharge head developed, the pumps operating efficiency, required power input, and net positive suction head are generally included on the same diagram.

(1) Efficiency and power input. Pump efficiency is the ratio of the useful power output to the input, or brake horsepower, and is given by:

$$E = \frac{wQ\ TDH}{(bhp)(550)}$$

where

E = pump efficiency (100 E = percent)

w = specific weight of fluid in pounds per cubic foot

Q = pump capacity in cubic feet per second

TDH = Total dynamic head, and

bhp = brake horsepower

Pump efficiencies usually range from 60 to 85 percent. Most characteristic curves will indicate a best efficiency point (BEP) at which pump operation is most efficient. Where possible, pumps will be selected to operate within a range of 60 to 120 percent of the BEP.

(2) Net positive suction head. When pumps operate at high speeds and at capacities greater than the BEP, the potential exists for pump cavitation. Cavitation can reduce pumping capacity and may in time damage the pump impeller. Cavitation occurs when

the absolute pressure at the pump inlet drops below the vapor pressure of the fluid being pumped. To determine if cavitation will be a problem, the net positive sunction head (NPSH) available will be computed, and compared with the NPSH required by the pump. The NPSH is not normally a problem when discharge heads are less than 60 feet. However, when heads are greater than 60 feet, or when the pump operates under a suction lift, or far out on its curve, the NPSH will be checked. The NPSH available at the eye of the impeller in feet will be calculated with the following formula:

$$NPSH_A = H_8 + P_a/w - P_a/w$$

where

H_8 = total energy head at pump suction nozzle = P8/w + V2 /2g + Z,

P_a = atmospheric pressure in pounds per square foot absolute, and

P_V = vapor pressure of fluid being pumped in pounds per square foot absolute

All head terms are in feet.

(3) Affinity laws. A set of relationships derived from flow, head and power coefficients for centrifugal pumps, can be used to determine the effect of speed changes on a particular pump. These relationships are known as affinity laws and are as follows:

$$Q_1/Q_2 = N_1/N_2$$

$$H_1/H_2 = N^2_1/N^2_2$$

$$P_1/P_2 = N^3_1/N^3_2$$

where

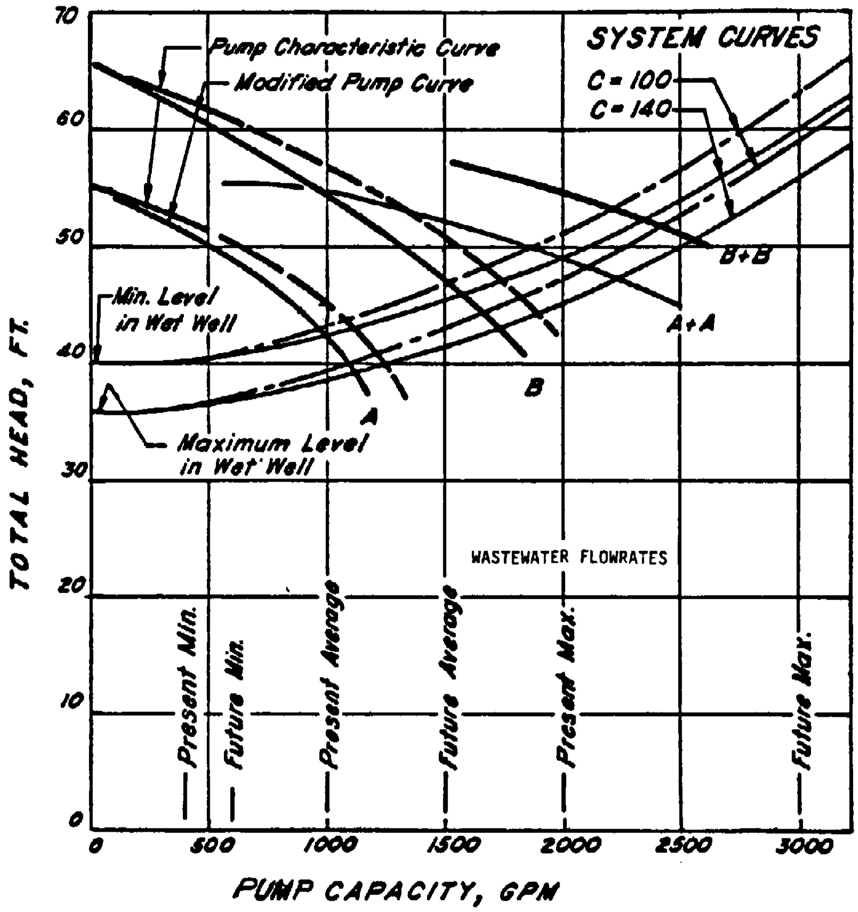
N_1, N_2 = pump speeds in revolutions per minute (rpm)

Q, H and P terms represent pump capacity, discharge head, and power output respectively, at speeds N_1 and N_2. These relationships will be used in analyzing variable speed pump operation in the absence of manufacturer's characteristic curves, or where characteristic curves do not show performance at the desired speeds.

d Pump selection. System analysis for a pumping station will be conducted to select the most suitable pumping units which will meet service requirements, and to determine their operating points, efficiencies, and required horsepower.

(1) Single pump operation. A system head-capacity curve will be prepared showing all conditions under which the pump is required to operate. The system curve will then be superimposed onto a pump head-capacity curve, or characteristic curve, to define the pump operating point. The point where the two curves intersect represents the head and capacity at which the pump will operate in the given piping system.

(2) Multiple pump operation. Where two or more pumps discharge into a common header, the head losses in individual suction and discharge lines will be omitted from the system head-capacity curve. This is because the pumping capacity of each unit will vary depending upon which units are in operation. In order to obtain a true picture of the output from a multiple pump installation, the individual suction and discharge losses are deducted from the pump characteristic curves. This provides a modified curve which represents pump performance at the point of connection to the discharge header. Multiple pump performance will be determined by adding the capacity for points of equal head from the modified curve. The intersection of the modified individual and combined pump curves with the system curves shows total discharge capacity for each of the several possible combinations. Pumps will be selected so that the total required capacity of the pump installation can be delivered with the minimum level in the wet well and maximum friction in the discharge line. Pump efficiency will be a maximum at average operating conditions. A typical set of system curves with pump characteristic curves is shown in figure 5-2.



U.S. Army Corps of Engineers

Figure 5-2. Typical pump-system curves.

5-3. Wet well design

a General. Wet wells will be constructed at pumping stations for the purpose of storing wastewater flows prior to pump operation. The storage volume required depends upon the method of pump operation, i.e., whether pumps are constant, adjustable or variable speed. In addition to providing adequate storage volume, wet wells will be designed to (1) allow for proper pump and level controls, (2) maintain sufficient submergence of the pump suction inlet, (3) prevent excessive deposition of solids, and (4) provide ventilation of incoming sewer gases. In smaller stations, bar racks or comminuting devices may be installed within the wet well in order to reduce costs. Overflows from wet wells are prohibited in all cases.

b Storage volume. If pumps are of constant or adjustable speed type, the wet well volume must be large enough to prevent short cycling of pump motors. For pumps driven by varible speed drives, the storage volume may be small provided pumping rates closely match the incoming flowrates. The volume required for the wet well will be computed with the following formula:

$$V = tq/4$$

where

V = required volume in gallons between start and stop elevations for a single pump, or a single speed step increase for adjustable or variable speed operation

t = minimum time in minutes of one pumping cycle (time between successive pump starts), or time required for a speed or capacity change, and

q = pumping capacity, or increment in capacity where one or more pumps are operating and an additional pump is started, or where pump speed is increased, in gallons per minute

Constant or adjustable speed pumps driven by squirrel-cage induction motors will be designed for minimum cycle times as shown in the following table.

Table 5-1. Minimum pump cycle times.

More size, bhp	t, minutes
Less than 20	10 to 15
20 to 100	15 to 20
100 to 250	20 to 30
Over 250	as recommended by manufacturer

The storage volume calculated for small stations (capacities less than 700 gpm) which utilize two identical constant speed pumps, may be reduced one half by providing a control circuit to automatically alternate the pumps. The storage volume required for variable speed pumps will be based on providing sufficient time for a change in capacity when a pump is started or stopped. When a pump is started, the motor must be ramped to the desired speed, and the pumps already in operation must be reduced in speed. The time required for this is usually less than 1 minute. A considerable amount of storage is normally available in large sewers which serve stations utilizing variable speed pumps. This volume may be considered in design by calculating backwater curves for the various operating levels. The maximum retention time in the wet well will not exceed 30 minutes to prevent septicity.

c. Suction pipe connections. Pump suction piping will be selected to provide a velocity of 4 to 6 feet per second. Pipe should be one or two sizes larger than the pump suction nozzle. Vertical pumps installed in a dry well which is adjacent to the wet well, will be fitted with a 90 degree suction elbow, followed by an eccentric reducer and a gate valve. The suction line will be extended through the wall into the wet well, and terminated with either a 90 or 45 degree flared elbow, or an elbow with a flared fitting. The most commonly used piping arrangements are illustrated in figure 5-3, where D is the diameter of the flared inlet, and S is the submergence depth.

Adequate submergence of the suction inlet is critical to prevent air from being drawn in by vortexing. Minimum required submergence depths are given in table 5-2 as a function of velocity. The net positive suction head (NPSH) will also be considered when determining S. See paragraph 5-2c (2).

Table 5-2. Required submergence depth to prevent vortexing.

Velocity at diameter D, fps	S, feet
2	1.0
4	2.6
5	3.4
6	4.5
7	5.7
8	7.1

Larger, conventional type pump stations will normally be constructed with wet wells divided into two or more sections, or compartments, so that a portion of the station can be taken out of service for inspection or maintenance. Each compartment will have individual suction pipes, and will be interconnected with slide or sluice gates. The floor of the wet well will be level from the wall to a point 12 to 18 inches beyond the outer edge of the suction bell, and then will be sloped upward at a minimum 1:1 slope.

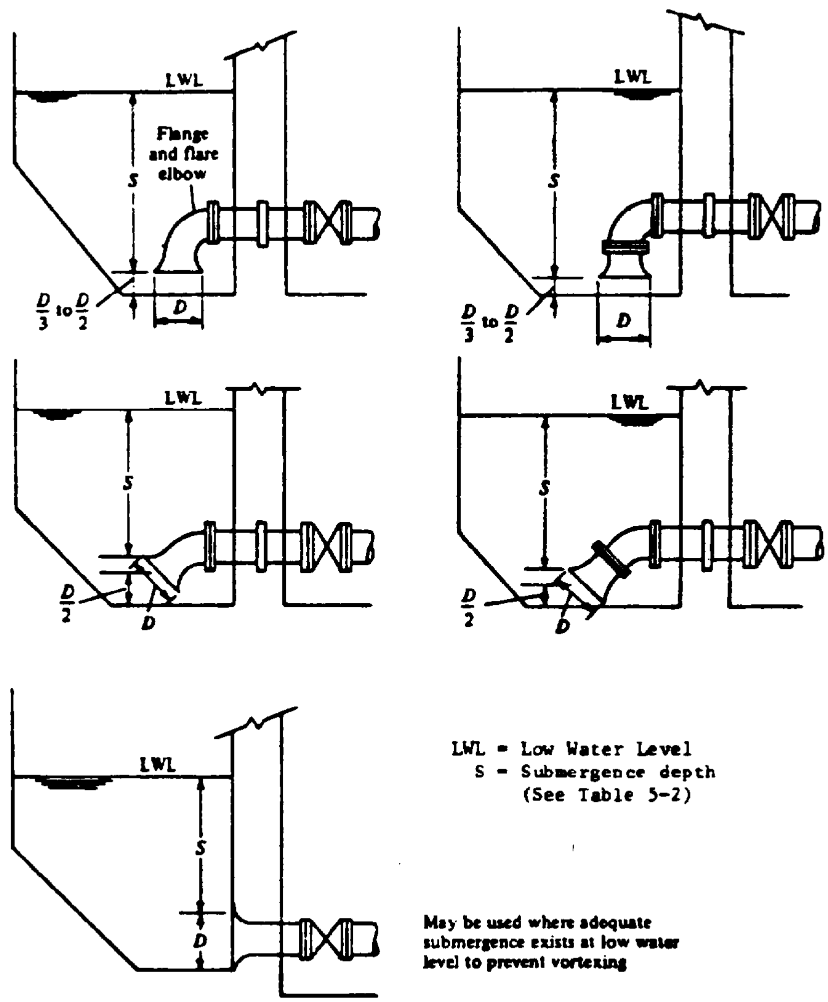
5-4. Pump controls and instrumentation

a. General. Instrumentation at a pumping station includes automatic and manual controls used to sequence the operation of pumps, and alarms for indicating malfunctions in the pumping system. Automatic control of pumps will usually be based on the liquid level in the wet well. Paragraph 4-4 contains a discussion of the various modes of pump operation, pump control systems, and a description of level detection devices. Manual control of pumps is always required in order to operate the pumps during emergencies, for maintenance purposes, or when automatic systems fail. Manual override will be set to bypass the low level cut-off, but not the low level alarm.

b. Selection of control points. A control range of at least 3.0 feet is required between maximum and minimum liquid levels in the wet well. A minimum of 6 inches will be required between pump control points used to start and stop successive pumps, or to change pump speeds. For small stations, the control range may be less, however control points will not be set closer than 3 inches.

(1) Constant or adjustable speed pumps require simple on-off switches to start or stop pumps, or to change from one speed step to the next.

(2) Variable speed pumps require a more complex control arrangement. The two basic types of level control for variable speed operation are (a) variable level, and (b) constant level. For variable level control, a narrow band of control points is established in the wet well. Pump speed is then adjusted in steps by the level detection system (usually a bubbler tube) as the level varies. Pumps operate at maximum



Source: Wastewater Engineering: Collection and Pumping of Wastewater by Metcalf & Eddy, Inc., 1981, p. 360.

Figure 5-3. Pump suction connections to wet well.

speeds near the HWL, and at minimum speeds near the LWL. However, pumps are started and stopped by level switches. Constant level control is seldom used, but may be required where a very narrow band of operation is necessary. In a constant level system, one level is set as the control point, and pump speed is adjusted in a stepless fashion as the liquid level rises above, or falls below this point.

c. Alarms. Alarms will be provided to signal high and low liquid levels in the wet well, pump failure, or a malfunctioning speed control system. The high level alarm will be set above the start point of the last pump in the operational sequence, but below the start point of the standby pump, if used. The low level alarm will be set below the shutoff point of the lead pump. An emergency, low level pump cutoff will be set below the low level alarm.

5-5. Surge phenomena

a. Water hammer. Sudden changes in flow and velocity in force mains can occur as a result of pump startup, pump shutdown, power failure, or rapid closing of a valve. These velocity changes can produce large pressure increases or surge phenomena known as water hammer. The most severe water hammer conditions are usually caused by a pump shutdown or power failure. An analysis of water hammer will include calculating the critical time, determining the maximum pressure increase, and selecting a method of control.

b. Critical time. When flow is suddenly changed in a force main, a pressure wave is generated which rapidly travels the entire length of conduit, and back to the point of change. The time required for this roundtrip is given by:

$T_c = 2L/a$

where

T_c = critical time in seconds

L = length of force main between point of flow change and point of discharge in feet, and

a = velocity of pressure wave in feet per second

When flow is completely stopped (Q = O) in a time interval greater than Tc, the maximum theoretical pressure increase is not fully developed. However, when flow is stopped in a time interval less than or equal to Tc, the change is said to be instantaneous, and the maximum pressure increase is developed as given below.

c. Maximum pressure increase. The maximum theoretical pressure increase or surge caused by water hammer is calculated from the following:

$h_w = aV/g$

where

h_w = pressure increase in feet

V = velocity of fluid in the pipeline prior to flow change in feet per second

g = acceleration due to gravity, or 32.2 ft/sec2 at sea level, and

a = velocity of pressure wave in feet per second

Some typical values of a are given in table 5-3 below.

Table 5-3. Water hammer wave velocities.

Pipe Material	a, ft/sec
Asbestos-cement	2700--400
Ductile iron	3100--4200
Steel	2700--3900
Concrete	3300--3800
Plastic	1100--1500
Fiberglass	1200--1600

d. Methods of control. Whenever a pump is shut down, or power to the station fails, the pump motor is suddenly cut off. Pump speed along with flow and velocity in the force main are quickly decelerated by pressure waves, which travel up the pipeline and back in accordance with Newton's second law of motion. When the velocity is reduced to zero, reverse flow through the pump would occur if a gravity operated check valve or an automatic control valve were not installed on the pump discharge line, and did not close properly. Reverse flow fully accelerated through the pump could cause transient flows and pressures well above maximum design conditions. A swing check valve which stuck open temporarily, and then slammed shut under these conditions, would re5-8 suit in a large pressure surge as given by paragraph c above. In order to control and limit these surge phenomena, the following practices will be followed.

(1) Gravity check valves. For simple cases involving small to medium sized pump stations with gradually rising force mains (no intermediate high points) of less than 1000 feet in length, and with static discharge heads of less than 50 feet, a gravity operated check valve will usually be sufficient. Gravity type check valves may be either swing checks utilizing outside lever and weight (or spring) set to assist closure, or then may be ball checks. Swing check valves are usually installed horizontally, while ball check valves may be either vertical or horizontal. For additional protection, a pressure relief valve may be installed in conjunction with check valves to allow reversing flow to reenter the wet wall. Pressure relief valves must be specially designed for sewage applications. As an alternative to relief valves, a hydro-pneumatic tank may be utilized.

(2) Automatic control valves. In situations where long force mains are required, pipe profiles must conform to existing ground elevations for economic reasons. This normally will result in high points in the force main, with the possibility of water column separation at the high points in the force main, with the possibility of water column separation at the high points during pump shutdown or power failure. The pressures generated when these separated columns come to rest against closed valves or against stagnant columns may be large, and are again determined by paragraph c above. In general, where force mains are greater than 1000 feet in length or contain intermediate high points, and where pumping stations are large in capacity, or static discharge heads are greater than 50 feet, control valves will be automatically operated (1) cone, (2) plug, (3) ball, or (4) butterfly valves. Normal operation of these valves upon pump shutdown, is to slowly close the valve while the pump continues to run. When the valve is closed, a limit switch then stops the pump motor. On power failure, an emergency hydraulic or other type operator closes the valve slowly. The time of valve closure is of utmost importance. Valves should be half closed when the velocity in the force main has dropped to zero. The time required to reach zero velocity can be calculated with the following formula:

$t = LV/g\ H_{av}$

where

t = time in seconds

L = length of force main in feet

V = velocity of fluid in pipeline in feet per second, and

H_{av} = average decelerating head including pipe friction in feet

The types of valve operators most often utilized are hydraulic, electric and pneumatic. Valves and operators specified for use will be fully adjustable for closure times ranging from t to 4t minimum. In some large pumping stations, the use of automatically controlled valves alone will not be sufficient. Extremely long force mains (over 1 mile) may require very long valve closing times, and thus result in excessive backflow to the wet well and reverse rotation of the pump and motor. To solve these problems, a pump bypass with surge relief valve will generally be required. Valves used for surge relief will be automatically controlled cone or butterfly valves, similar to the pump discharge valves. Normal operation upon pump shutdown now will require the pump discharge valve to be fully closed when the velocity has dropped to zero. The surge relief valve will be fully open allowing backflow to enter the wet well at a reduced rate. As before, the relief valve must close slowly to avoid water hammer. Most cases involving large pump stations with long force mains, which contain several intermediate high points, will be too complex to solve by hand using conventional methods such as graphical solutions, arithmetic integration, or water hammer charts. Many computer programs are now available for water hammer analysis, and are recommended for use in those instances.

5-6. Screening and comminuting devices. Centrifugal pumps are susceptible to clogging by rags, trash, and other debris normally found in wastewater. To protect pumps from clogging, equipment will be installed to screen or cut up these materials prior to pumping. Small pump stations with capacities of less than 200 gpm, including grinder pumps and pneumatic ejectors, are exempt from this requirement. The types of equipment to be used include bar racks, screens, and comminutors which are installed in the wet well, or in a separate influent channel. The design of these facilities is covered in TM 5-814-3/AFM 88-11, Vol. 3. At most medium to large sized pump stations, the use of mechanically cleaned bar screens or comminutors will be required. However, at smaller stations in remote areas, manually cleaned racks may be more feasible. The smallest clear opening between bars is normally 1 inch, and spacings of less than 3/4 inch will not be permitted. All electrically operated equipment in wet wells will have explosion proof motors.

