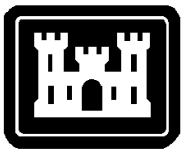
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30 March 1994



**US Army Corps
of Engineers**

ENGINEERING AND DESIGN

Mechanical and Electrical Design of Pumping Stations

ENGINEER MANUAL

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

CECW-ET

Manual
No. 1110-2-3105

30 November 1999

Engineering and Design
MECHANICAL AND ELECTRICAL DESIGN OF PUMPING STATIONS

1. This Change 2 to EM 1110-2-3105, 30 Mar 94:

   Updates Chapter 7, paragraph 7-4c.

2. The following pages have been substituted:

Chapter	Removed	Inserted
Chapter 7	7-2 & 7-3	7-2 & 7-3

FOR THE COMMANDER:

RUSSELL L. FUHRMAN
Major General, USA
Chief of Staff

DEPARTMENT OF THE ARMY
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EM 1110-2-3105
Change 1

CECW-EE

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No. 1110-2-3105

31 August 1994

Engineering and Design
MECHANICAL AND ELECTRICAL DESIGN OF PUMPING STATIONS

1. This Change 1 to EM 1110-2-3105, 30 Mar 94:

a. Updates Appendix B.

b. Updates Appendix E.

c. Adds Appendix I.

d. Updates the Table of Contents to reflect the changes in Appendix B and the addition of Appendix I.

e. Adds a reference in Appendix I to Appendix A.

2. Substitute the attached pages as shown below:

Chapter	Remove page	Insert page
Table of Contents	iii	iii
Appendix A	A-1 thru A-5	A-1 thru A-5
Appendix B	B-21 thru B-24	B-21 thru B-24
Appendix E	E-l and E-2	E-l and E-2
Appendix I		I-l thru I-4

FOR THE COMMANDER:

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Colonel, Corps of Engineers
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EM 1110-2-3105

CECW-EE

Manual
No. 1110-2-3105

30 March 1994

Engineering and Design
MECHANICAL AND ELECTRICAL DESIGN OF PUMPING STATIONS

1. Purpose. The purpose of this manual is to provide information and criteria pertinent to the design and selection of mechanical and electrical systems for flood-control pumping stations. Elements discussed include equipment requirements, design memorandum, Operation and Maintenance manuals, pumping equipment and conditions, discharge system, engines and gears, pump drive selection, pump and station hydraulic tests, earthquake considerations, power supply, motors, power distribution equipment, control equipment, station wiring, station and equipment grounding, surge protection, electrical equipment, environmental protection, station service electrical system, and station service diesel generator.

2. Applicability. This manual applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibilities.

FOR THE COMMANDER:

8 Appendixes
(See Table of Contents)

WILLIAM D. BROWN
Colonel, Corps of Engineers
Chief of Staff

This manual supersedes EM 1110-2-3105, dated 10 December 1962.

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

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Engineering and Design
MECHANICAL AND ELECTRICAL DESIGN OF PUMPING STATIONS

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Chapter 1
Introduction

1-1. Purpose

This manual provides information and criteria pertinent to the design and selection of mechanical and electrical systems for flood-control pumping stations. It is applicable to all such work within the Corps of Engineers' responsibility.

1-2. Applicability

This manual applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibilities.

1-3. References

Required and related publications are listed in Appendix A.

1-4. Limitations

a. Information covered in other manuals. The procurement and specifying of certain major items of equipment, including pumps, electric motors, switchgear and slide/roller gates are covered in other engineer manuals and guide specifications. Information contained herein is to aid in the preparation of design memoranda and contract plans and specifications.

b. Detailed design. This manual is not intended as a comprehensive step-by-step solution to pumping station design. The designer is responsible for exercising sound engineering resourcefulness and judgment while using this manual. Used as a guide, it provides experience-oriented guidance and a basis for resolving differences of opinion among the competent engineers at all levels. Other material useful in pumping station design, which is readily available in standard publications, is not generally repeated or referenced herein.

1-5. Design Procedures

a. General design practices. Plate 1 provides the recommended procedure for development of flood control pumping station design. The chart prescribes the design sequence and preparation and approval procedure.

(1) The design should include the quality of the materials to be used and the workmanship involved. Designs should be as simple as practicable. Increased complexity tends to increase initial and future operation and maintenance costs. Designs and equipment and material selection that require less frequent maintenance are recommended.

(2) All design computations should be provided. Design computations should be clear, concise, and complete. The design computations should document assumptions made, design data, and sources of the data. All references (manuals, handbooks, catalog cuts, existing stations), alternate designs investigated, and planned operating procedures should also be provided. Computer-aided design programs can be used but should not be considered a substitute for the designer's understanding of the design process.

(3) Equipment backup requirements should be evaluated both on the probability and the effect of a malfunction. Usually a backup is provided only for equipment that would cause the entire pumping station to be inoperable. Spare equipment should be considered for equipment whose design is unique or one of a kind construction which would make replacement lengthy or very costly. Spare equipment for most pump stations should consist of bearings, shaft sleeves, temperature probes, relays, switches, lubricators, and any other types of auxiliary equipment being used on the pumping unit. Spare equipment could also include a spare impeller and pump bowl section if there are a large number of pumping units at the project (five or more) or there are multiple stations using the same size and type of pump procured under the same contract. Spare parts should also be provided for the prime mover.

(4) During construction, the designer should be involved in the review of shop drawings and as-built drawings, preparation of the operation and maintenance manual, and field and shop inspections. The designer should also be consulted when a field change is recommended or required.

b. Alternative studies. The selection of the type of equipment to be used should be based on alternative studies. When a choice of different equipment is available and will perform the same function, all applicable types should be considered. The selection should be based on reliability and least annual costs. Since

reliability cannot be easily assigned a cost, it should be evaluated on the basis of what effect an equipment failure would have on the operation of the station. A piece of equipment whose failure would still permit partial operation of the station would be more desirable than an item that would cause the entire station to be out of operation. The annual costs should include the first costs, operating costs, maintenance costs, and replacement costs based on project life. As certain items of equipment may affect the layout of the station including the location and suction bay and discharge arrangement, the structural costs associated with these designs should be included in the cost analysis. On major equipment items, this study should be included as part of the Feature Design Memorandum. For stations over 30 cubic meters per second (m^3/s) (1,060 cubic feet per second (cfs)) capacity, a separate Feature Design Memorandum should be prepared for the pumping equipment before the design is started on the station.

c. Other design information.

(1) Sources. Important design information is available from sources besides the prescribed Corps of Engineers manuals and standard handbooks. Design memoranda and drawings from other projects, manufacturers' catalog information, sales engineers, project operation and maintenance reports, field inspectors, operation and maintenance personnel, and the pumping station structural design personnel are all valuable and readily available sources. Communication with HQUSACE and other USACE District and Division offices can often provide information to solve a particular problem.

(2) Evaluation. All existing information should be carefully examined and evaluated before applying a new product. Relying on previous satisfactory designs requires that the design conditions and requirements be carefully compared for applicability. The design engineer should consult with field engineers and make field trips to pumping stations under construction. Consultation with pump station operators is also very helpful. Obtaining and evaluating information from field sources is improved by making personal acquaintances and observations at stations under construction or operating stations as well as by making visits to pump manufacturers' plants. Office policies should permit and encourage these visits.

d. Large pumping plant designs. For pumping plants 30 m^3/s (1,060 cfs) or larger, the engineering and design will be performed by the Hydroelectric Design Center in accordance with ER 1110-2-109.

1-6. Deviations

This manual allows the designer considerable design flexibility. Some requirements, such as sump design, must be followed. When a deviation to stated requirements is believed necessary, the designer should completely document the deviation and request higher authority approval.

1-7. Safety Provisions

Certain safety provisions will be required by EM 385-1-1, Safety and Health Requirements Manual, guide specifications, trade standards, codes, and other manuals referenced herein. Additionally, the requirements of the Occupation Safety and Health Administration (generally referred to as OSHA Standards) are to be considered minimum requirements in Corps of Engineers design. Areas of particular concern to mechanical and electrical design are safety, noise levels, personnel access provisions, working temperature conditions, air contamination, load handling provisions, and sanitary facilities. OSHA Standards are continuously being modified and expanded. Conformance to the latest published requirements is essential.

1-8. Appendices

Required and related references are provided in Appendix A. Appendix B presents a method to determine the size of a pump to meet pumping requirements; it also provides the dimensions for the sump and station layout once the pump has been selected. Three general categories of trash-raking equipment are described in Appendix C. In Appendix D, the procedures used in determining the size of gate closure, stem size, and operator size, and loads to be carried by the structure at the gate location are explained. The different methods and formulas used to determine the head losses occurring in a pumping station are given in Appendix E. Appendix F provides the format for an operation and maintenance manual for a typical stormwater pump station, and Appendix G contains an electrical data request. Appendix H is a glossary.

Chapter 2
Equipment Requirements

2-1. General

Pumping stations designed and built by the Corps of Engineers are mostly part of a flood-protection project and, as such, are used during emergencies. Some stations may pump a combination of sanitary sewage and storm water. They are usually maintained and operated by local interests and may sometimes be manned by operators who are not technically trained. Therefore, the equipment installed in these stations should be highly reliable and, whenever possible, should be of a type and construction that will require minimum maintenance and be relatively simple and easy to operate. It is recognized, however, that large diesel engine drives require a great deal of maintenance and are quite complex to operate. Some stations will be located in a corrosive atmosphere, especially those located along an urban sewer. At these locations, proper equipment and material selection and proper station ventilation designs are critical to minimize the effects of the corrosive atmosphere. It is expected that some of the equipment will be more expensive than regular grades that are commercially available. Recommendations of local interest preferences should also be considered.

2-2. Design Life

Most flood-protection projects are built for a 50-year life. Pumping station equipment, however, is not available, or it is not feasible to obtain equipment with a 50-year life. In general, the equipment selected should be built for the longest life span available. In some cases, it is necessary to do an economic analysis to determine the type of construction to use. Except for very special cases, a minimum design life of 35 years should be the guide to use for preparing specifications. Changes to the 35-year design life requirement should be fully documented in the Feature Design Memorandum. A general guide for budgeting on service life is found in ER 37-2-10, Appendix I.

2-3. Materials of Construction

The primary cause of equipment deterioration in pumping stations is idleness and associated moisture problems caused by this idleness. These conditions should be considered when preparing designs and specifications. The designer should give preference to those materials that require the least maintenance and have the longest life. Guide specifications covering the materials and construction considered best suited to meet the usual service conditions have been issued for various pumping station equipment. When applying the guide specifications to individual projects, modification of the specification provisions should be limited to those changes necessary for the operational requirements. Equipment problems caused by condensation and exposure to sewer gases in pumping stations used to pump sanitary sewage and storm water require additional corrosion resistant materials and sealants.

Chapter 3
Design Memorandum Requirements

3-1. General

The design memoranda are prepared in the preconstruction engineering and design (PED) phase of a project. This phase begins the most intensive engineering effort and culminates with the preparation of contract plans and specifications. The design engineer should also be involved in the reconnaissance and feasibility phases of the project. The applicable portions of ER 1110-2-1150 will govern the contents and formatting of the various required submittals. The submittals required for a particular project will be discussed at the earliest design coordination meeting, and the listing of design memoranda required will be established either at this meeting or as early as possible after this meeting. The following describes design documents developed during the design phase of a project. Other design documents, such as letter reports, can be substituted but should still contain the information and data required below.

3-2. Design Memoranda and Documents

For each project, there are different combinations of design memoranda prepared before proceeding to plans and specifications. These include General Design Memorandum, Feature Design Memorandum, Letter Reports, and Design Documents. Station layout and equipment selection should be investigated in sufficient detail, in the early design memorandum stage, to permit citing of the station and preparation of a cost estimate. Hydrology and hydraulic studies should present the required pumping conditions used for selection of the pumps. Information should include discussing the use of Government-furnished equipment if that method of pumping unit procurement is proposed. Detailed mechanical and electrical design data and computations should be included to allow approval of the final layout and design before preparation of plans and specifications. The results of alternative studies for the station layout and equipment selection should be presented. Design computations to determine size, strength, rating, adequacy, and interrelationships of mechanical, electrical, and structural items should be shown in sufficient detail to allow an engineering review. All formulas and assumptions used should be indicated. Copies of typical manufacturers' performance data for the proposed equipment and correspondence with manufacturers should be included. Any deviations from this manual must be indicated in the text portion of the memorandum. The memorandum should include an analysis of the schedules for the procurement of the pumping equipment and construction of the pumping station.

Chapter 4
Operation and Maintenance Manuals

4-1. General

An adequate operation and maintenance manual must be prepared to permit successful operation of the pumping station. The portion of the manual covering the mechanical and electrical equipment is generally prepared by the designers responsible for specifying this equipment. The manual should provide a platform for carry-over of information from the designer to the operating personnel. The manual should be prepared to aid the operating personnel in understanding the equipment and to set the guidelines for maintenance procedures. A manual provides a guide which can carry on beyond personnel changes and verbal instructions.

4-2. Coverage

a. General. The operation and maintenance manual should be complete. In most instances, this manual will be the only information available to operate and maintain the station. The contents are usually divided into three sections, operation, maintenance, and reference. Each section is described below, and some examples are included in Appendix F. General guidelines are included in ER 25-345-1, Systems Operation and Maintenance Documentation. Although ER 25-345-1 is for military construction, it also contains valuable information that pertains to civil works projects. The electrical fault protection coordination study, including protective device settings, should be provided with the operation and maintenance manual.

b. Operation. The operation portion is divided into three parts: criteria, constraints, and procedures. The criteria portion describes the operation of the facility that satisfies the project requirements. It deals with the overall operation of the station as opposed to operation of individual pieces of equipment. The constraints section should indicate all conditions that must be considered external to the station so that it can be successfully operated. These items usually consist of control structures away from the station that require certain gate opening and closing operations for the station to perform properly. The procedures part would include detailed operating procedures for each piece of equipment. The detailed equipment operating procedures are provided by the equipment manufacturers. The operations portion of the operation and maintenance manual should be coordinated with the hydraulics and hydrology (H&H) engineers.

c. Maintenance.

(1) General. A pumping station maintenance program should consist of inspections, standards, a control system, and lubrication. The available shop drawings on the equipment should be made a part of the manual so that they may be used when performing detailed maintenance or repair work.

(2) Inspections. The success of a maintenance program is dependent on adequate inspections. The inspections assure that the equipment receives proper attention and is ready for use. The extent of preventative maintenance inspections includes adjusting, lubricating, repairing, and replacing worn out or defective parts. A guide for the inspection frequencies and tasks for the various items of equipment is usually obtained from manufacturers' recommendations, but may need to be adjusted for flood control pumping station operating conditions. Any changes to manufacturers' recommendations should be coordinated with the manufacturer to avoid the possibility of voiding warranties.

(3) Standards. A balanced criteria maintenance program must be based on defined criteria that establish quality, extent, and quantity of maintenance desired. A quality program requires capable personnel, proper tools, use of quality materials, and a record of meeting program performance. The maintenance recommendations of most equipment manufacturers are usually for continuous operation, which is typically not the case for flood control pumping stations. Inspection and maintenance requirements must be keyed to the expected operation of the station.

(4) Control system. An effective maintenance control system should include comprehensive and accurate basic data, such as equipment records, historical inspection, maintenance, and repair records. Effective scheduling of maintenance work is required to ensure the most effective use of the operating agencies' personnel. The record filing system should consist of:

(a) An equipment data file. This file should be indexed by equipment name or title and contain all pertinent data for that specific item of equipment or facility, such as manufacturers' instruction books, operating pressure limits, parts catalogs, manufacturers' drawings, reference field tests, special reports on major repairs, dates of replacements and retirements, and changes in operating procedures.

(b) A preventative maintenance file. This file should contain a record of equipment inspections, maintenance data, a record of hours of operation, number of operations, or other significant operating data. Consideration should be given to furnishing the information on a computer database program for large and complex stations.

(5) Lubrication. Proper lubrication is an important part of a good maintenance program. Dependable operation and the life expectancy of equipment requiring lubrication are almost entirely dependent on the use of proper lubricants at the right time intervals and in the proper quantities. All equipment requiring lubrication should be surveyed and appraised for the type of bearings, gears, and service conditions under which the equipment must operate. After these operating conditions are fully analyzed, then it can be determined what characteristics the proper lubricant should have, such as resistance to moisture, temperature range, whether an extreme pressure lubricant is required, and the proper viscosity range. Some manufacturers recommend only the viscosity of the lubricant while others list the lubricants by trade name. The number of different types should be kept to a minimum. The frequency of lubrication used is recommended by the manufacturer. The frequency of lubrication may have to be adjusted based on special use or experience. The equipment must be examined in detail when preparing lubrication instructions, so that every grease fitting and oiling location can be indicated in the maintenance instructions. Manufacturers' information does not always show enough detail to permit accurate preparation of the lubrication instructions. Photographs of the various pieces of equipment showing the locations of all the lubricating points are very useful.

d. Reference. The reference section of the operation and maintenance manual should contain a listing of all data that are necessary to operate and maintain the station. These data should include all of the shop drawings for the equipment, as-built contract drawings, advertised specifications, and design memoranda used in the design of the station. Copies of all reference items except the design memoranda should be furnished to the user as an appendix to the operation and maintenance manual. The design memoranda should be furnished as a separate package. The contract specifications for the equipment should contain the requirement for the contractor to furnish as-built shop drawings of the equipment. Since this reference material is usually voluminous, it is recommended that a file cabinet be furnished as part of the construction of the station so that adequate storage is available at the station.

4-3. Schedule

The construction of a pumping station usually does not permit a final manual to be prepared before it is turned over to the user or operating agency. Because of this, an interim manual should be prepared to benefit the end user when they receive the station. The interim manual should include complete operating instructions and any maintenance instructions prepared to that time. The operating instructions should be prepared early enough so that they may be checked during the preliminary and final testing of the station. The final operation and maintenance manual should be available for the user within 1 year of the turnover date of the pumping station.

4-4. Testing and Exercise

Since flood control pumping stations are usually operated on an infrequent basis, trial operation is required between flood events. All equipment should be operated at least every 30 days. It is acceptable to operate the pumping equipment in the dry providing that equipment is designed for dry operation and the water level present is below the bottom of the pump suction bell or umbrella. Wet testing of pumping equipment should occur only if the water present is above the minimum pumping level. These test operations should be included in the maintenance schedule. The duration of the exercise period should be coordinated with the equipment suppliers but should be limited to as short a period as possible.

Chapter 5
Pumping Equipment

5-1. General

The following types of centrifugal class of pumps are used for flood-protection pumping stations:

a. Axial-flow impeller type.

(1) Fixed-blade, vertical type.

(2) Adjustable-blade, vertical type.

(3) Fixed-blade, horizontal type.

b. Mixed-flow impeller type.

(1) Fixed-blade, vertical type.

(2) Volute type.

c. Centrifugal volute or radial-flow type.

The type that should be used for any particular installation is dependent upon the service conditions, head requirements, and station layout. Chart B-1, Appendix B, shows the approximate useful range of capacity and head for each type of pump that is described. The appropriate pump type should be chosen only after a detailed study of the possible choices.

5-2. Pump Characteristics and Types

a. General.

(1) Pumps are usually classified by their specific speed. Specific speed is defined as the speed a pump would have if the geometrically similar impeller were reduced in size so that it would pump 1 gallon per minute (gpm) against a total head of 1 foot. In SI, N_s is called type number with Q in liters per second and H in meters. Specific speed is expressed as:

$$N_s = N_t (Q^{0.50}) / H^{0.75} \quad (5\text{-}1)$$

where

N_s = pump specific speed

N_t = pump rotative speed, revolutions per minute (rpm)

Q = flow at optimum efficiency point, gpm

H = total head at optimum efficiency point, feet

(2) Suction specific speed is a dimensionless quantity that describes the suction characteristics of a pumping system, designated as available, or the suction characteristics of a given pump, designated as required. The suction specific speed required must exceed the suction specific available to prevent cavitation. The suction specific speed available, based on the lowest head pumping condition, is often used to determine the maximum permissible speed of the pump.

$$S = N_t (Q)^{0.5} / (NPSHA)^{0.75} \quad (5\text{-}2)$$

where

S = suction specific speed available

N_t = pump rotative speed, rpm

Q = flow rate, gpm

NPSHA = net positive suction head available, feet

b. Axial flow. The impellers of these pumps have blades shaped like a propeller. This type of pump develops most of its head by lifting action of the blades on the liquid. The pumped fluid travels in a direction parallel to the shaft axis, hence the name "axial flow." It can also be constructed as an adjustable blade pump in which the pitch of the blades is varied to provide different pumping rates and/or reduced starting torque. Axial flow pumps are primarily used to pump large quantities of water against low heads and are typically used in open sump pumping stations in a vertical configuration. The value of N_s for this type of pump is typically above 9,000.

c. Mixed flow. The impeller of these pumps develops head or discharge pressure by a combination of both a lifting action and a centrifugal force. The path of flow through the impeller is at an angle (less than 90 degrees) with respect to the pump shaft. This pump can be constructed with multistages; however, for most Corps stations, a single stage will develop sufficient head to

satisfy most head requirements. The pump can be constructed similar to an axial flow pump with water flowing axially from the pumping element, or the impeller can be placed in a volute (spiral casing), where the water flows from the pump radially. The volute design would be used either for large pumps where a volute would allow the pump to operate at lower heads or for small pumps where it is desirable to have a dry pit installation with the discharge pipe connected near the pumping element. The value of N_s for this type of pump should be limited to 9,000.

d. Centrifugal. The impeller of these pumps develops head only by centrifugal force on the water. The path of flow through the impeller would be at a 90-degree angle with respect to the pump shaft. A special design of this pump has a non-clog impeller which makes it very useful for pumping sewage. This type of pump is used for pumping small flows and in applications where a dry pit sump is desirable. It is generally used in a vertical configuration and can be constructed to operate in a wet or dry sump. The value of the N_s is typically less than 4,000.

e. Net positive suction head. This term is used to describe the suction condition of a pump; it is commonly abbreviated with the letters NPSH. Two forms of NPSH are used. One is used to describe what suction condition is available to the pump and is called Net Positive Suction Head Available (NPSHA), and is a function of the station layout and suction water levels. NPSHA is defined as the total suction head in feet of liquid absolute, determined at the suction nozzle and referred to datum, less the absolute vapor pressure of the liquid in feet of liquid pumped. See Appendix B for formula and terms used. The other term Net Positive Suction Head Required (NPSHR) is a property of the pump and indicates what suction condition is required for the pump to operate without cavitation. NPSHR is determined by the pump manufacturer by running cavitation tests on the pump.

5-3. Pump Arrangements

a. Vertical. Most pumps used in flood-control pumping stations are of the vertical type. This type of pump has a vertical shaft with the driver having a vertical or horizontal shaft arrangement. A vertical motor is usually direct connected to the pump, whereas a horizontal motor or engine requires the use of a right-angle gear. The vertical arrangement usually requires the least floor space per unit of pumping capacity. While the vertical motor could cost more than the right-angle gear reducer and higher speed horizontal motor combined, the decreased reliability and increased operation and maintenance costs due to the additional auxiliary equipment involved may offset the first cost savings. One problem associated with a vertical pump layout is that the pump dimensions may locate the discharge elbow higher than the minimum head required by hydraulic conditions. The higher head will require greater energy. Other type layouts such as a siphon discharge or volute, horizontal, and flower pot type pumps will permit lower minimum heads or in the case of a siphon only the discharge system losses. Vertical pumps are used with open or closed sumps, wet or dry, and are suspended from an operating floor or an intermediate floor.

b. Horizontal. Horizontal type pumps are usually limited to applications where the total head is less than 6 meters (20 feet) and the quantity of water to be pumped is large. Horizontal pumps are seldom less than 2,500 millimeters (100 inches) in diameter. Smaller horizontal pump installations are generally more expensive than vertical installations. The pumps are not self-priming, and the design must provide a separate priming system.

c. Formed suction intake. Formed suction intakes are not really a pump type but are suction arrangements that generally improve flow conditions to the pump. They are applied to vertical pumps and are used in place of the standard bell arrangement. Typical dimensions of a formed suction intake are shown in Figure B-12, Appendix B.

d. Submersible.

(1) General. Submersible pumps are considered for stations that have pumping requirements with each pump having a capacity less than 6 m^3/s (200 cfs). These pumps have the electric motor close coupled to the pumping element with the entire pumping unit being submerged in water. The size and selection of these units are limited by the number of poles in the motor or the size of the gear unit, if used, and its resultant encroachment on the water passage. These types of pumps should be removable from above the floor without any unbolting of the discharge piping. Their use allows the superstructure of the station to be greatly reduced. Substructure requirements are approximately the same as for vertical pumps. Submersible pumps used for flood control pumping stations are of three different types: axial flow, mixed flow, and centrifugal volute.

(2) Axial or mixed flow. These pumps consist of an axial- or mixed-flow impeller close coupled to a submersible electric motor. The impeller may be on the same shaft as the motor or a set of gears may be between the motor and the impeller to permit greater variety of speed. The pump is suspended above the sump floor inside of a vertical tube that extends to the operating floor. The tube allows placement and removal of the pump and forms part of the discharge piping. These pumps are used in a wet pit-type sump. Some pumps of this design are constructed so that the blades are detachable from the propeller hub and are connected to the hub in a manner that allows a multitude of blade angle settings. The blade angle adjustment feature also permits changing the pump performance characteristics very easily. This permits a pump installation to meet a different future hydrology condition with adjustment of the blade angle.

(3) Centrifugal. These pumps consist of a volute casing close coupled to a submersible electric motor. The impeller and motor are on the same shaft. The pumping unit is guided to its operating position from the operating floor level by a system of guide rails or cables. The volute attaches to the discharge piping flange by means of a bracket using the weight of the pump to seal the connection. These pumps are used for smaller flows than the axial- or mixed-flow type and when pumping heads are high. These pumps are also suitable for use in a dry pit sump. These pumps are usually equipped with a water jacket surrounding the motor to cool the motor with pumped fluid. For special applications, these pumps can also be fitted with a different diffuser which allows them to be tube mounted similar to the axial-flow submersible pumps.

5-4. Selection of Pump Type

a. General. Many items must be considered during the pump selection process. Alternative station layouts should be developed in sufficient detail so that an annual cost of each layout over the life of the project can be determined. The annual cost should include the annualized first cost, operating costs which include cost of energy, maintenance, and replacement costs. It is usually best to consider all of the above types of pumps when developing the station layout unless it is obvious that certain ones are not applicable. The station layout and pump selection should be done in sufficient detail to permit the reviewer to follow the process without reference to additional catalogs or other such sources.

b. Capacity. The capacity requirement for the pump is determined from the hydrology requirements of the station. This information is provided by the H&H engineers. The number of pumps used should be kept to a minimum and determined as set forth in EM 1110-2-3102. If more than one capacity requirement exists, the pump is selected to satisfy all of the conditions. This means that the pump will most likely be over capacity for some of the requirements. Variable capacity pumping units may be economically justifiable. Variable capacity can be achieved by using variable speed drives or pumps that are equipped with variable pitch blades.

c. Head. The head requirements of the pump are also determined from the hydrology requirements plus the losses in the pumping circuit which are a function of the station layout. The pump head requirement is called total head and is a summation of all heads for a given capacity. The method of computation of these heads is included in Chapter 6. Selection of pumps should strive to achieve the lowest total head requirement to provide the smallest size driver and lowest energy cost. The best pump operation occurs when the pump is operating at or near the head that occurs at the pump's best efficiency point. With the wide range of heads that occur for flood-control pumping stations, this is usually not possible. The pump must be selected to satisfy all the required conditions. However, if a choice exists, the pump should be selected so that the best efficiency point is near the head where the most pumping operation occurs. Some pumps, particularly the axial flow type, may have a curve which contains what is called a "dog-leg." This part of the curve consists of a dip in head which allows the pump to operate at as many as three different pumping rates, all being at the same head. Pump operation and priming at this head must be avoided due to unstable operation.

d. Net positive suction head. The suction conditions available for the pump should be determined for all pumping conditions. A diagram should be prepared showing the NPSHA for the entire range of pumping conditions. The method of computation of the NPSHA is shown in Appendix B. The NPSHA should meet the margins and limits indicated in Appendix B. In all cases the NPSHA should be greater than the NPSHR for the selected pump over the entire range of required pump operation. Pumps not requiring the cavitation tests should be specified to meet the suction limits developed over the entire range of required pump operation and the suction limit criteria as indicated in Appendix B.

e. Efficiency. Higher efficiencies available from the different types of pumping units are a consideration when the estimated amount of operation is great enough to affect cost considerations. Usually for stations with capacities less than 14 m^3/sec (500 cfs) and operating less then 500 hours per year, differences in operating efficiencies of various types of pumping equipment need not be considered. The highest efficiency that is commercially attainable should be specified for whatever type of pump is selected. This will not only control operating costs but will normally improve the operation of the pump through less vibration, cavitation, and maintenance requirements.

f. Other considerations. Certain limitations sometimes guide pump selection.

(1) Incoming electric service. Incoming electric service may limit the horsepower rating of the driver or may not permit the use of electric motors.

(2) Foundation conditions. Foundation conditions may increase the cost of excavation to the point where it may not be feasible to lower the sump to that required for some types of pumps.

(3) Available space. The available space at the proposed station site may limit the size of the station.

(4) Low discharge capacity. Axial- and mixed-flow pumps may have too small flow passages and would therefore be subject to clogging. A centrifugal pump would then be used because of its greater solid passing capability.

g. Selection procedure. The first step in developing a pump selection is to determine the approximate pump operating conditions. Total heads used for these approximate operating conditions can be determined from adding the static heads (discharge pool level or pump discharge elevation minus the lowest pump suction level) to an approximation of the system losses plus the velocity head. Use the capacities from the hydrology requirements, the approximate total heads, and Chart B-1 in Appendix B to determine the types of pump that may be suitable for the conditions. Using each pump type selected from the chart, a pump selection is made using the method indicated in Appendix B. A station layout for each type of pump can be developed. Dimensions for the pumping equipment and sump dimensions can be obtained from the procedure given in Appendix B. It may be necessary to refine the heads and therefore the station layout due to changes in head when the equipment is selected and located in the station. The information from the final pump station layout should be sent to a minimum of two pump manufacturers requesting their selection of recommended pumping equipment for the given station layout. It is important that the communication with the pump manufacturers takes place during the design memorandum phase of the project. See Chart B-3 in Appendix B for a typical pump manufacturer data sheet. The information thus obtained should be used to correct, if necessary, the station layout and finalize the alternate study layouts and costs. Operation, maintenance, and equipment replacement costs must also be considered in the selection of the type of station to use. Operation costs should consider the cost of energy and operating labor when the station is in operation. In some cases, these costs are very small due to limited operation and the detail in those cases can be limited. When the estimated operating costs for a station exceed $10,000 per year, it could be necessary to use a detailed energy cost analysis based on pump head, cycling effect, and any special considerations the supplier of the energy may require. Maintenance cost should be carefully considered since it goes on whether the station is in operation or not. The tendency is to underestimate this expense. Discussion with the eventual user could aid the designer in determining the maintenance methods that will be used. Replacement costs should be based on both wear out and obsolescence of the equipment. Equipment replacements are also made when the cost of maintenance becomes excessive and the reliability of the equipment is in doubt. Equipment manufacturers usually provide the expected life of their equipment while operating under normal conditions. When equipment operation will occur beyond the normal conditions, as defined by the manufacturer, the expected life should be adjusted accordingly. Selection is then based on annual costs and reliability factors.

Chapter 6
Pumping Conditions

6-1. General

This chapter includes the procedures used for determining the pumping conditions. Several different pumping conditions can occur for the same station layout due to multiple hydrology requirements. The determination of pumping conditions for the final station layout should be included as part of the design documents.

6-2. Capacity Determination

The capacity for the pumping conditions is determined from the hydrology requirements. Generally, the stormwater pumps in a station should have equal capacity; however, certain other conditions such as foundation, submergence, inflow requirements, and pump-drive match may dictate the need for pumps of different capacity ratings. Varying the size of the pumps may also be required to minimize pump cycling where ponding storage is small compared with the base flows that must be pumped. Generally, there is a different capacity requirement for low and high river conditions. Intermediate conditions are possible, and also special requirements such as siphon priming may occur. The capacity required for a self-priming siphon discharge is that capacity that provides a velocity of 2.2 meters per second (7 feet per second) in the discharge pipe at the crest of the protection. This value is conservative, and for large stations, a model test of the siphon discharge should be considered to determine the minimum priming velocity. A decrease in this velocity could affect the pump selection. Also, a siphon system that is long or contains many dips should be model tested as the 2.2-meters-per-second (7-feet-per-second) velocity criterion may not prime the siphon. For stations that have a baseflow pumping condition, a separate smaller pumping unit or units are provided to handle the baseflow. The source for the capacity determination should be indicated in the design memorandum.

6-3. Head Determination

a. General. The term used to specify the amount of lift that a pump must overcome when pumping is called total head. Total head is composed of static head, losses in that pumping circuit, and the velocity head developed. All the losses in the portion of the pump that is supplied by the pump manufacturer (generally between the suction bell or flange and the discharge flange or the end of the elbow) are considered internal pump losses and are not included in any head loss determination included with the pumping equipment specification. In those cases where the suction and discharge systems are complicated and form an integral part of the pump, a model test to determine the total head should be conducted by the Waterways Experiment Station (WES), Vicksburg, MS.

b. Static head. In most flood-control pumping station applications, the static head can be considered the difference between the pool elevation on the inside of the protective works and the pool elevation at the discharge point. Usually there are several different static head requirements for a given station layout or set of hydrology conditions. Consideration should be given to the differences in static head caused by the variation in pumping levels on the intake side between the project authorized level of protection and the minimum pumping level. The static head for satisfying the hydrology requirements is determined from many different sump elevations. These include the minimum pumping elevation, the pump starting elevation, and the average sump elevation. These elevations should be determined during the hydraulic/hydrologic studies. The lowest stopping elevation along with the highest elevation to be pumped against (this elevation is determined according to the type of discharge system being used or the maximum elevation of the discharge pool) is used to determine the maximum static head that will be used to select the pumping unit. A reduction in capacity for this maximum head condition is permitted and should be coordinated with the H&H engineers. If the discharge is to operate as a self-priming siphon, the static head is the difference between the top of the discharge pipe at its highest point and the pump's lowest starting level. For the priming phase of a siphon system and for a vented nonsiphon system, it is assumed that discharge flows by gravity past the highest point in the discharge line, except as noted hereafter. Discharge systems having long lengths of pipe beyond the crest of the levee may have a head profile greater than the top of the pipe at the top of the levee. Typical static head conditions for various types of stations is illustrated on Plates 2-8.

c. Losses.

(1) General. The losses consist of friction and other head losses in the conveying works, before the pump (intake losses), and after the pump discharge (discharge losses). Intake losses include trashrack, entrance gates, entrance piping losses, and any losses in intake channels. Discharge losses include discharge pipes, discharge chamber losses, and backflow preventer valves. These

losses should be considered for different numbers of pumps operating. Generally, the losses will be lowest with one pump operating and highest with all of the pumps in operation. For the majority of pumping stations, the entrance losses, except the loss across the trashrack, will be minor, and in most cases can be neglected.

(2) External losses. These losses start at the station forebay or sump entrance. This is usually the sewer or ditch adjacent to the station. The losses would be from this point to the sump where pump suction occurs. The losses are calculated by applying "K" factors to the various elements of flow and then multiplying them by the velocity head occurring at that location. Based on observations at operating stations, the losses through the trashrack are usually assumed to be 150 millimeters (6 inches). The other losses are those occurring on the exit side of the pump piping and could include the losses occurring in the discharge chamber and its piping system to the point of termination as identified in the hydrology report. The losses in the discharge chamber and piping entrances, exits, and bends are calculated with "K" factors similar to those on the entrance side. A special case occurs in narrow discharge chambers where a critical depth of flow may occur causing the water level in the chamber to be higher than that occurring downstream of the chamber. This usually occurs only for the low head condition. Appendix E provides design information for handling this case.

(3) Pump piping losses. These losses will include all losses in the connecting pipes to the pump including both the entrance and exit losses of this piping. The Darcy-Weisbach formula should be used for determination of piping friction losses. An explanation of the formula and terms used is shown in Appendix E. Methods and factors to be used in determining losses in fittings, bends, entrance, and exits are shown in Appendix E.

d. Velocity head. The velocity head represents the kinetic energy of a unit weight of liquid moving with velocity V and is normally represented as the difference of the kinetic energy of the suction and discharge piping. However, when the pump does not have any suction piping and is fitted with a suction bell, the velocity head is that calculated for the discharge pipe. The velocity head is considered a loss for free discharges and partially or totally recovered for submerged discharges. For the purposes of determination of system losses, and as a safety margin, the entire velocity head will be considered unrecoverable and thereby added to the other losses.

e. Total system head curves. A total system head curve is a curve that includes all the losses plus the static head in the pumping circuit plotted against the pumped capacity. The losses would include both the external and pump piping losses plus the velocity head. A different total system head curve occurs for each static head condition. In determining the total system head curves, the worst-case condition should be considered when multiple pumps of equal rating are used. In a multi-pump station, the piping system that has the greatest losses would be used to determine the total system curve for the highest head condition, while the piping system with the least losses would be used for the lowest total system head. For pumps discharging into a common manifold, the highest head occurs with the maximum discharge level and all pumps operating. The total system head curves for the final station layout shall be submitted in whatever design document preceeds the P&S.

6-4. Suction Requirements

a. General. The two factors to be considered are the NPSHA, resulting from pump submergence, and the flow conditions in the sump. Successful pump operation is not possible without satisfying the effects of these two influences. NPSH is defined in Chapter 5.

b. Submergence. Submergence is defined as the setting of the impeller eye of the pump with respect to the water surface in the suction sump area. Principal factors involved in the determination of submergence requirements are cavitation limits and the prevention of vortexes in the suction sump. Minimum submergence requirements, based on estimated annual operating hours, are provided in Appendix B. Submergence requirements, with respect to the inlet of the pump, to prevent the formation of vortexes in the sump are presented in ETL 1110-2-313 and Appendix B, Chart B-2. The information provided above could yield more than one submergence requirement. However, the most conservative (largest) value of pump submergence should be selected. It must also be remembered that the impeller must be submerged at the start of pumping if the pump is to be self-priming.

c. Flow conditions. The layout of the station, the sump water levels, and the shape of the pump intake determine what flow paths occur in the sump. These flow paths can cause uneven distribution into the pump, which affects pump performance. The most observable detriments of these are vortexes. Certain dimensions that have been found by model testing should be used for

layout of the station. These dimensions are shown in Appendix B and are usable for all stations in which the upstream approach in front of the station is straight for a distance greater than five times the width of the pumping station. Stations with a sharp bend close to the station should be provided with a formed suction intake. The WES Hydraulics Laboratory personnel should be consulted concerning the station's layout and design. WES may be able to apply lessons learned from previous model tests to make design or layout recommendations to avoid possible future operational problems. However, if an unusual entrance condition exists, a model test of the station may be required.

6-5. Pump Requirements

After analysis of the application is made in accordance with Appendix B and the pump operating conditions defined, a pump may be selected to satisfy the design conditions. A suggested data sheet containing information to be forwarded to pump manufacturers is shown on Chart B-3, Appendix B. Selections may be made by the designer from pump catalogs, but it is usually best to confirm this selection with the manufacturers. A selection by a minimum of two manufacturers should be obtained. In some instances, the selection by the manufacturer may be different enough that the station layout may require a change. Before making these changes, an attempt should be made to determine why the manufacturer's selection differs from that selected by the designer. The designer and the pump manufacturer should discuss the basis of the selection. Some differences, such as the next larger sized pump or the next faster or slower driver speed, are probably acceptable since the pump manufacturer may not have an equivalent to the one selected by the designer. In other cases where the pump manufacturer recommends a different type of pump, such as a horizontal pump where a vertical pump was proposed, the change should be evaluated. The studies and pump selections made in accordance with this manual are not made to pick a specific model pump, but to show the design, the type of pump to use for station layout, and to provide guidance on preparing the pump specifications and the type of pump tests to run.

Chapter 7
Discharge System

7-1. General

The discharge system of a pumping station is used to convey the pumped water from the pumps to the receiving body of water. Additional discharge system information is contained in EM 1110-2-3102. Two types of systems are used, over the levee either with or without siphon recovery and through the line of protection. Alternative studies of different type discharges may be required in order to select the one that is best when considering the layout of the station, site requirements, and the selection of the pumping equipment.

7-2. Discharge Types

a. Over the levee. Discharge lines over the protection consist of individual lines for each pumping unit or a manifold discharge with one discharge line running from the station over the protection. The lines can terminate in a common discharge structure or each individual discharge line can be supported by piling with the surface below riprapped to prevent erosion. If the discharge system is to operate as a siphon, the design should be such that it is self priming and the lowest discharge level should not be lower than 8.5 meters (28 feet) from the top of discharge pipe (this limit, as illustrated in Appendix B, does not include piping losses, velocity head, etc.). The 8.5 meters (28 feet) may be obtained by terminating the discharge lines in a concrete box containing a seal weir at the proper elevation. An upturned elbow may also be used to obtain the seal elevation on individual lines. The invert of the discharge line at its highest point should be at or above the level of protection expected to be provided by the protection works. Manifolding of pump discharge lines into a single line is generally cost effective only for small pumps and when siphon recovery will not be used. When considering a manifold system, a cost comparison should be made between the cost of individual discharge lines and the extra shutoff and check valves needed in a manifold system. Pumps that discharge into an open discharge chamber are not considered to be manifold-type discharge.

b. Through the protection. Discharges through the protection usually consist of individual pump discharge lines terminating in a discharge chamber or wall of the protection. Flow from the discharge chamber would then be carried by conduit to the receiving body of water.

7-3. Selection Criteria

The type of discharge is sometimes set by the location of the station. For example, siphons may be used when the station is located behind the levee or as an integral part of the levee. In those cases where different types of discharge arrangements could be used, a study of alternatives should be made. Selection is based on a life-cycle cost analysis. Some of the variables would be operating, equipment, and structure costs. Operating costs would include the costs of energy, manpower, and operating supplies and maintenance costs. Energy and manpower needs should be determined using available hydraulic/hydrology data to determine amount of operation time and discharge levels. Forecasts of future energy costs can usually be obtained from the utility that furnishes the energy. Equipment costs could vary due to the difference in discharge head requirements of the various discharge systems. In most cases, only the driver size would change. Although over the levee discharges with a siphon recovery make pump selection more difficult due to the fact that the pump is required to operate over a greater head range, it does reduce the operating costs of the station. The static head for a siphon recovery discharge is based on the pool-to-pool head, whereas the static head for a non-siphon discharge is based on the maximum elevation of the discharge line. A study should be made of the first costs and operating power costs to determine if the siphon assist is justifiable.

7-4. Design

a. General. The size of the pipe is usually determined by a cost analysis of the energy used due to friction loss versus pipe cost. Through the protection, discharge lines are usually short lines and have the same diameter as the pump discharge elbow. Where any piping connects to a pump, it should be supported so that the pump does not support any of the weight of the pipe or its contents.

b. Through the protection. In general, two means shall be provided to prevent backflow when the discharge is through the protection. Discharge lines through the protection should terminate with a flap gate to prevent back flow. In addition to the flap gate, provisions should be made for emergency shutoff valves, emergency gates, or individual stop log slots to place bulkheads in case of flap gate failure. All discharge lines with flap gates should be fitted with a vent pipe located just upstream of the flap gate to prevent excessive vacuum bounce of the flap gate. The vent should extend 600 millimeters

(2 feet) above the highest discharge water level. Flap gates shall be of the type suitable for pump discharges. This type of gate is of heavier construction, and the arms that support the flap are double hinged so that the flap will fully close. Flap gates with a built-in hydraulic cushion effect are not required where the head on the gate is below 7.6 meters (25 feet). All non-cushion type flap gates used on pump discharges should have a rubber seat which aids in sealing and eliminating some of the closing shock. A station having this type of discharge arrangement is shown on Plate 5.

c. Over the levee. Pipes over the levee require an air release and a siphon breaker at the crest. If the pipe system does not operate as a siphon, a permanent vent opening can be used. Discharge pipes 1,500 millimeters (60 inches) and less can usually be operated as a self-priming siphon if the flow velocity at the crest is 2.2 meters per second (7 feet per second) or greater when priming is initiated. Model tests should be considered for discharge pipes of greater diameter and those pipes having an arrangement different from the standard type discharge shown on Plate 4. For pipes operating as a siphon, the use of a remotely operated valve to break the siphon should be used. This valve is air-operated except for small sizes in which electric operation is possible. The valve is operated from a signal initiated by the starting of the pumping unit. A timer is placed in the circuitry to provide a time delay of valve closing after start-up to vent the discharge pipe system. There are flow-operated siphon breakers available, but care should be taken that they are designed for heavy duty operation and are adjusted correctly after installation to prevent air leakage into the pipe. The siphon valve is sized according to the formula provided at the end of this paragraph. When the calculated result indicates a non-standard size valve or piping, the next larger standard sized valve and piping should be used. A manual valve of the same size shall be used in addition to the siphon valve for emergency breaking of the siphon. All of the siphon breaker piping and valves should be located near the descending leg in an enclosure. Problems in priming the siphon can occur when the changes in discharge line gradient occur on the discharge side of the protection. The section of pipe after the down leg should be as flat as possible to prevent these problems. Manufacturers of air and vacuum valves should be consulted for proper valve sizing. Vent size can be calculated using the following formula.

$$D_v = 0.25\ D_p \times (2/h)^{0.25}$$

where

D_v = diameter of vent, ft
D_p = diameter of discharge pipe, ft
h = minimum submergence over outlet, ft

7-5. Pipe Construction and Material

a. Construction. Discharge piping to pump connections is generally made by means of a flexible coupling with harness bolts across the connection. Rigid or flanged connections could be used for pullout design pumps and for those pumps that may be cast into the structure. All buried piping needs to be connected with flexible couplings with harness bolts whenever the pipe runs into or out of a concrete structure, at bends, and at other points where differential settlement or normal expansion or contraction of the pipe is anticipated. Where piping leaves a structure and goes underground, the first flexible coupling should be placed within 1.5 meters (5 feet) of the wall with an additional flexible coupling placed 1.5 meters (5 feet) farther downstream. An embedded wall flange should be provided for all piping passing through concrete walls. Pipe selected should be of the minimum wall thickness that will satisfy the requirements of the installation and, if possible, should be of a standard stock wall thickness. Where corrosion may be a problem, an increase in thickness of 25 percent may be considered for steel pipe. In addition to the tensile circumferential stresses resulting from the normal internal water pressure, stresses due to the following may be a consideration in the design of some pump discharge lines.

(1) Excess stress due to water hammer.

(2) Longitudinal stresses due to beam action of the pipe, when the pipe is exposed and supported by piers or suspended supports.

(3) Stresses caused by external loading.

(4) Stresses caused by collapsing pressures due to formation of vacuum in the pipe.

(5) Stresses due to temperature changes.

(6) Stresses due to differential settlement.

The discharge pipe and its support system including anchors, thrust blocks, and tie rods should be designed in sufficient detail so that the above considerations can be checked. American Water Works Association (AWWA) Manual M-11 should be referenced for recommended design and installation practices for steel pipe. Preparation of detailed pipe shop fabrication drawings should be made the responsibility of the Contractor subject to the approval of the Contracting Officer.

b. Material. Discharge piping should be constructed of steel or ductile iron. Ductile iron pipe would generally be

used for piping of 300 millimeter (12-inch) diameter and under. Exposed steel piping inside of stations may be flanged or flexible coupling connected, whereas ductile iron pipe should be fitted with mechanical joints or flanged. Steel and ductile iron pipe should conform to the applicable AWWA standard specifications. All discharge line pipe should be protected on the inside with a smooth coating. The designer should consult with the paint laboratory at the Construction Engineering Research Laboratory, Champaign, IL. Buried pipe should also be provided with an outer protective coal-tar coating and a felt wrapping. Shop coatings should be used to the maximum extent possible due to the better quality control. Flanges should conform to AWWA specifications for the pressure rating required. The applicable AWWA standards are listed in Appendix A. Valves should be selected that will be easily maintained. Unless larger than 1,200 millimeters (48 inches), gate and butterfly type valves are preferred. Gate valves with cast iron bodies should be bronze fitted. Butterfly valves should be rubber seated. The type of valve operator, either electric or manual, is the designer's choice based on site-specific requirements, e.g., accessibility, frequency of use, and anticipated loads.

Chapter 8
Engines and Gears

8-1. General

Internal combustion engines used for pump drivers are of the diesel or gas-fueled type. Engine drives offer the advantage of variable speed, which may be a benefit when compared with other types of pump drives that operate at essentially constant speed. Selection criteria for internal combustion engines and electric motors are provided in Chapter 10.

8-2. Engines

Engines of the two- or four-cycle type are used for pump drives. Natural gas engines are preferred where a dependable natural gas supply is available; otherwise, diesel-operated engines should be used. Skid-mounted engines should be used when possible with all the auxiliaries except fuel tank, mounted thereon. Engines for flood control pumping service should be rated in accordance with the Diesel Engine Manufacturer Association. All rating should be based on continuous duty operation. The engine should be rated 10 percent in excess of the maximum operating requirements that would include the maximum pump horsepower requirement and losses through the drive system. The engine should also be capable of operation at 110-percent full-load rating at rated speed with safe operating temperatures for periods of 2 hours in 24 hours. Engine speed should be as indicated in the table below.

Engine Horsepower Rating	Maximum Speed - RPM
1,050 kilowatt (kW) (1,400 horsepower (HP)) and over	900
450 kW (600 HP) to 1,050 kW (1,400 HP)	1,200
Less than 450 kW (600 HP)	1,800

a. Cooling systems. Two basic types of cooling systems are radiator and heat exchanger. Selection criteria include engine size, space availability, raw or sump water supply, initial cost, operation and maintenance cost, and environmental concerns. A radiator system may have the radiator mounted on the engine base or remotely mounted. The radiator will always be located where an adequate supply of cooling air is available. For larger engines, the physical size of the radiator may make it an impractical choice. The selection of the fan and radiator location would include the noise level, heat produced, and size requirements. The heat exchanger cooling system will be the closed type. It can be an elaborate system with raw or canal water supply pumps, a shell and tube heat exchanger, and a traveling water screen (screen the raw water to the supply pumps) to cool the engine's jacket water. It could also be a simplified submerged pipe type. This type circulates engine jacket water through pipes submerged in the pump sump. Selection will be based on engine cooling requirements and the recommendation of the engine manufacturer. Some problems associated with heat exchanger cooling are freezing climates, foul cooling water, rejecting heated raw water to the canal, and engine testing restrictions when the sump or entering ditch is dry.

b. Control equipment. All engines will be designed for manual starting. Manual and automatic control devices should be of the types regularly furnished by the engine manufacturer for similar service. Automatic engine shutdown is required for engine overspeed. Visual and audible alarms and automatic engine shutdown (as a minimum) should occur for high jacket water temperature, high lubricating oil temperature, low lubricating oil pressure, gear reducer high lubricating oil temperature, or gear reducer low lubricating oil pressure. The type of speed control devices will depend upon the desired scheme of operation, but a governor to maintain speed and a suitable speed indicator should be provided in all cases. Consideration can be given to an engine shutoff method for low sump water elevation. Engine controls are generally located adjacent to the engine. Redundant remote read-out of critical engine, pump, and gear parameters may be located in an operating office for large pumping stations. The control system should be designed so that the engines can be started and operated when the electric power to the station is interrupted and automatic engine shutdown should not occur due to minor fluctuations in commercial power. A control system for engines less than 300 kW (400 HP) rating can be equipped with a rechargeable battery system for its operation. Larger sized engines will require a separate engine-generator to provide electrical power for the control system. The controls should permit operation of the engine's jacket water pump to allow cool down of the engine if required by the engine manufacturer. If the jacket water pump is engine driven, then an auxiliary motor driven jacket water pump should be considered for cool down, if required. A means needs to be furnished to manually shutoff the intake air supply to the engine to provide for critical shutdown. Crankcase explosion relief valves should be provided for diesel engines.

c. Engine equipment and auxiliaries.

(1) Clutches. Engines less than 450 kW (600 HP) may be equipped with a manual clutch mechanism, which allows the engine to be started and operated without running the pump. This permits testing of the engine without regard to water levels that may not allow pump operation.

(2) Flexible drive shafts. Flexible drive shafts eliminate the need for critical alignment of the engine to the gear reducer. The drive shaft consists of a center section with a flexible joint on each end. One of the flexible joints incorporates a splined slip joint that permits longitudinal movement to occur. The drive shaft manufacturer's published rating at the maximum engine speed should be at least 1-½ times the maximum torque of the pump that usually occurs at its maximum head condition. A drive shaft minimum length of 900 millimeters (36 inches) is desirable to allow for intentional or accidental misalignment. A vertical difference of approximately 15 millimeters (0.5 inch) (for 900 millimeters (36-inch) shaft length) should be provided between the engine output shaft and the gear input shaft to provide continuous exercise for the flexible joints. There are other types of engine-to-gear connections, such as direct through flexible couplings. This can be investigated if site conditions prevent the use of the drive shaft described above.

(3) Starting system. The engine starting system should be pneumatic except for small engines. The air system should contain a reservoir of sufficient size to permit two starts of each unit without recharge by the air compressor. The time for the air compressor to recharge the reservoir should not exceed 2 hours. Two air compressors should be provided for reliability. Unless a standby generating unit is provided for the station, one of the air compressors should be engine driven so that the air pressure can be built up during electric power outages.

(4) Prelubrication. Engine manufacturer's should be consulted as to any requirements for a prelubrication pump. Factors that are normally used to determine the need for prelubrication requirements are engine size and the expected period of time between operations.

8-3. Fuel Supply System

a. Fuel oil. The type of fuel oil used should be recommended by the engine manufacturer for the type of environment the engine will operate in. An adequate supply of fuel oil is required to ensure station operation without the need for emergency replenishment. The volume of the storage tank system should provide for a minimum of 2 days of continuous operation of all units operating at maximum horsepower. The volume provided may be increased for those stations that are remote or of such a size that quantities required would not permit ready replenishment. The location and type of fuel storage should be determined after review of the applicable local, state, and national Environmental Protection Agency (EPA) regulations.

b. Natural gas. Stations equipped with engines operating on natural gas supplied from a utility system need to be provided with a stored gas backup system if reliability of the source could cause the station to be out of operation for more than 24 hours. The volume of the gas storage system should provide for a minimum of 2 days of continuous operation of all units operating at maximum load. The storage usually consists of one or more pressure tanks above ground. All gas tanks should be installed with foundations attached to the tanks, which preclude floating of the tank in case of flooding. A station with natural gas-operated engines must be provided with devices capable of measuring air content for explosive conditions and indicating this condition with alarms both inside and outside the station. The ventilating system must be suitable for operating in an explosive atmosphere and capable of being turned on from outside the station. The sump should be ventilated in a similar manner. All installations need to be designed and installed in accordance with the National Fire Protection Association (NFPA).

8-4. Gear Drives

Most applications for pumping stations will use a vertical pump with a right-angle gear to transmit power from the horizontal engine shaft to the vertical pump shaft. Gear drives may also be used with horizontal electric motors driving vertical pumps. This permits the use of less expensive high-speed horizontal drive electric motors. Horizontal pump installations may use chain drive or parallel shaft gear reducers. The gear units should have a service factor of 1.25 when driven by an electric motor and 1.5 when driven by an engine. The service factor should be based on the maximum horsepower requirement of the pump. Right-angle drives should be of the hollow shaft type to permit vertical adjustment of the pump propeller at the top of the gear. All right-angle gear drives should be designed to carry the full vertical thrust from the pump. The gear unit should be equipped with an oil pump directly driven from one of the reducer

shafts and be capable of delivering sufficient oil to all parts when operating at less than rated speed. The transmission of power through the gear produces significant heating of the lubricating oil, and some means must be provided to reject this heat. The heat removal can be accomplished by placing an oil cooler in the engine's cooling water system or by using a separate oil radiator placed in the air stream from the engine-driven fan or located with its own fan. Engines that use heat exchangers should also use a similar system for cooling the reduction gearing. All gears should be equipped with a thrust-bearing temperature thermometer, an oil pressure gage and temperature thermometer, and oil level indicators. Automatic shutdown of the pumping unit and visual and audible alarms should be provided for high thrust-bearing temperature, high oil temperature, or low oil pressure. When cold weather operation is expected, oil heaters should be used in the gear to reduce oil thickening between operational periods. A backstop device should be attached to the low or intermediate shaft of the gear reducer to prevent reverse rotation of the pump and engine.

Chapter 9
Miscellaneous Equipment

9-1. Sump Closure

a. Purpose and use. Pumping stations with wet pit type sumps and with motor-operated closure gates should be kept in a dry condition during non-operation periods of 6 months or longer to prevent increased deterioration of the equipment located therein and to provide opportunity for inspection and repair of the pumps. Some means of sump closure are required for all stations except where hydrology conditions provide long periods where the entrance to the station is dry and the station sump can be made self draining. Consideration should also be given to the need for unwatering the sump to perform inspection or maintenance and repairs during pumping operations when operational periods are long. Due to their structural design, some pumping stations cannot be completely unwatered at one time. Individual sump bays may be required so the whole station does not need to be shutdown.

b. Types. Stop logs and gates are two types of sump closure. Stop logs or bulkheads are barriers that are placed in wall slots across a flow path. Gates are usually of the slide or roller type depending on their size and provided with an individual operator for raising or lowering. Selection of the sump closure should consider opening size cost and the severity of flow disturbance created by the different types of closures. Usually sidewall disturbance is less with stop log and roller gate slots than with slide gate construction.

(1) Stop logs. Most closures by stop logs require multiple stop logs, stacked, to reach the level of protection desired. Stop log placement usually requires a mobile crane. A mobile crane will not be furnished as part of the station construction. Sufficient stop logs should be furnished to allow one pump sump to be unwatered. Stop logs should be constructed of a material that requires a minimum amount of maintenance. In most cases, aluminum stop logs best satisfy the weight and corrosion requirements. Storage at the station with convenient access should be provided.

(2) Gates.