CHAPTER 6
PIPING, VALVES AND APPURTENANCES

6-1. Pipe materials, fittings and joints

a. General. Factors to be considered in the selection of pipe materials and piping systems for force mains are: -Flow characteristics or friction coefficient.

-Life expectancy and history of use.

-Resistance to scour and abrasion.

-Resistance to acids, alkalis, high temperature or corrosive wastes, and corrosive soils.

-Ease of handling and installation.

-Physical strength and pressure ratings.

-Joint watertightness and ease of installation.

-Availability of pipe in required sizes, strengths, etc.

-Availability of fittings, connections and adapters.

No pipe manufactured is suitable for all installation requirements and conditions. The pipe materials covered in this paragraph are the ones most often used for force mains carrying sanitary and industrial wastes. Each type of pipe will be evaluated to determine its suitability for the particular design. Where iron or concrete pipe are to be considered, special attention will be paid to subsurface and soil conditions. 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 of acidity, electrical conductivity, dissolved salts, and moisture content. The relative potential for corrosion may be estimated by evaluating the degree of corrosion of existing metallic or concrete pipelines previously buried in the soil. Facility engineer personnel will normally have knowledge of these matters. When this information is not available, or is nonconclusive, resistivity tests of the soil will be conducted and results evaluated as required in TM 5-811-4/AFM 88-11, Vol. 4. Pipe materials found inappropriate for use will be deleted from the project specifications.

b Ductile iron. Ductile iron (D.I.) pipe is suitable for force mains used at pumping stations and wastewater treatment facilities. Special uses include river crossings, pipe located in unstable soil, highway and rail crossings, and piping installed above ground. D.I. pipe is susceptible to corrosion from acid wastes and aggressive soils. Cement linings, bituminous coatings or polyethelene linings are usually provided for interior protections. For extremely corrosive soils, a polyethelene encasement is recommended for external protection. Pipe is available in 3-inch through 54-inch diameters, and with mechanical, push-on or flanged joints. Flanged joints are restricted to interior piping. The Handbook of Ductile Iron Pipe, Cast Iron Pipe published by the Cast Iron Pipe Research Association (CIPRA) will be used for guidance in designing ductile iron force mains.

c. Steel. Steel pipe may be used for force mains when lined with cement mortar or bituminous materials to provide internal protection. A bituminous coating must be applied for external protection also. Lined and coated steel pipe is available in diameters 6-inch through 144-inch. Galvanized steel pipe will be used for small diameter force mains and pressure sewers from 1/4-inch to 4-inch in size. Joints for steel pipe less than 6-inch will be threaded. Pipe 6-inch in diameter and larger will have mechanical, push-on, or flanged joints. Threaded and flanged joints will be used only for interior piping. Steel pipe will be installed in accordance with the manufacturer's recommendations, and Manual No. M11-Steel Pipe Design and Installation published by the American Water Works Association (AWWA).

d. Concrete. Concrete pressure pipe will generally be used where high strength or large diameter force mains are required. The type of cement used for concrete will be selected in accordance with paragraph 6-5a of TM 5-814-1/AFM 88-11, Vol. 1. Pretensioned reinforced concrete pressure pipe is available in diameters 10-inch through 42-inch, prestressed concrete pressure pipe in diameters 16-inch through 144-inch, and reinforced concrete pressure pipe in diameters 24-inch through 144-inch. Each type utilizes bell and spigot joints with rubber gaskets. The Concrete Pressure Pipe Manual, Manual No. M9 published by the American Water Works Association (AWWA) will be used for design of force mains.

e. Asbestos-cement. Force mains constructed of asbestos-cement (A.C.) pressure pipe are durable and light in weight. However, A.C. pipe is affected by corrosive wastes and aggressive soils, and must be provided with plastic linings for protection. The type of material required for A.C. pipe will be type II in accordance with ASTM C 500. Pipe is available in diameters 4-inch through 42-inch, and will be joined by means of couplings utilizing rubber gaskets. Design of A.C. force mains will conform to the manufacturer's recommendations.

f. Plastic. Characteristics which make plastic pipe highly desirable for force main use include high corrosion resistance, light weight, and low coefficient of friction. Disadvantages include the possibility of excessive pipe wall deflections when installed improperly or subjected to high temperature wastes, and chemical breakdown caused by prolonged exposure to sunlight. The following types of plastic pipe are suitable for use:

(1) Polyvinyl chloride (PVC). PVC pipe is available in diameters 4-inch through 12-inch, and with screw, push-on, or solvent weld joints.

(2) Polyethylene (PE). PE pipe may be used in diameters 11/2-inch through 48-inch. Pipe joints consist of mechanical, flanged, or heat fusion type.

(3) Polypropylene (PP). Pipe diameters available with polypropylene pipe are 1/2-inch through 4-inch. All pipe will be joined by heat fusion methods. Screwed and flanged joint pipe will not be used underground. Manufacturer's recommendations will be used in design of plastic pipe, in addition to the Handbook of PVC Pipe-Design and Construction published by the Uni-Bell Plastic Pipe Association.

g. Fiberglass. Fiberglass pipe provides a good alternative for use in large diameter force mains. High structural integrity, low pipe friction coefficient, and a high resistance to internal/external corrosion and to high temperature wastes, are important properties of fiberglass pipe. The following types of fiberglass pipe may be used:

(1) Reinforced thermosetting resin pipe (RTRP). RTRP pipe may be installed in diameters of 6inch through 144-inch. Jointing systems for RTRP pipe include bell and spigot, flanged, or special mechanical type couplings. Elastomeric gaskets are used to provide flexible joints.

(2) Reinforced plastic mortar pipe (RPMP). Pipe diameters available for RPMP pipe range from 8-inch to 144-inch. Pipe joints are made with grooved couplings or bell and spigot joints utilizing rubber gaskets. Design of fiberglass force mains will follow the manufacturer's recommendations.

h. Interior piping. Pump suction and discharge piping inside the station will normally be ductible iron or steel. However, other pipe materials covered in this paragraph are not precluded from use. Pipe, fittings and joints serving as force mains will be selected to withstand the maximum internal operating pressures, including transient surges, as determined in chapter 5. The project specifications will indicate the appropriate pressure class and rating for each pipe application.

6-2. Valves and appurtenances. The use of valves in wastewater pumping can be divided into the following categories:

a. Isolation or shutoff valves. Where the need to isolate pumps or part of the piping system occurs, manually operated shutoff valves will be used. Gate valves or butterfly valves generally serve as shutoff valves, however ball valves or plug valves may also be used. Shutoff valves are required on the suction and discharge sides of all pumps.

b. Surge control valves. To protect pumps and piping from surges caused by pump shutdown or power failure, gravity operated swing check or ball check valves, or automatically operated cone, plug, ball or butterfly valves will be installed in the pump discharge line. The operation of surge control valves is discussed in paragraph 5-5.

c. Blowoff valves. A valve outlet installed at the low point in a force main, and arranged to drain or flush the pipeline, is termed a blowoff. Normally, blowoffs will be required only on long depressed sections of force main, or where an accumulation of solids is likely to occur. Blowoff connections will be installed in manholes or valve structures, and will be protected against freezing. A means of discharging to a suitable location materials flushed from the system will be provided. The pipe size of the outlet connection should coincide with the size of the force main.

d. Air valves. Air valves will be installed at high points in force mains for the purpose of admitting and releasing air. When the pipeline is taken out of service for draining, flushing and filling operations, a manually operated valve will be adequate. However, where air pockets or pressures less than atmospheric are likely to occur with the pipeline in service and under pressure, automatic air release and/or air vacuum valves will be used. Manual valves can also be used with the pipeline under pressure by leaving the valve partially open. Automatic valves are not recommended due to maintenance problems, and should be used only where absolutely required. Automatic valves will be of a type specially designed for sewage, and will be provided with backflushing connections. All valves will be installed in a manhole or valve structure with adequate drainage and protection against freezing.

6-3. Installation

a. Structural design. Structural design of force mains will be in accordance with the requirements set forth for sewers in chapter 5 of TM 5-811/AFM 88-11, Vol. 1.

b. Thrust restraint. Force mains will be restrained to resist thrusts that develop at bends, tees, wye connections and plugs in the pipe. The magnitude of such forces can be calculated with the use of formulas found in standard hydraulics textbooks. Required methods of restraint will consist of tie rods and clamps, or concrete thrust blocks, and will be designed in accordance with Section VI of the CIPRA Handbook of Ductile Iron Pipe, Cast Iron Pipe.

c. Depth of cover. Force mains will be installed with sufficient depth to prevent freezing, and to protect the pipe from structural damage. A minimum cover depth of 3 feet will ordinarily be required for freeze protection. However, in unusually cold climates, a greater depth may be required.

d. Protection of water supplies. Force mains and pressure sewers will not be installed closer than 10 feet horizontally to potable water lines. If conditions prevent a 10-foot clearance, a minimum distance of 6 feet will be allowed provided the bottom of the water pipe is at least 12 inches above the top of the pressure pipe. Where a pressure pipe must cross a potable water line, the pressure line will always be installed below the water line with a minimum vertical clearance of 2 feet. Pressure pipe joints will not be closer than 3 feet to the crossing unless fully encased in concrete.

CHAPTER 7
PUMP STATION COMPONENTS

7-1. Construction requirements

a. Station configuration. The space requirements of pumps, piping and equipment, along with the storage volume required in the wet well, will be carefully determined so that the proper size, shape and configuration of the pumping station can be selected. The size and shape of the station will often be dictated by equipment other than pumps, such as bar screens, comminutors, grit collectors, etc. Rectangular or square structures normally have more usable interior space than circular ones, and will be employed whenever possible in the design of medium to large sized pumping facilities. However, where the below ground portion of the station must be made deep to accommodate incoming sewers, and where foundation conditions are poor, circular caisson type structures will be required if lateral earth pressures are excessively high. Factory assembled or package type stations will generally be circular in design, and will be anchored to base slabs where warranted by subsurface conditions. Pump stations located in cold regions or in seismic zones will require special design considerations.

b. Designing for operation and maintenance. The design of medium to large sized, conventional type pumping facilities will include adequate floor openings, doorways, or access hatches for the installation, removal, and replacement of the largest items of equipment. Interior dimensions in the dry well will provide a minimum clearance of 4 feet between adjacent pump casings, and a minimum of 3 feet from each outboard pump to the closest wall. Other major items of equipment will be provided similar spacing. A 7-foot minimum clearance between floor and overhead piping will be maintained where practicable. Smaller package type stations will be furnished with necessary access openings for removal of pumps and equipment, however interior dimensions and clearances will generally be less than for field erected stations. Wet wells for medium to large sized stations will be divided into two or more compartments to facilitate cleaning and repairs. Wet wells for all stations will have no length, width or diameter smaller than 4 feet. Eye bolts or trolley beams will be provided in smaller stations, and overhead bridge cranes in large stations, for hoisting and removing equipment from mountings. Stairs will be provided in medium to large sized stations so that personnel may inspect and maintain equipment. Smaller stations, except those utilizing submersible pumps, will require the use of vertical safety ladders. A suitable means will be provided to service and maintain all equipment. A floor drainage system will be provided in the dry well, and throughout the superstructure, for collection of wash down, seepage, and stuffing box leakage. These wastes will be piped or conveyed to the wet well, either by gravity or by sump pump. Openings to the wet well and dry well through the main floor of the station will be above the maximum flood level, or will otherwise be protected from flooding.

c. Materials of construction. Large to medium sized, conventional type stations will ordinarily be constructed of reinforced concrete. The above ground portion of the building may be of masonry, wood or metal panel construction. The requirements of Department of Defense (DOD) Construction Criteria Manual 4270.1-M will be followed in designing for fire resistive structures. Small package type stations will generally be manufactured of steel or fiberglass, with separate wet wells constructed of precast concrete or fiberglass manhole sections. Where steel structures are used, cathodic protection or appropriate corrosion control measures will be provided for the underground steel shell in conformance with TM 5-811-4 or AFM 88-45. Alternatively, steel structures may be protected by a concrete or gunite coating where proof can be furnished by the manufacturer of satisfactory design life. All structures will be designed to withstand flotation.

d. Personnel safety. Guards will be placed on and around all equipment where operators may come in contact with moving parts. Railings will be required around all floor openings, and along platforms or walkways, where there is a danger that personnel may fall. Warning signs will be placed at all hazardous locations. Rubber mats will be provided in front of all electrical equipment where the potential exists for electrical shock. Adequate lighting and ventilation will be provided as required in paragraphs 7-2 and 7-3. In attended stations where the possibility exists for toxic, explosive, or otherwise hazardous atmospheres, proper design for personnel safety will be in conformance with chapter 19 of TM 5-814-3/AFM 88-11, Vol. 3. Design for fire protection will be in accordance with DOD Manual 4270.1-M and TM 5-812-1. Wastewater pumping stations will be classified as light hazard, industrial type occupancies.

7-2. Heating and ventilation

a. Heating. All pumping stations subject to possible freezing will be supplied with automatically controlled heaters in the equipment areas. For unattended stations, temperatures will be maintained at 40 degrees F. Attended stations will be heated to 65 degrees F. Although wet wells are generally unheated, thermostatically controlled heaters may be used to prevent condensation on walls and floors during cool weather, provided the ventilation system is shut off.

b. Ventilation.

(1) Wet wells will be provided with a positive ventilation capacity of 30 air changes per hour during occupancy, based on the wet well volume below grade and above the minimum wastewater level.

(2) Unattended dry wells will be provided with a positive ventilation capacity of 30 air changes per hour. Attended dry wells will be provided with a continuously-operated ventilation capacity of 6 air changes per hour, supplemented with additional ventilation in warm climates to remove pump motor heat to within 5 degrees F. of the outside air temperature. Supply intakes and exhaust outlets must be located properly to introduce fresh air and remove hazardous gases or fumes. The wet and dry well sides of the station will be provided with separate ventilation systems.

7-3. Electrical equipment and lighting. Pump station equipment will be suitable for operation at either 208V, 230V, or 480V, 60 Hz, three phase power supplies. However, equipment with motors smaller than 0.5 horsepower, including meters, switches, timers, clocks, and similar equipment, will be suitable for operation at a 125V, 60 Hz, single phase power source.

a Service transformers. Service transformer installations will conform to the requirements of TM 5-811-1/AFM 889, Chap. 1.

b. Motor starters and controls. Motor starters and controls will be provided and housed in a factory assembled, free-standing control center located on the ground floor. The center will include motor starters, switches or circuit breakers, instrumentation and controls. A pump station requiring a few small sized starters is an exception, and will employ wall mounted or stand mounted equipment.

c. Control for submersible pumps. Enclosures for submersible pump controls will be installed above grade.

d. Trouble alarms. Local trouble alarms will be provided at all pump stations. Alarms will be annunciated remotely from unattended stations. Alarm systems will be provided with manual silencing.

7-4. Standby power. The requirement for fixed, standby power at wastewater pumping stations will depend upon the type, location, and critical nature of each pumping facility. For stations situated in low lying areas, or in areas remote from a treatment plant, standby capability will be provided if a power outage would result in flooding of the station, overflows at sewer manholes, backup of wastes into buildings, or any unlawful pollution of the environment, or health hazard to personnel. Pumping stations located at or in conjunction with treatment facilities, such as those required for influent pumping, recycling or bypassing of flows, and pumping of effluent, will require standby power capability if the pumping is essential to critical treatment processes, plant flow control, or is necessary to maintain compliance with the discharge permit. If fixed standby power is required, refer to paragraph 4-2 for design criteria when selecting pump drive units, and descriptions of various arrangements to be used in providing fixed, standby power capability at wastewater pumping stations.

7-5. Water supply. A potable water supply is required at all large pump stations to supply washroom and toilet facilities, hydrants, hose bibs and pump seal systems. A wash basin and toilet facilities will be provided at pump stations which are attended regularly. Hose bibs will be provided in wet wells, dry wells and bar screen rooms. Freeze proof wall hydrants will be required for outdoor use. A positive separation will be maintained between the potable water system and any piping or appurtenances subject to contamination. Warning signs will be posted at all water taps not directly connected to the potable water supply. The positive separation will be accomplished either by providing a break with an air gap, or by installing backflow prevention devices. Air force facilities will comply with AFM 85-21.

7-6. Flow measurement. Flow meters installed to indicate and record the discharge from the pump station, and from individual pumps, will be provided at all medium to large sized stations. A meter installed in the discharge header provides valuable information on the operation of the station, and will be required where pumping capacity is expected to increase significantly in the future. Pressure gages are required on individual pump discharge lines, and on the station discharge header. Elapsed time clocks will be mounted on all pump motor starters. For smaller stations utilizing constant speed pumps, an elapsed time clock may be used in lieu of a pipe mounted flow meter to measure pump discharge. This will also aid in scheduling routine maintenance on the motor since most small stations are unattended. A noncorrodible depth gage installed in the wet well will generally suffice for very small pumps; flows can be estimated from depth measurements taken manually. The types of flow measuring devices to be used for large wastewater pumps of the constant, adjustable or variable speed type, include flow tubes, venturi meters, magnetic and ultrasonic flow meters.

7-7. Paints and protective coatings. The use of paints and protective coatings at wastewater pumping stations will be in accordance with Water Pollution Control Federation (WPCF) Manual of Practice No. 17. A thorough investigation will be made in the design of protective coating systems. Paint materials selected will be appropriate for the types of surfaces being protected, both submerged and nonsubmerged. Coating systems will be designed to resist corrosion from the wastes being handled, and from gases and vapors present, taking into consideration the expected temperature and humidity variations within the station. Coating systems will consist of adequate surface preparation, and the application of prime and finish coats using compatible materials as recommended by the coatings manufacturer. All pumps and equipment will receive protective coatings in conformance with the manufacturer's recommendations. All ferrous materials including galvanized surfaces will be protected. Particular care will be taken to protect welds and threads at connections. Package type stations will be shipped to the construction site with factory applied paints and coatings sufficient for the required service.

APPENDIX A
REFERENCES

Government Publications

Department of Defense

DOD 4270.1-M	Construction Criteria Manual

Departments of the Army and the Air Force

TM 5-811-1/AFM 88-9, Ch. 1	Electric Power Supply and Distribution
TM 5-8114	Electrical Design: Corrosion Control
TM 5-812-1	Fire Prevention Manual
TM 5-814-1/AFM 88-11, Vol. 1	Sanitary and Industrial Wastewater Collection-Gravity Sewers and Appurtenances
TM 5-814-3/AFM 88-11, Vol. 3	Domestic Wastewater Treatment
TM 5814-8	Evaluation Criteria Guide for Water Pollution Prevention, Control and Abatement Program

Department of the Air Force

AFM 85-21	Operation and Maintenance of Cross Control and Backflow Prevention Devices
AFM 88-45	Civil Engineering Corrosion Control-Cathodic Protection System

Nongovernment Publications

American Society for Testing and Materials (ASTM): Race St., Philadelphia, PA 19103

C 500	Testing Asbestos-Cement Pipe

American Water Works Association (AWWA), 6666 W. Quincy, Denver, Co 80235

Manual No. M9	Concrete Pressure Pipe (1979)
Manual No. M11	Steel Pipe Design and Installation (1964)

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

Handbook of Ductile Iron Pipe, Cast Iron Pipe (1978)

Uni-Bell Plastic Pipe Association, 2655 Villa Creek Dr., Suite 150, Dallas, TX 75234

Handbook of PVC Pipe-Design and Construction (1977)

Water Pollution Control Federation (WPCF), 2626 Pennsylvania Ave., NW, Washington, DC 20037

Manual of Practice No. 17	Paints and Protective Coatings for Wastewater Treatment Facilities (1969)

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Morris, H. M. and Wiggert, J. M., *Applied Hydraulics in Engineering*, 2nd ed., Ronald Press, New York, 1972.

Water Pollution Control Federation, *Design of Wastewater and Stormwater Pumping Stations*, WPCF Manual of Practice No. FD4, Washington, D.C., 1981.

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	Engineering and Design STRUCTURAL AND ARCHITECTURAL DESIGN OF PUMPING STATIONS	
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30 June 1989

US Army Corps
of Engineers

ENGINEERING AND DESIGN

Structural and Architectural Design of Pumping Stations

ENGINEER MANUAL

DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
Washington, D. C. 20314-1000

CEEC-ED

Engineer Manual
No. 1110-2-3104

30 June 1989

Engineering and Design
STRUCTURAL AND ARCHITECTURAL DESIGN OF PUMPING STATIONS

1. Purpose. The purpose of this manual is to present the primary features common to pumping station facilities intended for interior drainage on civil works flood protection projects and to present guidance for their architectural and structural design. Much of this guidance is general in nature with liberal reference to appropriate Corps manuals and other design guides. However, specific design guidance is provided for areas involving loading or other factors unique to pumping station structures.

2. Applicability. This manual applies to all HQUSACE/OCE elements and field operating activities having civil works responsibilities.

3. Discussion. EM 1110-2-3105, Mechanical and Electrical Design of Pumping Stations, dated 10 December 1962, is being revised and is scheduled for completion in FY 90. A formed suction intake will be incorporated in the revised EM 1110-2-3105. The formed suction intake has not been incorporated in this EM.

FOR THE COMMANDER:

ALBERT J. GENETTI, JR.
Colonel, Corps of Engineers
Chief of Staff

This manual supersedes EM 1110-2-3103 dated 29 February 1960 and EM 1110-2-3104 dated 9 June 1958.

Table of Contents (Continued)

CHAPTER 4
STRUCTURAL ANALYSIS AND DESIGN

4-1. Foundations. The foundation materials encountered may be a determining factor in the siting and layout of a pumping station. In some areas, the measures required to provide a proper foundation for the structure may be prohibitive and may dictate relocation of the plant site. Sufficient soil sampling and testing should be done prior to selecting a site so that the type and extent of foundation work required can be estimated. Investigations, including sampling and testing, should be performed in accordance with the provisions of EM 1110-1-1804.

a. Soil Foundations. For structures founded on soil, a determination of soil type, shear strength, cohesion, internal friction angle, and unit weights in dry, moist, and submerged (or saturated) conditions must be made for each material to be used in backfill or embankment sections and for each material in the foundation. From these parameters, the allowable foundation bearing value will be determined. Also from these parameters, structure and embankment settlement and slope stability for excavation and embankments will be assessed. The results of the settlement analyses will be used by the structural engineer in designing discharge piping connections and the low flow and discharge culverts. These designs should be coordinated between the geotechnical and structural design elements. Therefore, contact between these design elements should be established early and coordination maintained throughout the design process.

b. Rock Foundations. Where small structures are to be founded on rock it will usually be unnecessary to make comprehensive rock tests. However, early in the design process sufficient coring and testing must be accomplished to determine the load carrying capacity of the foundation material, and to identify any faults, seams, or other potential problem areas. For large structures, a comprehensive program of foundation exploration must be initiated early in the design process so that sufficient foundation information will be available for use in the facility siting studies. This exploration program should progress from a general investigation of various sites to an in-depth investigation of the finally approved site. Pumping station substructures are generally formed of reinforced concrete having compressive strength of from 2,500 to 3,000 psi, and the proportioning of the structure for allowable base pressure is controlled by the compressive strength of the soil foundation material. However, for structures founded on rock, the compressive strength of the foundation material may be greater than the bearing strength of the substructure concrete. In these instances, the structure base must be proportioned so that these pressures do not exceed the strength of the concrete. Also, in some instances the foundation rock may be fractured or contain seams which could shift or compress under loading, causing movement of the structures above. In these instances, the structures may be founded on drilled caissons with the foundation grouted to preclude underseepage.

c. Pile Foundations. If the foundation materials do not have sufficient bearing capacity to sustain the imposed structure loads, and if other stabilizing methods are impracticable or unfeasible, foundation piles may be required. The piles may be of wood, concrete, or steel, but the use of wood piles should be restricted to those locations where the pile cut-off elevation is below the minimum ground water level. Design loading for piles and pile lengths required to sustain a given loading should be verified by driving and loading test piles in accordance with the provisions of EM 1110-2-2906. For small plants requiring foundation piles, the cost of pile load tests may be prohibitive. In these cases, conservative values may be assumed for pile design and load tests may be omitted. Large horizontal loadings are sometimes imposed on pumping stations and appurtenant structures. When these structures are founded on piles, they must be designed to withstand this horizontal loading. Battering the piles is one effective technique for this purpose. Vertical piles can also be used if documented by appropriate analysis. The method used in designing the pile foundations will generally be dictated by the size of the structures and resulting size of the supporting pile group. For nominally loaded structures requiring small pile groups, conventional pile design methods may be used. For large structures involving extreme horizontal loading, more detailed analysis and design methods may be required, as discussed in EM 1110-2-2906.

d. Foundation Alternatives. If investigations indicate that the foundation materials are incapable of sustaining the imposed loads without failure or unacceptable amounts of settlement, a variety of alternative compensatory measures may be taken. Some of the possible alternatives are:

(1) Provide footings outside the lines of the substructure walls.

(2) Excavate and replace unsuitable material to a sufficient area and depth to provide a stable foundation on good

material.

(3) Employ in-situ foundation improvement methods such as dynamic compaction, vibro-replacement, in-situ densification, and preloading and drainage using wick drains.

e. Ground Water Control. Management of ground water during construction and under operating conditions is often a sizeable task. During construction, the ground water level must be lowered enough to allow the work to proceed. This is a particular problem for pumping stations because they are usually located in low lying areas to facilitate water intake. Under operating conditions, it may be necessary to suppress the ground water level to keep uplift pressures within acceptable limits. Ground water control is usually accomplished by relief wells from which water is pumped to lower the ground water level. Another problem related to water handling is the seepage of water beneath the structure. Measures to lengthen the path of this underseepage and thus reduce its effects on structure stability include the placement of a concrete cutoff wall or construction of a monolithic structural key to some depth beneath the structure foundation elevation and near the face of the structure at which seepage originates.

4-2. Primary Structural Components. The primary structural components of a pumping station are the substructure, operating floor, superstructure, crane runways, and discharge facilities.

a. Substructure. The conventional pumping station substructure includes the sumps and water passages required to conduct water to the pump intakes. The structural components comprising the substructure include the sump floors and base slabs for the water passages, the outer walls of the structure, and the sump separator walls. The sump area components are generally analyzed as a frame extending from the foundation to the operating floor. The forebay area is similarly designed assuming a frame extending from the foundation to the top of the side walls or to the top of the exterior forebay deck. For both of these analyses, care must be taken to assure that the assumed degree of fixity at the frame joints reflects as nearly as possible the actual behavior of the structural components under critical design loading conditions. For some pumping stations, other areas will require detailed structural analysis, such as the intake/trashrack deck, the discharge chamber if constructed integrally with the pumping station, dewatering sump areas required in some installations, and retaining wall or flood wall sections constructed monolithically with the pumping station.

b. Operating Floor. The primary interior structural floor is the operating floor. The electrical and mechanical water handling and control equipment is mounted on this floor, subjecting it to the dead weight of the pumping and control equipment, and the hydraulic thrusts generated during the pumping operation. The design of the operating floor is complicated by the presence of the necessary hatchways, pump openings, etc., which interrupt the continuity of the structural floor. The layout of this floor for spans over sump walls, location of machinery, and location and size of openings, is a coordinated effort involving hydraulic, electrical, mechanical, architectural, and structural requirements. The floor is usually designed as a system of beam sections and slabs laid out about the various openings and spanning across the supporting walls below. The sump layout determines the location of these supporting walls and the location of the pumps on the floor. This layout is also a coordinated effort involving input from mechanical, hydraulic, and structural requirements to arrive at the optimum arrangement for each plant. Once the general layout and loading configuration for the operating floor are determined, the design of the structural elements can be undertaken. These elements may be designed assuming the floor to act independently of the supporting wall sections below, or the operating floor, supporting walls and sump floor may be designed as a continuous frame. The assumptions made will be dictated by the relative size of the components and the general configuration of the plant structure, and must be consistent with the way the structure is expected to behave under the design conditions.

c. Superstructure. Most pumping plant installations will be of the indoor type. This means that an enclosure is provided for the equipment and personnel areas in the plant. This enclosure must be sufficiently tight to protect the equipment from the elements and sufficiently durable to be economically maintained. It must also withstand the loading conditions given in paragraph 4-4. Pumping station superstructures are commonly constructed of reinforced concrete, or concrete masonry unit and/or brick wall sections. In structures of brick or concrete masonry, a separate framework is usually provided inside the outer enclosure to support the bridge crane. It is often economical to incorporate this framework in the structural wall and/or roof section to provide additional strength and support; however, with larger cranes, the operating forces may dictate that the crane support framework be separated from the wall sections so these forces will not be transmitted to the superstructure walls.

d. Crane Runways. As prescribed in EM 1110-2-3105, indoor type plants are usually equipped with bridge cranes for equipment removal and handling unless other workable and economical means can be used. The runways for the bridge crane may be mounted on structural steel or reinforced or prestressed concrete beam sections supported on structural steel framework, on reinforced concrete column or haunch sections, or on ledges formed in reinforced concrete. Generally, only in larger installations with reinforced concrete superstructures will the walls be large enough to support the crane loads.

e. Discharge Facilities. The facilities incorporated into a pumping station for discharge across the protection line can be of various types and configurations. A station located on the protection line will usually discharge directly, either by pumping into open water or into a discharge chamber constructed monolithically with the pumping station. This type of installation requires the least amount of discharge piping, but is subjected to maximum hydraulic loading from the discharge side. Also, if a discharge chamber is constructed in the pool, it must be gated and designed for maintenance access to the gates. This access can be provided by periodic unwatering under full external hydraulic load, or by an arrangement that allows the gates to be removed for maintenance. Pumping stations not located on the protection line require extensive discharge piping. This piping may be installed over, through, or under the protection line as required by the specific situation. The structural design of this piping, its supports, appurtenant gate structures, and discharge structures can be undertaken only after the coordinated plant arrangement has been determined, incorporating input from hydraulic, mechanical, and structural elements. All piping inside the pumping station should be of ductile iron, and discharge piping will usually be of ductile iron, steel, concrete pressure pipe, or cast-in-place reinforced concrete. Whether the pumping station is located on the protection line or not, it is often necessary to provide a low flow gravity discharge structure. This structure will usually include an intake headwall with bulkhead slots, a gravity discharge conduit through the protection line, a gate structure near the discharge end of the conduit, and a headwall and stilling structure at the conduit outfall. There are many variations on this arrangement including combination of the various components of the pumping station and pump discharge system and the components of the low flow discharge system. Plant arrangements involving innovative facilities or arrangements should be thoroughly reviewed from a construction and operations standpoint during the planning and layout stages to assure constructability and to facilitate operation and maintenance over the life of the project. These unique features and arrangements should also be thoroughly coordinated with higher authority.

f. Miscellaneous Structural Items. There are, in any pumping plant, various miscellaneous items which must be addressed by the structural engineer. These include retaining walls, channel lining and slope protection slabs, and gates, flap valves, and bulkheads and their associated guides and mountings. These items generally constitute a small portion of the total project cost and are not usually designed until late in the design process. However, they should be accounted for in all estimates of project construction costs either separately, as in the case of relatively large concrete retaining wall sections, or in general terms, as in the summary "miscellaneous metal" cost item for gate guides, etc.

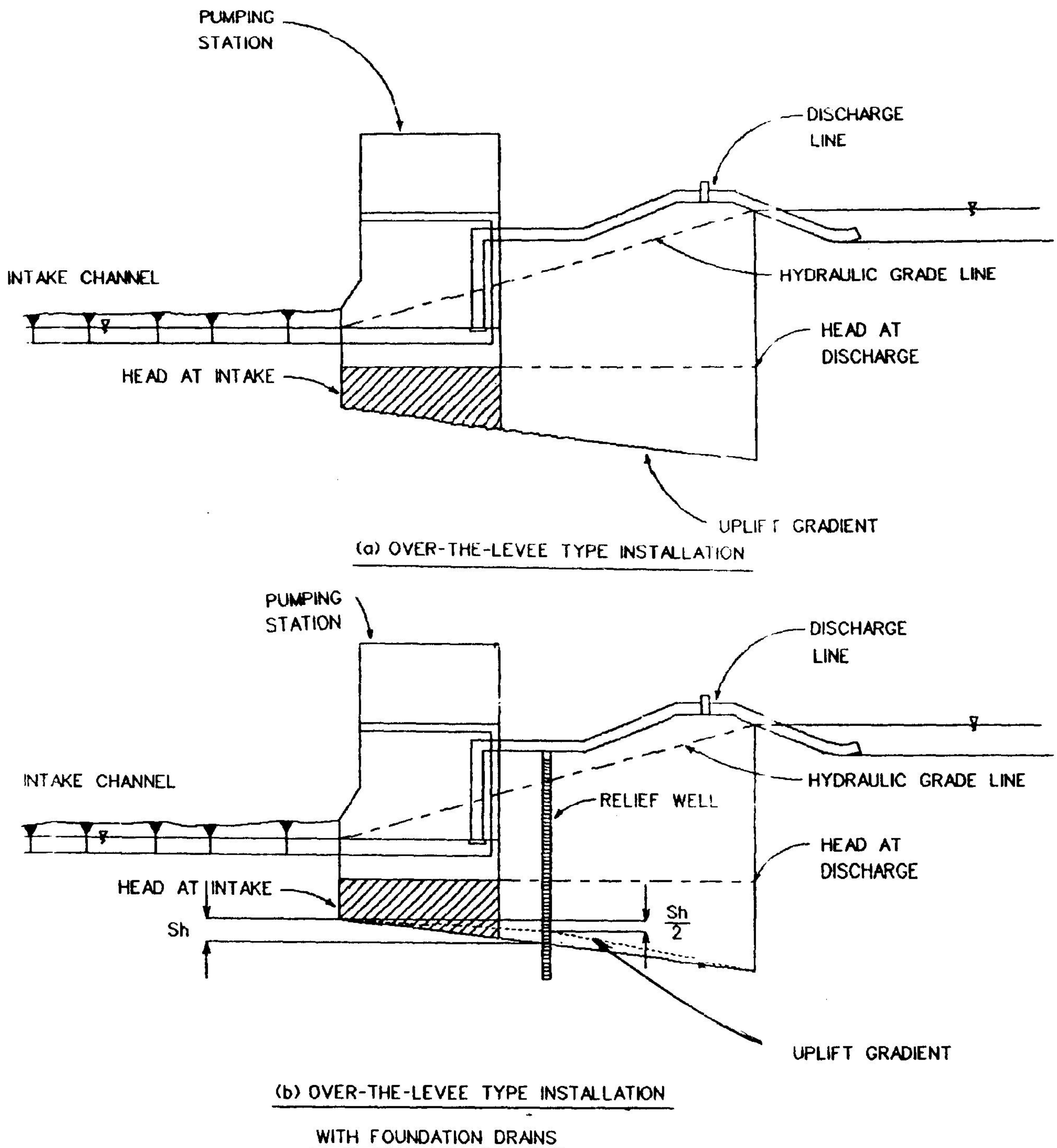
4-3. Structural Loads.

a. Soil Loading. Lateral soil loads for stability analyses and determination of base pressures should be computed by the method in EM 1110-2-2502. In many instances, the design of vertical walls below grade and wing walls and retaining walls will be greatly affected by wheel loads or other surcharge loads on the ground surface. These loads should be considered in structural stability calculations and in detailed structural design as appropriate. They should be derived based on the heaviest piece of machinery likely to be placed on the fill during construction or operation and maintenance of the facility.

b. Hydrostatic Loads. For the portion of the hydrostatic loading not included in the soil load calculations (water above the ground line) the conventional triangular distribution of water pressure with depth should be used. The water surface elevation will depend on the hydrologic situation at each site and must be coordinated prior to beginning structure design. A station located on the protection line will usually experience larger differential hydrostatic loads than one located inside the protection line. If a discharge chamber is used, the hydrostatic loading under unwatered conditions may be more severe with the chamber located in the discharge reservoir. The hydrostatic loading on a station inside the protection line will be related to the hydraulic gradient between the free water surfaces on the discharge side of the protection line and at the pumping station intake. This gradient is affected by the presence of foundation drains, the proximity of the station to the protection line, and the type of protection used (levee or flood wall).

c. Uplift. The uplift experienced by a pumping station will vary with its proximity to the protection line. Stations located on the protection line will generally be subjected to larger hydrostatic loads and correspondingly larger uplift pressures than those located inside the protection line. The uplift forces used in the structural design may be derived from actual field data, but more commonly will be based on an assumed flow path relating the head at the discharge side of the protection line to that at the pumping station intake. This relationship is usually assumed to be a straight line variation with the uplift at the pumping station assumed to be that portion of the gradient envelope intercepted by the vertical projection of the structure base as shown in Figure 4-1(a). The full uplift may be modified by incorporation of maintainable foundation drains into the site design, However, the uplift reduction may not exceed 50 percent of the difference between the full uplift head at the pumping station intake and that at the point of the drain (Figure 4-1(b)).

d. Seismic Loading. Seismic investigations and design should be performed in accordance with the provisions of ER 1110-2-1806. As a minimum, an investigation should be performed to determine the types and extent of defensive design measures which may be economically justified for the project to resist the effects of seismic events. These measures may include arrangement of the facilities to minimize seismic damage, use of flexible couplings on discharge conduits, and restricting the height of structures to a minimum to reduce the effects of earthquake motion. A seismic coefficient analysis, using the minimum coefficients specified in ER 1110-2-1806 should be used to calculate sliding and overturning stability for all structures subject to earthquake loading. In addition, a dynamic response analysis is required in high seismic hazard locations as specified in ER 1110-2-1806 to determine areas of high stress within the structure. The seismic forces for the components of the pumping station include the building components, fixed operating machinery, and other fixed equipment should be calculated using the procedures of TM 5-809-10. In the stability analyses, water inside the structure, confined between structure walls placed perpendicular to the direction of earthquake acceleration, is treated as part of the structural wedge, as is any saturated or moist earth mass bearing vertically on any projecting structure footing or sloping exterior wall face. Free water above the ground surface and above a structure footing or sloping exterior face Is not included as part of the structural wedge. Seismic forces for inclusion with static forces from earth and



TYPICAL STRUCTURE UPLIFT DERIVATION

Figure 4-1

water impinging on the sides of the pumping station are computed in accordance with the provisions of EM 1110-2-2502. For structures having sloping exterior walls, or footings extending outside the structure walls, the force wedges used for structure stability analysis will originate at a vertical plane projecting upward from the outer edge of the structure footing or wall at the foundation. Seismic forces due to water above ground acting in the same direction on opposite sides of a structure are calculated by the Westergaard approximation.

e. Wind Loading. Wind loads should be applied according to the provisions of ANSI A58.1. These loads should be applied in conjunction with other loads as prescribed in paragraph 4-4. Wind loads will also be applied to the appurtenant structures as applicable.

f. Floor Loads. The structural support system for the operating floor should be designed for dead loads including the weight of the pumps in their operating locations plus a minimum live load of 100 pounds per square foot. Since the pumping equipment may be removed for repairs, the floor area must be designed to support the heaviest work piece anywhere it might be placed on the floor. The machinery loads, for both service and maintenance conditions, should be furnished by the pump designer. The service loads will include the machinery weight plus the weight of the water column for most pumps, with a 50 percent increase in water column weight to account for dynamic effects. However, for some pump arrangements the pump motor and pump impeller are supported at different levels. For this arrangement, the floor supporting the motor must carry the full downward hydraulic thrust under operating conditions in addition to the weight of the rotating element and the motor. The pump support must carry the weight of the impeller and water column which will be partially offset by the upward hydraulic thrust against the pump casing. All personnel areas inside the pumping station should be designed using the applicable minimum dead loads given in ANSI A58.1. Table 4-1 gives minimum uniformly distributed live loads. For areas not covered in this table, refer to TM 5-809-l. The live loads indicated in Table 4-1 may be reduced 20 percent for the design of a girder, truss, column, or footing supporting more than 300 square feet of slab, except that, for pump room and erection floors, this reduction will be allowed only where the member under consideration supports more than 500 square feet of slab.

TABLE 4-1

MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS

	LB/SO FT
Roofs	50
Stairways	100
Floors:	
Offices	100
Corridors	100
Reception Rooms	100
Toilets and Lock Rooms	100
Equipment and Storage Rooms	200
Control Room	200
Erection Floor	1,000
Maintenance Shop	300
Operating Room	100*
Forebay Deck (Outdoor Pumping Station)	300 or H20**
Electrical Substation Deck	200
Forebay Deck Grating	300 or H20**
Pumping Station Access	300 or H20**

* Operating floor must be designed to allow placement of the heaviest machinery piece anywhere on the floor unless specific areas are designated for this purpose.