(a) Slide gates. Slide gates are classified as either pressure-seating or pressure-unseating type and having either a rising or a non-rising stem. In all cases, slide gates should be designed to provide positive seating by means of suitable wedges. Slide gates provide a more positive means of sealing than any other types of closure. In selection of sizes and shapes of slide gates, the utilization of manufacturers' standard products should be used in order to avoid necessity for special designs. Figure D-2, Appendix D shows dimensions of typical standard slide gates. In general, the use of pressure-unseating gates should be avoided unless the stem threads are exposed to fouling or abrasive materials, it would be difficult to maintain the wedges due to continuous submergence, or it would be costly to either bulkhead or cofferdam the upstream side. Rising-stem gates are preferred due to their easy maintenance and the locations of thread engagement outside the corrosive area. Non-rising stems are to be used only if there is insufficient head room for a rising stem. Slide gates are normally limited to a 3.0-meter (10-foot) opening width. Gates used for pumping station service are usually of the flush bottom style. This style gate permits station design without steps in the flow line. All slide gates should be mounted on an "F" type wall thimble which is cast into the concrete wall. A flange back type gate is recommended since they are the strongest. The slide gate frame and slide should be of cast material with all wedges, seats, and fasteners to be constructed of bronze or stainless steel. The gate stems should be made of stainless steel.

(b) Roller gates. Roller gates are used when the gate opening is too large for slide gates. A roller gate consists of a fabricated steel leaf with cast iron wheels and rubber seals. Vertical recesses at the sides of the gate opening are provided with opposing rails to guide movement of the leaf. The top and side rubber seals on the gate seat on embedded stainless steel rubbing plates. These seals are of the "J" bulb type and are aided in sealing by water pressure deforming the stem of the seal. The bottom seal is usually a strip of heavy rubber across the bottom of the gate leaf which seats on an embedded stainless steel plate in the floor of the opening. Roller gates can be constructed with the wheels on the dry side of the leaf; however, this construction makes it more difficult to obtain a seal since an unseating head is on the seals. Since current construction uses self-lubricating bearings on the wheels, the need to be in the dry is not as important. In most cases, the structural design of the leaf is done by the gate manufacturer. The embedded metal rail assemblies on each side of the gate along with the top and bottom embedded metals are furnished by the gate manufacturer. Installation of all of the embedded metals for the roller gates should be supervised by an erection engineer from the gate manufacturer. Roller gates have a higher maintenance cost, and it is more

difficult to obtain a water tight seal; therefore, they are to be used only when standard-size slide gates are not available.

(c) Operators. Slide and roller gates are usually raised and lowered by means of a manual or electric motor-operated geared hoist. In special cases, hydraulic cylinders can also be used for raising and lowering operations. For manual operation, portable electric power wrenches may be used when the gates are small, easily accessible, gate operation is infrequent, and the time required to open or close the gates is short. For larger gates, when electric service is available (less than 1.49 square meters (16 square feet)), the gate operator should be motor operated. Where the size and weight of a gate, or the quantity of gates, are such that manual operation would require two persons for more than 30 minutes, provision for power operation should be considered. Fixed power operators should be provided when portable units must be manhandled to inconvenient and difficult to reach places. These hoists should be equipped with torque and position-limiting devices. All power hoists should also be equipped for manual operation. Tandem-operated hoists using two stems but one motor are required for any gate whose width is equal to or greater than twice its vertical height, or for a roller gate whose width is greater than 3.66 meters (12 feet). The hoist is usually mounted on a steel beam system which must be designed to take both the up thrust developed during seating and the down thrust developed during unseating. A computation method used to determine thrust loads and stem diameters is shown in Appendix D. The surface finish on the threads should not be greater than 63 rms, a radius of 0.76 millimeters (0.030 inch) should be provided on the thread corners, and the lift nut and stem should be manufactured at the same location so that their fit may be confirmed. Hydraulic cylinder operation of the gate stems is usually considered only for large stations with eight or more gates where the costs required for multiple hydraulic units are justified. Operator motors should be rated for continuous duty.

9-2. Trash Protection

a. General. Trashracks are required to protect the pumps from debris which could clog or damage the pumps. Accumulated debris in front of the racks should be removed to prevent structural damage to the trashracks or damage to the pumps due to restricted flow into the pump sump. Hand raking and power raking are two methods used for removing trash from the rack. Hand raking should be used only for the smallest stations and then only when the amount of trash can be handled with manually raked methods. Hand raking should not be used when the rake handle has to be longer than 20 feet to reach the bottom of the rack with the operator standing on the trashrack platform. Trashrack sizing and bar spacing are furnished in EM 1110-2-3102. Pump manufacturers should also be consulted concerning their recommended bar spacing. Any hand rake to be furnished that is of a length greater than 2.74 meters (9 feet) should be constructed of a non-electrically conductive material as the operator may inadvertently touch energized overhead electrical lines while cleaning the trashrack. Handrailing should be provided for safe hand-raking operations.

b. Power rake types. There are three general types of power-raking equipment: cable hoist, mechanical, and catenary. These types were classified based on operating characteristics or drive mechanisms used to remove trash. Each of the types has several sub-categories. All the types are described and shown in Appendix C. In general, only one raking unit will be provided for a station if it is of the type that can be moved from trashrack to trashrack. On large stations with four or more pumps or those stations where extreme amounts of trash are possible, multiple trashrakes should be used. Most types of rakes will not handle all types of trash. They should be selected to handle the trash that will be in greatest quantity and is most likely to cause clogging problems. Power-raking units should not be remotely operated unless specifically designed to protect the mechanism from breakage should a lock up occur due to trash. Consideration should be given to the method of handling the trash after it is raised to the forebay platform.

c. Selection. Selection of the type of trashraking equipment is based on the anticipated types of trash and its quantity. Field surveys may be performed to determine the type of trash and possible amounts. Similar drainage basins can also be used for comparison as can other pumping stations in the same general area. An attempt should be made to estimate the amount of trash to be removed and the time period during which this trash would accumulate at the station. In general when comparing two different drainage basins, the amount of trash per unit of area diminishes as the total contribution area increases. The greatest quantity of trash usually occurs during the first peak inflow to the station during rising water conditions. Consideration should be given to the installed equipment costs, operating costs, and maintenance costs in addition to the rake's efficiency. Because of its raking capabilities, it is sometimes necessary to select the raking system that might have the

highest costs. Additional information on selection procedures used is indicated in Appendix C.

9-3. Equipment Handling

a. General. A station crane should be provided, for all but the smallest stations, for handling the major items of equipment. Small stations may be built with removable ceiling hatches so that a mobile crane may be used when work is required.

b. Station cranes. Since the service expected of the crane is standby, a Class 1-A in accordance with the Crane Manufacturers Association of America can be used. Bridge-type cranes are usually used, but a monorail type over the pumping units may be used if that is the only requirement for the crane and it is capable of doing the job. Cranes of less than 2,722-kilogram (3-ton) lifting capacity should be of the manual type. Cranes with capacities from 2,722- to 9,072-kilogram (3- to 10-ton) lifting capacity may be equipped with a motorized hoist while still retaining manual travel arrangements. Cranes over 9,072-kilogram (10-ton) capacity should be of the three-motor type, where all functions of the crane are motorized. Hoist and travel speeds can be kept to a minimum since the crane will be used only for major maintenance. Cranes over 10-ton capacity should be equipped with multi-speed type controls with speeds such that "inching" is possible to permit close positioning of the loads. The high position of the crane hook should be at such an elevation to permit removal of the pump in pieces; however, allowance should be made for use of slings and lifting beams plus some free space. If a hatch is provided in the operating floor, the crane hook should have sufficient travel to reach the sump floor to permit removal of items from the sump. The crane should have a capacity large enough to lift either the completely assembled motor or pump, but not both at the same time except for submersible pumping units, in which case the entire unit is lifted. Consideration should be given to removal of equipment from the station when determining the crane travel requirements. It may be necessary to run the crane rails to the outside of the station in order to load the equipment onto hauling equipment rather than provide space inside the station for this equipment. Because most stations are usually located some distance from rail facilities, trucks should be considered for movement of the equipment to or from the station. Station design may permit the use of chain blocks from I-beams or from arrangements of hooks in the operating room ceiling where the loads are small. Permanently embedded eyes or hooks in the sump may be required for those pump parts that cannot be raised overhead with the station crane. This is usually required only for those pumps that have part of the pump bowl embedded in the sump ceiling.

9-4. Ventilation

a. General. Ventilation is provided for both safety and heat removal purposes. Ventilation facilities should be segregated between pump sump and operating areas. Except for those stations in urban areas where explosive conditions are known to occur in the sewer adjacent to the station or in the sump area, gravity ventilation will be adequate for all zones during inoperative periods. For those cases where the hazard of an explosion exists, the station should be designed so that it may be completely ventilated. All equipment used in connection with the ventilating system should be electrically rated for use in the explosive condition expected. The operating period, equipment ratings, duct arrangements, locations of outlets and fresh air inlets, and all other details should be based on accepted principles outlined in publications of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

b. Sump ventilation. Mechanically forced ventilation should be provided for all wet and dry sumps during operating periods to prevent accumulation of gases. Gravity ventilation of the sump will be adequate if the trashrack is not enclosed, operation is not required from a lower platform, and the sump is not exposed to sewer gases. The mechanical ventilation of sumps should be accomplished using motor-driven blowers removing air from the sump while fresh air is ducted into the sump. The blower should be located outside the sump and should be connected to ductwork from the sump and to ductwork which discharges to the atmosphere outside the station. The discharge from the blower should be located such that recirculation of fumes into the operating area is minimum. The suction ducts from the blower should run to a point near the sump floor and shall be equipped with louvers that allow suction from either the floor or ceiling area of the sump. The louvers should be operable from outside the sump. If the sumps are separated in such a way that openings are not located at both the top and bottom of the sumps, individual ventilation will be required for each sump. It is a requirement that all sump areas must be ventilated before any personnel enter. The ventilation rate should provide a minimum of 15 air changes per hour based on the total volume of an empty sump. The fresh air inlet areas should be a minimum of twice the outlet area to prevent high losses. For stations pumping sanitary flows or a mixture thereof, the

ventilation system should be in operation continuously when in a pumping mode.

c. Operating area ventilation. The operating area is ventilated to remove any gases and to remove excess heat buildup caused by the operation of the electrical and mechanical equipment. The system design is based on the amount of air to be removed in order to have an inside temperature not greater than 40 degrees C (104 degrees F). The design should consider outside maximum temperatures occurring coincident with operation. As a minimum, the ventilation equipment should be designed for at least six air changes per hour to provide ventilation during nonpumping periods. Gravity or mechanical ventilating equipment can be used to satisfy these requirements.

9-5. Equipment Protection

Various means have been used to protect equipment, particularly the electrical equipment, of flood-protection pumping stations from deterioration and general moisture. The methods employed are:

(1) Providing electric heaters within the housings of the motors and switchgear.

(2) Heating the operating room.

(3) Dehumidification of the operating-room area, which includes sealing of the motor room and the application of vapor barrier material to the interior surfaces.

(4) Heating the interior of the motors and switchgear by means of a central heating plant.

(5) Dehumidification of the interior of the motors and switchgear by means of individual dehumidifiers.

Operating experience indicates that method (1) above is the most practical and economical for small- and medium-size stations. For the larger stations, using motors rated 1,500 kW (2,000 HP) and above, methods (4) and (5) may be feasible. Dehumidification methods are usually less costly to operate; however, maintenance and replacement costs are such that local users seldom keep the units running after initial failure. The sizing of electric heating elements in system (1) is done by the equipment supplier; however, the ambient conditions should be specified for this equipment.

9-6. Sump Unwatering

a. General. Provisions should be provided to unwater the sumps between pumping periods for inspection and to perform maintenance and repairs. The unwatering may be accomplished by means of one or more sump pumps. The wet sumps should be made to drain to an unwatering sump location where the sump pump is installed. The sump pumps should be of the submersible motor/nonclog pump type. The sump pumps should be sized to allow stations of 11 m^3/s (400 cfs) of less capacity to be completely unwatered within a 6-hour period. The 6-hour period allows the unwatering to be accomplished within a normal work day. For large stations with more complex systems, the unwatering system may be designed to unwater one-third of the station within the 6-hour period. Unwatering sumps are normally located outside the main pump sumps to avoid disturbing flow patterns to the main pumps. Any interconnecting piping should be kept to a minimum and should be installed so that it may be unclogged. Consideration should be given to designing the unwatering piping and valve arrangement or providing other means to allow rewatering of the sumps. If bulkheads are used as the means of sump closure, this can be accomplished by providing a valve on the bulkhead.

b. Sump pumps.

(1) General. The sump pump should be of the submersible motor, nonclog sewage type suitable for passing maximum-sized trash. The pump should be rated to pass a minimum of 64-millimeter- (2.5-inch-) diameter solids. The pump/motor should be capable of pumping down until it breaks suction and rated to run with its motor above the water surface for a minimum of 1 hour without damage.

(2) Semipermanent. This type of sump pump is mounted on a discharge shoe that allows the pump to be removed using a system of rails or cable guides without unbolting from the discharge piping. Unless the station crane can be centered over the pump, a separate hoist should be provided for pump removal. This is usually accomplished by using a wall-mounted jib with a hoist. Head room limitations may require multiple lifts to be made. This is accomplished by fitting the lifting chain connected to the pump with evenly spaced eyes on short lengths of chain that allow the pump to be hung from a

beam or embedded hook while releasing the load from the lifting hoist for a lower attachment.

(3) Portable. The pumps used for this type would be similar to the semipermanent type except that it would discharge through a hose. When this type of pump is used, a means of placing and removing must be furnished if the pumping unit weighs more than 27 kilograms (60 pounds). Usually the station crane provided for equipment removal can be used if a lifting chain similar to that described in the previous paragraph is provided along with an access opening in the operating floor. Usually two different-sized pumps are provided, since it may not be possible to use a depressed sump. In this case, a larger pump would be used to unwater down to approximately 0.5 meter (1.5 feet) (shutoff point of pump provided) of water remain. A small pump would then be used to remove the remainder of the water and handle leakage. This method usually does not permit complete removal of water from the sump floor.

(4) Control. Operation of the semipermanent sump pumps is by means of a bubbler system or electrodes. Portable sump pumps are usually operated by manual means; some pumping units are equipped with current sensors that control the on-off cycling of the pump by sensing the change in motor current which occurs when the pump breaks suction.

9-7. Pump Bearing Seal and Lubrication Systems

Grease lubrication of all mixed-flow/axial-flow vertical lineshaft pump bearings is the standard lubrication utilized because of the type of bearing system used and the usual infrequent periods of operation. Rubber pump bearings are not used since a dependable water supply is usually not available and the use of pumped liquid for lubrication is not always available when periodic test operation is necessary. Bearings exposed to water pressure should be provided with seals. Usual pump construction provides for a shaft seal immediately above the impeller. This seal is usually a lip-type seal installed so the water pressure seats the lip against the shaft. In time these seals will leak, letting pumped water at discharge bowl pressure enter the shaft enclosing tube. To preclude this water from traveling up the tube and leaking onto the operating floor, the pump should be equipped with an overflow pipe connected to the enclosing tube and leading to the sump or a built-in catch basin where the shaft leaves the baseplate with a drain to the sump. Individual seals for each bearing are not used except for the bearing below the impeller, if used. Guide Specification CW15160, Vertical Pumps, Axial and Mixed Flow Impeller Type, has a section that covers the grease lubrication system for stormwater pumps. Each bearing should have a separate grease line and a feed indicator. All lubrication lines below the maximum water level should be protected against damage or breakage from floating debris. The lubrication system should be automatic with a control system that provides a prelube cycle before the pumps are allowed to start and an adjustable period between greasing cycles. Manual greasing systems should be considered for use only on pumps such as sump pumps and for flood control pumps whose capacity is less than 600 liters per second (ℓ/s) (20 cfs) and where the time of operation is such that daily greasing would not be required. The frequency of greasing is based both on the manufacturer's recommendations and how the equipment will be operated.

9-8. Pump Bearing Temperature System

Pumping units with discharges greater than 600 millimeters (24 inches) should be fitted with detectors to determine the temperature of each pump bowl bearing. If the pump will operate less than 100 hours per year, a temperature detector should be installed only at the impeller bearing. The system should consist of resistance temperature detectors (RTD) mounted so that they are in contact with the bearing, and a monitoring system that allows display of individual bearing temperatures and alarms when preset high temperatures are exceeded. It is recommended that the monitoring and alarm system be designed as part of the electronic control system of the station and not part a separate system. A detail of a pump bearing RTD mounting is shown on Plate 9.

9-9. Pump Reverse Rotation Protection

Pumping units are subject to reverse rotation when the unit is shut down. Depending on the available head and the design of the unit, reverse rotation may reach 165 percent of the forward running speed of the unit. This can occur as a planned operation such as occurs for pumping units when the water runs out of piping between the top of the protection or the discharge flap gate and the pump or possibly on an extended basis during failure of a siphon breaker valve or discharge flap gate. All pumping units should be designed to withstand this reverse rotation. Two means are used for this protection. The first is to prevent reverse rotation by the use of a reverse ratchet or overrunning clutch mounted on the motor or gear reducer. The second is to design the pumping unit, including the drive motor, to withstand the maximum speed possible during reverse rotation. Units

driven by engines must be equipped with a reverse ratchet or overrunning clutch since any reverse rotation could damage the engine. Reverse ratchets of the rolling pin or drop pin design should be used.

9-10. Comfort Heating and Air Conditioning

A heated and air-conditioned space should be provided for operator use during pumping operations. This space can be heated and cooled with a small packaged unit. The entire operating room should be provided with electric heat capable of maintaining a temperature of 13 degrees C (55 degrees F) when outside temperatures are at the normal low for that area. These heaters are provided to permit maintenance operations at any time of the year and are usually electric since their operation time will be limited.

Chapter 10
Pump Drive Selection

10-1. General

Several options are available to the designer when considering the selection of a pump drive for flood-protection pumping stations. The two factors that must be investigated when making this selection are reliability and cost. Alternative studies should be made considering these two factors. The two types of drives to be considered are electric motors and internal combustion engines. Gear drives are required as part of the drive system when using engines. Gear drives can also be used with electric motors permitting the use of a less expensive higher speed motor and allowing a greater variation of the pump speed than permitted with direct drive.

10-2. Reliability

The primary consideration in the selection of any pump drive is reliability under the worst conditions likely to prevail during the time the station will be required to operate. The reliability of the electrical power source should be determined from power company records of power outages in that area and their capability to repair any outages. Consideration of power from two different power grids within a company may be advisable for large pumping stations. The reliability of the various different types of equipment must also be studied. Electric motors and engines are usually very reliable while the necessary accessories to operate these units are less reliable. The complexity to operate and repair the piece of equipment by the operating personnel should also be considered. Equipment repair requiring specialized service personnel may require much greater time to put it back into service.

10-3. Cost Considerations

a. General. Unless reliability considerations are important enough to decide what type of drive to use, annual cost comparisons should be made of all systems under study. The annual costs should include the installed, operating, maintenance and replacement costs. After all costs have been established, a life-cycle cost analysis can be performed.

b. Installed costs. The installed costs include the construction costs of all the equipment and the electric power supply costs, which usually would include the cost of the substation plus the power line to the station. These costs should be figured on an annualized basis using the number of years determined for the project life.

c. Operating costs. The operating costs would include the cost for energy and manpower expenses. To accurately estimate the total energy costs, an estimate of the amount of pumping required for each month of the year must be obtained. The source of pumping time should be obtained from hydrology period-of-record routing studies. The current price schedule for electric power from the supplying utility or the market price of engine fuel can be used to determine the costs for all stations except for large stations. For large stations, a study of future energy costs over the life of the project is justified. In determining the total cost of electricity, it is important to include both the cost for the energy used (kilowatt hours) plus any demand (capacity) charges. Demand charges by some power companies may be a major part of the energy costs.

d. Maintenance costs. Maintenance costs include manpower and materials for both preventative and major repairs. Unless the station has specialized equipment, these costs are usually estimated using the following percentages of the installed equipment costs:

Station Size	Percentage (%)
25 ℓ/s (1.0 cfs)	0.5
15 m^3/s (530 cfs)	5.0

Percentages for intermediate station sizes are determined proportionally with the above values. The maintenance cost of unusual or specialized equipment would be determined separately and would be an additional amount.

e. Rehabilitation and replacement costs. Rehabilitation and replacement costs include those costs required to keep the station operable for the project life. For a normal 50-year station life, most of the equipment would be rehabilitated or replaced at least once, except for very large pumping stations. The periods between the rehabilitation/replacement could be shorter if the operating time were great. Major items such as pumps, drivers, and switchgear are figured to be rehabilitated or replaced once during the 50-year life. This major equipment rehabilitation or replacement is usually estimated to occur between 20 and 40 years after placing the station into operation. Rehabilitation costs for major equipment can be estimated to be 35 to 45 percent of replacement costs depending on the condition of the equipment. Other items of equipment may be replaced several times during the project life depending on their use or may require

only partial replacement. It is most likely that equipment, except for the pump and motor, may not be replaced in kind. Therefore, the replacement cost should include all engineering and structural modification costs as well as the equipment costs. In any event, the equipment removal costs including the cost of all rental equipment plus the installation cost of all new equipment should be included.

Chapter 11
Pump and Station Hydraulic Tests

11-1. General

Two types of tests are generally performed in connection with a pumping station and its pumping equipment before the station is built. Tests are run on pumps, either full size or model, to determine their performance and to demonstrate that the performance of the pump complies with specification requirements. Physical hydraulic model tests of the pumping station substructure may also be conducted to assess its hydraulic performance.

11-2. Pump Tests

a. General. The pump performance tests are conducted at the pump manufacturer's facility. Field testing to prove performance at the completed station is more difficult and costly if not impossible in many cases. All pumps should be factory tested to determine their capacity, total head, efficiency, and horsepower requirements. Pumps normally should also have a cavitation test performed. This test is usually performed on a model. Model testing specifications and parameters can be found in Guide Specification CW 15160, Vertical Pumps, Axial and Mixed Flow Impeller Type.

b. Description. Factory pump tests are either performed on full-size pumps or performed on a model pump of the full-size pump. If a model pump is used, it should be geometrically similar to that of the full-size pump and of the same specific speed. Either type of test is acceptable to check the ratings of the pump; however, because of size limitations, most manufacturers limit full-size tests to pumps of less than 2 m^3/s (75 cfs) capacity. A pump test consists of determining the total head, efficiency, and brake horsepower for a range of capacities. All testing should be witnessed by the District office design personnel performing the station design. The dimensions of the model and prototype impellers should be made by using drawings, measurements, and scaling factors. The performance factors measured include capacity, pressure head, horsepower, and suction pressure when cavitation performance is to be determined.

c. Performance tests. All pumps for flood-control pumping stations should have their performance verified by tests. For installation of identical pumps in a station, only one of the pumps needs to be tested. Tests on similar pumps used for another station will not be acceptable as equivalent tests. The test setup should permit, and the specifications require, the pump to be tested over a range of heads starting at least 600 millimeters (2 feet) greater than the highest total head requirement or at shut-off and extending down to the lowest head permitted by the test setup. The test should, if an unstable range ("dog leg" in the head curve) exists. Sufficient test points should be run to adequately define the unstable range. This allows the pump manufacturer to demonstrate that their pump does not operate in the unstable range. The lowest head tested should be at least equal to the total head that occurs for 95 percent of the operation time during low head pumping conditions. For pumps with capacities greater than 11 m^3/s (400 cfs), the model tests should be required to cover the complete head range required by the specifications including down to the lowest total head specified. All performance tests should be run at the same head at which the pumps will operate during actual duty. The readings of capacity and brake horsepower along with the total head will be used to determine the pump efficiency. For model tests, no correction factor for efficiency due to size differences will be allowed. Tests will be performed at water levels similar to that which will occur during actual operating conditions. An actual scale model of the station's inlet and discharge systems is not warranted except for pumps over 14 m^3/s (500 cfs). This requirement should also be used when the sump is not designed by the Government and is a part of the pump contract or has some complicated flow passage which has not had a sump model test. The pump test is used to ascertain the performance of the pumps, not how it reacts in the prototype sump except in the cases listed below. It is expected that the factory sump would be free of vortexes and adverse flows so that good results are obtained. Manufacturers are responsible for furnishing a pump that conforms to the specifications and meets the performance in the sump to be provided by the Government. The pump manufacturer should be held responsible for poor sump design, evidenced by vortexing and bad flow conditions within the sump, when the contract specifications require the sump to be designed by the pump manufacturer. Except for this special case, the pump manufacturer warrants performance of the pumps only, not the sump, and the activity within the sump would be the responsibility of the Government. Duplicate model pump sumps should include the sump from the inside of the trashrack. Any pump using a formed suction intake should be tested with this formed suction intake. Vertical pumps should be tested only in the vertical position.

d. Cavitation tests. Cavitation tests are performed to indicate the operating conditions in which the pump will start cavitating. For purposes of design, it is assumed

that cavitation starts when the pump performance starts to decrease as the effective sump level is reduced. The inception of cavitation definition has not been agreed upon by all the pump suppliers and users. A typical pump test consists of operating the pump at a fixed capacity while reducing the pressure on the suction side of the pump. As the suction pressure is reduced, a point is reached where a plot of the head-capacity curves deviates from a straight line. The Corps specifies the start of cavitation at a point where the curve starts to deviate from the straight line. Others use as the start of cavitation, a point where a 1- or 3-percent deviation in performance from the straight line occurs. Submergence requirements, as used in this manual, are based on the Corps criterion of zero deviations from the straight line portion. In most cases, some cavitation has already started at either point; therefore, a design allowance of extra submergence should be provided in addition to that indicated by the tests results. The submergence allowance is based on the estimated number of operating hours expected annually. The amounts of allowance are indicated in Appendix B. In all cases, the cavitation tests should be performed in a test setup that uses a variation of water levels on the suction side of the pump.

11-3. Station Tests

a. General. Hydraulic model tests of pumping station sumps and discharge systems should be performed by WES for stations with unique or unusual layouts. The procedure in ER 1110-2-1403 should be followed when requesting model tests. A decision should be made on the requirement for model testing during the General Design Memorandum stage so that the results of any testing are available during the design of the station. Test results are usually not available until 6 to 9 months after forwarding a work order to the test agency.

b. Sump model tests. The primary purpose for performing a model test of a pumping station sump is to develop a sump design that is free of adverse flow distribution to the pump. Optimal flow into a pump impeller should be uniform without any swirl and have a steady, evenly distributed flow across the impeller entrance. However, it is usually not possible to obtain the optimal flow conditions without considerable added expense. Acceptable pump operation will occur when a deviation in the ratio of the average measured velocity to the average computed velocity is 10 percent or less and when the swirl angle is 3 degrees or less. Swirl in the pump column is indicated by a vortimeter (free wheeling propeller with zero pitch blade) located inside the column. Swirl angle is defined as the arc tangent of the ratio of the blade speed at the tip of the vortimeter blade to the average velocity for the cross section of the pump column. There should not be any vortex formations allowing entrance of air into the pump. In order to accurately simulate the field conditions, the model should include sufficient distance upstream of the station to a location where changes in geometry will not affect flow conditions in the sump. The prototype-to-model ratio is usually determined by the testing agency, but it should not be so large that adverse conditions cannot be readily observed. Normally the model should be sized to ensure that the Reynold's number in the model pump column is equal to or exceeds a value of 1×10^5. Reynold's number is defined by the following equation:

$$R = dV/r \qquad (11\text{-}1)$$

where

R = Reynold's number
d = column diameter
V = velocity
r = viscosity of water

c. Discharge model tests.

(1) General. These tests are performed to evaluate the performance of a discharge system. Usually two types of systems are investigated, discharges which form a siphon and/or through the protection discharges for large stations where the friction head loss would be a substantial portion of the total head of the pump.

(2) Siphon tests. The siphon tests are run to determine that a siphon will prime the system in the required time. This test is recommended when the down leg of the siphon system is long or it contains irregular flow lines and for pumps of 20 m^3/s (750 cfs) or greater having a siphon built into the station structure.

(3) Discharge tests. A head loss test should be considered only for pump discharges with capacities of 20 m^3/s (750 cfs) or greater and where the accuracy deviation for estimating the total head exceeds 20 percent of the total head. Other considerations would be the sizing of the pump and its driver. In some cases, a safety factor of 10 to 20 percent of the total head may not change the pump unit selection, and therefore the expense of a discharge test may not be warranted. For those stations where the size of the driver is close to its rating, a test may be in order to ensure that the driver would not be overloaded due to error in head determination.

(4) Other tests. Additional tests may also be required to fully prove the station acceptable. These could include energy dissipation tests of a saxophone outlet and a stilling basin or apron. Tests can also be made on models of existing pumping station sumps where operating difficulties have been experienced.

Chapter 12
Earthquake Considerations

Seismic investigation of the pumping station, as specified in EM 1110-2-3104, will indicate if required measures are necessary for the pumping station. If the foremen-tioned investigation shows that damage from earthquakes is possible, the design of anchorages and support for the mechanical and electrical equipment shall be in accor-dance with TM 5-809-10. If the seismic investigation indicates that seismic design is not required, design methods as indicated in TM 5-809-10 should be followed where the additional cost is minimal.

Chapter 13
Power Supply

13-1. General

When the power requirements for the pumping station have been tentatively established, the adequacy of the intended source of electrical power and any limitations of that source must be determined before proceeding with station design (Plate 10). The design investigations should disclose the optimum system operating voltage, capacities, and location of existing utility facilities which may be involved in the supply of power to the pumping station, supply system reliability, voltage regulation, inrush current limitations, power factor restrictions, and short circuit characteristics. The Electric Power System Data Sheet in Appendix G is a convenient means to organize the information received.