** Use whichever is more critical and where mobile cranes might be used, applicable loading including impact loads should be applied if more critical than those listed.

g. Stairway and Landing Loads. Stairways and landings should be designed using the live load given in Table 4-1 unless special loading in excess of this amount is indicated.

h. Roof Loads. Roofs should generally be designed for dead load, live load, and either wind or seismic loading, whichever is the more critical for the plant location. In certain localities live load produced by snow accumulation must be considered. Snow loads should be determined and distributed according to the provisions of ANSI A58.1. Snow load is not included in the minimum design live loads indicated for roofs in Table 4-1. Roof live loads from Table 4-1 and imposed snow loads are per square foot of horizontal projection.

i. Crane Runway Loads. Crane wheel loads should be treated as live loads in the design of crane runways and maximum wheel loads should be computed from the weight of the crane and trolleys plus the rated live load capacity of the crane. The load should be placed in the position that produces maximum loading on the side of the runway under consideration. The design load should include allowances for dead load, live load, impact (for power operated cranes), longitudinal forces, and lateral forces. In addition, crane stops at each end of the runway should be designed to safely withstand the impact of the loaded crane traveling at full speed with power off, and the resulting longitudinal forces should be provided for in the design of the crane runway. Acceptable allowances for impact, longitudinal forces and lateral forces are as follows:

Impact................ 10% of Maximum vertical wheel loads for cranes over 80 ton capacity. 12% to 18% of maximum vertical wheel loads for all others.

Longitudinal forces... 10% of maximum vertical wheel loads (applied at top of rail).

Lateral forces........ 10% of trolley weight plus rated crane capacity (3/4 of this amount to be distributed equally among crane wheels at either side of runway and applied at top of rail).

j. Moving Concentrated Live Loads. Medium to large pumping stations may be designed with forebay and discharge decks to accommodate trucks and heavy cranes for handling and transporting stoplogs and gates and for disposal of trash raked from intake trash racks. These decks should be designed for dead load plus the worst case live load considering the minimum uniform loading from Table 4-1 or the weight of the heaviest piece of equipment (truck crane, tractor trailer, etc.) fully loaded. Load distribution for truck loading should be made in accordance with AASHTO "Standard Specification for Highway Bridges." It may be advisable to place load limit signs at the entrances to these deck areas where these load limits are the controlling factor in the design.

4-4. Loading Conditions and Design Criteria. The following loading conditions should not be regarded as a comprehensive list. In many instances, unique site specific factors such as water conditions, station arrangement and location, pump type, pump and discharge arrangement, etc. will dictate modification of some of these loading conditions to fit the specific site. The conditions described should be used as a guide to the range of stability analyses required. The external structure forces and distributed loads should not be factored for stability analysis, but may be subsequently factored when applied to the concrete members of the structure for use in reinforcement design in accordance with EM 1110-2-2502. Design of the miscellaneous structures associated with the pumping station (wing walls, headwalls, discharge piping, culverts, gate structures, etc.) should be based on the applicable design water levels, earth levels, etc. for those structures, and their design load conditions should be adapted from the basic loading conditions. See paragraph 4-7 for design loading and guidance to be used for these structures. Wind and snow loads should be applied in conjunction with the basic loading conditions as applicable depending on the meteorological condition at the site. Stability and stress criteria vary according to the nature of the loading condition imposed on the structures. For the purpose of criteria application, there are three categories of loading conditions; usual, unusual, and extreme. Usual conditions are defined as those related to the primary function of a structure and expected to occur during its life. For pumping stations, all of the operating flood conditions should be considered usual. Unusual conditions are those which are of infrequent occurrence or short duration. Construction condition, maximum design water level condition, maintenance conditions, rapid drawdown condition, and blocked trash rack condition are examples of unusual loading for pumping stations. Extreme conditions are those whose occurrence is highly improbable and are regarded as emergencies, such as those associated with major accidents or natural disasters. For pumping stations, pumping station inundated and earthquake conditions should be considered extreme. The basic loading conditions for design and their categories are listed below.

a. Construction Condition. Pumping station complete with and without fill in place, no water loads. Unusual.

b. Normal Operating Condition. Plant operating to discharge routine local floods over a range of exterior flood levels for which the pumps are operating at approximately 100% efficiency. Usual.

c. Start-up Condition. Station empty with water at pump start elevation or maximum pump level. Usual.

d. Pump Stop Condition. Water below pump start elevation on intake side, levee design flood on discharge side. Usual

e. High Head Condition. Maximum design water level outside protection line, minimum pumping level inside. Usual.

f. Maximum Design Water Level Condition. Maximum operating floods both inside and outside protection line, maximum pump thrust. Unusual.

g. Maintenance Conditions. Maximum design water level inside with one, more, or all intake bays unwatered. Unusual.

h. Rapid Drawdown Condition. Water at pump stop elevation, sumps unwatered. (Apply to stations inside protection line only.) Unusual

i. Blocked Trash Rack Condition. Five foot head differential across trashracks. Unusual.

j. Pumping Station Inundated. Maximum flood levels inside and outside protection line, pumping station inoperative, foundation drains inoperative, protection line intact. Extreme.

k. Earthquake Conditions. Earthquake loading combined with normal operating condition. Extreme

4-5. Stability. Analyses should be made for stability of structures against overturning, sliding, flotation, and foundation pressure.

a. Overturning. For overturning stability, all structures should meet the criteria given in Table 4-2 for percent of base in compression.

b. Sliding. The resistance to sliding under various loading conditions will be analyzed according to EM 1110-2-2502. The result of this analysis is expressed in terms of a sliding safety factor which is the ratio between the total shear strength available in the soil-structure wedge system and the applied shear stress. The minimum sliding safety factors for various types of loading are shown in Table 4-2.

C. Flotation. The analysis of structures for stability against flotation should be performed in accordance with the procedure in Appendix B. Required safety factors are given in Table 4-2.

Table 4-2

STABILITY CRITERIA FOR PUMPING STATIONS

Aspect	Usual	Unusual	Extreme
Percent Base In Compression, Soil Foundation	100	75	0 1/
Sliding Safety Factor	2	2	1.33
Flotation Safety Factor	1.5	1.3	1.1

1/ Resultant must be within the base.

d. Foundation Pressure. In conjunction with the overturning analysis, the base pressures and foundation pressures for each loading condition should be calculated and the maximum values compared with the maximum allowable values determined for the foundation material. These maximum allowables should not be exceeded for any loading condition. The allowable values should be coordinated between the geotechnical and structural engineers.

4-6. Design Stresses. Allowable working stresses for structural materials will generally be as prescribed in EM 1110-1-2101, except that reinforced concrete structures should be designed in accordance with the strength design method given in EM 1110-2-2502. Working stresses for use in proportioning masonry structural components should be taken from TM 5-809-3. For earthquake loading, design stresses should be evaluated in accordance with guidance given in ER 1110-2-1806 and TM 5-809-10.

4-7. Miscellaneous Features.

a. Discharge Lines. Design of the pump discharge lines is based on the type of protection works, consideration of backflow effects, and economics. There are two general categories of discharge piping, over the protection line and under or through the protection line. The under or through type is more susceptible to backflow problems and should be avoided if possible. However, a properly designed system is acceptable and may result in significant cost savings compared to the over-the-protection line type. Discharge piping passing over levees should be of steel or ductile iron suitable for use with dresser or other flexible couplings. The pipe should be supported by the embankment surface on the inside slope and crown of the levee and buried in a trench on the discharge side, with adequate cover to protect it from damage or exposure by erosion. It should be anchored to prevent flotation during high water. The anchorage can be concrete supports placed at intervals along the length, a continuous concrete bedding, or other approved means. The principal loads imposed on the pipe are positive and negative hydraulic pressures and external compressive pressure from fill material and vehicular surcharge. EM 1110-2-2902 contains procedures for the design of conduits under embankment and backfill loading. Embankment settlement should be considered in the design of the pipe joints. Over-the-levee type pipes are sometimes designed as siphons, using the pumps to establish flow. This introduces an additional design loading consideration. At the levee crest, a negative pressure of up to 1 atmosphere could occur. This load must be combined with the external compressive loads from fill and water. Guidance for siphon design is contained in EM 1110-2-3105. Discharge pipes passing through or under the protection line are pressure pipes and the internal hydraulic pressures are therefore greater than for the over-the--protection line type. When the protection line is a levee, careful attention must be given to insure that no leakage or infiltration is allowed in the pipe or joints which would affect the integrity of the embankment. The materials used in these pipes are ductile iron, steel, concrete pressure pipe, and cast-in-place reinforced concrete. To prevent leakage, steel and ductile iron pipe should be joined with flexible, watertight couplings, and concrete pipe should have alignment collars and waterstops at each joint. Materials used for discharge piping should conform to CEGS-02724 N7. The piping materials should be selected on the basis of strength, durability, and project life economics.

b. Discharge Conduit Gates. A pressure discharge conduit from a pumping station through the protection line must be provided with an emergency closure gate on the river side of the floodwall or levee to prevent backflow into the protected area in case of failure of the pump or rupture of the conduit. For a levee type installation the gate usually will be in a well in the riverside levee slope, accessible from the levee top. When the pumping station is integral with a flood wall, the discharge pipes usually discharge into a surge chamber through flap valves. Stoplogs are usually provided at the end of each pipe and upstream of each pump so that, in the event of a flap valve failure, flow can be stopped in order to prevent flooding of the plant. For a pressure pipe under a flood wall, the gate will usually be in a well integral with the floodwall. A simple slide gate for the smaller sizes, or wheel-type gate for larger sizes is suitable. On pressure pipes, gates should be designed with operators capable of opening and closing the gates under all head conditions so that flow can be discharged after an interior flood in order to prevent excessive pressure build-up on the gate. Well type gate structures should be constructed of reinforced concrete and designed in accordance with strength design provisions given in EM 1110-2-2502. The design loading conditions will vary with the placement and configuration of the gate structure. A gate well placed on the discharge side of a levee will experience fill loading, uplift and vertical water loads, and possibly rapidly varying pool levels. In most instances it will be required that the gate structure be unwatered for maintenance purposes. The top of the gate structure must be designed to withstand gate operating forces. See EM 1110-2-3105 for further discussion of forces on the gate structure induced by gate operation. In areas of high seismicity, defensive structural layout may dictate that the concrete mass extending above the ground line be kept to a minimum. Restriction of the gate structure projection above the ground line might also be of value in areas subject to high wind loads. These factors must be addressed early in the layout and design process and the configuration of the gate structure must be set based on functional, economic, and technical considerations.

c. Trashracks. All pumping stations should be provided with trashracks at the station intake. These racks are generally constructed of structural steel and are either attached to the face at the forebay side of the structure or inserted into formed slots near the intake face of the substructure. Trashracks should be designed for a minimum of 5 feet of head differential acting toward the pumping station for small to medium sized plants. For larger plants, higher head differentials may occur. This should be addressed in an early design conference and definite design criteria established.

d. Trash Removal. The types of raking devices used to remove trash from the trashracks depends on the size of the plant, frequency of operation, type and size of the pumps, and type of inflow facilities (pipe, open ditch, etc.). When a boom across the inlet channel or other means is used to remove a large portion of the trash before it reaches the intakes, mechanical trash removal devices may not be required. However, for most installations some positive means of trash removal should be provided. This may be done by hand on very small plants, but for medium to large size stations, mechanical trash rakes should be provided. These trash rakes are manufactured in a variety of configurations, each applying forces to the structure in different ways and to varying degrees. Before final design of the intake area and trash deck is begun, the type of raking system must be determined and these forces identified. In the design of both trashracks and trash raking equipment, durability under adverse operating conditions and harsh environment must be considered. These items should be designed to function dependably with a minimum of maintenance over the life of the station. For the design of various types of trash raking equipment, see EM 1110-2-3105.

e. Trash Deck. For some large plants, the trash deck may be designed for heavy vehicular traffic and can be used as a work area for a truck mounted crane and trash hauling equipment. This arrangement might be used in conjunction with, or in lieu of, conventional trash raking equipment. The method of trash removal and handling should be coordinated early in the design process, and provision for removal of trash from the intake channel and from the trash deck should be considered as a fundamental part of the station layout and design.

f. Contraction Joints. Joints between separate monoliths on large installations, and between the pumping station and adjacent wall sections when the pumping station is located on the protection line, should be contraction joints. Each joint should be constructed in one plane and no reinforcement should be allowed to cross the joint unless required as dowelling for alignment. If alignment dowels are used, they should be firmly fixed in the concrete on only one side of the joint. These joints should be made with no initial separation between adjacent placements except as required near the concrete surfaces to prevent spalling of the corners. This can usually be controlled by using V-grooves at monolith joints. However, in some cases such as a thin wall section abutting the end wall of the pumping station, deeper separation may be desirable.

g. Construction Joints. Reinforced concrete portions of pumping stations may be placed in segments, separated either vertically or horizontally by construction joints. These joints are meant only to facilitate the construction process by dividing the work into manageable units and should be arranged so they will not disrupt the continuity of the structure. In large placements, construction joints can also serve to minimize crack formation. Reinforcing steel should pass through these joints, and surfaces should be cleaned and scoured as necessary to provide good bond between the concrete placements. In very large mass concrete placements having vertical joints between the first and second placements, it may be expedient to provide keys to assure transfer of stresses across the joints. However, in normal construction this will be accomplished by reinforcement and by bond between concrete surfaces.

h. Waterstops. Waterstops across contraction joints are necessary to prevent leakage and obtain dry operating and working conditions. They exclude water under head in the substructure and ensure weather tightness of the joints in the superstructure. Experience in the use of molded rubber or extruded polyvinyl chloride (PVC) waterstops in joints of conduits and hydraulic structures has proven the practicability and advantages of using these materials. Their superior performance under conditions of differential settlement or lateral displacement make them particularly desirable. Metal waterstops may be used in structures with dependable foundations, but may fail where a yielding foundation results in uneven settlement in adjacent monoliths. A greater width waterstop is required in the substructure where large concrete aggregate is used and high water pressures exist than in low-pressure areas or for sealing against weather only. Waterstops should be placed as near to the surface as practicable without forming weak corners in the concrete that may spall as a result of weathering or impact, and should create a continuous barrier around the protected area. All laps or joints in metal waterstops should be welded or brazed; joints in rubber waterstops should be vulcanized or cemented together, and joints in PVC waterstops should be adequately cemented or heat sealed. Waterstops in contact with headwater for structures founded on rock should terminate in a recess formed by drilling holes a minimum of 18 inches deep into the rock, and should be carefully grouted in place. Occasionally, double waterstops are desirable in pier joints and other important locations, to insure watertightness in case of failure of one of them. For pumping stations located on the protection line, waterstops should be placed between the pumping station and adjacent wall monoliths and should extend from embedment in the foundation, or attachment to a seepage cutoff wall to the nominal top elevation of the protection line.

4-8. Appurtenant Structures and Facilities.

a. Gravity Drainage Structures. A gravity drainage system may be constructed to carry normal runoffs through the protection line. It may be constructed separate from the pumping station or integral with it. The system will consist of an intake structure, discharge conduits, a gate structure, and a stilling basin.

(1) Intake Structure. Where the gravity drainage system is constructed separately from the pumping station structure, it should include an intake structure arranged so that it can be closed off for maintenance of the conduit and for emergencies. This is usually accomplished by stoplogs. Thus the headwall must be designed for the loads imposed by fill placed behind it and for loads on the stoplogs. When there are existing outlet structures on a site or where site space is limited, it may be economical to incorporate the intake for gravity drainage into the pumping station. This will require special gating and careful hydraulic and structural planning and coordination among all affected disciplines throughout the functional layout and design process.

(2) Drainage Conduits. The drainage conduit should be designed according to the provisions of EM 1110-2-2902. The shape of the conduit will be dictated by the height of the overlying fill and the hydraulic capacity and flow characteristics required. A gravity drainage culvert should not generally be designed for pressure flow and should be gated near the discharge end to prevent high reservoir water from flowing back into the protected area. All joints in the gravity conduit should be sealed against seepage and infiltration. This may be done using flexible couplings for metal pipes, steel joint rings with solid-ring rubber gaskets for concrete pressure pipe, or waterstops and seepage rings at each joint in cast-in-place reinforced concrete construction. When a new facility which includes a gravity outlet system is being designed, it may be desirable to provide two or more separate gravity outfall conduits. This will allow one conduit to be dewatered for inspection and maintenance of the conduit and gate structure without completely stopping normal flow during these operations. Common types of conduits used under various conditions of fill height, hydraulic requirements, facility location and importance, etc., include corrugated metal with protective coatings, reinforced concrete, precast prestressed concrete cylinder pipe, and cast--in-place concrete culvert. These will generally provide the most economical and serviceable gravity drainage conduits. However, under certain circumstances other materials may be desirable because of special site specific requirements such as the presence of deleterious chemicals in the soil or water. These other conduit materials may include reinforced plastic masonry (RPM), fiber reinforced plastic (FRP), or certain high strength plastics for pipes in smaller sizes. These types of pipe will usually be much more expensive than the more common types. Also, the performance experience over time may be very limited for some of

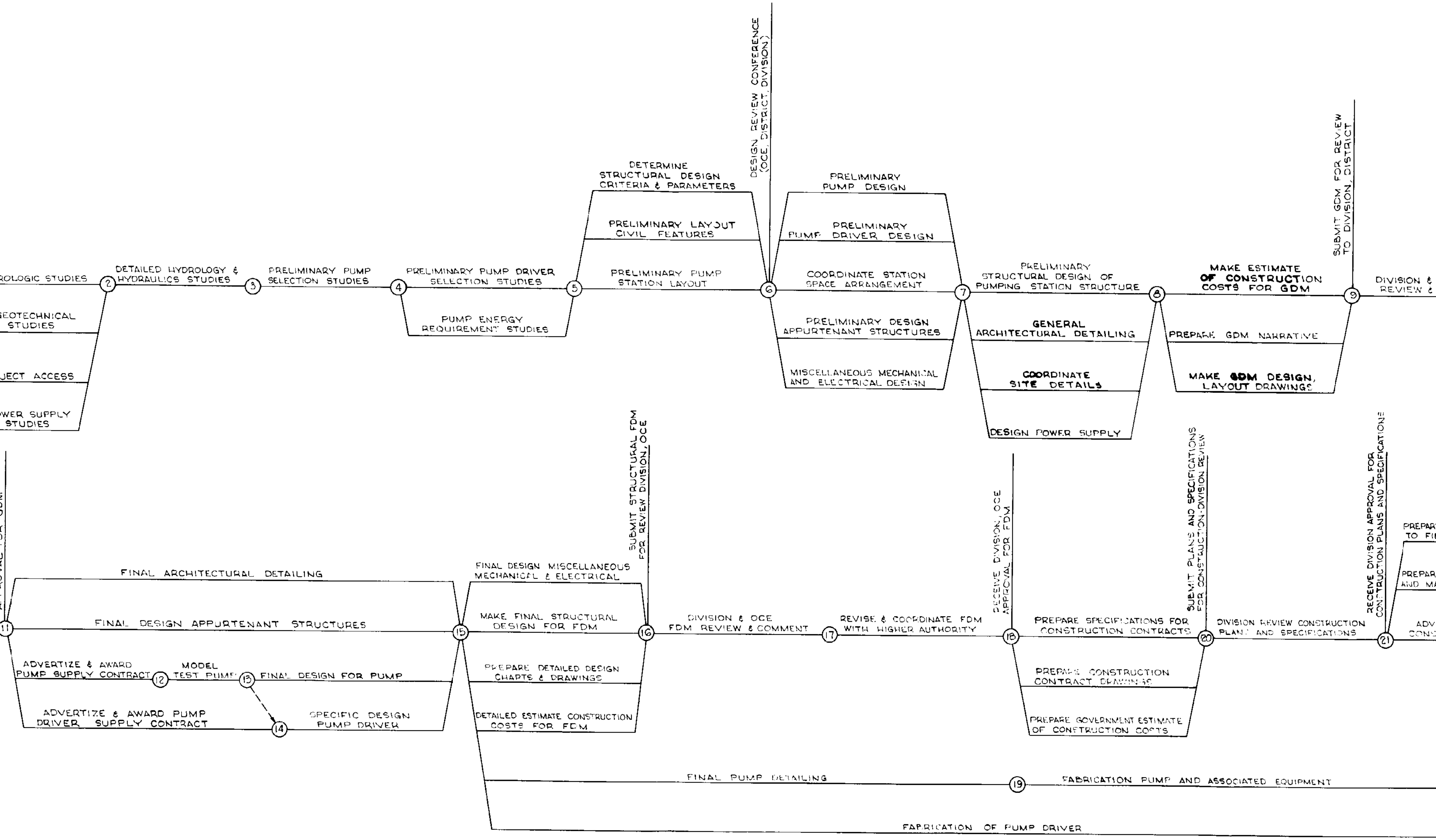
these materials. Use of specialized types of pipe must be closely coordinated with higher authority and may require special testing as well as special placement procedures. Generally, reinforced concrete pipe should be used for urban levees and other levees where loss of life or substantial property damage could occur. Corrugated metal pipe (CMP) with protective coating may be used as an option on agricultural levees. When CMP is considered as an option, a life cycle cost study should be done. Generally a minimum of one CMP replacement should be assumed during the life of the project. For further guidance concerning the type of pipe for use in gravity outlet systems, see Appendix C.