13-2. Station Operating Voltage

It is extremely important that the proper operating voltage for the motors be selected, if the minimum overall installed cost of equipment is to be realized. Most flood-control pump stations operate at either 480 or 4,160 volts. As a general rule-of-thumb, motors of 150 kW (200 HP) and below are usually most economically operated at 480 volts. Above 150 kW (200 HP), 2,300- or 4,000-volt motors should be considered. Once the station capacity has been determined, the utility should be contacted to determine what utilization voltages are available. The utility rate structure and discounts such as untransformed service credit must also be obtained and analyzed. Determination of the most economical operating voltage requires accurate estimation and comparison of the complete electrical installation costs required for each operating voltage considered. Costs which must be considered include line construction, substation installation, motors, controls, conduit/cable sizes, and floor space required.

13-3. Power Supply Reliability and Availability

a. General. The first step in assuring an adequate power supply to a pumping station is to define the degree of reliability needed. This is not an easy task that results in the assignment of a numerical value. It is, instead, an evaluation of the tolerable power outages versus the additional costs to reduce the probability of outages. Some factors to consider in determining the degree of reliability needed in the power supply are:

(1) The type of property being protected. Is it cropland, industrial plants, or urban areas?

(2) The consequences if the pumping station fails to operate when required. Would an industrial plant be inundated causing immediate damage or could crops planted in a rural area tolerate submergence for a short time? Is ponding available? Would residential areas be flooded? Could there be potential human injury?

(3) The frequency and duration of outages that are acceptable to prevent any of the above.

(4) The time of year flooding is likely to occur. Does that pose any special problems such as overloading total utility capabilities?

Once the designer has established a feel for the need of continuity of service, contact with the utility is necessary to establish a system to meet that need. Several meetings or correspondences may be required to work out final details of the system. Chart G-1 of Appendix G is a flowchart for interfacing with the power company.

b. Availability. Availability could be defined as the long-term average that the electric service is expected to be energized. Outage data, given over a 5-year period, are usually available from the utility. The number of outages and duration of those outages over the 5-year period for the substation which will supply the pumping station can be used to calculate the availability.

c. Distribution system alternatives. Plate 11A depicts the functional components of a typical electric power system. The pumping station designer will primarily be concerned with subtransmission and distribution systems when discussing reliability considerations with the utility. Basically, there are two types of distribution systems:

(1) Radial.

(2) Network.

A radial system has only one simultaneous path of power flow to the load; a network has more than one simultaneous path of power flow to the load. A complete listing of the variations of these two broad groups falls outside the scope of this document. For an in-depth description of the various configurations, consult *Electric Utility Engineering Reference Book--Distribution Systems* by the Westinghouse Electric Corporation (1980). Plate 11B

indicates some of the more commonly used distribution system configurations. Beginning at the top left of the drawing with the network primary feeder, the system's reliability increases as one moves clockwise around the loop. In general, the usage of a radial feed should be limited to projects where either the economics or characteristics of the protected property do not justify or require a more expensive network. Not all of the network schemes shown will be available from every utility. Consultation with each utility will be necessary to provide the appropriate system for the particular application.

13-4. Pumping Station Distribution Substation

a. Layout and design. Normally the Government contracts with the local utility to design, construct, operate, and maintain the power supply to the pump station. In some cases, the electric utility will ask the Government to provide the transformer pad as part of the pumping station contract. In such cases, close coordination between the utility, the Government, and the contractor will be necessary to ensure pad sizes, and mounting bolt locations are as required by the utility's transformers or other substation equipment. The substation should be located as close to the pumping station as possible. Further guidance on rights-of-way, ownership, operation, etc., of the transmission line and substation may be found in TM 5-811-1, Electric Power Supply and Distribution.

b. Transformers. The type of transformer used, i.e., whether single-phase or three-phase, should generally be determined by the availability of replacements from the local power company stock. Most utilities keep an inventory of replacement transformers of the various sizes necessary to provide quick replacement. The designer should inquire as to the location of transformer storage and the length of time required to transport and install it in an emergency. All transformers used must be non-PCB to comply with all Federal, State, and local laws. It is common in rural areas to employ three single-phase transformers connected either wye-delta or delta-delta so that, in the event of a transformer failure, they can remain in operation when connected in an open-delta configuration. However, this configuration should be used with caution since it prohibits the application of ground fault relaying as well as producing inherent unbalanced voltages which could result in the overloading of motors. Another, more attractive, option would be the furnishing of a fourth single-phase transformer or a second three-phase transformer as a spare.

13-5. Supply System Characteristics

An interchange of information between the designer and the utility is necessary if the pumping station electrical system is to be compatible with the power supply furnished. The designer should obtain the data requested in Appendix G from the local utility supplying power to the proposed pump station. To prepare the short-circuit studies indicated in Paragraph 23-3, the designer will need to obtain the maximum fault current available from the utility as well as information concerning the distribution substation transformer impedance. The designer should transmit station loads and motor starting requirements to the local utility as soon as they become available so that the utility can prepare an analysis of the impact upon their system. The utility can then advise the designer of power factor and motor inrush current limitations. After details of the electrical system have been coordinated, the designer should request time-current curves of the substation primary side protective devices so that a coordination study as described in Paragraph 23-2 can be prepared.

13-6. Pumping Station Main Disconnecting Equipment

For guidance on selection of the pumping station main disconnecting equipment, see Paragraph 15-2.

Chapter 14
Motors

14-1. General

a. Motor types. Constant-speed motors of either the squirrel-cage induction or synchronous type are the preferred drives for pumps installed in flood-protection pumping stations. Both squirrel-cage and synchronous motors are available in speed ranges and sizes that embrace most requirements.

b. Vertical-type motor construction. Usually, the vertical-type motor construction is preferred since it requires a minimum of floor space, which contributes significantly to an economical pumping station layout. The simplicity of the vertical motor construction also contributes to station reliability. Horizontal motors with gear drives have been used in some applications, but any first cost advantages must be weighed against increased operation and maintenance costs as well as decreased reliability over the life of the project. The gear reducer and its associated auxiliary equipment are additional components that are subject to failure. Comparative costs should include installation and maintenance costs for gear lubricating pumps, cooling water pumps, associated piping, monitoring equipment, etc.

c. Full-voltage starting. All motors should be designed for full-voltage starting, even if incoming power limitations indicate that some form of reduced-voltage starting is required. For installations having siphonic discharge lines, the power required to establish prime should not exceed the motor rating plus any additional service factors. This is necessary to assure successful operation in case siphon action is not established.

d. Contractual requirements. The contractual requirements for the majority of induction and synchronous motors used in flood-control pumping stations are described in Guide Specifications CW 15170, Electric Motors 3-Phase Vertical Induction Type (for Flood-Control Pumping Stations) and CW 15171, Electric Motors 3-Phase Vertical Synchronous Type 1500 Horsepower and Above (for Flood-Control Pumping Stations).

14-2. Induction Motors

a. Squirrel-cage. The squirrel-cage induction motor has a stator winding which produces a rotating magnetic field that induces currents in a squirrel-cage rotor. The squirrel-cage consists of a number of metal bars connected at each end to supporting metal rings. Current flow within the squirrel-cage winding produces the torque necessary for rotor rotation. Squirrel-cage induction motors have very simple construction, with no electrical connections to the rotor, and hence they possess a very high degree of reliability. However, the squirrel-cage rotor does not rotate as fast as the revolving magnetic field setup by the stator winding. This difference in speed is called "slip." Because of this inherent feature, squirrel-cage motors are not as efficient as synchronous motors, whose rotors rotate in synchronization with the magnetic field. There are three basic variables that classify motor performance types. These are:

(1) Starting torque.

(2) Starting current.

(3) Slip.

Motors can have high or low starting torques, starting currents, and slip. However, these six variables are not produced in every combination. For example, high resistance rotors produce higher values of starting torque than low resistance rotors. But high resistance in the rotor also produces a "high slip" motor. A high slip motor, by definition, has higher slip losses, hence lower efficiency, than an equivalent low slip motor.

b. Wound-rotor. The wound-rotor induction motor has coils instead of conducting bars in the rotor circuit. These coils are insulated and grouped into poles of the same number as the stator poles. The coil winding leads are attached to slip-rings. The brushes that travel along the slip-rings are connected to variable external resistances. High starting torques with relatively low starting current can be obtained by adding external resistance to the rotor circuit. As the motor comes up to speed, the resistance is gradually reduced until, at full speed, the rotor is short-circuited. Within certain limits, the motor speed can be regulated by varying resistance in the rotor circuit. It is not commonly used in flood-control pumping stations.

14-3. Synchronous Motors

a. Operating principle. The synchronous motor starts and accelerates its load utilizing the induction principles common to a squirrel-cage motor. However, as the rotor approaches synchronous speed (approximately 95 to 97 percent of synchronous speed), a second set of windings located on the rotor is energized with direct current. These field coil windings are responsible

for providing the additional torque necessary to "pull" the rotor into synchronism with the revolving magnetic field established by the stator windings. The time at which direct current is applied to the field coil windings is critical and usually takes place when the rotor is revolving at approximately 95 to 97 percent of synchronous speed.

b. Field coil winding excitation. There are several methods commonly employed to achieve field coil winding excitation. Generally, brushless field control is the preferred method of field application. In a brushless motor, solid state technology permits the field control and field excitation systems to be mounted on the rotor. The motor, its exciter, and field control system are a self-contained package. Application and removal of field excitation are automatic and without moving parts. The brushes, commutator collector rings, electromagnetic relay, and field contactor are eliminated. Thus, the extra maintenance and reliability problems usually associated with older brush-type synchronous motors are greatly reduced.

c. Load commutated inverter. A recent development that may have limited application in pumping station design is the load commutated inverter (LCI). It is a promising adjustable-frequency drive for variable-speed high-voltage, high-power applications utilizing synchronous motors. Because of the internal counter electromotive force generated in a synchronous motor, the design of inverter circuits is greatly simplified. This device provides continuously variable speed regulation of from 10 to 100 percent of synchronous speed. It also limits inrush currents to approximately rated full-load current. Being a solid state device, however, the LCI may cause harmonic currents in the neutral conductors. Neutrals should be sized to 1.732 times the phase current. Further guidance can be found in CEGS 16415, Electric Work Interior.

d. Flow- or propeller-type pumps. Synchronous motors find their application as pump drives in the large capacity, low rpm mixed flow- or propeller-type pumps. In general, their usage should be limited to pumps of at least 375 kW (500 HP) and above, and at speeds of 500 rpm and below. Careful attention must be given to available pull-in torque to "pull" the rotor into synchronism with the revolving magnetic field. At this point, the motor must momentarily overspeed the pump past the moving column of water. Knowledge of the pump speed torque curve, voltage drop at the motor terminals, and the ability of the motor field application control to provide the best electrical angle for synchronism must all be considered.

14-4. Submersible Motors

Submersible motors have been used very effectively in smaller stations where economy of design is paramount. Where the possibility exists that combustible gases or flammable liquids may be present, the motor should be rated for explosion-proof duty. Thermal sensors should be provided to monitor the winding temperature for each stator phase winding. A leakage sensor should be provided to detect the presence of water in the stator chamber. If the possibility exists that rodents may enter the sump, special protection should be provided to protect the pump cable(s).

14-5. Common Features

Guide Specifications CW 15170 and CW 15171 give detailed requirements for common motor features such as enclosures, winding insulation, overspeed design, or anti-reversing device and core construction.

14-6. Shaft Type

Motors can be furnished with either a hollow or solid shaft. Commonly, however, hollow shaft motors are available only up to about 750 kW (1,000 HP). The hollow shaft motor provides a convenient means to adjust the impeller height. Other factors such as station ceiling height and the ability of the crane to remove the longer pump column must be considered in the decision of the type of shaft to employ.

14-7. Starting Current Limitations

Guide Specifications CW 15170 and CW 15171 limit the locked rotor current to 600 percent of rated (full-load) current. However, when utility requirements necessitate, lower inrush current induction motors may be specified not to exceed 500 percent of the rated full-load current. (Note: Starting inrush varies with efficiency; therefore, specifying reduced inrush will result in a somewhat lower efficiency.) The motor manufacturer should be contacted before specifying a reduction of inrush current for a synchronous motor. If 500 percent is not acceptable, reduced-voltage starting of the closed-transition autotransformer type should generally be used. Autotransformer starters provide three taps giving 50, 65, and 80 percent of full-line voltage. Caution must be exercised in the application of reduced voltage starting, however, since the motor torque is reduced as the square of the impressed voltage, i.e., the 50-percent tap will provide 25-percent starting torque. Connections should be made at the lowest tap that will give the required starting

torque. Reactor-type starters should also be given consideration for medium voltage motors. Solid state motor starters employing phase-controlled thyristors are an option to reduce inrush currents for 460-volt motor applications. However, the reliability, price, availability of qualified maintenance personnel, and space considerations should all be studied carefully before electing to use solid state starters.

14-8. Duty Cycle

Care should be taken in the selection of the number and size of pumps to avoid excessive duty cycles. Mechanical stresses to the motor bracing and rotor configuration as well as rotor heating are problems with frequently started motors. The number of starts permissible for an induction motor should conform to the limitations given in MG-1-20.43 and MG-1-12.50 of NEMA MG-1, as applicable. Synchronous motors should conform to MG-1-21.43 of NEMA MG-1. The motor manufacturer should be consulted concerning the frequency of starting requirements if other than those prescribed above. Economic comparisons of different pumping configurations should include the reduction in motor life as a function of increased motor starting frequency.

14-9. Starting Torque

a. General. Most stations use medium or high specific speed propeller-type pumps with starting torques in the range of 20 to 40 percent of full-load torque. The motor must be designed with sufficient torque to start the pump to which it is connected under the maximum conditions specified, but in no case should the starting torque of the motor be less than 60 percent of full load. For a more detailed discussion of torque values, see the particular motor type below.

b. Squirrel-cage induction motors. Normally, motors specified in CW 15170 will have normal or low starting torque, low starting current. Each application should be checked to ensure that the motor has sufficient starting torque to accelerate the load over the complete starting cycle. CW 15170 requires a minimum starting torque of 60 percent of full load. Breakdown torque should not be less than 200 percent of full load unless inrush is reduced to 500 percent of full load. If 500 percent is specified, the breakdown torque must be reduced to 150 percent of full load.

c. Synchronous motors. Synchronous motors must usually be specially designed for pumping applications. The load torques and WK^3, so called "normal" values, on which NEMA MG-1 requirements are based are generally for unloaded starts and are therefore relatively low. Starting and accelerating torque shall be sufficient to start the pump and accelerate it against all torque experienced in passing to the pull-in speed under maximum head conditions and with a terminal voltage equal to 90 percent of rated. The minimum design for a loaded pump starting cycle should be: 60-percent starting torque, 100-percent pull-in torque, and 150-percent pull-out torque for 1 minute minimum with a terminal voltage equal to 90 percent of rated. This would produce inrush currents of 550 to 600 percent of full load.

d. Amortisseur windings. Double-cage amortisseur windings may be required to generate the uniformly high torque from starting to pull-in that is required by loaded pump starting. They consist of one set of shallow high-resistance bars and one set of deeper low-resistance bars.

14-10. Selection

a. General. The choice between a squirrel-cage induction and synchronous motor is usually determined by first cost, including controls, and wiring. In general, the seasonal operation of flood-control pump stations results in a fairly low annual load factor, which, in turn, diminishes the advantage of the increased efficiency of synchronous motors. A life-cycle cost analysis should be performed that includes first costs, energy costs, and maintenance costs. Another factor that should be considered is the quality of maintenance available since the synchronous motor and controls are more complex than the induction motor. The additional cost of providing power factor correction capacitors to squirrel-cage induction motors, when required, should be included in cost comparisons with synchronous motors. Also, the extra cost to provide torque and load WK^2 values higher than normal for a synchronous motor because of loaded pump starting characteristics must be taken into account.

b. Annual Load Factor (ALF): The ALF can be estimated from data obtained from a period-of-record routing (PORR) study or from the electric billing history of a similar pumping station. If a PORR or billing history is used, ALF would be defined as

$$ALF = We/(Pd \times 8{,}760) \qquad (14\text{-}1)$$

where

We = total amount of energy consumed during year

Pd = maximum of 12 peak demands occurring during year

8,760 = number of hours in a year

14-11. Power Factor Correction

a. General. Power factor is the ratio of total watts to the total root-mean-square (rms) volt-amperes. Utility companies may meter the reactive or out-of-phase component (kvar) of apparent power (kva) as well as total energy (kwh). They may charge additionally for higher capacity requirements driven by peak loads and low power factor. A rule of thumb is that about 12 to 14 percent of line loss can be saved by improving the power factor 10 percent.

b. Flood-control pumping stations. In flood-control pumping stations, the power factor for induction motors will vary according to size and rpm. The power factor should be corrected to 92 to 95 percent at full load through the addition of power factor correction capacitors. The power factor correction capacitors are usually located either within or on top of the motor control center. The capacitors should be switched in and out of the circuit with the motor.

14-12. Noise Level

The Department of Defense considers hazardous noise exposure of personnel as equivalent to 85 decibels or greater A-weighted sound pressure level for 8 hours in any one 24-hour period. The guide specifications provide requirements to obtain motors that meet this limitation. The designer, however, should evaluate the advantages and disadvantages of providing either the more expensive motors that meet these requirements or a room to isolate the operating personnel from the noise exposure. American National Standards Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) Standard No. 85, Test Procedures for Airborne Sound Measurements on Rotating Machinery, and NEMA MG-1 provide more information on the subject.

14-13. Variable Speed Drives

a. General. Variable speed pump drives are not normally required in flood-control pump stations. Normally, if base flows are anticipated, a smaller constant speed vertical or submersible pump is furnished to avoid excessive cycling of larger stormwater pump motors. Variable speed drives are more frequently employed in sewage stations where the ability to match flow is more critical. If it has been determined, however, that a variable speed drive is necessary, the designer should determine the most efficient and economical method that meets the needs of the application. Two common methods of speed control are discussed below:

b. Variable frequency. Adjustable speed is obtained by converting the fixed-frequency alternating current (AC) line voltage into an adjustable voltage and frequency output that controls the speed of a squirrel-cage motor. A rectifier converts power from 60-Hz AC to direct current (DC). An inverter, then, reconverts the DC power back to AC power, which is adjustable in frequency and voltage. Drives are available in sizes up to 600 kW (800 HP) with variable frequency operation from 2 to 120 Hz. Inrush currents can be reduced to 50 to 150 percent of rated. Variable frequency drives are very efficient and provide a wide range of speed adjustment.

c. Wound-rotor motors. The speed of a wound-rotor motor is varied by removing power from the rotor windings. This is usually accomplished by switching resistance into the rotor circuit via the use of slip-rings and brushes. As resistance is added, the speed of the motor decreases. This method is not efficient, however, because of the loss in the resistors. Starting torques of the wound-rotor induction motor can be varied from a fraction of rated full-load torque to breakdown torque by proper selection of the external resistance value. The motor is capable of producing rated full-load torque at standstill with rated full-load current. The motor has low starting current, high starting torque, and smooth acceleration. In general, however, speed stability below 50 percent of rated is unsatisfactory. Additional maintenance is required because of the slip-rings and brushes required to access the rotor windings.

Chapter 15
Power Distribution Equipment

15-1. General

The power distribution equipment for motors used in flood-protection pumping stations must be as simple as possible, compact, and reliable, and since the equipment will stand idle for long periods and be subject to wide temperature variations, provisions must be made to prevent condensation within control enclosures (Plates 12-19). See Chapter 20, "Electrical Equipment Environmental Protection," for recommended protective requirements.

15-2. Main Disconnection Device

a. General. The main pumping station disconnecting device should be located within the station as part of the motor control center (for low-voltage stations) or the motor controller line-up (for medium-voltage stations). The main for the motor control center could be a molded case circuit breaker, power air or vacuum circuit breaker, or a quick-make, quick-break fusible interrupter switch. Similarly, the medium-voltage motor controller line-ups can utilize high-voltage load interrupter switches or power circuit breakers of the air or vacuum type.

b. Design decision. The design decision between a fusible interrupter switch and a circuit breaker ultimately depends upon the specific application. In some cases, continuous current requirements or interrupting capacities will dictate. Below 600 volts, circuit breakers and fuses are generally available in all continuous current ratings and interrupter ratings likely to be encountered. At the medium-voltage level, however, fuses are usually limited to 720 amperes continuous with 270 mVA maximum interrupting capacity. Additionally, at this continuous current level, the slow interrupting characteristics of the fuse often presents coordination problems with the utility's overcurrent protective relaying. A new product, current limiting electronic fuses, improves the fuse reaction time by electronic sensing of the rate of change of current. It should be considered when coordination is a problem. In any event, the utility should be advised of the choice of main disconnect in order to ensure compliance with their standards and to prevent coordination problems. If a fusible interrupter switch is selected, protection from single phasing should also be provided.

c. Fusible interrupter switch. Some general advantages and disadvantages of a fusible interrupter switch include:

Advantages	Disadvantages
Simple and foolproof	Requires spares
Constant characteristics	Self-destructive
Initial economy (3:1 or 4:1 versus medium-voltage breakers)	Nonadjustable
No maintenance	No remote control

d. Circuit breaker. Some general advantages and disadvantages of a circuit breaker:

Advantages	Disadvantages
Remote control	Periodic maintenance
Multipole	Higher initial cost
Smaller, convenient (at low voltage)	Complex construction (at medium voltage)
Resettable	
Adjustable	

15-3. Low-Voltage Stations

a. General. In general, motor control centers are preferred over "metal enclosed low-voltage power circuit breaker switchgear" for control of motors 480 volts and below in pumping station design. While metal-enclosed switchgear is a high quality product, its application is found more in feeder protection and starting and stopping of infrequently cycled motors and generators.

b. Maintenance. Experience has shown that frequent operation of power circuit breakers requires additional maintenance of the various mechanical linkages that comprise the operating mechanisms. Since maintenance of pumping station equipment is usually a local levee or sewer district responsibility, every effort should be made to reduce system maintenance and optimize station reliability. Magnetic starters provide a simple, reliable, and less expensive alternative to the usage of power circuit breakers. Combination magnetic starters are available in either the circuit breaker or fusible type.

c. Motor protection. Protection of the motor is provided by thermal overload relays, which are normally built into the starter itself. The relays contain

high-wattage electric heaters, in each phase, which are heated by the passage of motor current. The heat generated either bends a bi-metallic strip or melts a low temperature (eutectic) fusible alloy. The bent bi-metallic strip opens contacts that interrupt the current to the contactor-operating coil. The melted alloy frees a spring-loaded shaft that rotates and breaks contacts in the operating coil circuit. The bi-metallic relay has two advantages not found in the fusible-alloy type: it can reset itself automatically and can compensate for varying ambient-temperature conditions if the motor is located in a constant temperature and the starter is not. The heaters must be sized to accept the starting current of the motor for the expected starting time without causing the contactor to open. To achieve this with a variety of connected loads, conventional starters are available with a range of standard heaters, which can be selected according to the application.

d. Undervoltage protection. Undervoltage protection is supplied inherently by the action of the operating coil. An abnormally low supply voltage causes the motor to run well below synchronous speed, drawing a current which, even though not as high as the starting current, quickly overheats the motor. A low supply voltage, however, also means a low current to the holding coil and causes the contactor to drop out and isolate the motor. If more protection from undervoltage is required, an undervoltage relay can be added for increased protection.

e. Combination motor controllers. Combination duplex or triplex motor controllers are sometimes provided by the pump manufacturer as part of a pump, motor, controller package. This is often the case for smaller stations employing submersible motors. This is a viable option, where applicable, and assures one manufacturer responsibility should problems arise.

15-4. Medium-Voltage Stations

a. General. The designer must choose between a medium-voltage motor controller (incorporating a magnetic contactor) and an air-magnetic or vacuum circuit breaker. While "metal-clad" switchgear is the highest quality equipment produced by the industry, motor controllers are still preferred. Circuit breakers in metal-clad switchgear are used as motor starters primarily by utilities, where a motor, once started, may run a week or more without stopping. In industry, circuit breakers find their application as main or feeder breakers that are not frequently opened or closed.

(1) Circuit breaker benefits. The benefit of circuit breakers is that although the contact mechanism is not designed for a large number of operations, it is designed to interrupt short-circuit currents of high magnitude and be returned to service immediately. While vacuum bottle technology increases the number of operations possible, contactors are still the preferred mechanism for frequently started motors.

(2) Cost. Another consideration in the choice between the two is the relative cost. Metal-clad switchgear is approximately three times as expensive as an equivalent line-up of motor controllers. Where required, air or vacuum circuit breakers can be used as mains with transition sections to accommodate the motor controller line-up.

b. Medium-voltage motor controllers. The medium-voltage controllers should comply with NEMA ICS 2-324, "A-C General-Purpose High-Voltage Class E Controllers" and UL Standard 347 (Underwriters Laboratories, Inc. 1985). They may be described as metal-enclosed high-interrupting capacity, drawout, magnetic-contactor type starter equipments with manual isolation. Medium-voltage motor controllers are available for reduced-voltage and full-voltage starting of non-reversing squirrel-cage and full-voltage starting of synchronous motors typically used in pumping stations.

(1) High- and low-voltage sections. Each motor controller enclosure is divided into a high- and low-voltage section. The high-voltage section contains the magnetic contactor and its protective fuses. The low-voltage section contains the controls and protective relaying. Contingent upon motor size and relaying requirements, one, two, or three starters can be located in one vertical section. Power for control relays is usually 115 volts but may be 230-volt AC or 48-, 125-, or 250-volt DC.

(2) Fuses. The contactor itself is not capable of interrupting a short circuit and must be protected by silver-sand type current limiting fuses. Fuses are generally mounted on the contactor itself and can be drawn out of the cabinet for replacement by withdrawing the contactor. One limitation of such fuses is that, should a short-circuit occur on one phase only, only that fuse will blow, and the motor will continue to operate on the single phase between the remaining two lines. Current drawn in that phase is twice full-load current and will rapidly overheat the motor. This can be avoided by the addition of suitable relaying, as described later, but, in

some cases, the contactor may also incorporate a trip mechanism that is actuated by the blown fuse itself. The trip mechanism causes the contactor to open immediately when the fuse is blown, isolating the motor. Either protective relaying or a mechanical trip mechanism should be provided.

c. Motor protection.

(1) General. The following gives general guidance for protection of medium-voltage motors. For further information on motor protection, refer to ANSI/IEEE 242, "Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems." For motor protection against lightning and switching surges, refer to Chapter 19.

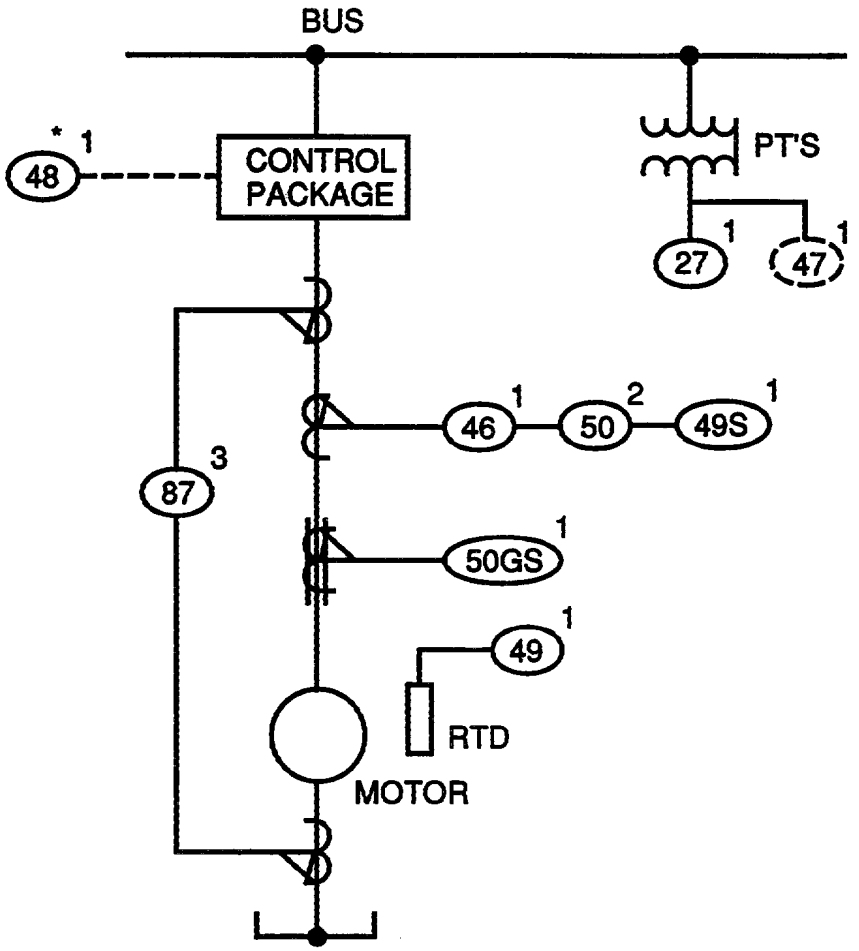
(2) Induction motor protection. It is logical that more extensive protection be considered for larger motors than for smaller motors, since they represent a larger capital investment. Therefore, minimum recommended protective relaying is divided into two groups: one for motors rated below 375 kW (500 HP), and the other for those rated 375 kW (500 HP) and above.

(a) Motors below 375 kW (500 HP). Referring to Figure 15-1, for motors rated below 375 kW (500 HP), protection against loss of voltage or low voltage is generally provided by the single-phase time-delay undervoltage relay, Device 27. Where it is desired to secure three-phase undervoltage protection, such as when the motor is fed through fuses or from an overhead open line wire, Device 47 would be used in place of Device 27. In addition, Device 47 would provide protection against phase sequence reversal should it occur between the source and the motor's associated switchgear. The Device 49/50 provides short-circuit, stalled-rotor, and running overload protection; this relay has a thermally operated time-overcurrent characteristic. It is therefore generally to be preferred for this application over an inverse time-overcurrent relay such as the Device 51 relay. The instantaneous device on the Device 49/50 relay is normally set at 1.6 to 2 times locked-rotor current. Sensitive and fast ground-fault protection is provided by the instantaneous ground-sensor equipment, Device 50GS. Device 49 operates from a resistance-temperature detector embedded in the machine stator winding. This type of running overload protection is to be preferred over the stator-current-operated device, since it responds to actual motor temperature. The Device 40S provides protection against stalled rotor conditions. This device is necessary since the resistance-temperature detector used with Device 49 will not respond immediately to fast changes in the stator conductor temperature as would be the case under stalled conditions. The Device 49S relay includes a special high-drop-out instantaneous-overcurrent unit which is arranged to prevent its time-overcurrent unit from tripping except when the magnitude of stator current is approximately equal to that occurring during stalled conditions. Device 48, the incomplete sequence timer, would be included where the control package is of the reduced-voltage type. It provides protection for the motor and control package against continued operation at reduced voltage which could result from a control sequence failure. For wound-rotor motors where the starting inrush current is limited, more sensitive short-circuit protection can be provided with the addition of the Device 51 time over-current relays. With the motor inrush current limited, these relays can generally be set to operate at full-voltage locked-rotor current with all secondary resistance shorted.

(b) Motors rated 375 kW (500 HP) or above. For the larger motors rated 375 kW (500 HP) and above, a current-balance relay, Device 46, is included to provide protection against single-phase operation. Differential protection for larger motors is provided by Device 87. This device provides sensitive and fast protection for phase-to-phase and phase-to-ground faults.

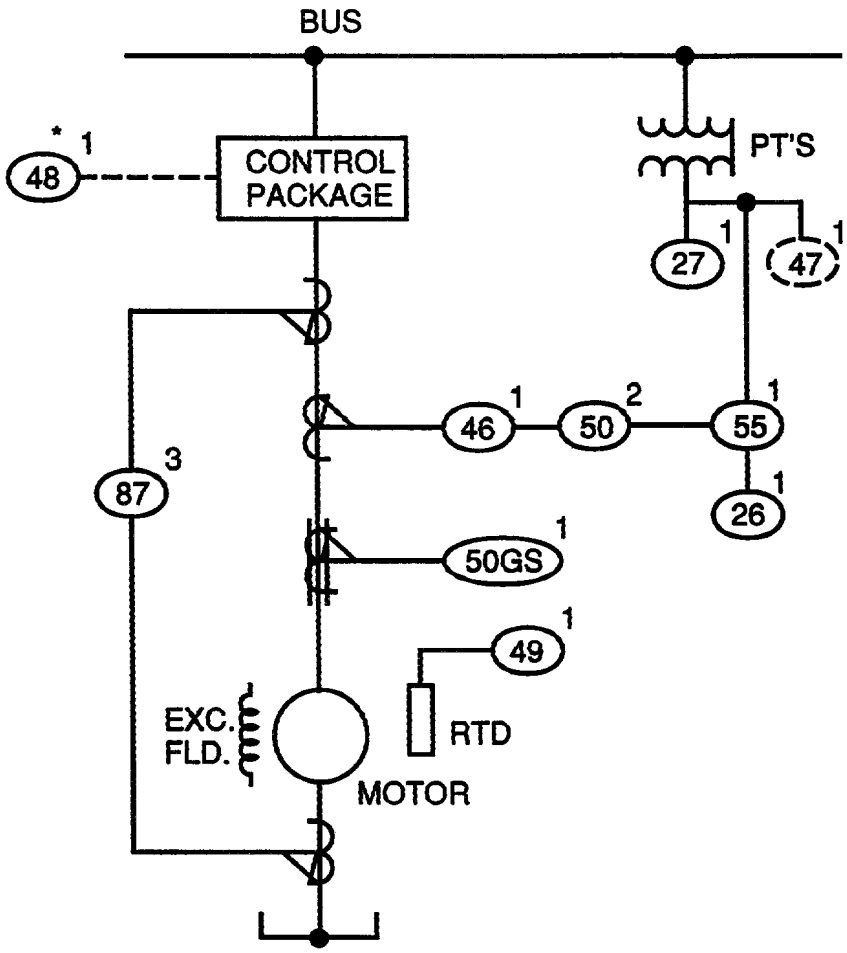
(3) Medium-voltage brushless synchronous motor protection. Figure 15-2 covers the recommended minimum protection for brushless synchronous motors. Device 26 has been included to provide stalled-rotor protection. It is a stator-current operated device. The characteristic and rating of this device is provided by the equipment manufacturer and must be closely coordinated with the starting and operating characteristics of the individual motor being protected. The power factor relay Device 55 has also been included to protect the motor from operating at sub-synchronous speed with its field applied. This commonly called out-of-step operation will produce oscillations in the motor stator current, causing them to pass through the "lagging" quadrature. The power factor relay is connected to sense this current and will operate when it becomes abnormally lagging. Upon operation, excitation is immediately removed from the motor, allowing it to run as an induction machine. After excitation has been removed, the control is arranged to shut down the motor.

(4) Microprocessor-based motor protection systems. Microprocessor-controlled motor protective systems are a relatively recent development that combines control, monitoring, and protection functions in one assembly.



DEV.
27▲UNDERVOLTAGE
46-CURRENT BALANCE (375 KW (500 HP) THRU 2200 KW (3000 HP))
49-THERMAL
49S-THERMAL (STALLED)
50-INST. SHORT CIRCUIT
50GS-INSTANTANEOUS GROUND SENSOR
87-DIFFERENTIAL (375 KW (500 HP) THRU 2200 KW (3000 HP))
47▲3#UNDERVOLTAGE & REVERSE PHASE ROTATION
48-INCOMPLETE SEQUENCE-TIMER FOR WOUND ROTOR MOTORS ADD 2-DEV. 51
IF 87 IS SELF-BALANCING PRIMARY CURRENT ADD 2 DEV. 51
*INCLUDE IF CONTROL PACKAGE IS REDUCED VOLT. START
▲OMIT DEV. 27 WHEN DEV. 47 IS INCLUDED.

Figure 15-1. Recommended minimum protection for medium-voltage induction motors (all horsepowers except as noted)



DEV.
26-APPARATUS THERMAL DEVICE
27▲UNDERVOLTAGE
46-CURRENT BALANCE (375 KW (500 HP) THRU 2200 KW (3000 HP))
47▲3▲UNDERVOLTAGE & REVERSE PHASE ROTATION
48-INCOMPLETE SEQUENCE-TIMER
49-THERMAL
50-INST. SHORT CIRCUIT
50GS-INSTANTANEOUS GROUND SENSOR
55-POWER FACTOR RELAY
87-DIFFERENTIAL (375 KW (500 HP) THRU 2200 KW 3000 HP))
IF 87 IS SELF-BALANCING PRIMARY CURRENT
ADD 2 DEV. 51
*INCLUDE IF CONTROL PACKAGE IS REDUCED VOLT. START
▲OMIT DEV. 27 WHEN DEV. 47 IS INCLUDED.

Figure 15-2. Recommended minimum protection for medium-voltage brushless synchronous motors (all horsepowers except as noted)

Most protection packages provide complete motor protection for any size motor. The packages usually include motor overload protection, overtemperature, instantaneous overcurrent, ground fault, phase loss/phase reversal/phase unbalance (voltage), phase loss and unbalance (current), overvoltage, undervoltage, and motor bearing temperature protection. The monitoring features include current, voltage, watts, frequency, power factor, and elapsed time. Some units can tabulate the number of starts per programmed unit of time and lock out the starting sequence, preventing inadvertent excessive cycling. The control features replace discrete relay logic for prestart, poststart, prestop, and poststop timing functions and various enabling signals. Programmable logic under the control of the processor performs these functions. The units can be programmed for simple, across-the-line starting or more complex starting sequences such as reduced-voltage autotransformer starting. Also included are adjustable alarm and trip parameters and self-diagnostics including contractor report-back status to enhance system reliability. In instances where motor conditions exceed the programmed setpoint values, an alarm and/or trip condition is automatically initiated. One of the advantages to these systems is that there are few options making it less likely that a desired protective feature will be overlooked in the specification process.

(5) Considerations. Microprocessor-controlled protection packages are a viable option when precise and thorough motor protection is required. After the designer has decided upon the minimum required protective features, as described above, an economic comparison should be made between standard methods of relay protection versus the microprocessor-based systems. Consideration should be given to the microprocessor system's added features such as the built-in logic capabilities, expanded motor protection, and monitoring and alarm functions when making the cost comparison. As with all solid state devices, careful consideration must be given to their operating environment. The typical operating range of the processor is -20 to 70 degrees centigrade. However, the operating temperature of the external face of the operator panel is limited to 0 to 55 degrees centigrade. Special coating of the circuit boards is, also, required to provide protection from the extremely humid environment of the typical pumping station. The applications department of the manufacturer should be consulted for each application.

Chapter 16
Control Equipment

16-1. Control Rooms and Consoles

In larger pumping stations, the complexity of the pumping system and the trend toward reducing the number of operating personnel will usually require the formation of a centralized monitoring and control room. Controls, alarms, and devices to indicate system status should be grouped on a control console so that one operator can conveniently initiate control sequences and observe the system response (Plate 20). Care should be taken to include a monitoring capability for all essential pumping system parameters. Some alarms that may be required include motor and pump bearing temperatures, motor winding temperature, motor trip and lockout relays, motor or gear cooling water failure, excessive pump discharge piping pressures or flow rates, lubrication system failures, abnormal water levels, trashrake malfunction, etc. A graphic display is an effective means of grouping alarm and status information.

16-2. Programmable Controllers

A programmable controller (PLC) should be considered for usage when the controls or monitoring requirements of the station become complex. When appropriately applied, this device provides the processing power and flexibility necessary to efficiently control a complicated system.

a. Advantages. Advantages of the programmable controller include:

(1) The flexibility to reprogram or modify the control sequence.

(2) The ability to manipulate, compare, or perform arithmetic functions on data stored at various memory locations.

(3) A high degree of reliability when operated within their ratings.

(4) The ability to accept a wide variety of input and output devices.

(5) The capability to force inputs and outputs "on" or "off" to aid in troubleshooting.

b. Operator interfaces. Operator interfaces can range from simple pushbuttons and indicating lights to personal computers (PCs). The PC offers increased computing power, data logging, and graphics capabilities.

c. Cautions.

(1) Personnel. Some caution should be exercised, however, in applying PLCs and PCs to pump station applications. Most pumping stations are operated and maintained by local interests. The local levee or sewer district may not have the experience or expertise to maintain the PLC system. An evaluation should be made of the availability of qualified repair services and the competency level of the anticipated operating and maintenance personnel.

(2) Environment. Also, while PLCs are rugged devices which can normally be applied to pumping station environments with little concern for exceeding their environmental ratings, the designer should evaluate the need for any special provisions to ensure that the PLC will be operated within its temperature and humidity ratings. If the use of a PC is desired, it should be an industrially hardened version and should be kept in a conditioned environment.

d. Temperature and humidity ratings. Typical ambient operational temperature ratings are 0 to 60 degrees centigrade and -40 to 85 degrees centigrade during storage. Typical humidity ratings are from 5 to 95 percent without condensation. Operation or storage in ambients exceeding these values is not recommended without special consultation with the manufacturer.

e. Interposing relays. The output contacts of programmable controllers have limited current carrying capacity. Electrical devices which require significant amounts of current for operation, such as large solenoid devices, may require the addition of interposing relays to the system. However, to minimize complexity, the use of interposing relays should be avoided wherever possible.

16-3. Water Level Sensors

a. General. A variety of sensors are available for use in sensing water levels, including float-actuated mercury switches, float-actuated angle encoders, bubbler systems, bulb-type floats, etc. The use of float-actuated mercury switches is discouraged due to environmental

concerns. A comparison should be made of the particular pumping station requirements in relation to the various level sensor capabilities before deciding upon the system to be employed. In more sophisticated stations, it may be desirable to utilize an angle encoder. With its associated electronic packages, very accurate level comparisons and alarm functions are possible. Also, its output may be convenient for inputting to programmable controllers or computers. The selection of a sophisticated water level sensing system, however, must always be made with consideration of the quality of maintenance and repair services available to the station after construction.

b. Bubbler systems. Bubbler systems when used are usually of the air-purged type. The nitrogen gas purged type is usually employed at remote sensing areas where power to run the air compressor of an air-purged system is difficult to obtain. The air-purged system operates by purging air into a channel, sump, etc., through a tube and measuring the back pressure which varies in proportion to the variation in liquid level. A linear variable differential transformer is usually used to convert pressure readings to low voltage or current signals. When used in sufficient number, this system may be cheaper than an equivalent float-actuated system. However, it is more complex and is subject to clogging in highly siltatious waters.

c. Angle encoders. The transducer should be of the electromagnetic resolver type and nonvolatile. Each shaft position should be a unique output that varies as a function of the angular rotation of the shaft. If power is lost, the correct output should immediately be restored upon restoration of power. Units are available in single or multiturn construction.

16-4. Elapsed Time Meters and Alternators

To ensure even wear on pumping units as well as reducing the frequency of motor starting, it is recommended that elapsed time meters and alternators (where pumps are started automatically) be installed to provide a record of pump usage.

16-5. Timing Relays

Several timing relays are commonly employed in pump control circuits. If siphon breakers are required, an on-delay timer delays closing of the siphon breaker solenoids until the siphon system is fully primed. This feature reduces motor horsepower requirements to establish prime. The other is an off-delay timer which prevents the motor from being restarted until any reverse spinning of the pump has stopped.

16-6. Miscellaneous Circuits

The miscellaneous small power circuits commonly required in installations for the control transformers, potential transformers, lighting transformers, and control power should either be protected by standard circuit breakers or fuses of adequate rating.

Chapter 17
Station Wiring

17-1. General

The reliability of the entire electrical installation will be only as good as that of the wiring by which the various items of power supply, power distribution, control, and utilization equipment are interconnected. Selection of proper materials and methods of construction for the wiring system are therefore a matter of prime importance. The following basic principles should be observed in design of pump station wiring systems.

17-2. Conduit

For the mechanical protection of wiring and for the safety of operating personnel, all station wiring should be enclosed. Rigid galvanized steel conduit is the most commonly used material for raceways and is suitable for all locations where wiring is required within a pumping station. If it is necessary to run conduits exposed below the operating floor, consideration should be given to polyvinyl chloride (PVC) coated rigid galvanized steel or PVC conduit. All ferrous conduit fittings should be zinc-coated or otherwise suitably plated to resist corrosion due to moisture and fumes common to pumping stations. In large stations where extensive cabling is required, the usage of cable trays should be considered. If conduits are to be embedded, the use of nonmetallic conduits should be considered.

17-3. Conductors

Wire and cable for pumping stations should be furnished with moisture- and heat-resisting insulation. Details of cable construction and insulation can be found in CW 16120, Insulated Wire and Cable (for Hydraulic Structures). Sizes of conductors should be in accordance with the National Electrical Code (NFPA-70) for motor feeders and branch circuits.

17-4. Conductor Joints

The most common causes of trouble in completed wiring installations are imperfect joints and terminations of conductors that permit entrance of moisture under protective sheaths. The procedures to be followed in terminating conductors should be made a part of the installation contract specifications. No splicing of circuits of 480 volts or greater should be allowed in the contract specifications. This important detail of electrical construction should receive proper consideration by both designers and field inspectors.

Chapter 18
Station and Equipment Grounding

18-1. General

Following are the recommended practices for system and equipment grounding in pumping stations. However, special applications may require variations to the recommended practices. A thorough discussion of grounding principles can be found in ANSI/IEEE 142, Recommended Practices for Grounding of Industrial and Commercial Power Systems. Installations should also comply with the applicable provisions of Article 250 - Grounding of the National Electric Code (NFPA-70). Typical grounding plans are shown on Plates 21 and 22.

18-2. Station and Equipment Grounding

a. General. An effective grounding system is an essential part of a pump station electrical system. In general, 19-millimeter (3/4-inch) by 6-meter (20-foot) ground rods should be driven at the corners of the structure and exothermically joined to a ground bus run completely around the periphery of the pumping station. The ground bus should be installed a minimum of 0.5 meter (18 inches) outside the building wall and a minimum of 0.8 meter (30 inches) below the finished grade. Additional lengths or numbers of ground rods should be added as required to achieve a maximum resistance to ground of 25 ohms. In rocky ground where driven rods are impractical, it is sometimes more economical and desirable to use a grid system with cable spacings of approximately 3 meters (10 feet) being common. The cables should be placed 150 millimeters (6 inches) to 300 millimeters (1 foot) deep and encased in concrete.

b. Grounding conductors. At least four grounding conductors should be run from the ground bus or grid and exothermically welded to a ground loop embedded in the operating floor. All connections to either the ground loop or ground bus should be by exothermic welds.

c. Ground bus. The ground bus should be exothermically connected to the sump floor rebars, any steel columns of the structure, and metallic underground water piping where present.

d. Sizing of grounding bus and loop conductors. Sizing of grounding bus and loop conductors should be made in accordance with the applicable requirements of the National Electrical Code (NFPA-70). For mechanical strength, however, the grounding conductors should not be smaller than No. 2/0-AWG conductor. However, it may be desirable to exceed these values where exceptional precaution is required or where extremely high ground-fault currents are expected.

e. Frames and enclosures. The frames of stationary or permanently located motors, and the frames and enclosures of static equipment such as transformers should be grounded by direct connection to the operating floor ground loop through an equipment grounding conductor equal in size to the largest conductor in the line connected to the equipment, but in general not less than No. 6 AWG. The equipment grounding conductors shall be connected to the equipment through the use of a clamp-type connector.

f. Switchgear. To provide a convenient method of grounding switchgear, a ground bus should be provided as part of the equipment. The switchgear ground bus must not be smaller in current-carrying capacity than 25 percent of the highest continuous-current rating of any piece of primary apparatus to which it is connected. The switchgear ground bus should, in turn, be connected to the operating floor ground loop by conductors having a current-carrying capacity equal to that of the switchgear ground bus.

g. Other noncurrent carrying metal. All other noncurrent carrying metal such as ladders, fences, fuel-storage tanks, etc., shall be connected to either the ground bus or operating floor ground loop. All neutral conductors of grounded power supplies shall be solidly grounded to the station ground system.

h. Utility power. The utility furnishing power to the station should be contacted to determine if any interconnections are required between the pumping station ground grid and the substation ground grid.

18-3. System Grounding

a. General. The basic reasons for system grounding are the following:

(1) To limit the difference of electric potential between all uninsulated conducting objects in a local area.

(2) To provide for isolation of faulted equipment and circuits when a fault occurs.

(3) To limit overvoltage appearing on the system under various conditions.

b. Low-voltage systems. It is recommended that pumping stations with electrical systems of 1,000 volts and below be solidly grounded. Solid grounding is the least expensive way to detect and selectively isolate ground fault through the usage of fast-acting ground-fault relaying. However, use of a solidly grounded low-voltage distribution system increases the probability of damage from arcing ground faults. The driving voltage of these systems tends to sustain arcs rather than clear them through the standard phase overcurrent protective devices. High impedances associated with the arc may limit fault current to levels too low for detection by conventional over-current protective devices. For this reason, sensitive ground-fault relaying should be provided on the feeders and the main of all solidly grounded systems. Ungrounded operation of low-voltage systems is not recommended because of the potential over-voltage problems.

c. Medium-voltage systems. Modern power systems in this range of voltages are usually low-resistance grounded to limit the damage due to ground faults in the windings of rotating machines and yet permit sufficient fault current for the detection and selective isolation of individually faulted circuits. The lowest ground-fault current (highest resistance) consistent with adequate ground relay sensitivity should be used. High-resistance grounding is not recommended for medium-voltage systems.

Chapter 19
Surge Protection

19-1. General

a. Lightning-induced voltage surges. Pumping stations are particularly vulnerable to lightning-induced voltage surges on incoming power lines, since it is characteristic of their operation to be in use during thunderstorms. Therefore, special care should be taken to reduce the magnitude of these voltage surges to avoid major damage to the electrical equipment contained within. A relatively small investment can greatly reduce the voltage stresses imposed on rotating machinery and switchgear by lightning-induced surges.

b. Protective equipment. There are two transient elements of a voltage surge that require different protective equipment. The protection of the major insulation to ground is accomplished by station surge arresters which limit the amplitude or reflections of the applied impulse waves within the motor windings. The protection of turn insulation by reducing the steepness of wave fronts applied to or reflected within the motor windings is accomplished by protective capacitors.

19-2. Medium-Voltage Motors

To obtain the most reliable protection of the motor's major and turn insulation systems, a set of arresters and capacitors should be installed as close as possible to the motor terminals. The arresters should be valve-type, Station-Class designed for rotating machine protection. The capacitors should be of the non-PCB type. The leads from the phase conductor to the capacitor and from the capacitor to ground should be as short as possible. (If solid state motor controllers are used, the addition of capacitors at the motor terminals may not be recommended. Chopped-wave equipment such as SCR controlled motor starters can generate surges and harmonics. The capacitors can contribute to the problem by increasing resonance effects. The manufacturer should be consulted for the particular application.)

19-3. Low-Voltage Motors

Motors of 600 volts and below have relatively higher dielectric strength than medium-voltage machines. Normally, when higher speed motors of this voltage class are connected through a transformer protected by Station-Class arresters on the primary side, no additional protection is warranted. However, due to the more expensive slower speed motors employed in pump stations, plus the critical nature of these motors, the minimal additional cost of lightning protection is justified. A three-phase valve-type low voltage arrester should be provided at the service entrance to the station and a three-phase capacitor should be provided at each motor terminal.

19-4. Substation

The utility should be requested to supply valve-type Station-Class surge arresters on the primary side of the substation transformer.

Chapter 20
Electrical Equipment Environmental Protection

20-1. General

Since the electrical equipment will stand idle for long periods of time, special attention must be given to corrosion protection. Guide Specifications CW 15170 and CW 15171 provide recommended corrosion-protection requirements for induction and synchronous motors, respectively. The standard manufacturer's treatments of the medium-voltage motor controller line-ups and motor control centers consist generally of one undercoat of a phosphatizing rust inhibitor followed by one finish coat applied to both internal and external surfaces. In many stations where humidity is especially high or other conditions merit special consideration, two undercoats of the rust-inhibiting primer should be specified. In addition, all major items of electrical equipment including motors, control centers, controller line-ups, control consoles, wall-mounted combination starters, gate operator controllers, trashrake controllers, etc., should be equipped with space heaters sized per the manufacturer's recommendations. Heaters in motors and controllers should be interlocked with the motor starters to ensure de-energization when the equipment is in operation. Heaters are generally fed from the lighting panels, and as such pose a shock hazard. Therefore, all items of equipment containing space heaters should be clearly marked indicating the source of the space heater power. These heaters will require 120 VAC, single-phase service year-round.

20-2. Formulas

Standard formulas used to estimate the output ratings of equipment heaters to give a temperature rise above ambient are as follows:

$$Ph = 0.6 \times A \times dT \qquad (20\text{-}1)$$

where

Ph = panel heater output rating (watt)

A = panel external surface area (square feet)

dT = designed temperature rise above ambient (degrees Fahrenheit)

For motor-winding heaters giving a 10-degree-Fahrenheit rise above ambient,

$$Ph = D \times L / 2.52 \qquad (20\text{-}2)$$

where

Ph = motor winding heater output rating (watt)

D = end bell diameter (inches)
= "2D" (frame dimension from NEMA MG1)

L = motor length (inches)
= "2F + 2BA" (frame dimensions from NEMA MG1)

Chapter 21
Station Service Electrical System

21-1. Auxiliary Power Distribution

a. Low-voltage stations. In low-voltage stations, auxiliary loads of 480 volts and below are most conveniently distributed by means of a power panel(s) either mounted in a vertical section of the motor control center or in a strategic location along a station wall. This power panel(s) should be fed from a circuit breaker or fusible disconnect switch in the motor control center. A separate auxiliary or lighting service may be required to obtain the optimum rate schedule from the utility.

b. Medium-voltage stations. In medium-voltage stations, packaged unit substations are available that conveniently incorporate a high-voltage load interrupter switch, a 4160/480-volt transformer section, and a power panel section. It is not necessary to provide a main breaker on the power panel since the high-voltage interrupter switch provides a disconnecting means. Three-phase voltmeters should be provided to monitor the 480-volt service. A separate auxiliary or lighting service may be required to obtain the optimum rate schedule from the utility.

21-2. Lighting System

In general, 208/120-volt, three-phase, four-wire systems are recommended for lighting loads. A minimum of 20-percent spare circuits should be provided for future expansion. Operating floor lights, floodlights, and other lights that may be used for considerable periods of time should usually be of the high-pressure sodium-type due to their efficiency. Where possible, several operating floor fixtures should be furnished with quartz restrike lamps, automatically switched so that light is available immediately upon energization or during restrike. If selected fixtures do not have quartz restrike as an option, several incandescent fixtures should be provided for this purpose. Following are typical foot-candle levels for various pumping station areas:

Location	LUX	(Foot-candles)
Operating Floor	325	30
Control Room	540	50
Lavatory	215	20
Sump Catwalk	215	20
Forebay	55	5
Roadway	10	1

Chapter 22
Station Service Diesel Generator

In stations utilizing engine-driven pumps, it may be more economical to furnish a diesel-generator unit to furnish station auxiliary power requirements (if three-phase is required) than to provide a separate service from a local utility. However, a single-phase service to meet minimal space heating and lighting needs may still be necessary. Economic comparisons should be made to determine the most cost-effective method of supplying auxiliary power. The unit should be rated for continuous service, not for standby or emergency service.

Chapter 23
Station Studies

23-1. Voltage Drop Studies

a. General. A preliminary voltage drop study for motor start-up as well as for motor-running conditions should be made during the initial design phase. The final study should be made during the approval drawing and data review phase of the project. The voltage drop study must be updated whenever the electrical system is revised. Computer programs are available to calculate the system's voltage dips and currents from motor starting to full load speed. For further information on voltage studies, refer to ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants and ANSI/IEEE 339, Power System Analysis.

b. Motor start-up. Motor start-up voltage drop depends on the motor inrush current. Depending upon the method of motor start-up, the inrush current ranges from two to six times the motor full-load current. Excessive starting voltage drop can result in problems such as motor stalling, nuisance tripping of undervoltage relays, motor overload devices, and temporary dips in lighting system brightness or restriking of high-intensity discharge lamps. During motor starting, the voltage level at the motor terminals should be maintained at approximately 80 percent of rated voltage or higher as recommended by the motor manufacturer.

c. Motor running. Undervoltage during the motor running condition may produce excessive heating in the motor windings, nuisance tripping of undervoltage relays and motor-overload devices, dim lighting, and reduced output of electric space heating equipment. Approximately 5-percent voltage drop from the transformer secondary terminals to the load terminals is acceptable.

23-2. System Protection and Coordination Studies

a. General. When a short circuit occurs in the electrical system, overcurrent protective devices such as circuit breakers, fuses, and relays must operate in a predetermined, coordinated manner to protect the faulted portion of the circuit while not affecting the power flow to the rest of the system.

(1) Isolation of faulted section. Isolation of the faulted section protects the electrical system from severe damage. It also results in efficient trouble shooting since the faulted section is downstream of the tripped protective device. Efficient troubleshooting results in reduction of costly repair time and system downtime.

(2) One-line diagram of electrical system. A one-line drawing of the electrical system is an important element of the protection and coordination study. The one-line diagram is discussed in detail in paragraph 23-3*c*.

b. Procedures. The coordination study is accomplished by overlaying protective device characteristic curves over equipment damage curves. This method is applicable in the range of fault clearing times greater than approximately 0.016 seconds (1 cycle) on a 60-Hz basis. For clearing times faster than this, as is the case for protecting solid state inverters, protection and coordination studies are achieved by comparing let-through energy (I-squared-t) values of current-limiting fuses (CLFs) to withstand energy values of the equipment being protected. Similarly, coordination between CLFs is achieved by comparing values of let-through energy of upstream fuses with the values of the melting energy of the downstream fuses.

(1) Protection and coordination study. A protection and coordination study may be performed manually or with the aid of a computer. Computer software is available with pre-programmed time-current characteristic curves. The result of the computer study can be automatically drawn onto standard time-current characteristic paper by the computer printer.