(3) Gate Structures. Gravity discharge conduits should be gated so they can be closed against high water in the discharge area. The gates should be located on the discharge side of the protection line as near the conduit outfall as practicable. They should be situated in a gate structure which extends upward over the conduit to a sufficient height to provide dry access to the gate operators from the top of the levee under all operating conditions. This access may be provided by walkway bridge or embankment. Gate structures are usually constructed of reinforced concrete. The types of forces on the structure may vary, but will typically include hydrostatic and lateral earth pressures and uplift loading. Additionally, the top of the structure must be capable of withstanding the forces imposed by the gate operator. The structures should be designed to be unwatered to allow servicing of the closure gates. In certain circumstances it may be expedient to empty the pump discharge piping into the gravity drainage gate structure, thus limiting the length of discharge piping required and negating the need for construction of a second gate structure. This may offer particular advantages where a gravity outlet gate structure already exists. Such an arrangement should be analyzed carefully to assure that the outlet piping and stilling structure are adequate to handle the pumped flow. These layout procedures must be investigated and coordinated among the design elements and with higher authority from the earliest planning stages.

(4) Stilling Basin. At the outlet of the gravity drainage structure, some means of dissipating the discharge energy and protecting the surrounding bed and bank materials against erosion may be required. This may be accomplished by construction of a headwall and stilling basin with block type energy dissipators. This is a special type construction and may vary with each application. However, the design principles are fairly constant. The stilling structure must be designed to

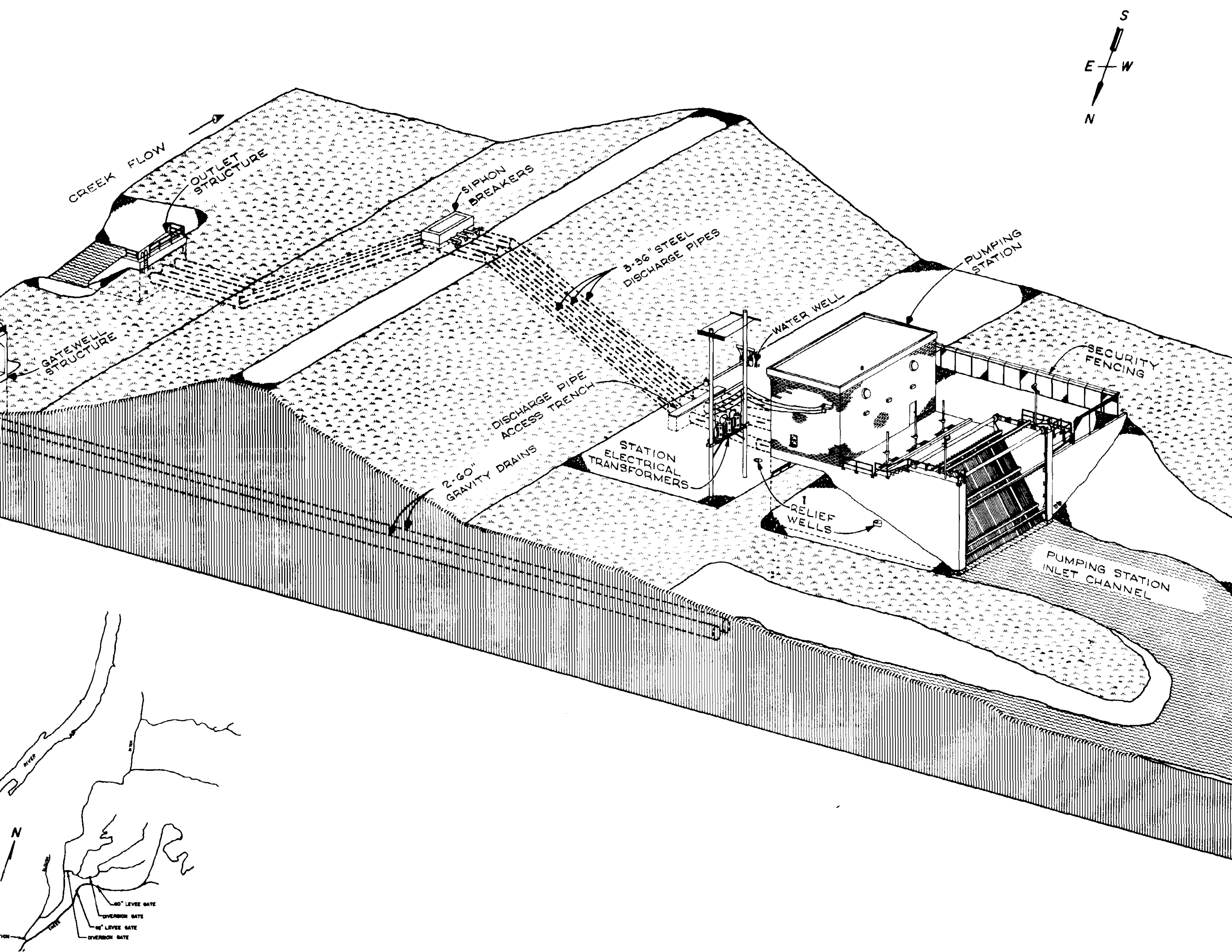
resist hydraulic thrusts imposed by flowing water in addition to the normal horizontal earth, hydrostatic, and uplift loads.

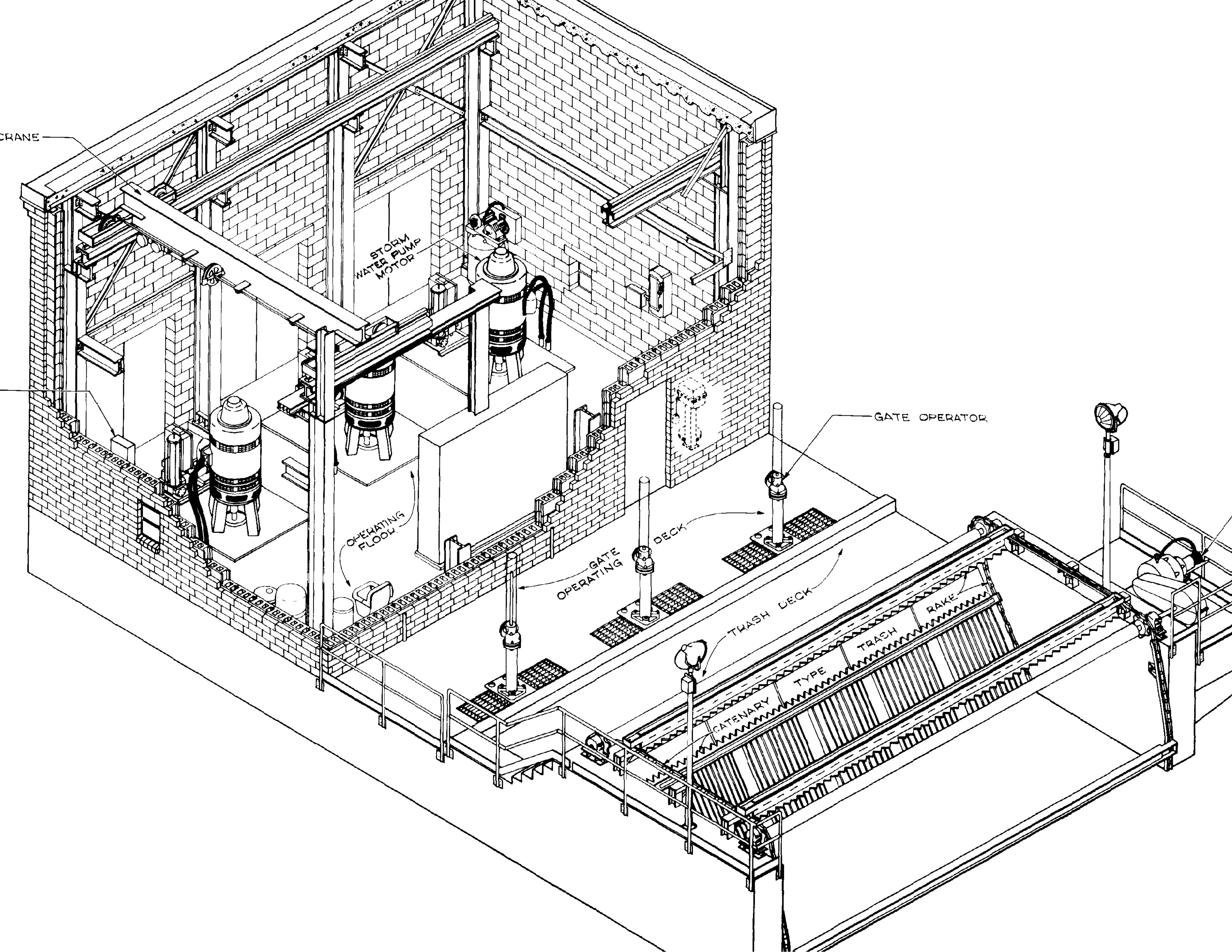
b. Retaining Walls. Walls and footings or slabs of reinforced concrete required to retain fill as a part of a pumping plant installation should be designed according to the provisions of EM 1110-2-2502. These features may be constructed as approach structures immediately upstream of the pumping station or gravity discharge structure, as wing walls adjacent to these inlets, or as simple retaining walls. They may be conventional T-wall sections or may be designed as U-frame structures. In areas of high seismicity, defensive layout measures may dictate that high cantilever walls be avoided where possible and that special treatment (alignment dowelling, etc.) be given to adjacent wall sections and walls abutting larger structures.

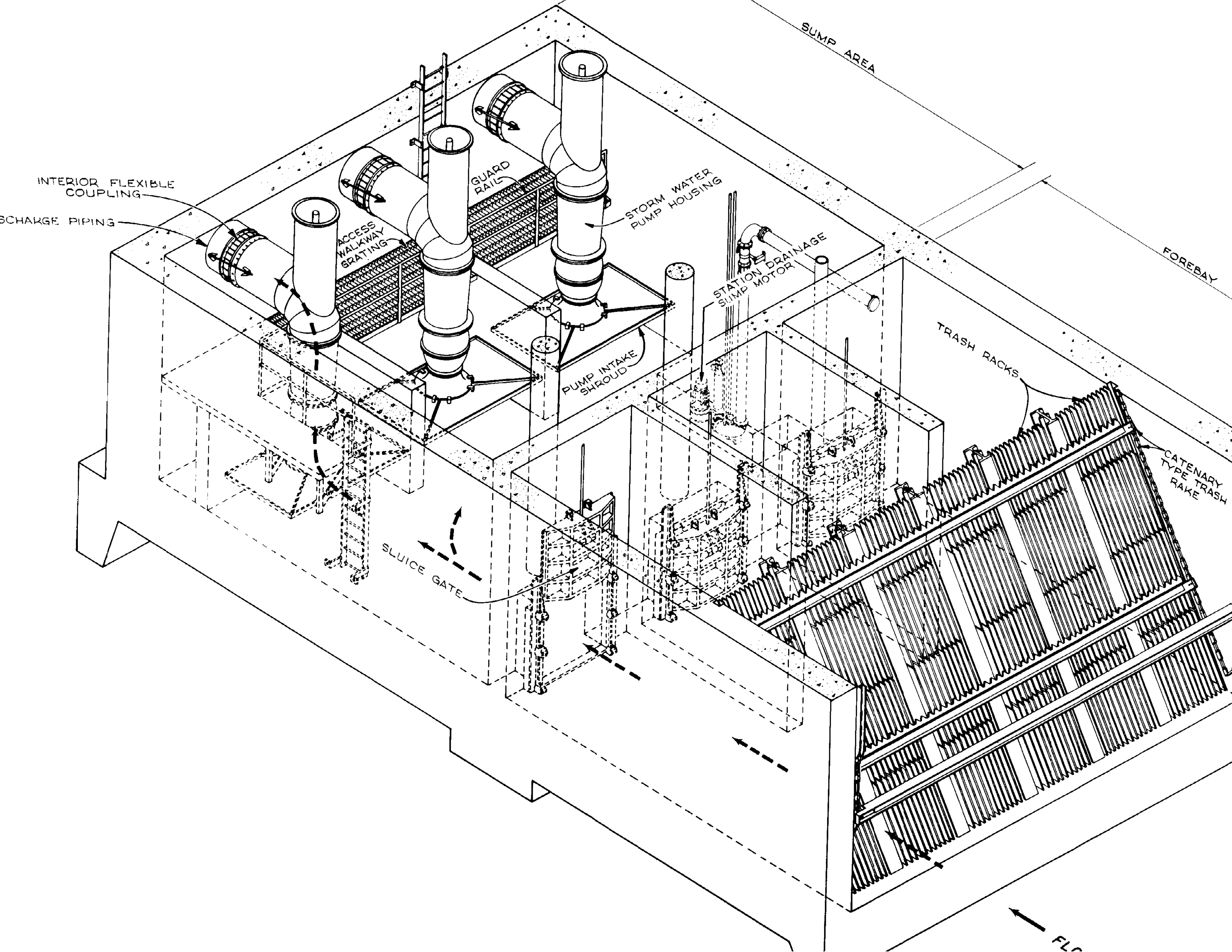


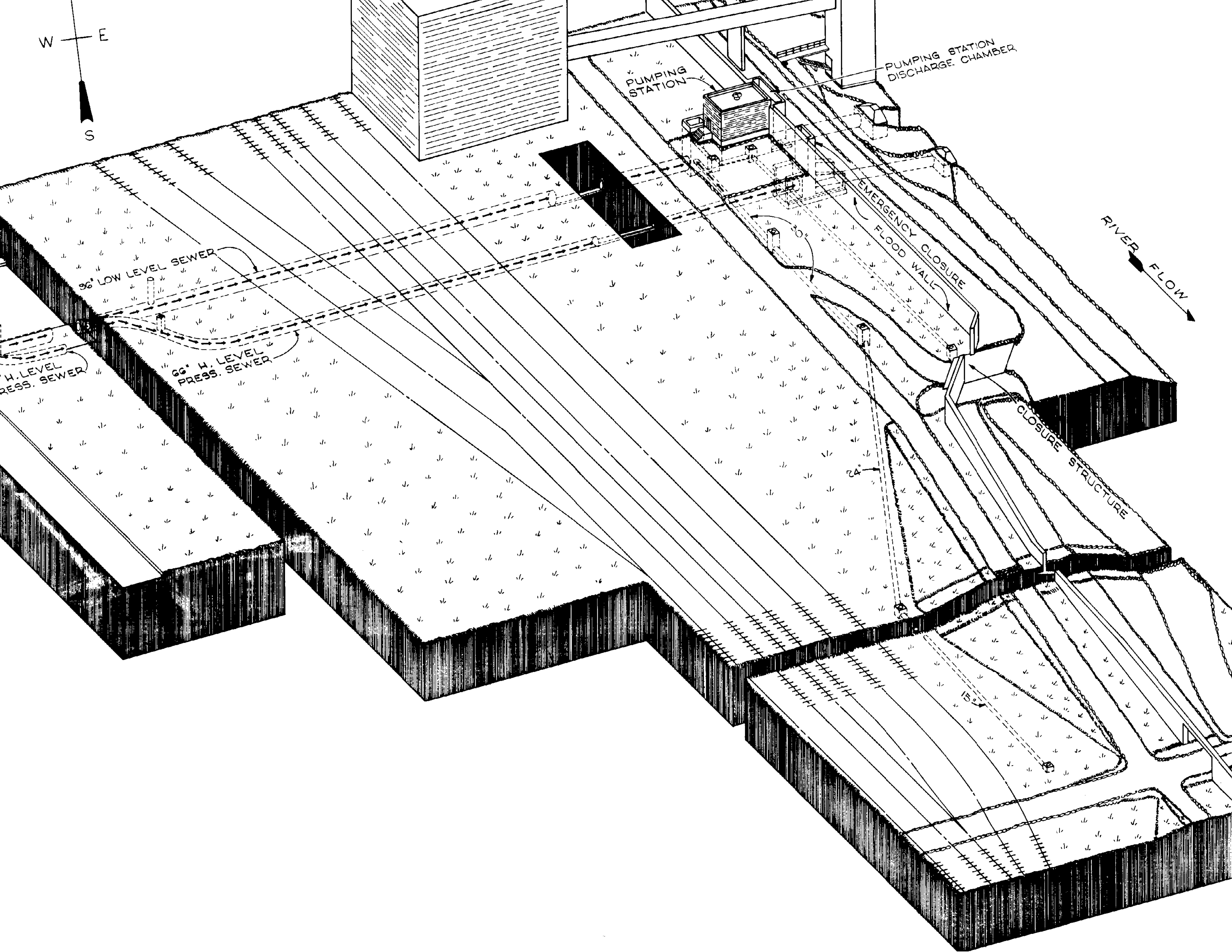
NUMBER, TIMING, AND FREQUENCY OF DESIGN REVIEW CONFERENCES WILL VARY FROM PROJECT TO PROJECT. THIS SHOULD BE AN ITEM FOR DISCUSSION AND RESOLUTION AT THE GENERAL DESIGN CONFERENCE.

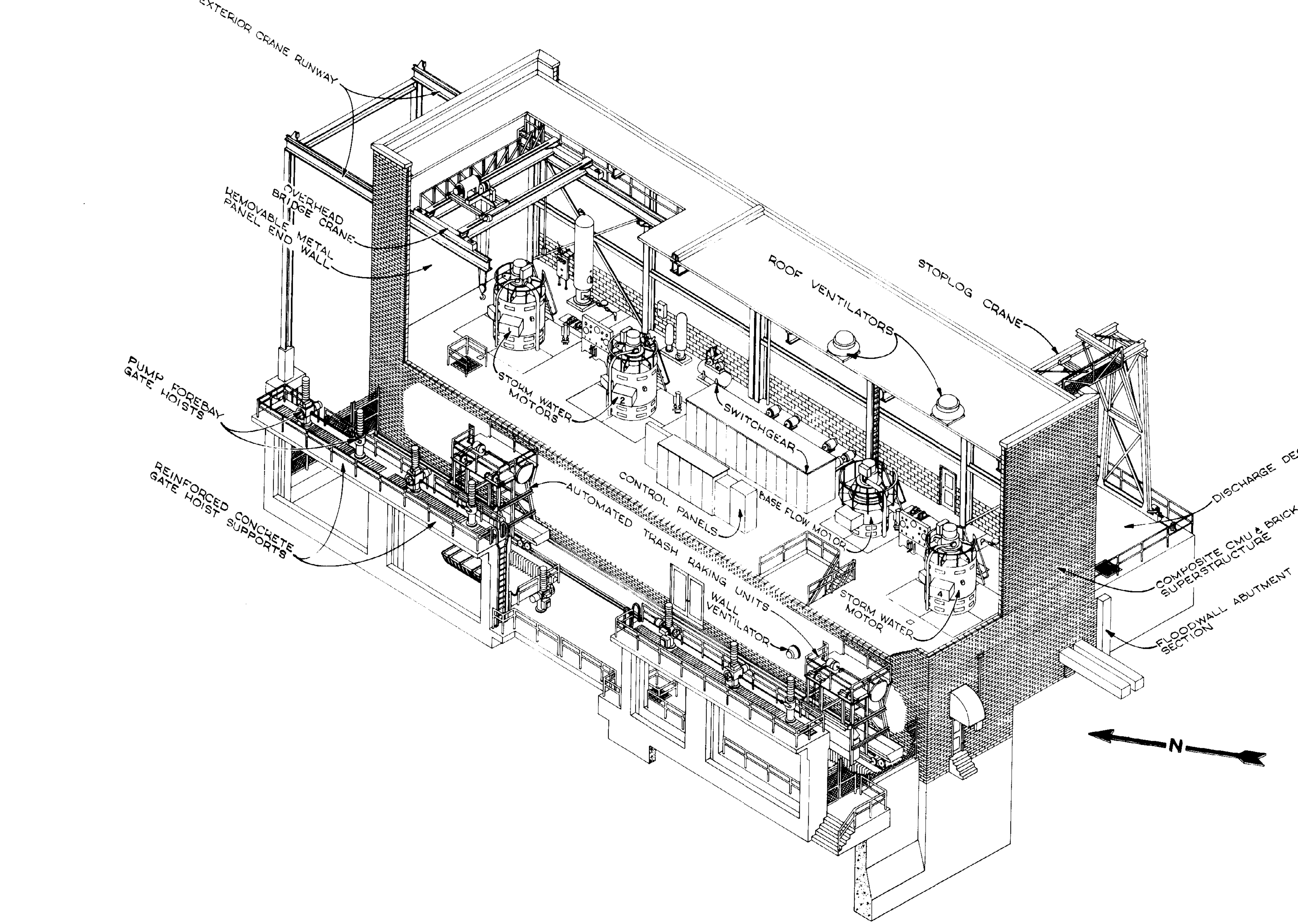
THESE CONTRACT ITEMS ARE REQUIRED ON LARGE CUSTOM DESIGNED AND FABRICATED PUMPS ONLY. FOR SMALLER STATIONS STOCK PUMPS AND MOTORS SHOULD BE USED IN THE INTEREST OF ECONOMY IN BOTH SHORT AND LONG TERM.