(2) Additional information. For further information on protection and coordination studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

c. Main disconnecting device. The utility supplying the power to the facility should be consulted regarding the type of protective device it recommends on the load side of the supply line which best coordinates with the source side protective device furnished by the utility.

d. Motors. Protective device characteristics must be coordinated with motor start-up characteristics. The devices must be insensitive enough to allow motors to start up without nuisance tripping caused by the relatively

high magnitude of motor start-up current. The devices must be sensitive enough, however, to operate during overload or short-circuit conditions.

e. Transformers. Transformer protection is similar to that of motor protection as discussed above. The protective device must be insensitive to the transformer magnetizing in-rush current, but sensitive enough to operate for a short circuit condition. Note, the new ANSI standard on transformer protection (ANSI/IEEE C57.109) could be used as an alternative to the classic method of transformer protection. Transformer magnetizing inrush should be specified as 8 X full-load current for transformers rated less than 3 MVA, and 12 X full-load current, otherwise.

f. Cables. Cable protection requires coordinating the protective device characteristics with the insulation smolder characteristics of the power cable. The insulation smolder characteristics of the cable are the same as the "short-circuit withstand" and "short-circuit heating limits" of the cable.

g. Specification requirements. The pump station construction specifications should require the contractor to furnish the completed protection and coordination study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clearly stated in the specifications that it is the contractor's responsibility to coordinate with his various equipment suppliers to produce a complete and accurate protection and coordination study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The construction specifications should require the contractor to submit the following items as one complete submittal:

(1) Full-size reproducibles of protective device characteristic curves.

(2) The motor-starting characteristics in the form of time versus current curves or data points.

(3) Data indicating the short-circuit withstand capability of motor control centers, panelboards, switchgear, safety switches, motor starters, and bus bar and interrupting capacities of circuit breakers and fuses.

(4) Transformer impedance data. These data should be submitted in one of three forms: percent IR and percent IX, percent IZ with X/R ratio, or percent IZ with no load and total watt losses.

(5) Cable insulation smolder temperature.

(6) Completed time-current coordination curves indicating equipment damage curves and device protection characteristics.

(7) A marked-up one-line diagram indicating ratings and trip sizing of all equipment.

23-3. Short-Circuit Studies

a. General. Short-circuit calculations are necessary in order to specify equipment withstand ratings and for use in conjunction with the protective device coordination study. Switchgear, motor control centers, safety switches, panelboards, motor starters, and bus bar must be capable of withstanding available fault currents. After the available fault current has been calculated at each bus in the electrical network, the available fault current withstand ratings are specified.

(1) Circuit breakers. Circuit breakers must be capable of withstanding the mechanical and thermal stresses caused by the available fault currents. They must be able to remain closed even though tremendous forces are present in such a direction as to try to force the breaker contacts open. The ability of circuit breakers to remain closed is indicated by their momentary ratings. The momentary rating is a function of the circuit breakers interrupting rating, which is the ability to interrupt a fault current without incurring excessive damage to the breaker.

(2) Fuses. Fuses must also be capable of safely interrupting fault current and are rated in terms of interrupting capacity.

(3) Motor starters. Motor starters furnished with motor circuit protectors are available with short-circuit withstand ratings up to 100,000 amperes. Starters furnished with fusible switches are available with withstand ratings up to 200,000 amperes.

b. Procedures. The basic elements of a short-circuit study are the short-circuit calculations and the one-line diagram of the electrical system. For pumping stations the three-phase bolted fault is usually the only fault condition that is studied. Utility systems line-to-ground faults can possibly range to 125 percent of the

three-phase value, but in pumping plants line-to-ground fault currents of greater magnitude than the three-phase value are rare. Line-to-line fault currents are approximately 87 percent of the three-phase fault current.

(1) Preliminary short-circuit study. A preliminary short-circuit study should be prepared during the design phase of the project. The final study should be prepared by the pump station construction contractor as described below.

(2) Calculations. The magnitude of the fault currents can be calculated using long-hand methods. However, software is available to reduce preparation time and simplify the task for large complex systems.

(3) Additional information. For further information on short circuit studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

c. One-line diagram. Plate 13 indicates the format of the one-line diagram developed as part of the preliminary and final protection and coordination and short-circuit studies. Plates 15 and 16 are typical of one-line diagrams to be issued with the plans and specifications.

(1) Standard symbols. Standard symbols for use on the one-line diagram are listed in ANSI Y32.2. Any nonstandard symbols that are used to show special features or equipment should be explained in the drawing legend to make their meaning entirely clear.

(2) Check list. The following is a check list of items that should be included on the study one-line diagram:

(a) Fault current. This is the available three-phase fault current of the utility supply at the pumping station metering point. This information can be presented in amperes, MVA, or as an impedance to the utility infinite bus (impedance in ohms or per unit on a specified base). The designer should also request the utility to provide an estimate of future three-phase fault levels. The estimate provides an indication of utility system changes which may affect the future short-circuit interrupting capability and withstand ratings of installed electrical equipment.

(b) Bus voltage.

(c) Transformers. The diagram should show winding connections, KVA rating, percent impedance, the X/R ratio, neutral grounding, if any, including the neutral ground impedance value, if not solidly grounded.

(d) Power cables. The diagram should show size, length, conductor material, whether single or multiconductor, and whether the cable is carried in a magnetic or nonmagnetic duct.

(e) Circuit breakers. The diagram should show type by appropriate symbol (for example, molded case or draw-out) and the following ampere ratings: interrupting rating, frame size, thermal trip setting, and magnetic trip setting. It should show also the range of adjustment of the magnetic trip, if adjustable, as well as the recommended setting as determined by a protective device coordination study.

(f) Switches and fuses. The diagram should show type of fuse or switch and the continuous and interrupting rating in amperes.

(g) Motors. The following should be given: horsepower or kilowatt rating, power factor, synchronous or induction type, mechanical speed (revolutions per minute), and subtransient reactance. The following additional data are required for synchronous machines: transient reactance, synchronous reactance, and the impedance of any grounding resistor.

(h) Location(s) where power purchased from a utility company is metered.

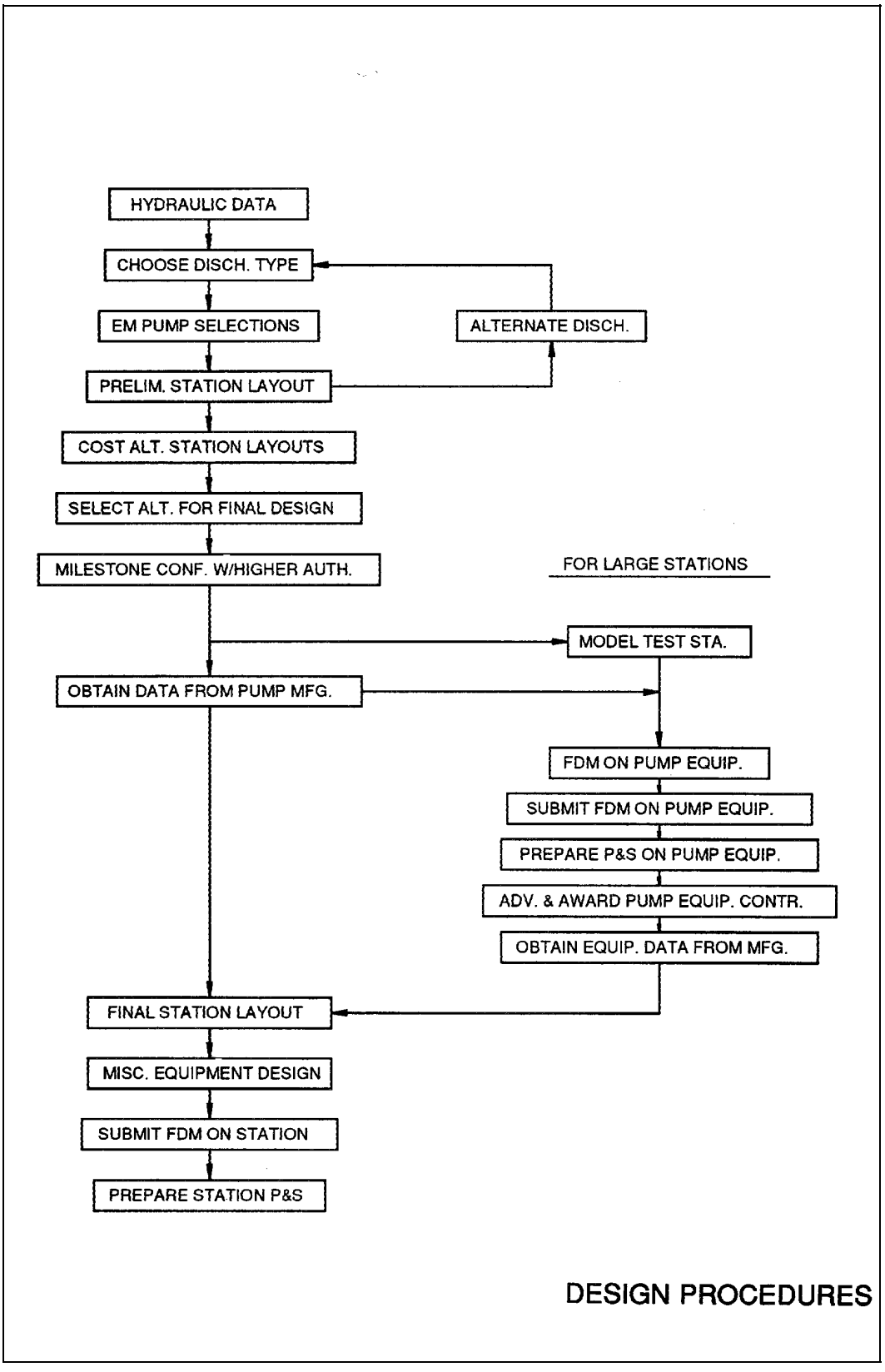
(i) The following information is required for preparation of the protection and coordination study: locations of potential and current transformers and relays and metering. Show location, quantity, and types of relays by standard IEEE device numbers, such as 51 for overcurrent relays, 67 for directional overcurrent relays. Device numbers are listed in ANSI/IEEE C37.2.

d. Specification requirements. The pump station construction specifications should require the contractor to furnish the final short-circuit study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clear in the specifications that it is the contractor's responsibility to coordinate with his various equipment suppliers to

produce a complete and accurate short-circuit study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The specifications must state that the cable sizes, ampere ratings of the protective devices, and the short-circuit withstand ratings of the equipment shown on the one-line diagram are preliminary and that the contractor shall furnish a complete and final one-line diagram upon completion of the coordination and protection and short-circuit studies.

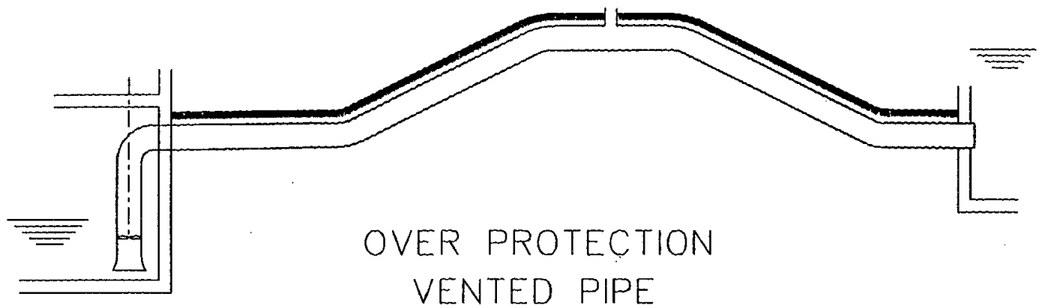
Chapter 24
List of Plates

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3. Discharge Arrangements, Large Stations
4. Pump Station With Over the Protection Discharge
5. Discharge Chamber Pump Station
6. Combination Gatewell/Pump Station Using Submersible Pumps
7. Plan Views: Combined Gatewell/Pump Stations
8. Profiles: Combined Gatewell/Pump Stations
9. RTD Installation for Vertical Wet Pit Pumps
10. One-Line Diagram for Electrical System Studies
11A. Power Supply System Configurations: Components of an Electric Power System
11B. Power Supply System Configurations: Typical One-Line Diagrams for Distribution-Type Substations
12. One-Line diagram of a Typical Low-Voltage Station
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15C. Typical Low-Voltage Motor Control Schematic Showing Reduced-Voltage Nonreversing Autotransformer Type (Closed Transition)
16. Typical Medium-Voltage, Full-Voltage Induction Nonreversing Control Relay Logic
17. Typical Medium-Voltage, Reduced-Voltage Induction Nonreversing Control Relay Logic
18. Typical Medium-Voltage, Full-Voltage Brushless Synchronous Nonreversing Control Relay Logic
19. Typical Medium-Voltage, Full-Voltage Induction Nonreversing Control Schematic Microprocessor-Based Protective Logic
20. Typical Remote Control Console
21. Typical Grounding Plan Utilizing Driven Electrodes
22. Typical Grounding Plan Utilizing Ground Grid
23. Vertical Wet Pit Pump
24. Submersible Propeller Pump
25. Submersible Volute Pump

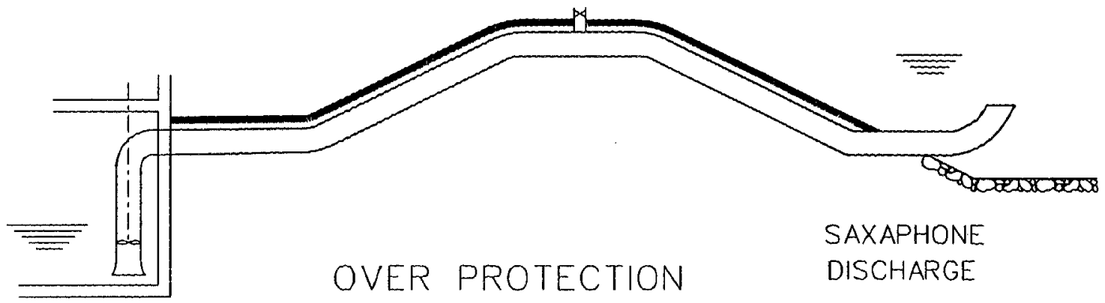

HYDRAULIC DATA
CHOOSE DISCH. TYPE
EM PUMP SELECTIONS
ALTERNATE DISCH.
PRELIM. STATION LAYOUT
COST ALT. STATION LAYOUTS
SELECT ALT. FOR FINAL DESIGN
MILESTONE CONF. W/HIGHER AUTH.
FOR LARGE STATIONS
MODEL TEST STA.
OBTAIN DATA FROM PUMP MFG.
FDM ON PUMP EQUIP.
SUBMIT FDM ON PUMP EQUIP.
PREPARE P&S ON PUMP EQUIP.
ADV. & AWARD PUMP EQUIP. CONTR.
OBTAIN EQUIP. DATA FROM MFG.
FINAL STATION LAYOUT
MISC. EQUIPMENT DESIGN
SUBMIT FDM ON STATION
PREPARE STATION P&S
DESIGN PROCEDURES