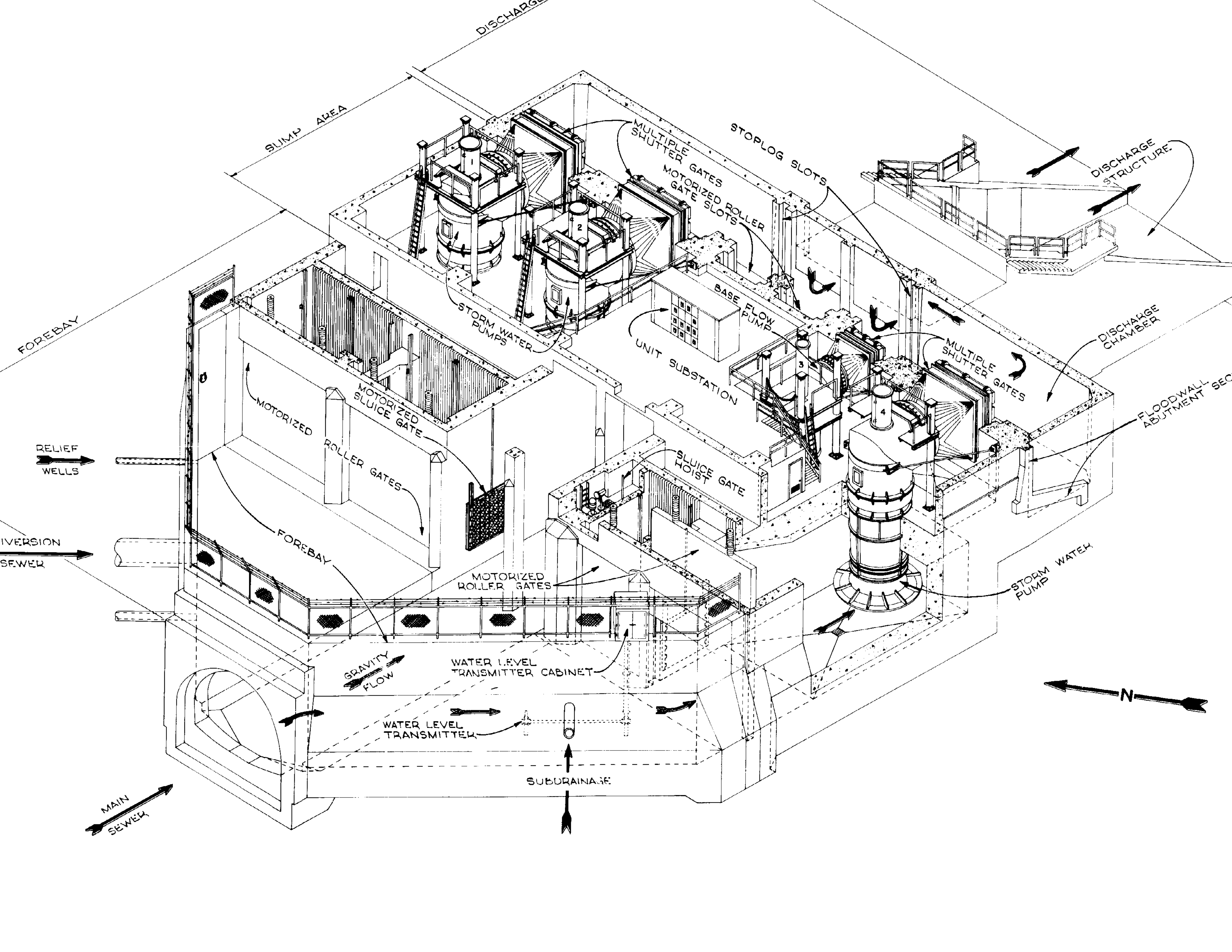

S
E
W
N
CREEK FLOW
OUTLET STRUCTURE
SIPHON BREAKERS
3-36" STEEL DISCHARGE PIPES
PUMPING STATION
WATER WELL
SECURITY FENCING
GATEWELL STRUCTURE
DISCHARGE PIPE ACCESS TRENCH
STATION ELECTRICAL TRANSFORMERS
2-60" GRAVITY DRAINS
RELIEF WELLS
PUMPING STATION INLET CHANNEL
RIVER
N
60" LEVEE GATE
DIVERSION GATE
DIVERSION GATE


CRANE
STORM WATER PUMP MOTOR
OPERATING FLOOR
GATE OPERATING DECK
GATE OPERATOR
TRASH DECK
CATENARY TYPE TRASH RAKE

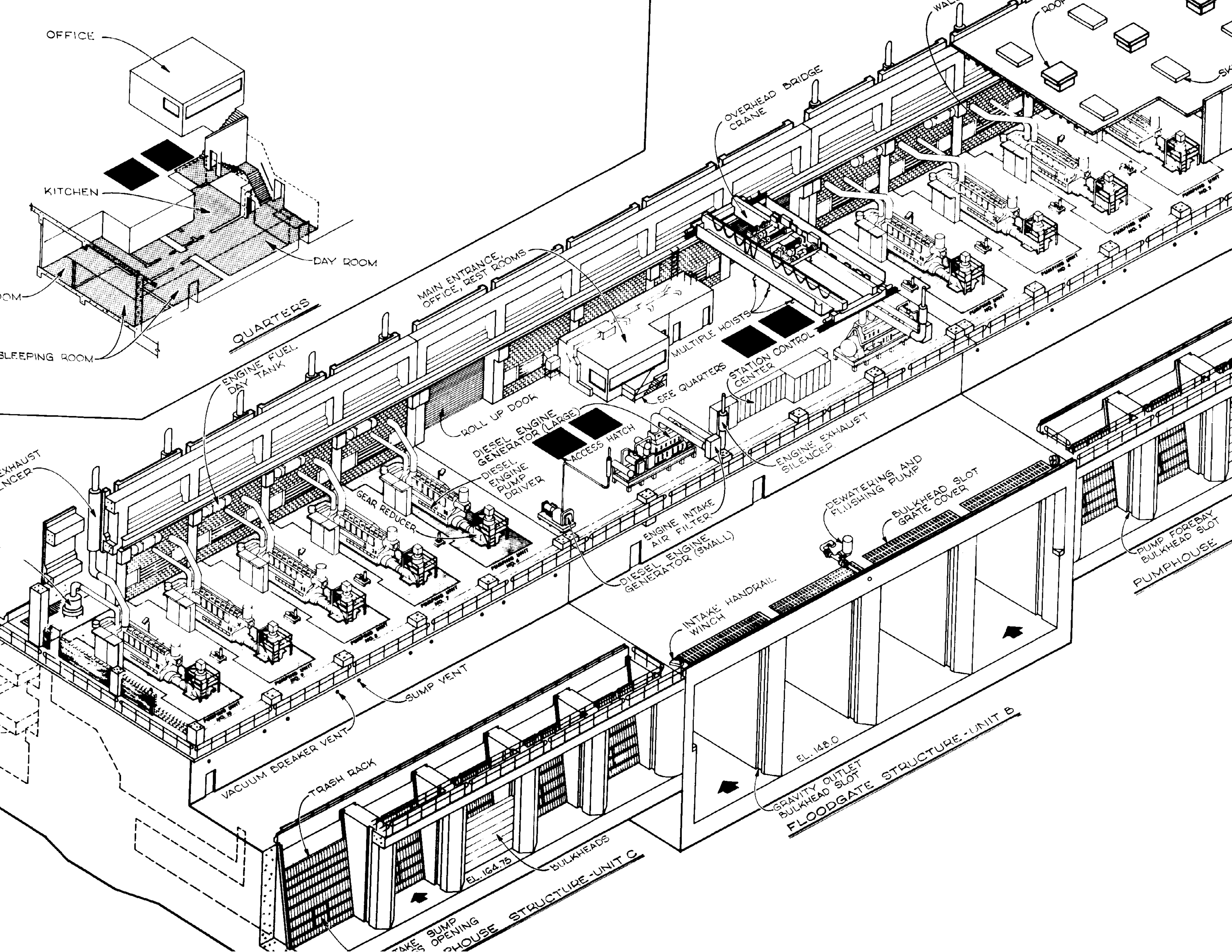

SUMP AREA
FOREBAY
INTERIOR FLEXIBLE COUPLING
SCHARGE PIPING
ACCESS WALKWAY GRATING
GUARD RAIL
STORM WATER PUMP HOUSING
STATION DRAINAGE SUMP MOTOR
PUMP INTAKE SHROUD
TRASH RACKS
CATENARY TYPE TRASH RAKE
SLUICE GATE
FLO


W
E
S
PUMPING STATION
PUMPING STATION DISCHARGE CHAMBER
EMERGENCY CLOSURE
FLOOD WALL
RIVER FLOW
CLOSURE STRUCTURE
30"
24"
15"
96" LOW LEVEL SEWER
66" H. LEVEL PRESS. SEWER
H. LEVEL
PRESS. SEWER

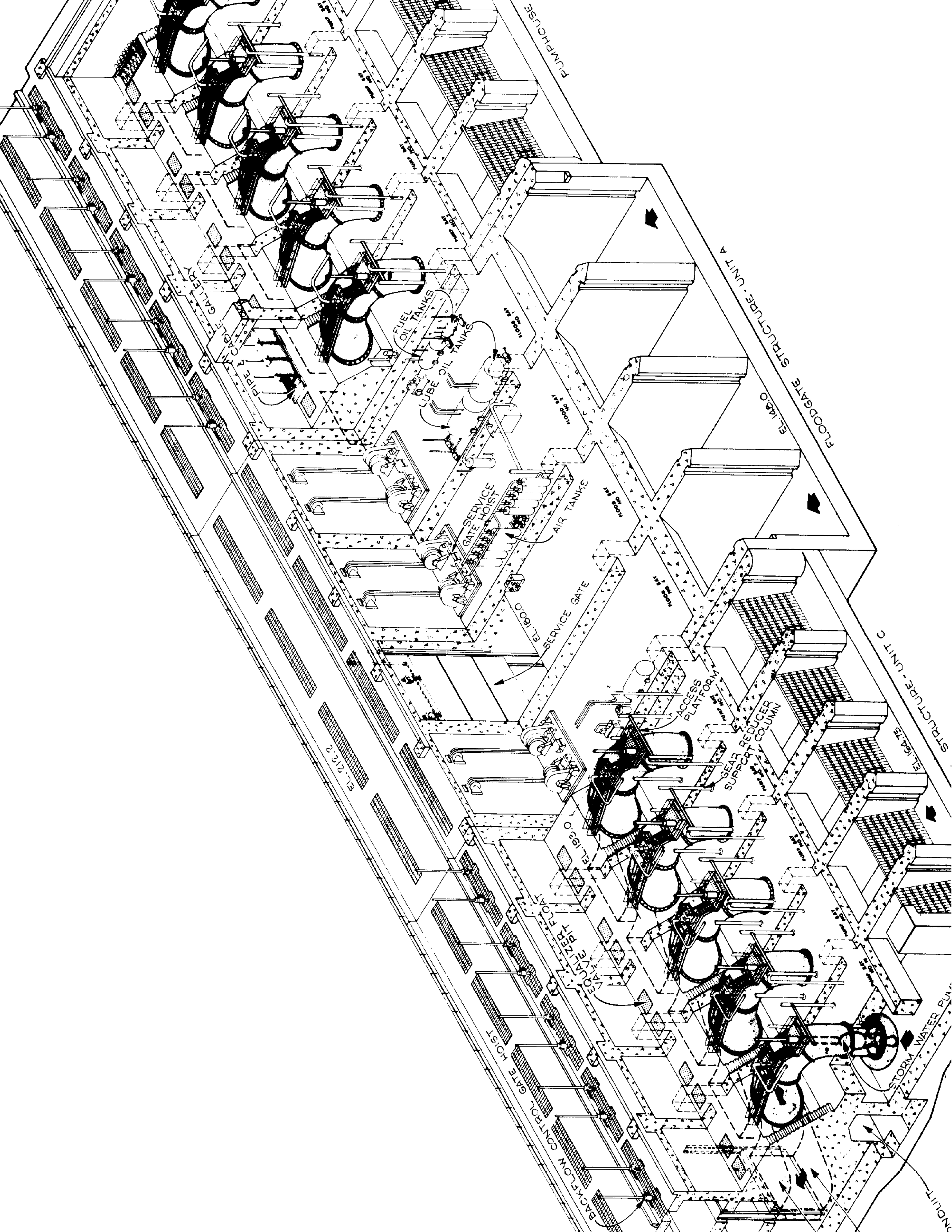

EXTERIOR CRANE RUNWAY
OVERHEAD BRIDGE CRANE
REMOVABLE METAL PANEL END WALL
ROOF VENTILATORS
STOPLOG CRANE
STORM WATER MOTORS
SWITCHGEAR
PUMP FOREBAY GATE HOISTS
CONTROL PANELS
BASE FLOW MOTOR
DISCHARGE DE
REINFORCED CONCRETE GATE HOIST SUPPORTS
AUTOMATED TRASH RAKING UNITS
COMPOSITE CMU & BRICK SUPERSTRUCTURE
WALL VENTILATOR
STORM WATER MOTOR
FLOODWALL ABUTMENT SECTION
N



FOREBAY
SUMP AREA
DISCHARGE
MULTIPLE SHUTTER GATES
MOTORIZED ROLLER GATE SLOTS
STOPLOG SLOTS
DISCHARGE STRUCTURE
STORM WATER PUMPS
BASE FLOW PUMP
UNIT SUBSTATION
DISCHARGE CHAMBER
MULTIPLE SHUTTER GATES
FLOODWALL ABUTMENT SEC
MOTORIZED SLUICE GATE
MOTORIZED ROLLER GATES
SLUICE GATE HOIST
RELIEF WELLS
IVERSION SEWER
FOREBAY
MOTORIZED ROLLER GATES
STORM WATER PUMP
GRAVITY FLOW
WATER LEVEL TRANSMITTER CABINET
WATER LEVEL TRANSMITTER
N
MAIN SEWER
SUBDRAINAGE



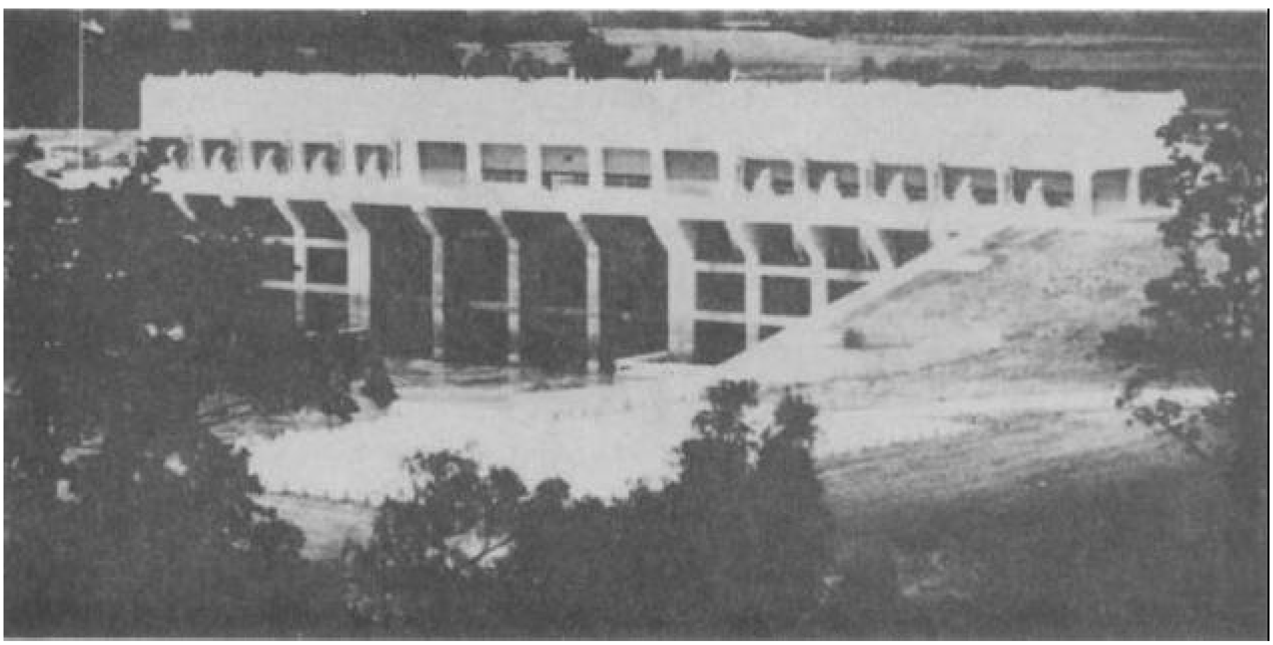
OFFICE
KITCHEN
DAY ROOM
SLEEPING ROOM
QUARTERS
ENGINE FUEL DAY TANK
MAIN ENTRANCE, OFFICE, REST ROOMS
OVERHEAD BRIDGE CRANE
MULTIPLE HOISTS
STATION CONTROL CENTER
SEE QUARTERS
ROLL UP DOOR
DIESEL ENGINE GENERATOR (LARGE)
ACCESS HATCH
DIESEL ENGINE PUMP DRIVER
GEAR REDUCER
ENGINE EXHAUST SILENCER
ENGINE INTAKE AIR FILTER
DIESEL ENGINE GENERATOR (SMALL)
DEWATERING AND FLUSHING PUMP
BULKHEAD SLOT GRATE COVER
PUMP FOREBAY BULKHEAD SLOT
PUMPHOUSE
INTAKE HANDRAIL WINCH
SUMP VENT
VACUUM BREAKER VENT
TRASH RACK
BULKHEADS
EL. 164.75
EL. 148.0
GRAVITY OUTLET BULKHEAD SLOT
FLOODGATE STRUCTURE-UNIT B
STRUCTURE-UNIT C


PUMPHOUSE
FLOODGATE STRUCTURE - UNIT A
EL. 140.0
STRUCTURE - UNIT C
EL. 164.75
STORM WATER PUM
CONDUIT
GEAR REDUCER SUPPORT COLUMN
ACCESS PLATFORM
EL. 193.0
EQUALIZER PIT FLOAT VALVE
SERVICE GATE
EL. 180.0
AIR TANKS
SERVICE GATE HOIST
LUBE OIL TANKS
FUEL OIL TANKS
PIPE & CABLE GALLERY
EL. 212.2
BACKFLOW CONTROL GATE HOIST

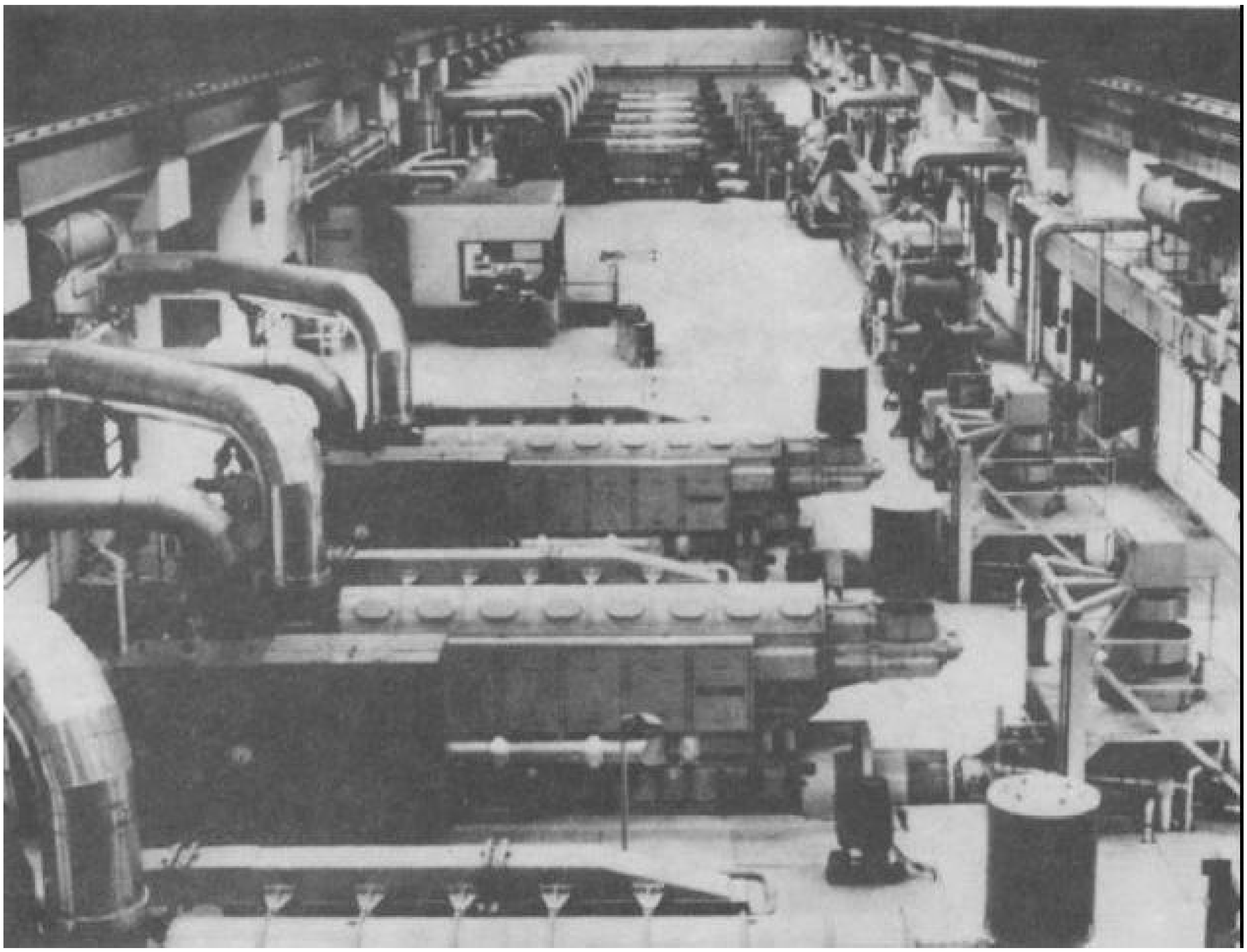
APPENDIX A

PHOTOGRAPHIC ARCHITECTURAL ILLUSTRATIONS

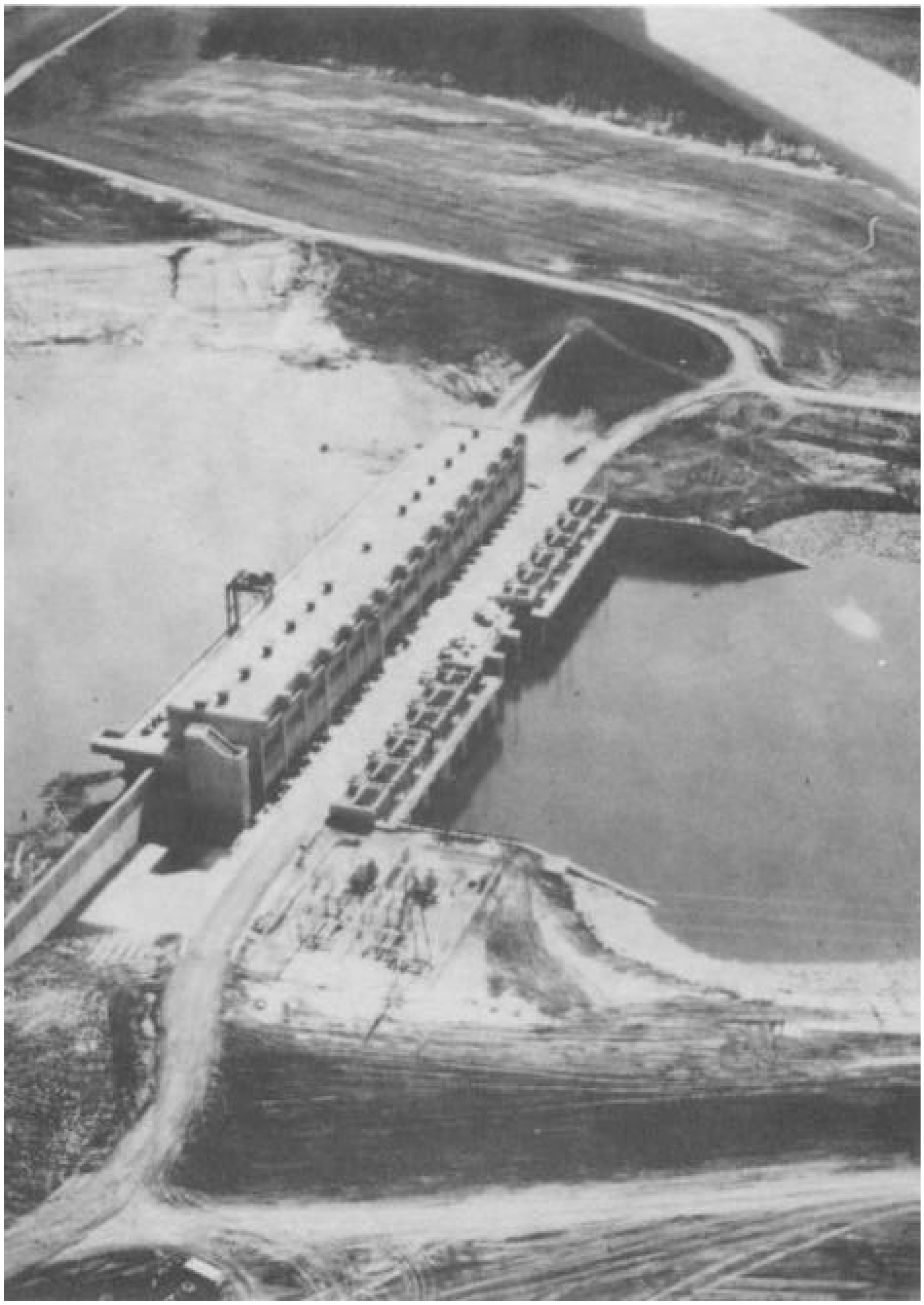
Photograph no



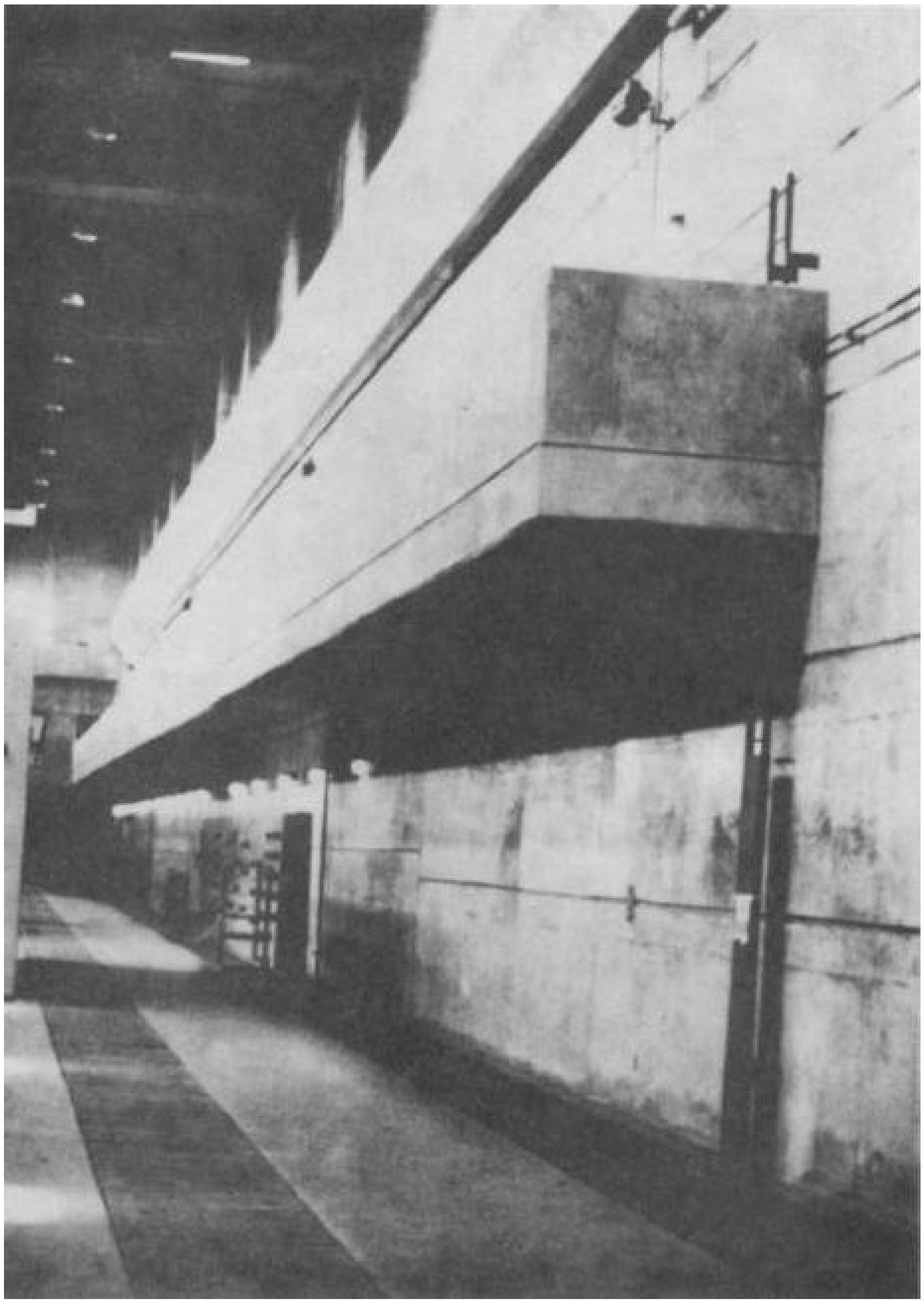
Photograph 1 W.G. Huxtable Pumping Station -- Exterior View



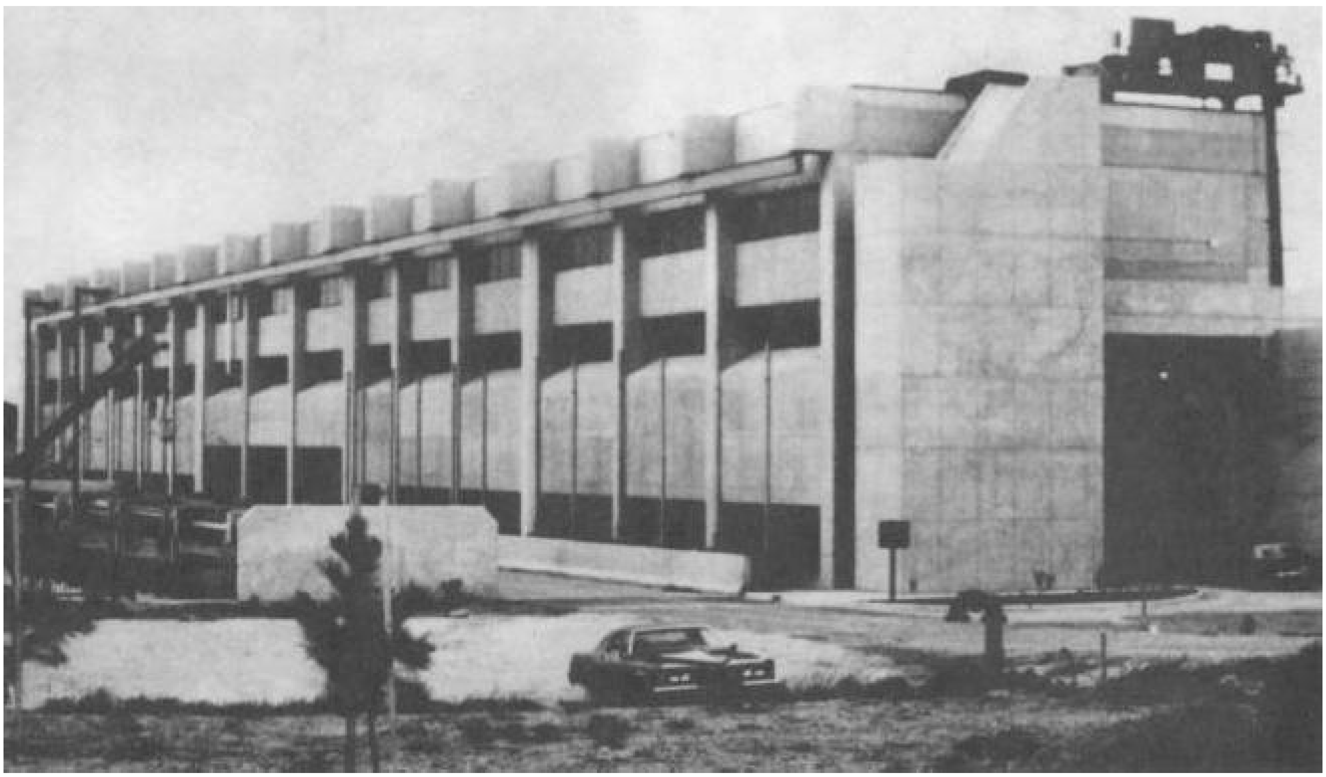
Photograph 2. W.G. Huxtable Pumping Station --
Interior View



Photograph 3. Lake Chicot Pumping Station -- Aerial View

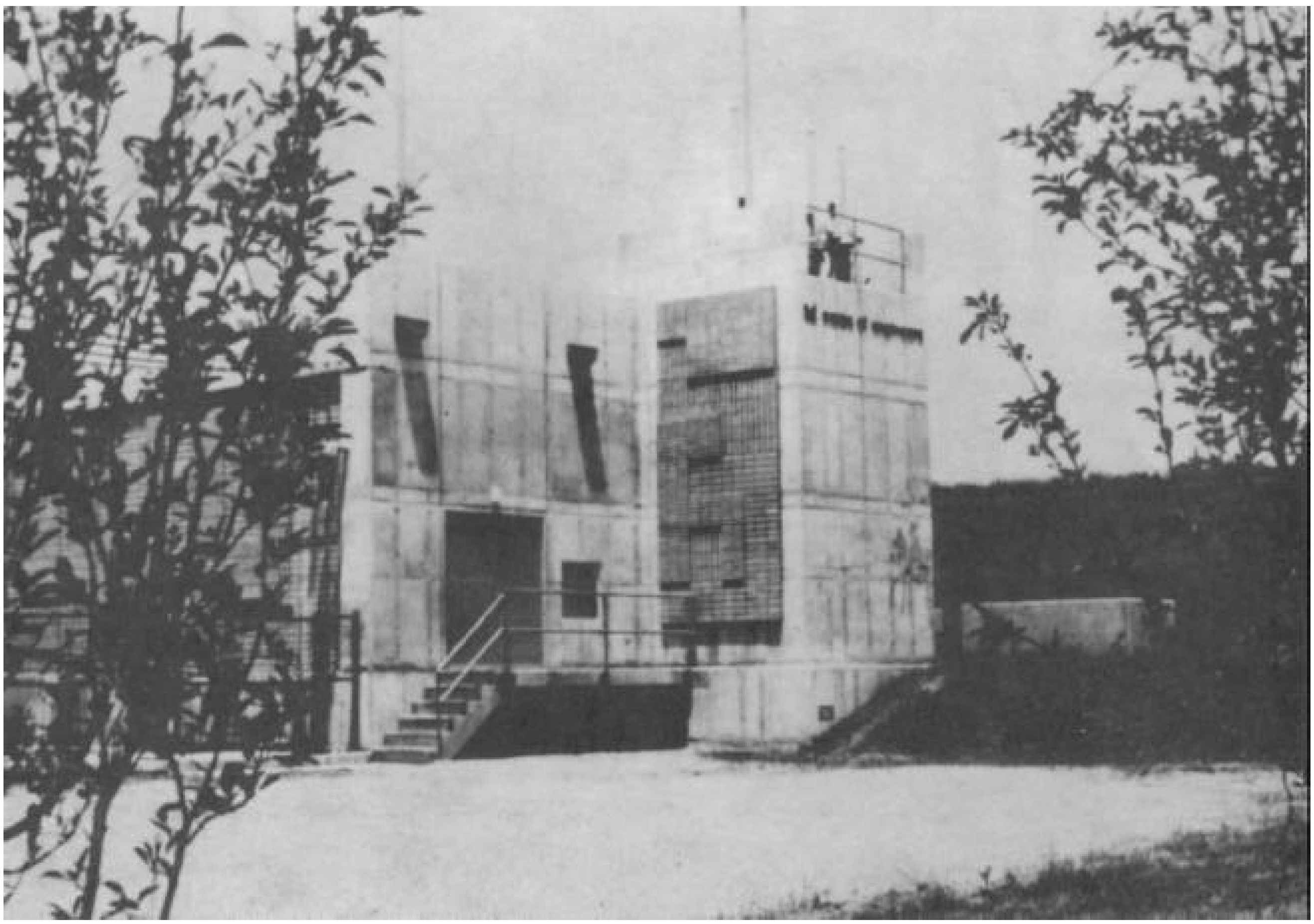


Photograph 4. Lake Chicot Pumping Station -- Interior View
(Note visitor balcony above operating floor)

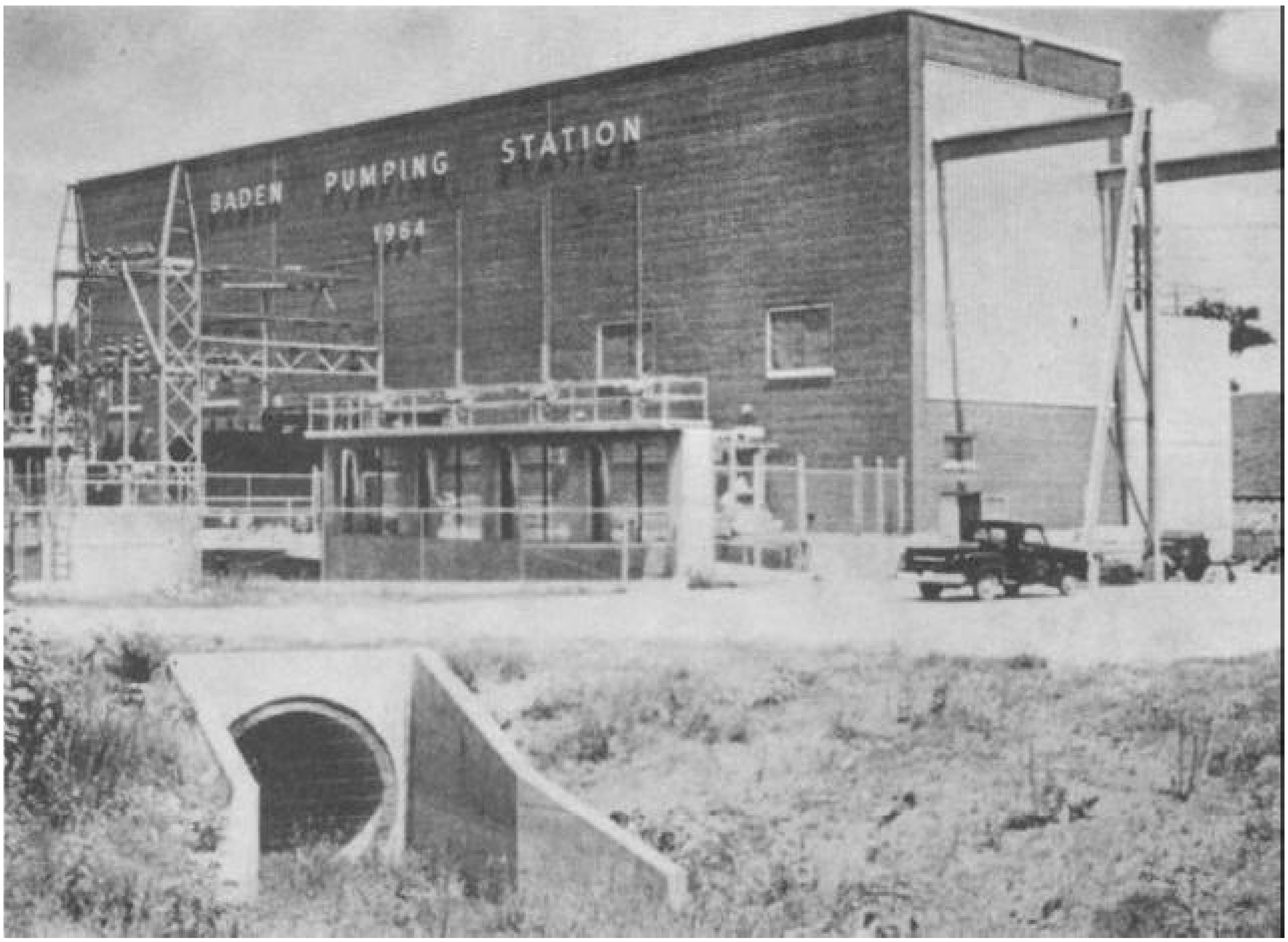


Photgraph 5. Lake Chicot Pumping Station --
Exterior View of Intake Side of Facility