DISCHARGE ARRANGEMENTS

CONVENTIONAL STATIONS

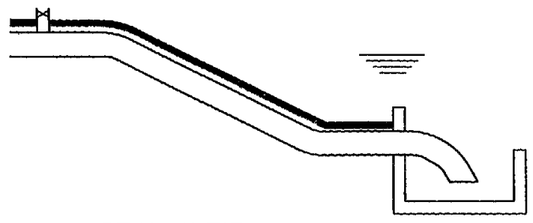


OVER PROTECTION
VENTED PIPE

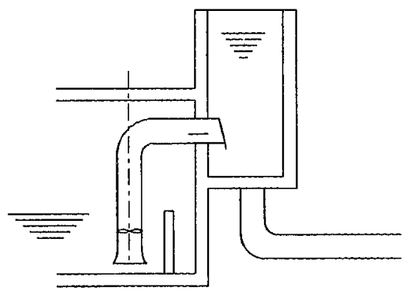


OVER PROTECTION
WITH SIPHON

SAXAPHONE
DISCHARGE

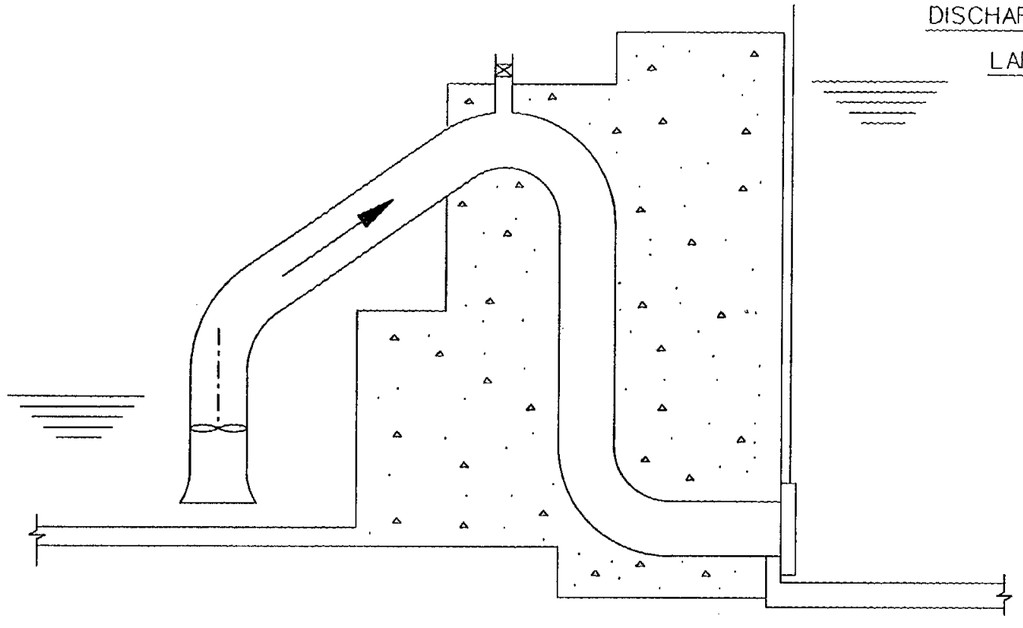


SEAL WEIR
DISCHARGE

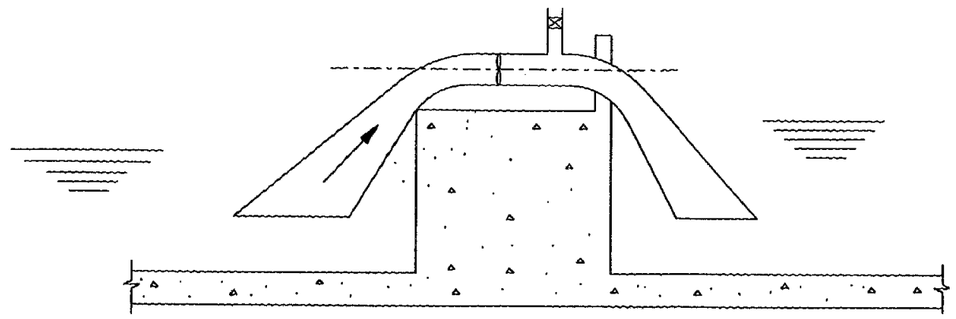


DISCHARGE CHAMBER

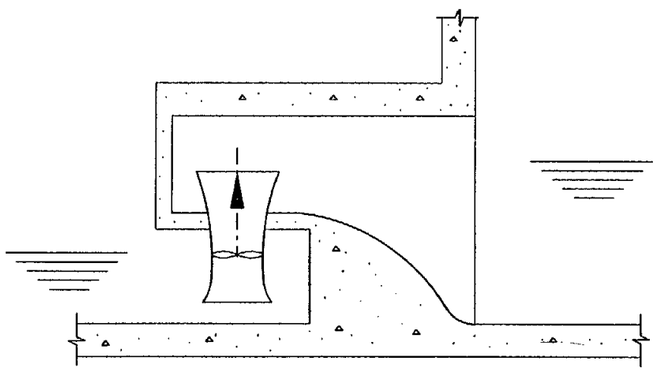
DISCHARGE ARRANGEMENTS
LARGE STATIONS



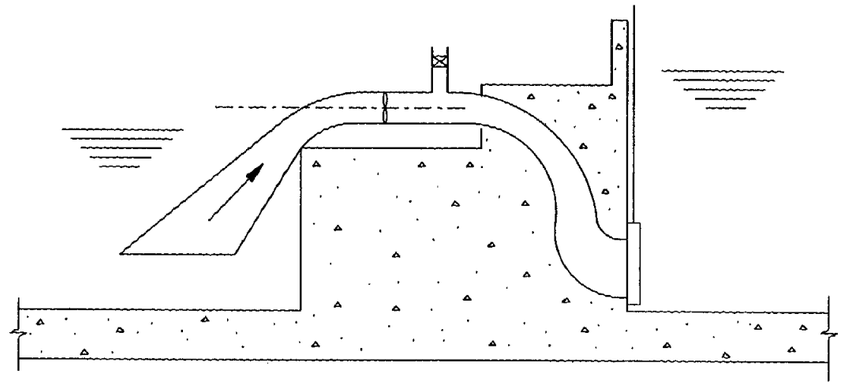
PARTIAL SIPHON
WITH MAX. WATER LEVEL
ABOVE SIPHON INVERT



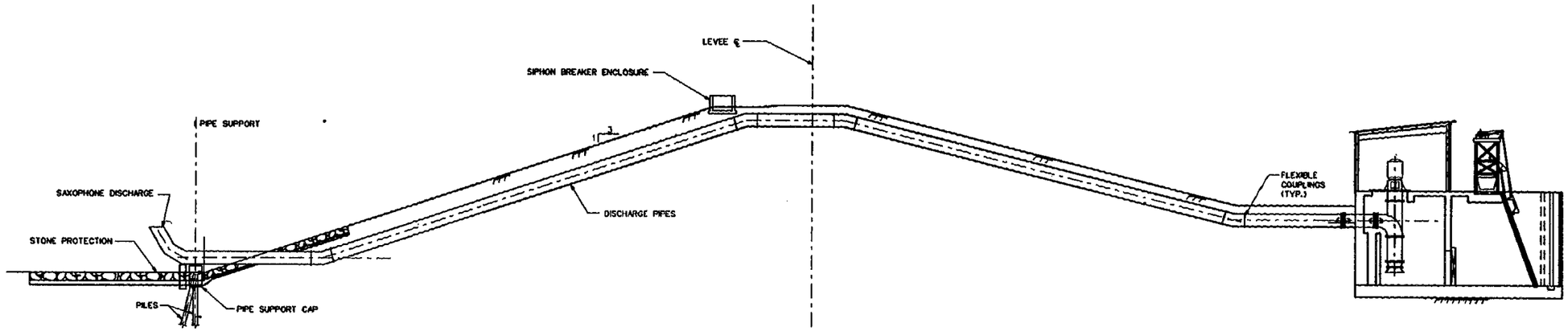
HORIZONTAL PUMP WITH IMPELLER
ABOVE DISCHARGE MAX. WATER LEVEL



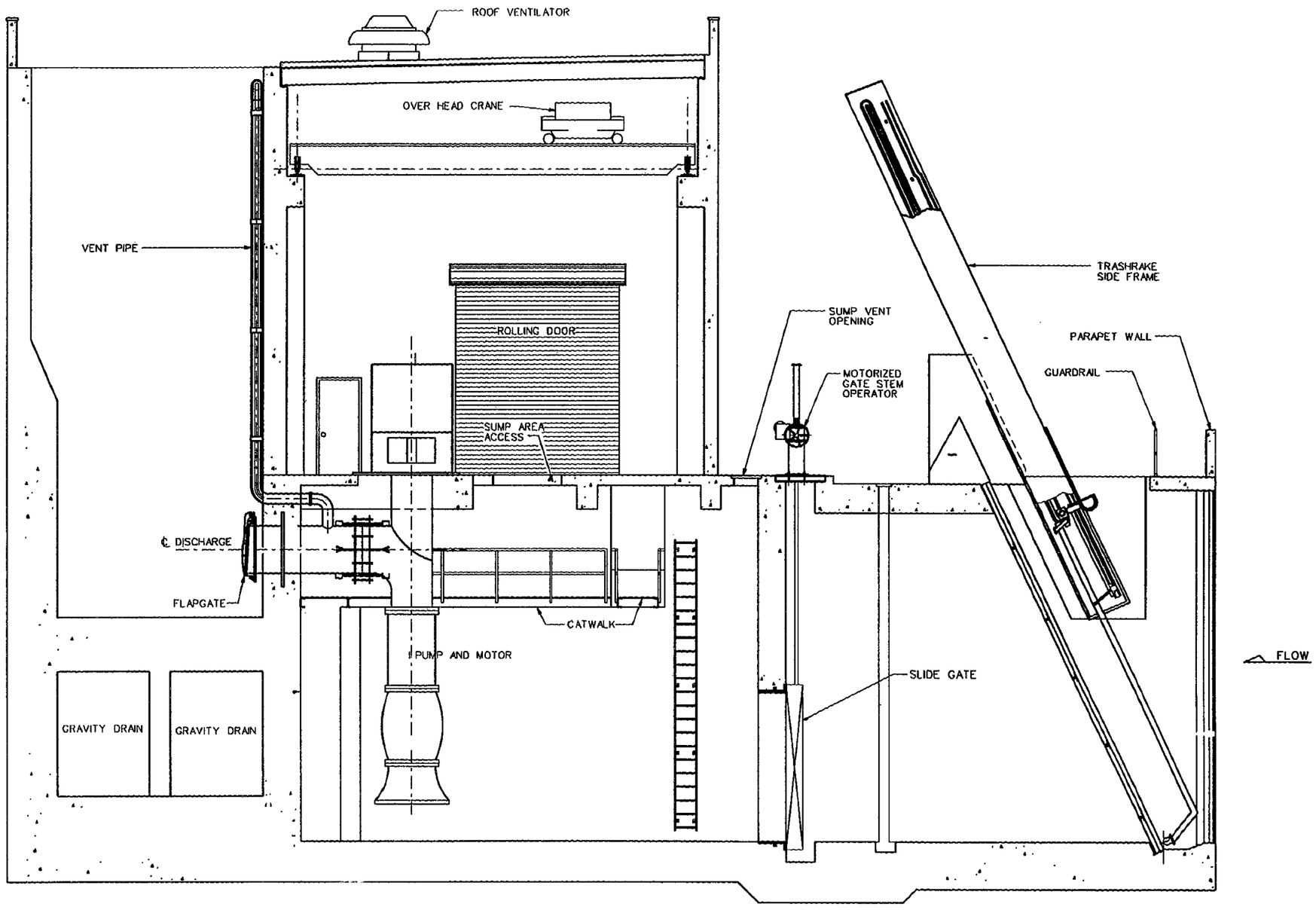
FLOWER POT



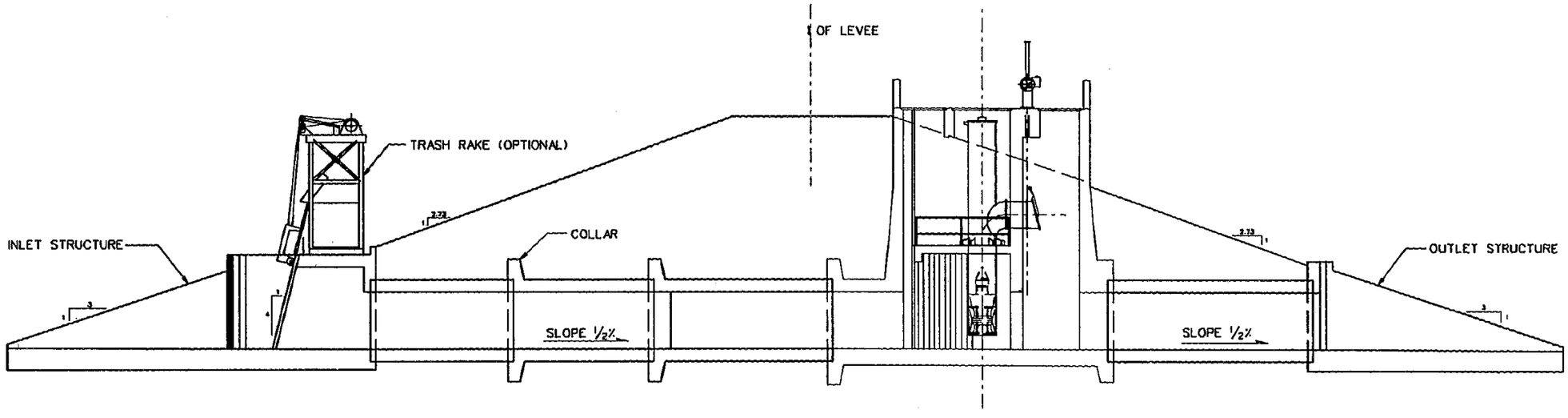
HORIZONTAL PUMP WITH IMPELLER
BELOW MAX. DISCHARGE WATER LEVEL



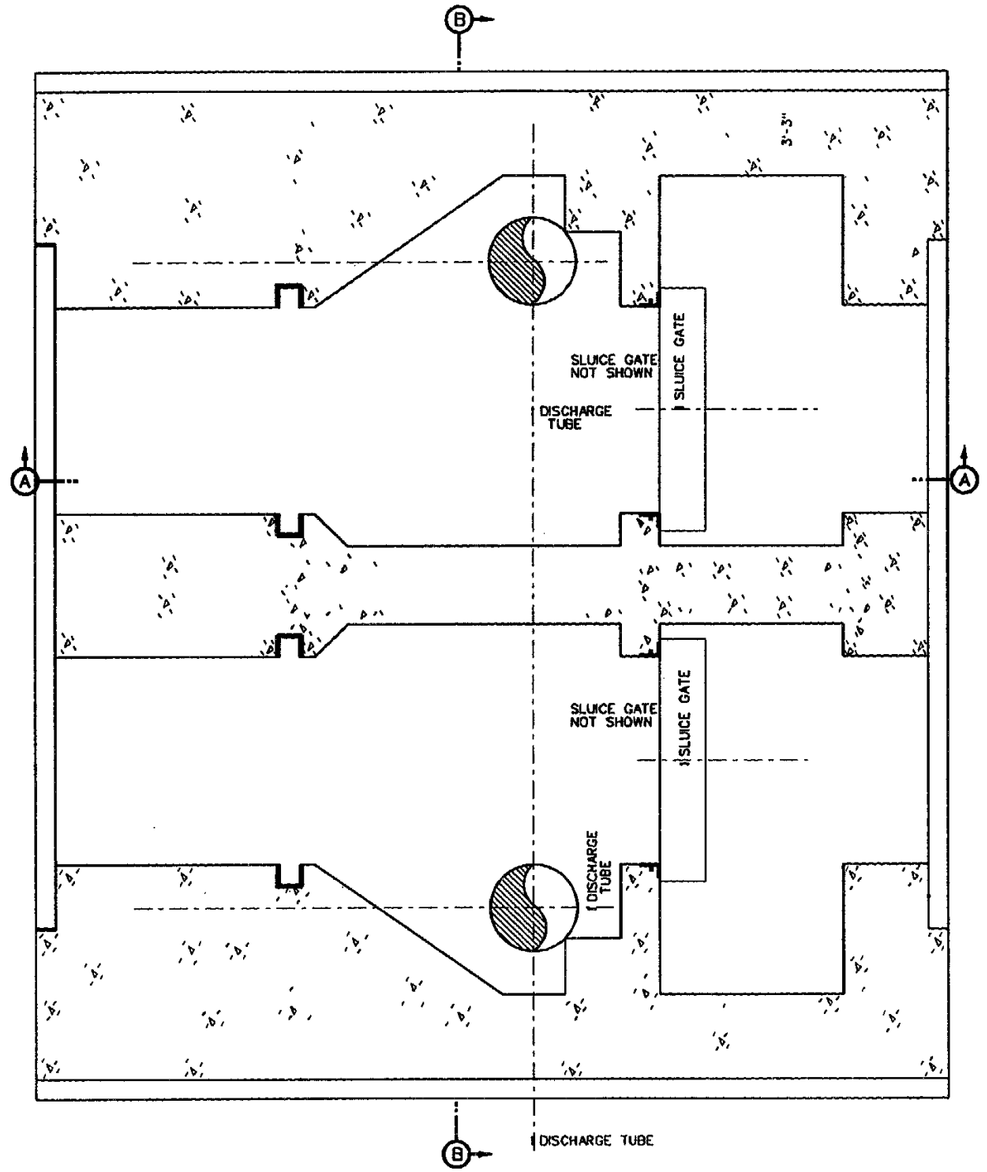
PUMP STATION WITH OVER THE PROTECTION DISCHARGE

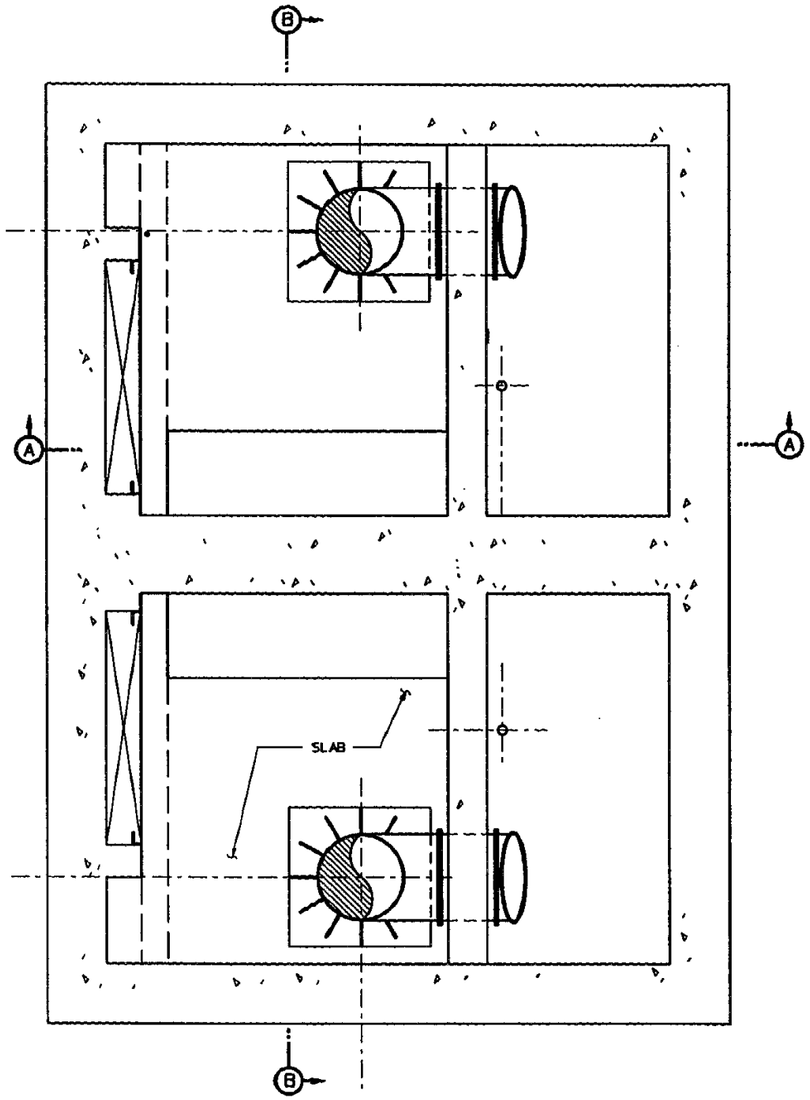


DISCHARGE CHAMBER PUMP STATION

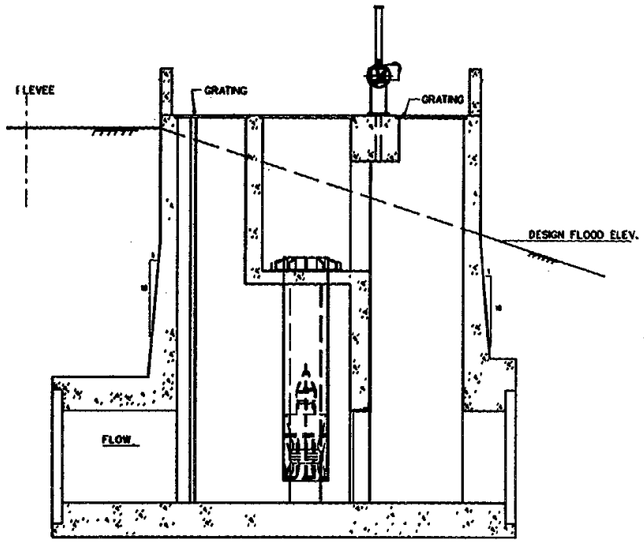


COMBINATION GATEWELL/PUMP STATION USING SUBMERSIBLE PUMPS

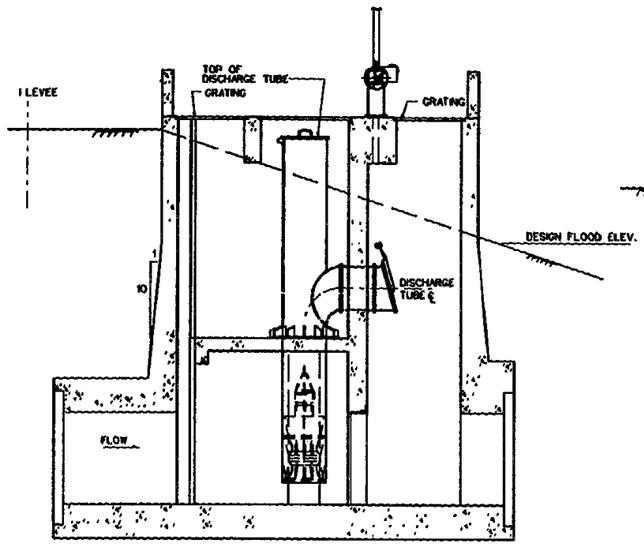




PLAN VIEWS: COMBINED GATEWELL/PUMP STATIONS

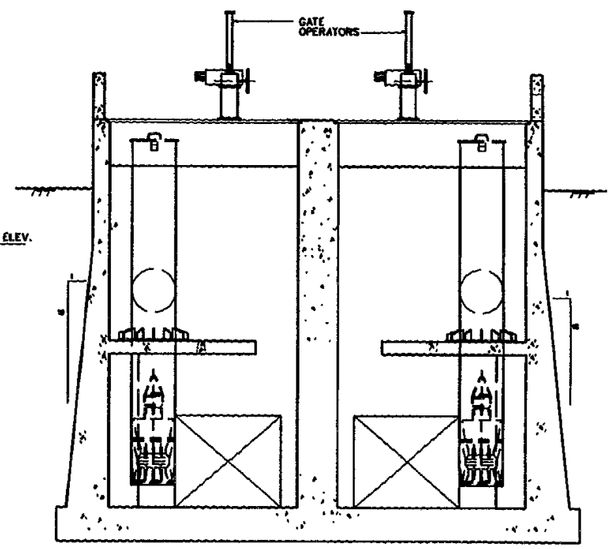


"FREE-FALL" DISCHARGE



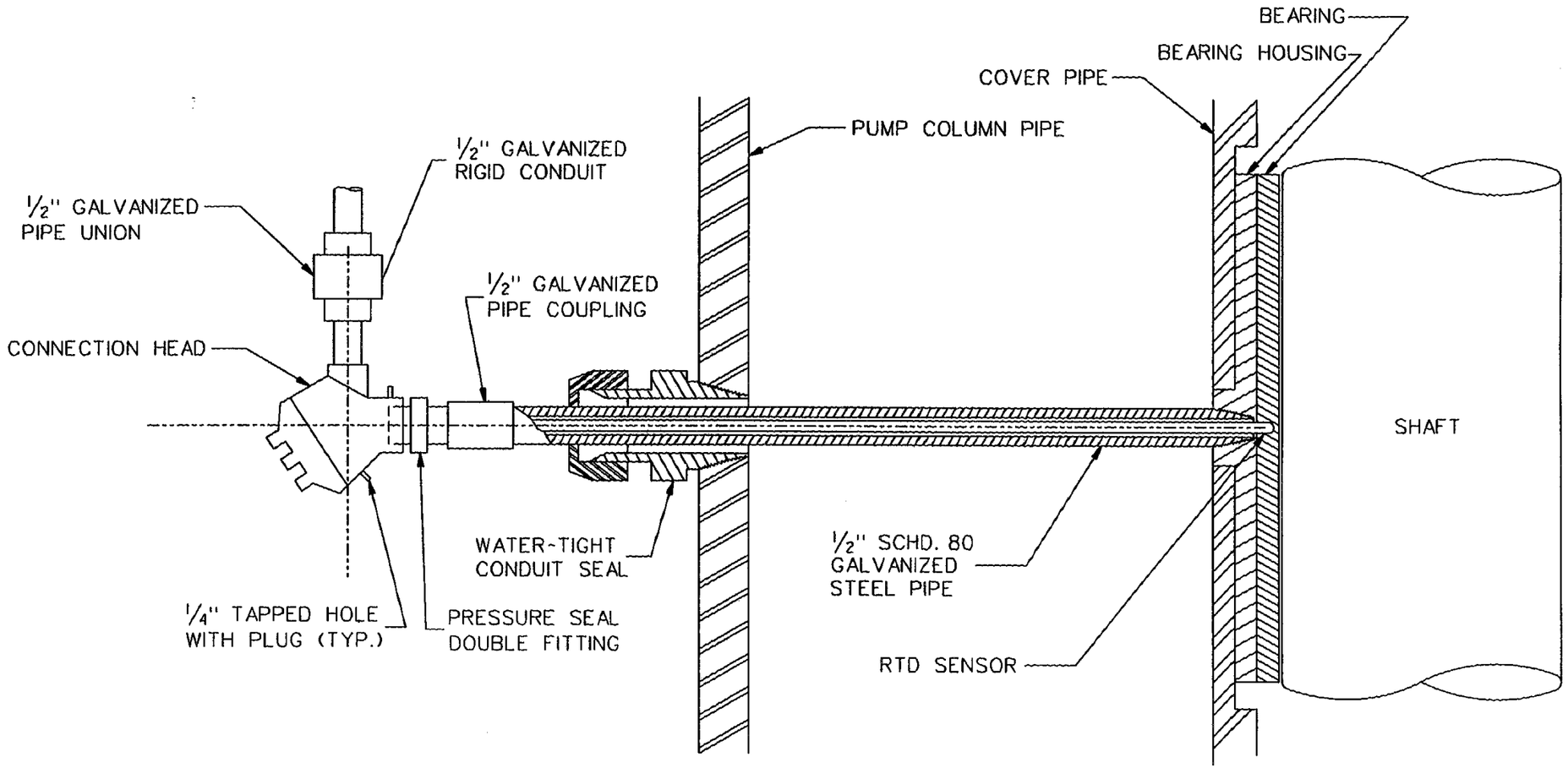
"FLAP GATE" DISCHARGE

SECTION A-A FROM PLATE G-7

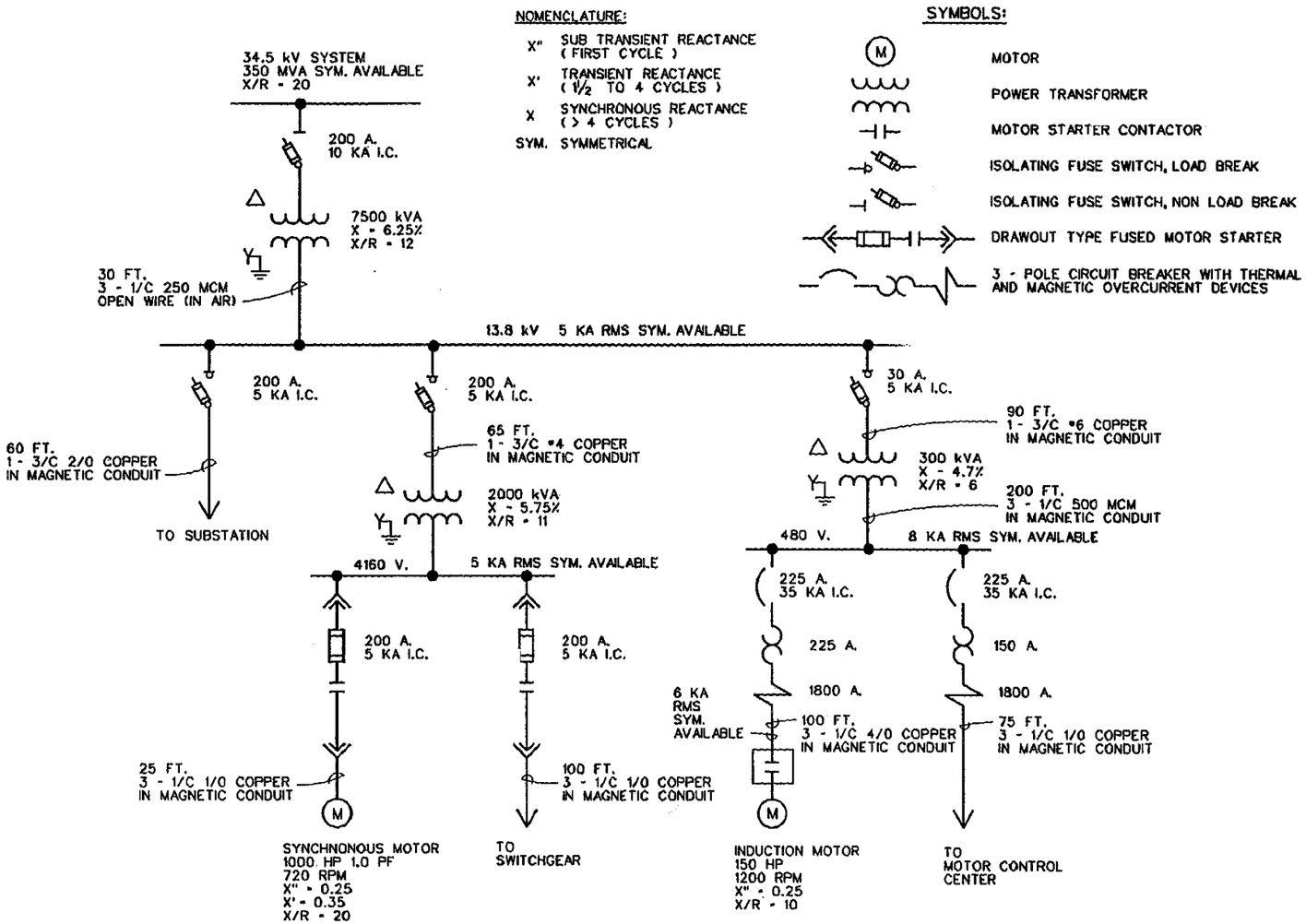


SECTION B-B FROM PLATE G-7

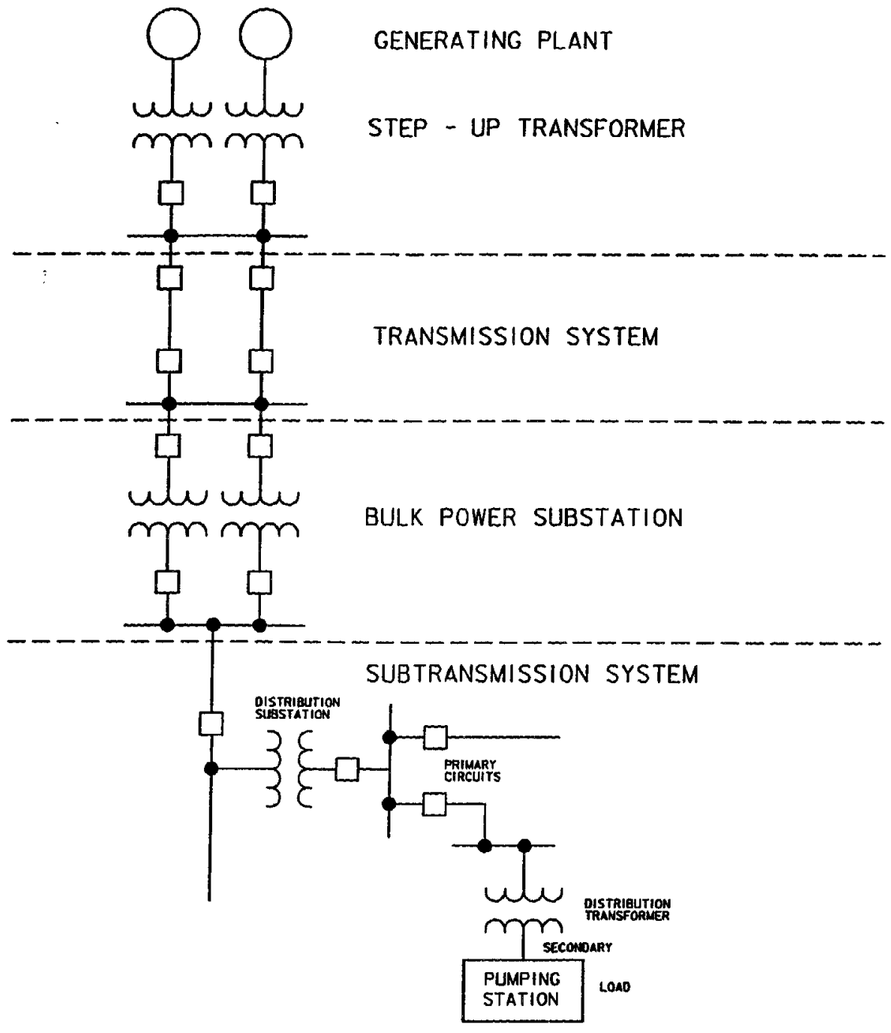
PROFILES: COMBINED GATEWELL/PUMP STATIONS