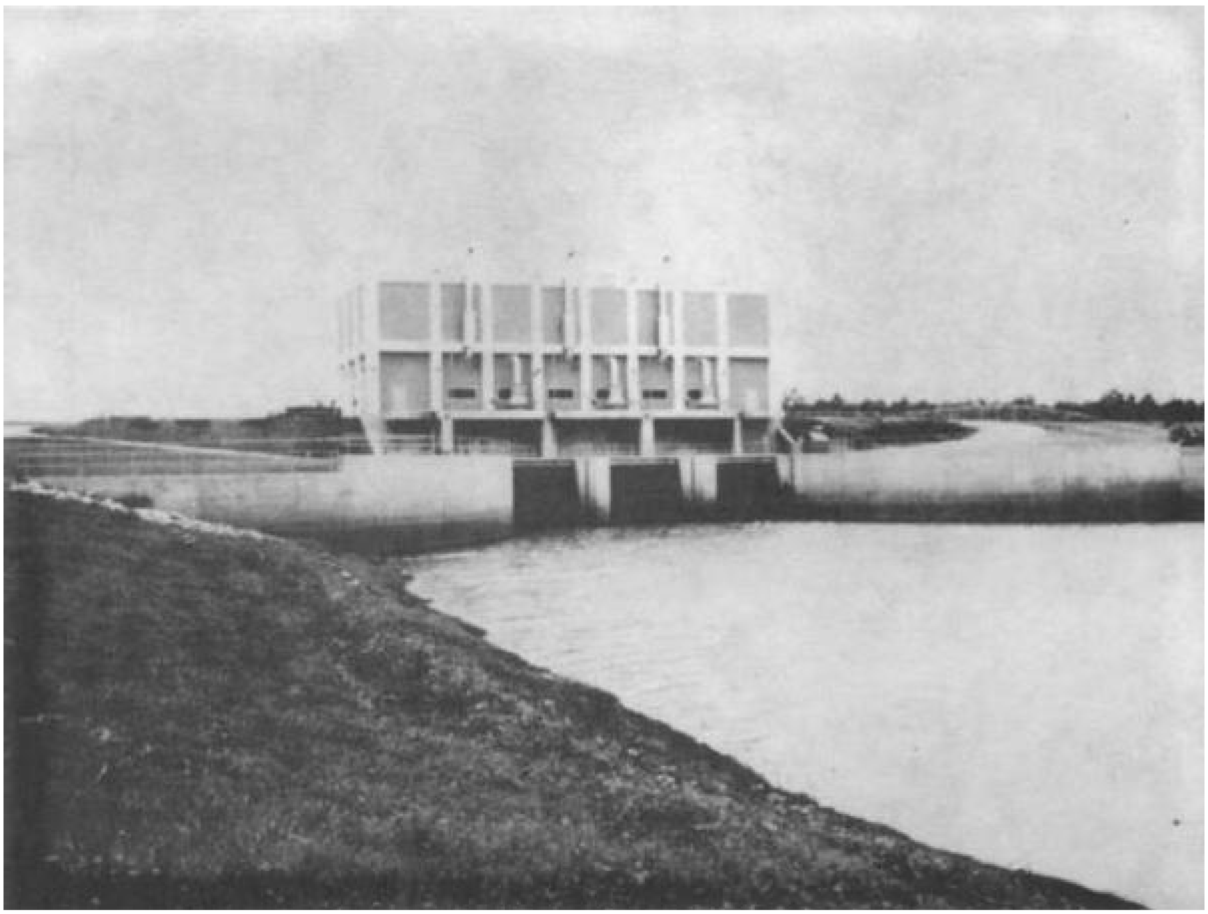
Photograph 6. Lake Chicot Pumping Station -- Blending Structures with Environment



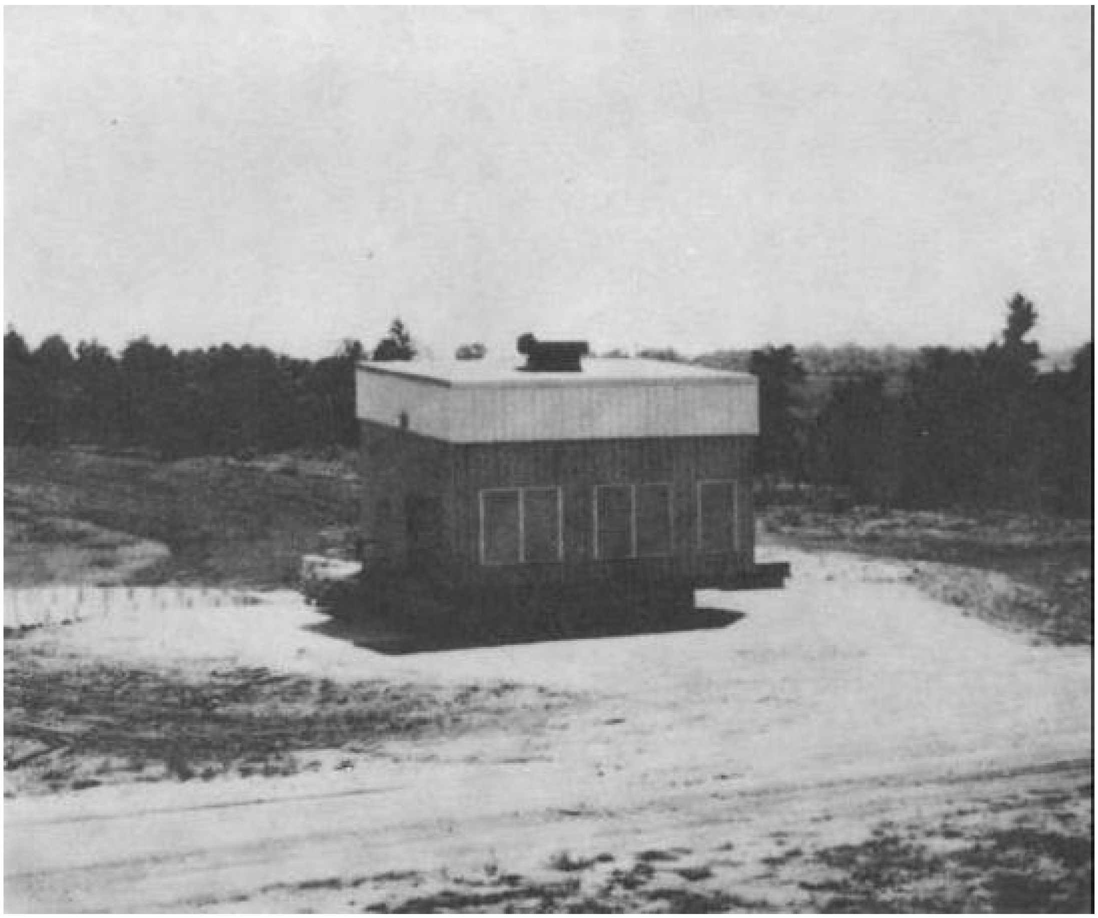
Photograph 7. Cario Pumping Station -- Exterior Approach in Urban Setting



Photograph 8. Baden Pumping Station -- Early Major Pumping Station



Photograph 9. Graham Burke Pumping Station -- Rural Facility



Photograph 10. Drinkwater Pumping Station --
Typical Agriculture Pumping Station

APPENDIX B

FLOTATION STABILITY

B-1. Flotation Safety Factor. The flotation safety factor, SF,, is defined as:

$$SF_f = \frac{W_s + W_c + S}{U - W_g} \qquad \text{(B-1)}$$

where W_s = Weight of the structure, including weights of fixed equipment and soil above the top surface of the structure. The moist or saturated unit weight should be used for soil above the groundwater table and the submerged unit weight should be used for soil below the groundwater table.

W_c = Weight of the water contained within the structure which is controlled by a mechanical operator (i.e., a gate, valve, or pump).

S = Surcharge loads.

U = Uplift forces acting on the base of the structure. The uplift forces should be calculated in accordance with EM 1110-2-2200.

W_g = Weight of surcharge water above top surface of the structure which is totally controlled by gravity flow.

When calculating SF,, the vertical resistance mobilized by friction along the exterior faces of the structure should be neglected. The basic assumptions and general derivation of flotation safety factor are given in Paragraph B-3.

B-2. Flotation Stability Criteria. Concrete hydraulic structures should be designed to have the following minimum flotation safety factors:

Loading Conditions	Minimum SF_f
Construction	1.3
Normal Operation	1.5
Unusual Operation	1.3
Scheduled Maintenance (e.g., structure dewatered with normal tailwater or normal lower pool)	1.3
Extreme Maintenance (e.g., structure dewatered with maximum tailwater or maximum lower pool)	1.1

Any relaxation of these values will be accomplished only with the approval of HQUSACE (CEEC-ED) and should be justified by a comprehensive study of the piezometric pressure data and engineering properties of the structure, foundation and backfill.

B-3. Basic Assumptions and Derivation of Flotation Safety Factor.

a. Definitions and Symbols

SF_f = Flotation safety factor.

W_s = Weight of the structure, including weights of fixed equipment and soil above the top surface of the structure. The moist or saturated unit weight is used for soil above the groundwater table and the submerged unit weight is used for soil below the groundwater table.

W_c = Weight of the water contained within the structure which is controlled by a mechanical operator (i.e., a gate, valve, or pump).

W_g = Weight of water above the top surface of the structure which is totally controlled by gravity flow.

S = Surcharge loads.

U = Uplift forces acting on the base of the structure.

N = Normal component of the base reaction.

L = Length of the base.

H_U, H_D = Lateral hydrostatic forces.

T = Tangential component of the base reaction.

p_U, p_D = Uplift pressure heads.

b. Basic Assumptions and Simplifications

(1) The structure is a rigid and impermeable mass.

(2) A mathematical definition of flotation safety factor should satisfy the equation of vertical equilibrium.

(3) Flotation occurs when the normal component of the base reaction, N, is equal to zero.

(4) Flotation is a state of neutral equilibrium which is independent of the submergence depth. Therefore, the flotation safety factor is also independent of the depth of submergence over the structure.

(5) Water which is contained within the structure should be treated as an additional weight. (This is why damaged ships sink as the interior is flooded).

(6) The flotation analysis is only uncoupled from the stability analysis if the location of the loading resultant is within the kern of the base. If the resultant is not within the kern, the uplift pressure distribution should be modified over the portion of the base which is not in compression.

c. Derivation of Flotation Safety Factor

The generic geometry and loading conditions are shown in Figure B-l.

From Figure B-l, the vertical equilibrium of the structure can be expressed as:

$$N + U - W_s - W_c - W_g - S = 0 \qquad \text{(B-2)}$$

As discussed in Paragraph B-3b, a flotation safety factor, SF,, should satisfy the following basic conditions:

(1) SF_f should be independent of the submergence depth.

(2) Water contained within the structure should be treated as additional weight.

(3) SF_f = 1 if N =0

The equilibrium equation (B-2) can be rewritten to satisfy conditions (a) and (b) as:

$$N + (U - W_g) = W_s + W_C + S \qquad \text{(B-3)}$$

The SF, can be defined to satisfy condition (3) as:

$$SF_f = \frac{N + (U - W_g)}{U - W_g} \qquad \text{(B-4)}$$

Substituting Eq. (B-3) into Eq. (B-4), we get

$$SF_f = \frac{W_s + W_c + S}{U - W_g} \qquad \text{(B-5)}$$

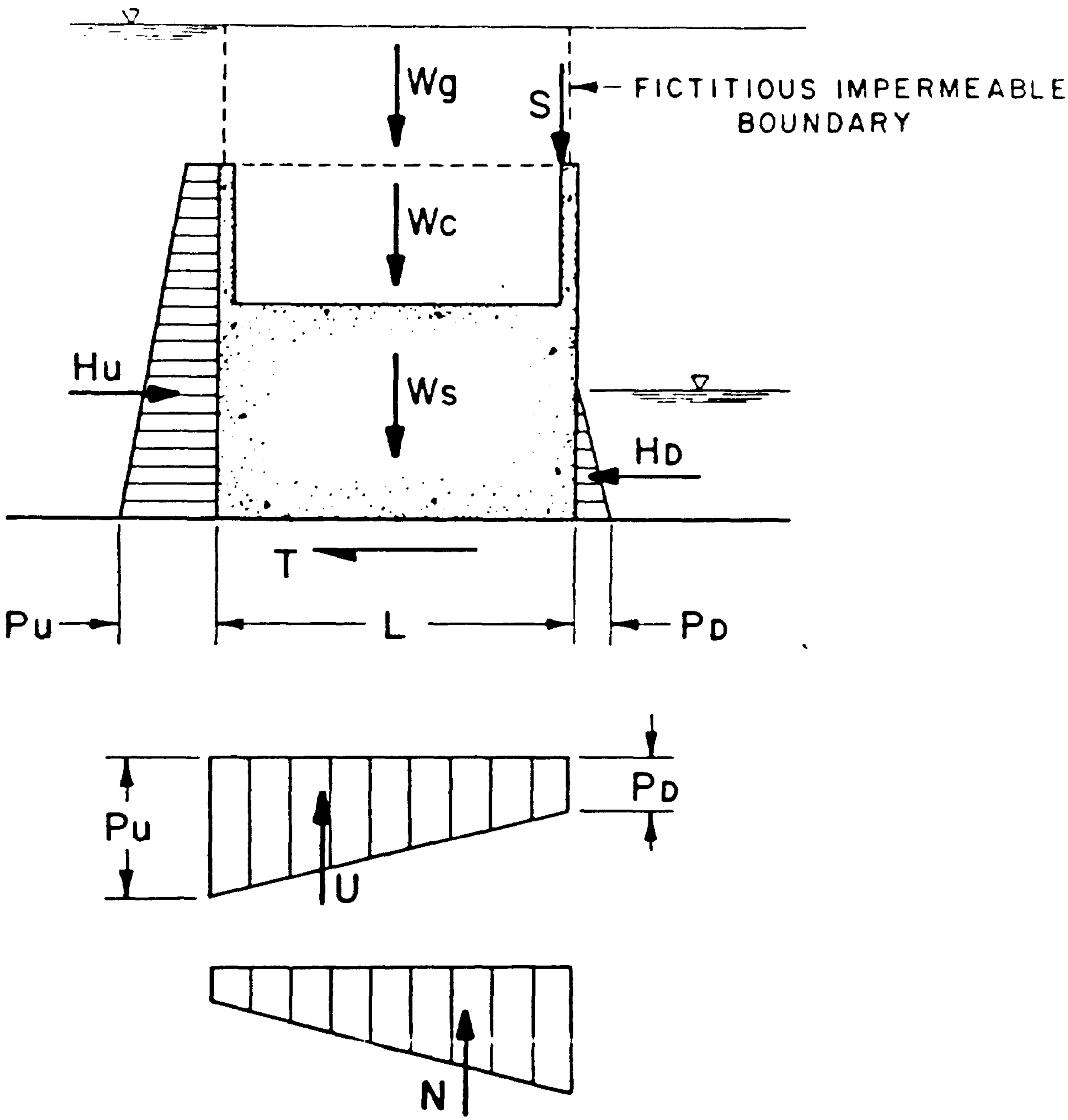


Figure B-1. Generic Geometry and Loading Conditions

Pumping Stations and Force Mains
Written by: John Southard, M.S., P.E.
Updated on: 5/28/2012

1. In certain situations however, a gravity sewer system can be utilized, but only at the expense of _________.

    a) deep trench excavation
    b) jacking
    c) boring
    d) all of the above

2. There may be areas so limited by high groundwater, subsurface rock, unstable soil, or steep topography that neither gravity seers nor centralized pumping stations will be feasible. In these cases, the use of _________ should be investigated.

    a) grinder pumps
    b) vacuum systems
    c) both a and b
    d) gravity sewers always work

3. The location of pumping facilities within a service area will be based primarily on topographic considerations and the need to provide for future development.

    a) True
    b) False

4. The invert _________ of incoming sewers will determine the depths of underground portions (substructure) of the pumping station.

    a) diameter
    b) elevations
    c) flow
    d) none of the above

5. The _________ centrifugal pump is the major type used for pumping raw wastes.

    a) radial flow
    b) mixed flow
    c) axial flow
    d) none of the above

6. The _________ maintains two distinct advantages over centrifugal pumps. It can pass large solids without clogging, and can operate over a wide range of flows with relatively good efficiencies.

   a) screw pump
   b) pneumatic ejector
   c) centrifugal
   d) none of the above

7. As a general rule, electric motors will be provided as the primary drive unit in sanitary and industrial wastewater pumping stations.

   a) True
   b) False

8. _________ is the simplest, most reliable, and more economical mode of pump speed operation.

   a) Constant speed drive
   b) Adjustable speed drive
   c) Variable speed drive
   d) none of the above

9. Level detection systems in standard use include all of the following, **EXCEPT** _________.

   a) float switches
   b) sonic meters
   c) electrodes
   d) piezometers

10. The pipeline that receives wastewater from a pumping station and conveys it to the point of discharge is called a _________.

   a) flow off main
   b) discharge pipe
   c) force main
   d) none of the above

11. A _________ is used to determine the head required of a pump or ground of pumps that would discharge at various flow rates into a force main system.

   a) head-capacity curve
   b) total dynamic head curve
   c) system wide pressure curve
   d) none of the above

12. Where two of more pumps discharge into a common header, the head losses in individual suction and discharge lines will be omitted from the system head-capacity curve.

    a) True
    b) False

13. In addition to providing adequate storage volume, wet wells will be designed to _________.

    a) allow for proper pump and level controls
    b) maintain sufficient submergence of the pump suction inlet
    c) prevent excessive deposition of solids
    d) all of the above

14. If pumps are of constant or adjustable speed type, the wet well volume must be large enough to prevent short cycling of pump motors.

    a) True
    b) False

15. Steel pipe may be used for force mains when lined with cement mortar or bituminous materials to provide internal protection.

    a) True
    b) False

16. The primary consideration in the hydraulic design of force mains is to select a pipe size that will provide the required _________ without creating excessive energy losses due to pipe friction.

    a) maximum velocities
    b) flow rate
    c) minimum velocities
    d) volume displacement

17. Pump efficiency is the ratio of the _________ to the input, or brake horsepower.

    a) gage pressure
    b) useful power output
    c) specific weight of fluid
    d) total power output

18. Maximum operating floods both inside and outside protection line, maximum thrust.

    a) Usual
    b) Unusual
    c) Extreme
    d) none of the above

19. All pumping stations subject to possible freezing will be supplied with automatically controlled __________ in the equipment areas.

    a) heaters
    b) freeze prevention controllers
    c) thermostats
    d) defrosters

20. The structural support system for the operating floor should be designed for dead loads including the weight of the pumps in their operating locations plus a minimum live load of __________ pounds per square foot.

    a) 115
    b) 200
    c) 125
    d) 100