RTD INSTALLATION FOR VERTICAL WET PIT PUMPS



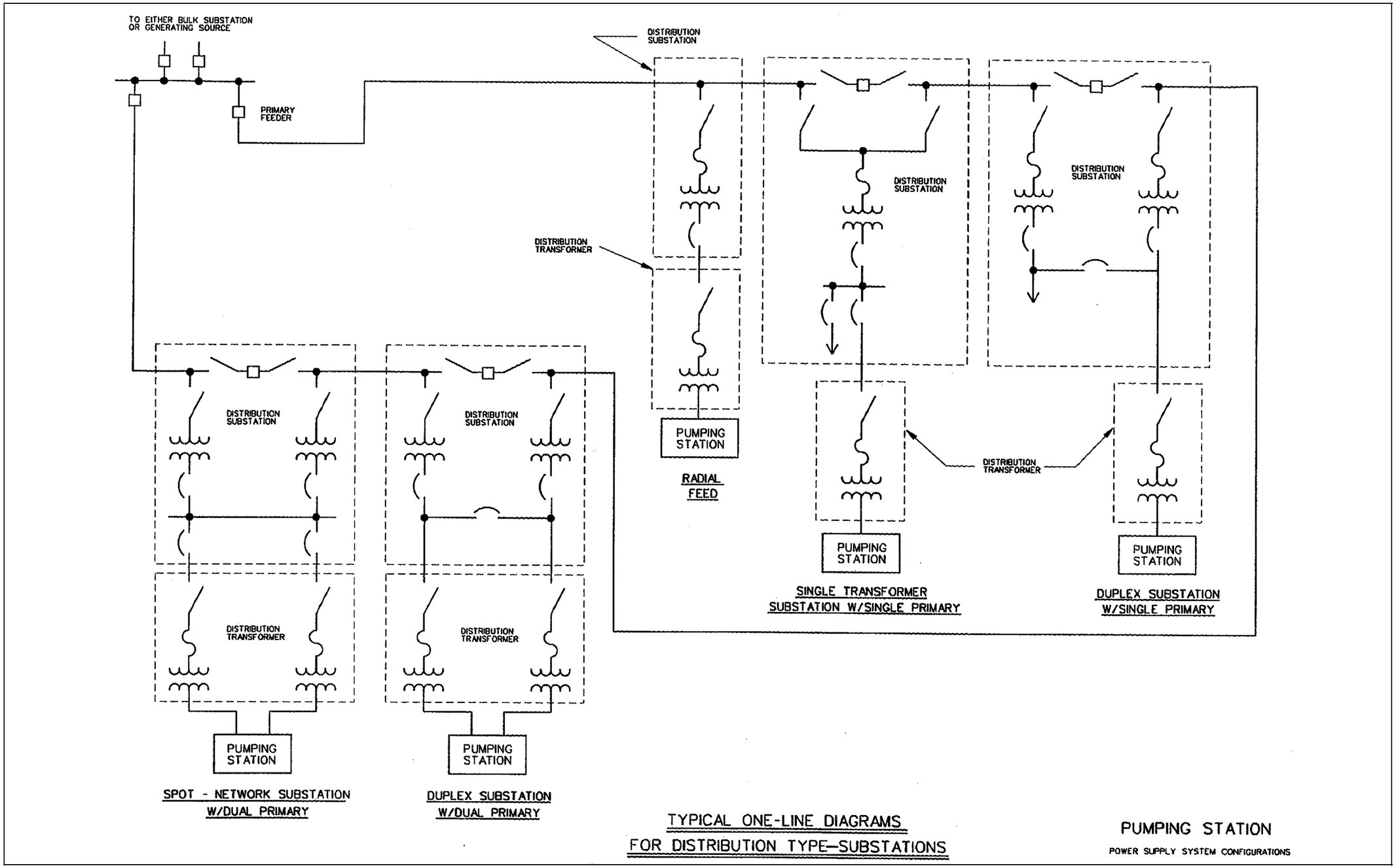
PUMPING STATION
ONE LINE DIAGRAM
FOR ELECTRICAL SYSTEM STUDIES



COMPONENTS OF AN ELECTRIC POWER SYSTEM

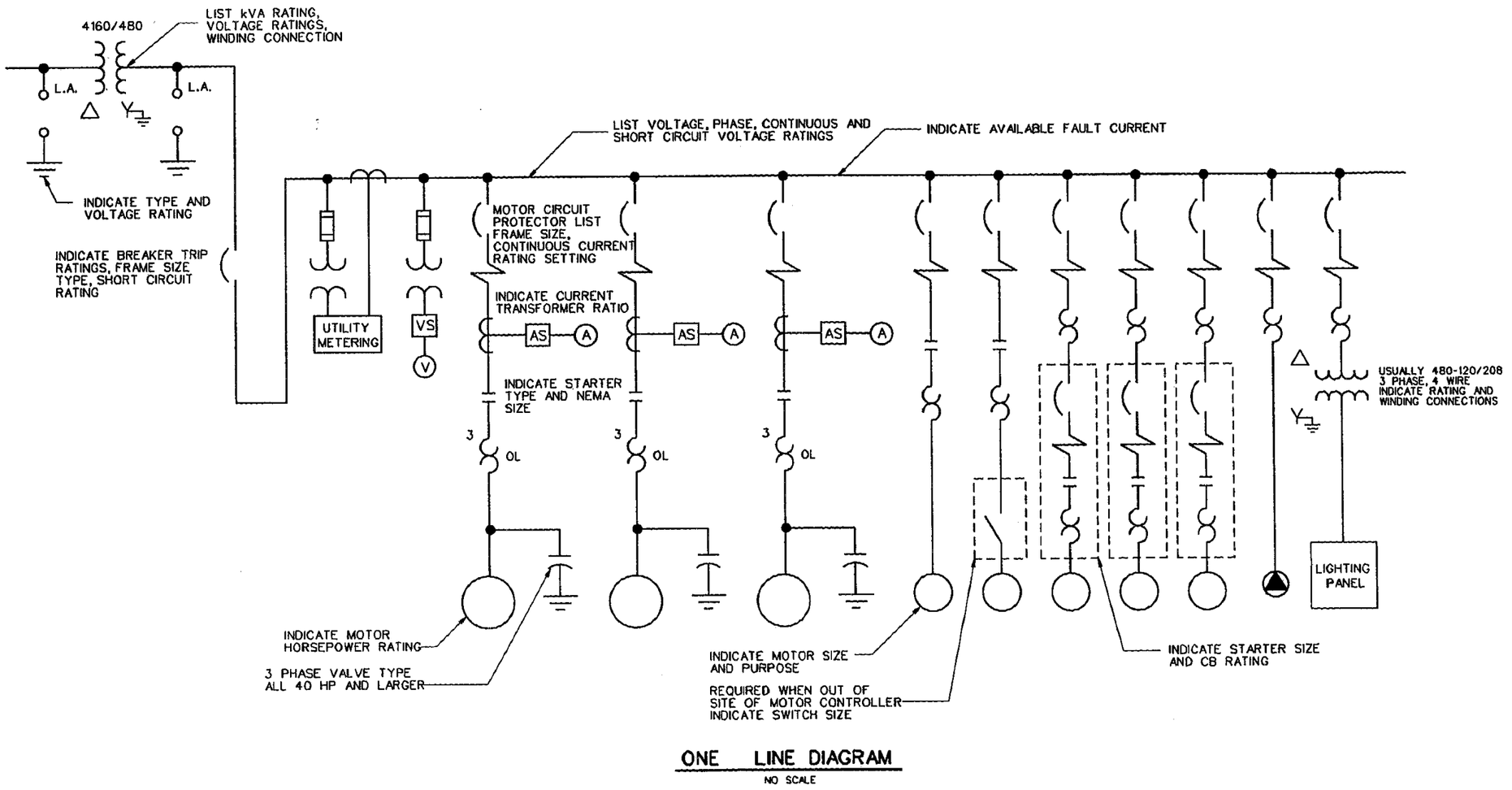
PUMPING STATION

POWER SUPPLY SYSTEM CONFIGURATIONS



TYPICAL ONE-LINE DIAGRAMS
FOR DISTRIBUTION TYPE–SUBSTATIONS

PUMPING STATION
POWER SUPPLY SYSTEM CONFIGURATIONS

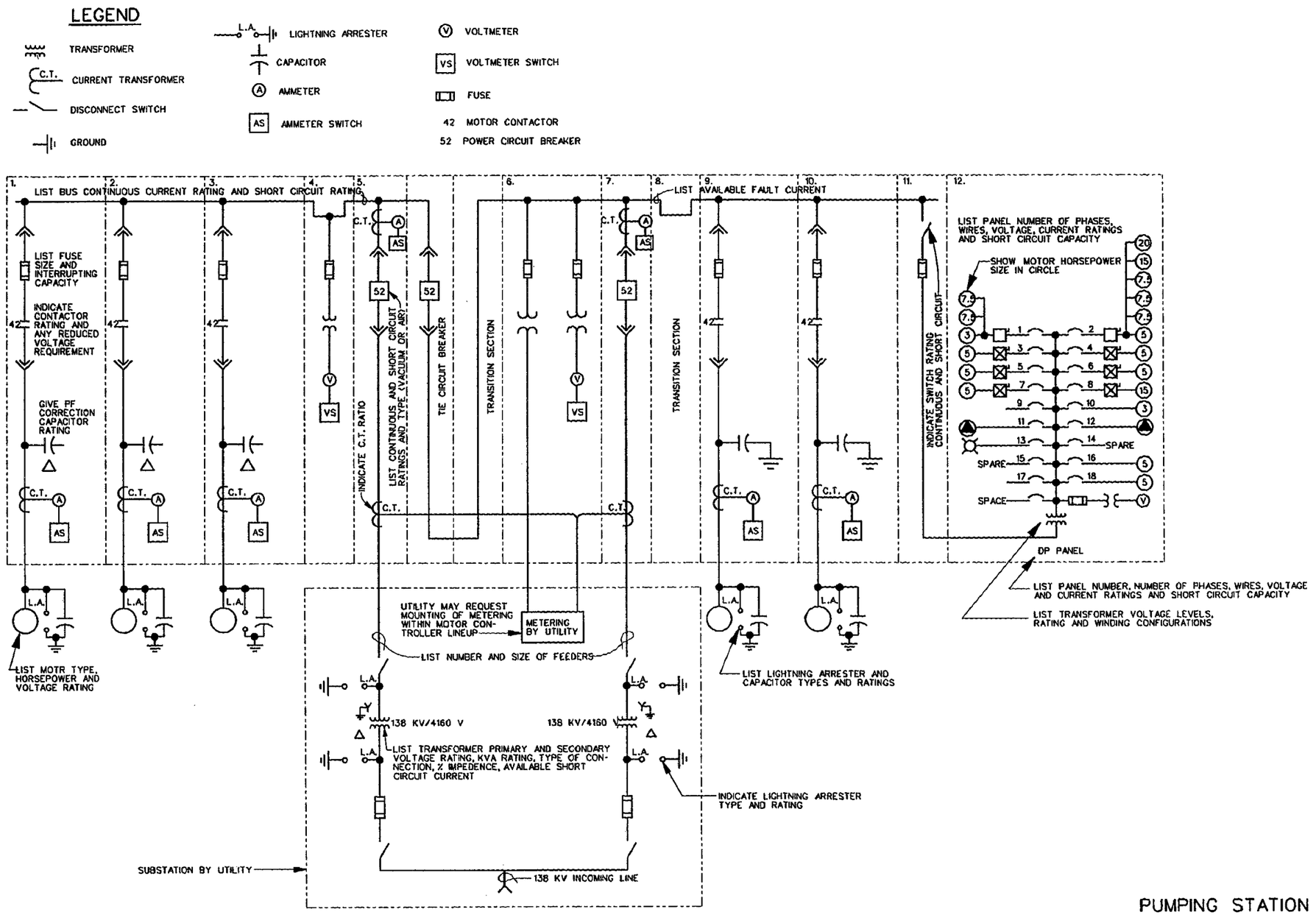


ONE LINE DIAGRAM

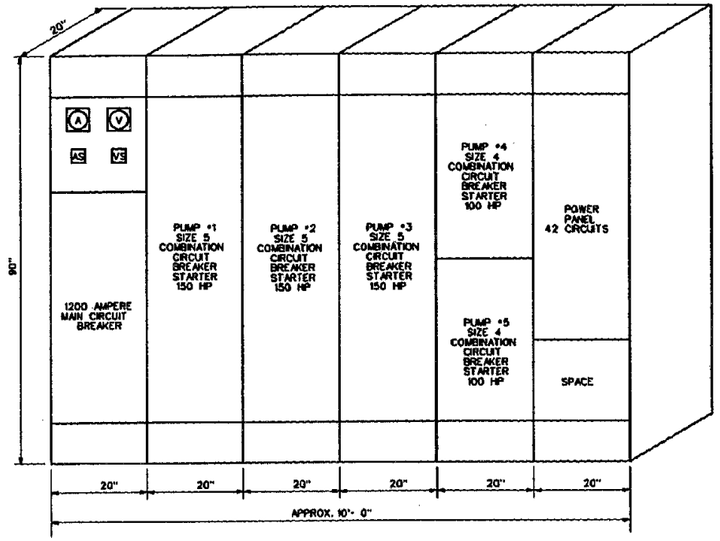
NO SCALE

PUMPING STATION

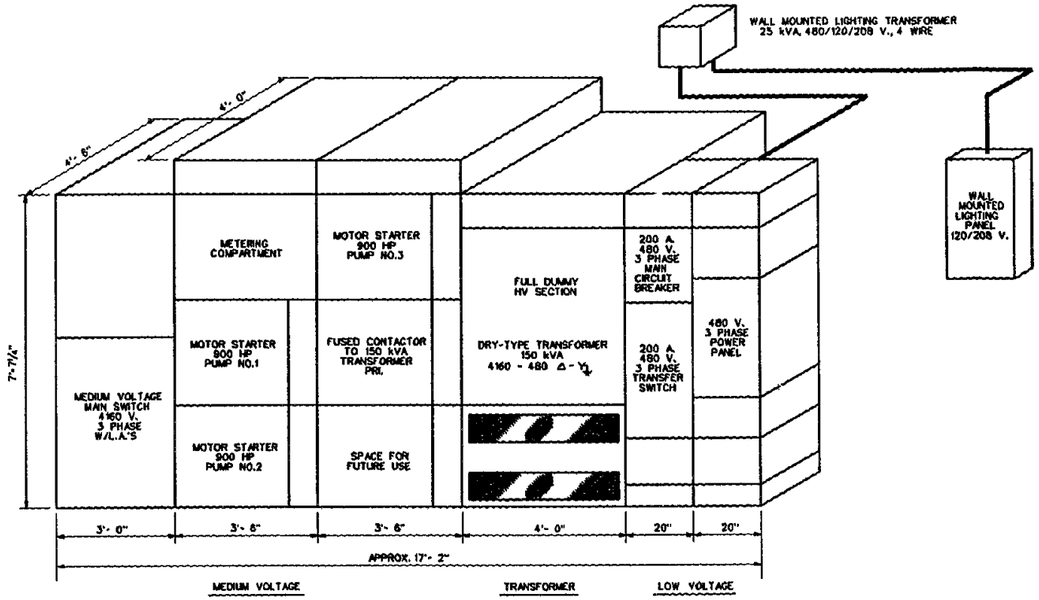
TYPICAL LOW VOLTAGE STATION ONE-LINE



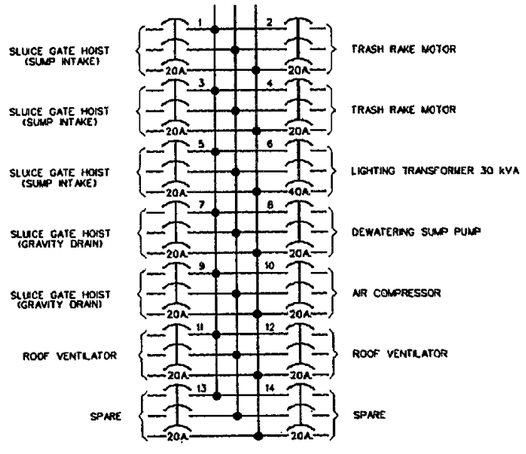
PUMPING STATION
TYPICAL MEDIUM VOLTAGE
STATION ONE-LINE



480 V. SWITCHGEAR - MOTOR CONTROL CENTER

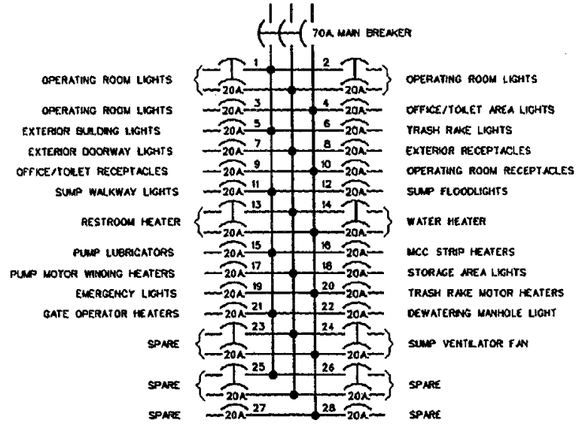


4160 VOLT MOTOR CONTROLLER LINEUP



DISTRIBUTION POWER PANEL - DP1

480 VOLTS, 3 PHASE, 3 WIRE, 60 HERTZ

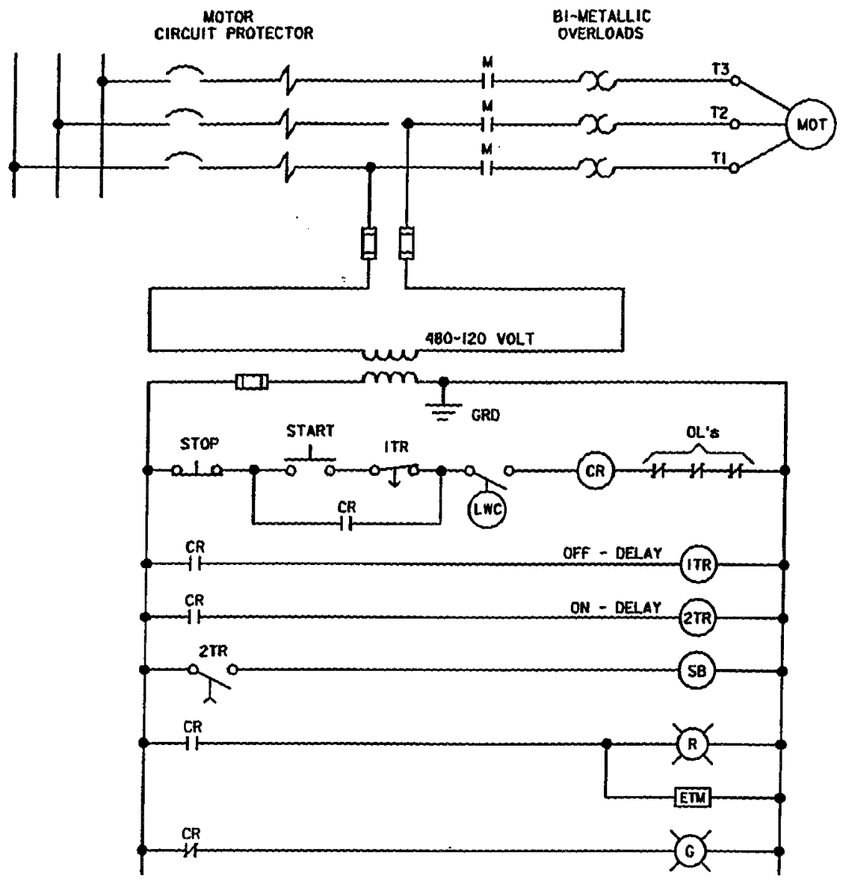


LIGHTING PANEL

120/208 VOLTS, 3 PHASE, 4 WIRE, 60 HERTZ

PUMPING STATION

TYPICAL CONTROLLER LINEUP
AND POWER & LIGHTING PANEL LAYOUTS



FULL VOLTAGE NON-REVERSING
CIRCUIT BREAKER TYPE

SYMBOLS:

	TRANSFORMER
NCTC	CLOSED CONTACTS WITH TIME DELAY CLOSING FEATURE
NOTC	OPEN CONTACTS WITH TIME DELAY CLOSING FEATURE
	CIRCUIT BREAKER
	SOLENOID
LWC	LOW WATER CUTOFF
	NORMALLY CLOSED MOMENTARY PUSHBUTTON
	NORMALLY OPEN MOMENTARY PUSHBUTTON
ETM	ELAPSED TIME METER
	RELAY
	THERMAL OVERLOAD
	NORMALLY OPEN CONTACTS
	NORMALLY CLOSED CONTACTS
	FUSE

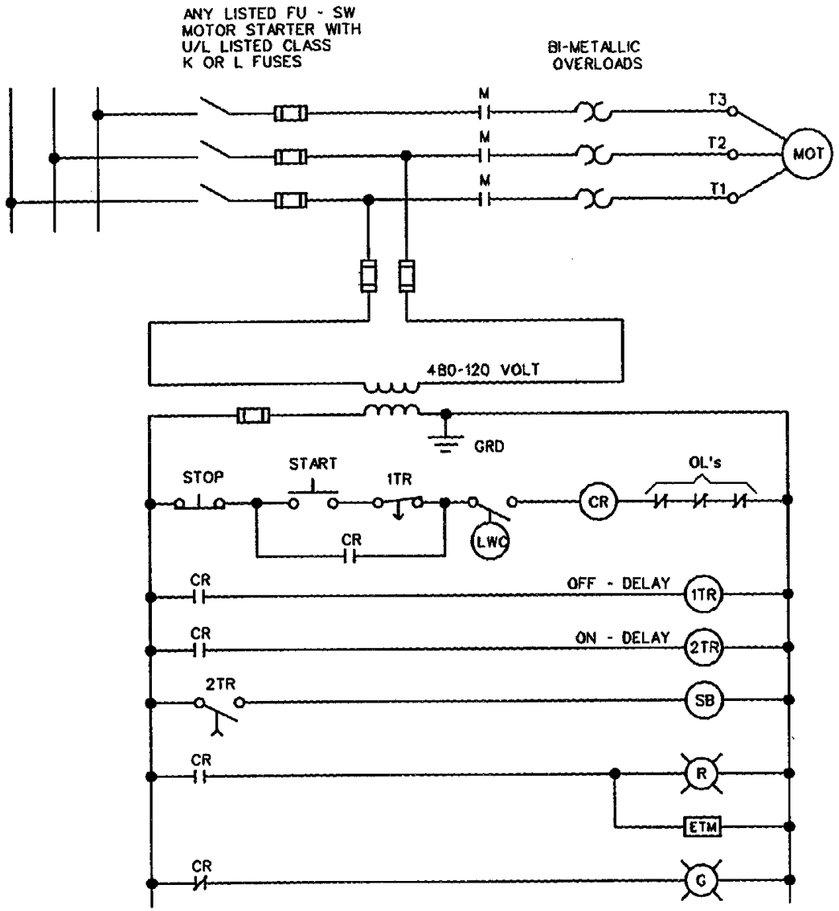
NOMENCLATURE:

AT	AUTOTRANSFORMER
1S,2S	STARTING CONTACTORS
GRD,GND	GROUND
R	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS ON STARTER OR MOTOR
SB	SIPHON BREAKER
ETM	ELAPSED TIME METER
CR	CONTROL RELAY
TR	TIMING RELAY
ITR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)

NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION
TYPICAL LOW VOLTAGE
MOTOR CONTROL SCHEMATIC



FULL VOLTAGE NON-REVERSING
FUSIBLE SWITCH TYPE

SYMBOLS:

	CONTROL CIRCUIT TRANSFORMER
NCTC	CLOSED SWITCH WITH TIME DELAY CLOSING FEATURE
NOTC	OPEN SWITCH WITH TIME DELAY CLOSING FEATURE
	SWITCH
	FUSE
LWC	LOW WATER CUTOFF
	NORMALLY CLOSED MOMENTARY PUSHBUTTON
	NORMALLY OPEN MOMENTARY PUSHBUTTON
ETM	ELAPSED TIME METER
	RELAY
	THERMAL OVERLOAD
	NORMALLY OPEN CONTACTS
	NORMALLY CLOSED CONTACTS

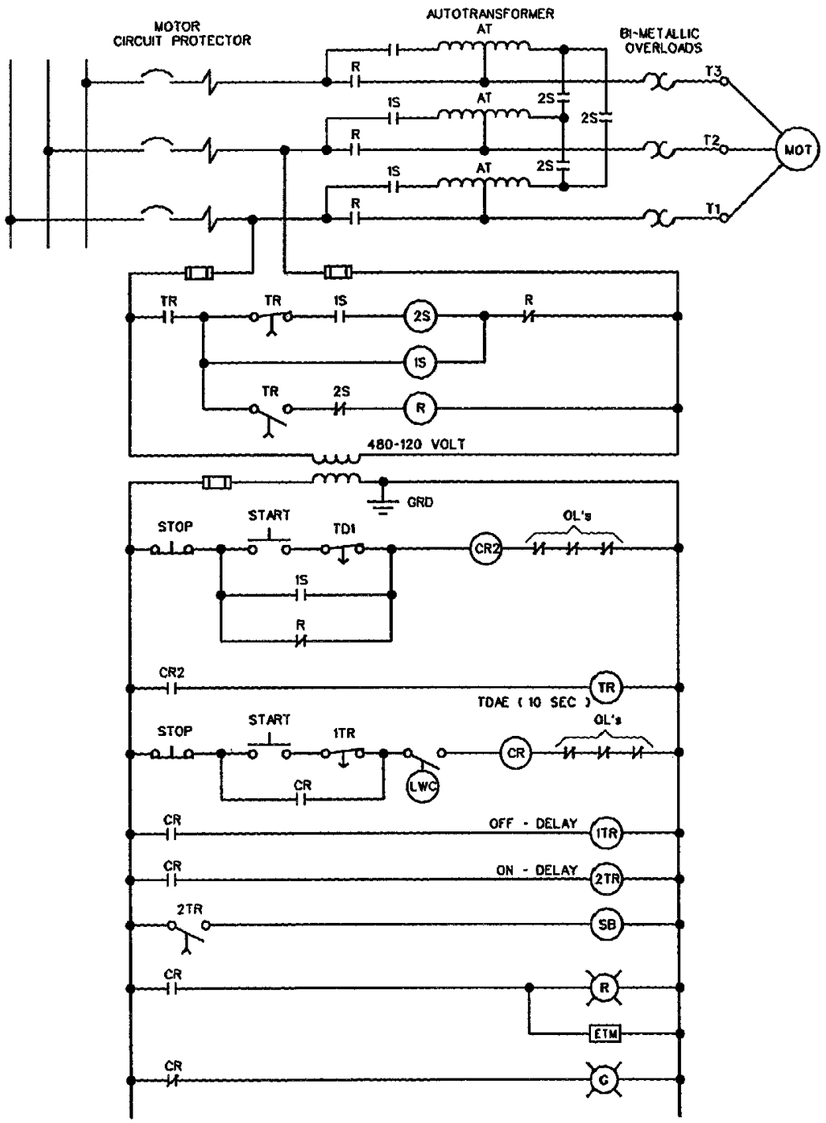
NOMENCLATURE:

AT	AUTOTRANSFORMER
1S,2S	STARTING CONTACTORS
GRD	GROUND
R	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS
SB	SIPHON BREAKER
ETM	ELAPSED TIME METER
CR	CONTROL RELAY
TR	TIMING RELAY
1TR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)

NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION
TYPICAL LOW VOLTAGE
MOTOR CONTROL SCHEMATIC



REDUCED-VOLTAGE NON-REVERSING
AUTOTRANSFORMER TYPE (CLOSED TRANSITION)

SYMBOLS:

- TRANSFORMER
- NCTO — CLOSED SWITCH WITH TIME DELAY OPENING FEATURE
- NCTC — CLOSED SWITCH WITH TIME DELAY CLOSING FEATURE
- NOTC — OPEN SWITCH WITH TIME DELAY CLOSING FEATURE
- CIRCUIT BREAKER
- SOLENOID
- LOW WATER CUTOFF
- FUSE
- NORMALLY CLOSED MOMENTARY PUSHBUTTON
- NORMALLY OPEN MOMENTARY PUSHBUTTON
- ELAPSED TIME METER
- RELAY
- THERMAL OVERLOAD
- NORMALLY OPEN CONTACTS
- NORMALLY CLOSED CONTACTS
- SWITCH

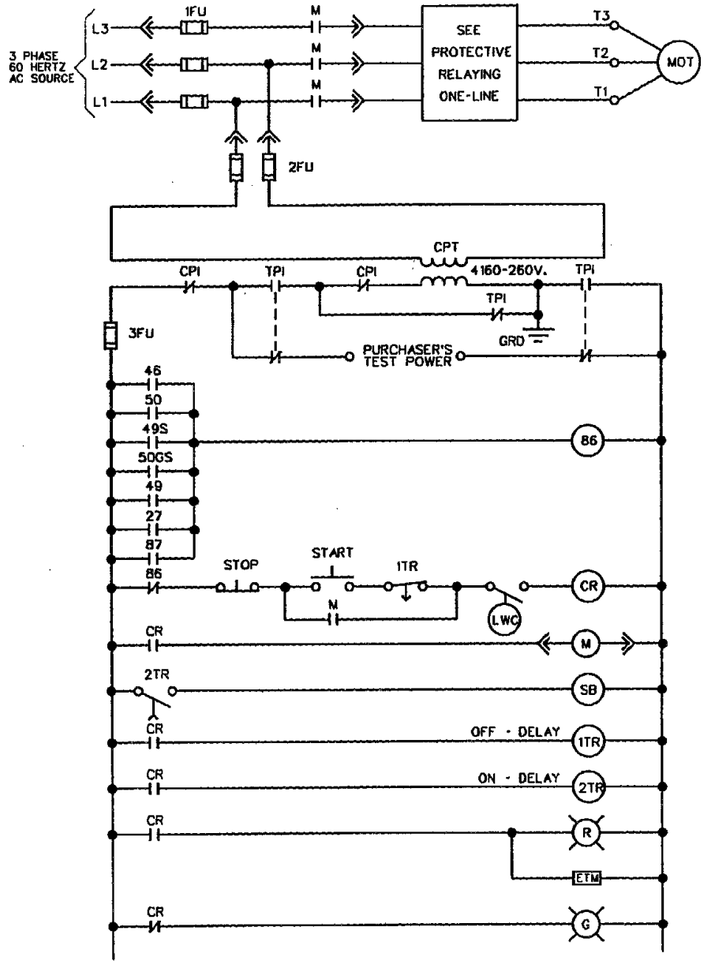
NOMENCLATURE:

AT	AUTOTRANSFORMER
1S,2S	STARTING CONTACTORS
GRD	GROUND
R	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS
SB	SIPHON BREAKER
ETM	ELAPSED TIME METER
CR	CONTROL RELAY
TR	TIMING RELAY
1TR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)

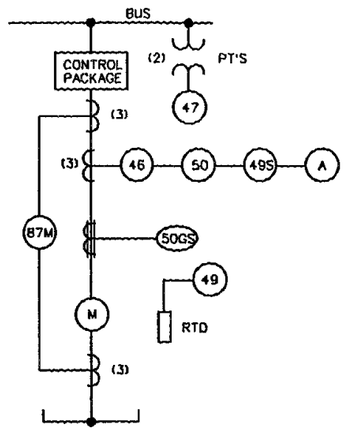
NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION
TYPICAL LOW VOLTAGE
MOTOR CONTROL SCHEMATIC



TYPICAL INDUCTION - MOTOR CONTROL
FULL VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING
FULL-VOLTAGE NON-REVERSING INDUCTION MOTOR

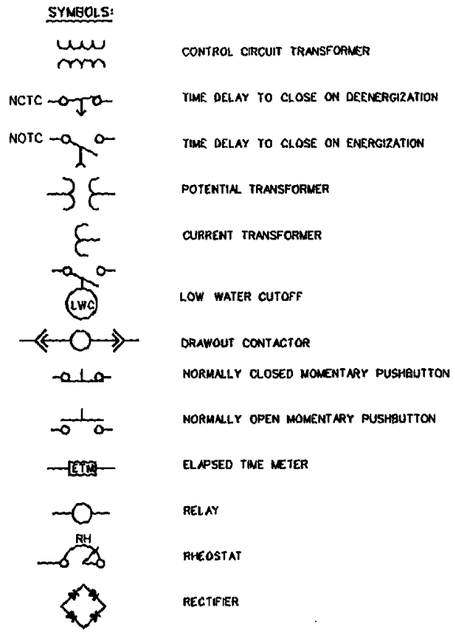
NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK
1,2,3, CT	CURRENT TRANSFORMER
1,2,3, FU	FUSE
GRD	GROUND
M	LINE CONTACTOR
MOT	MOTOR
CPT	CONTROL POWER TRANSFORMER
TPI	TEST POWER INTERLOCK
L1,L2,L3	INCOMING TERMINALS
T1,T2,T3	OUTGOING TERMINALS
A	AMMETER
SB	SIPHON BREAKER
1TR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
ETM	ELAPSED TIME METER
CR	CONTROL RELAY

DEVICE NUMBERS:

26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

SYMBOLS:

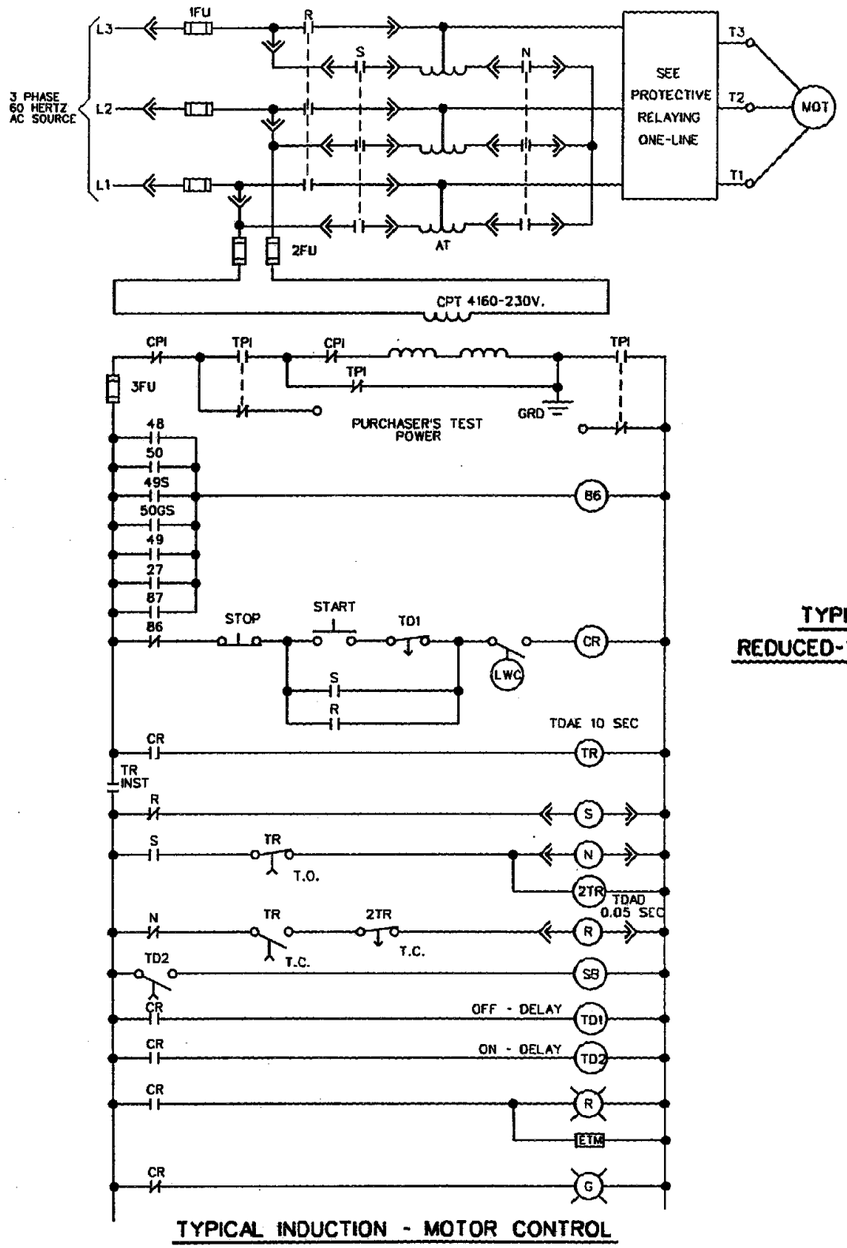


NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

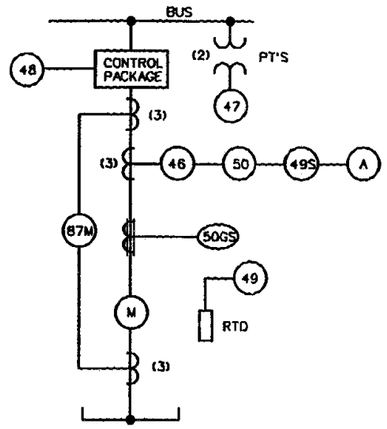
PUMPING STATION

TYPICAL MEDIUM VOLTAGE FULL - VOLTAGE
INDUCTION NON - REVERSING CONTROL SCHEMATIC
RELAY LOGIC



TYPICAL INDUCTION - MOTOR CONTROL

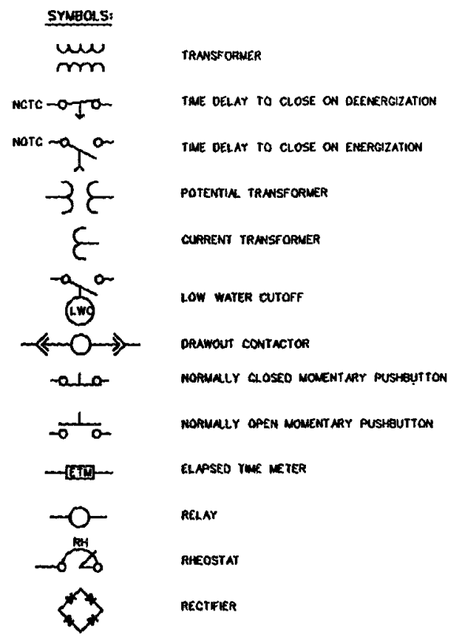
AUTOTRANSFORMER REDUCED-VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING

REDUCED-VOLTAGE NON-REVERSING INDUCTION MOTOR

SYMBOLS:



NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK	TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
1,2,3, CT	CURRENT TRANSFORMER	TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
1,2,3, FU	FUSE	ETM	ELAPSED TIME METER
GRD	GROUND	CR	CONTROL RELAY
M	LINE CONTACTOR	S	STARTING CONTACTOR
MOT	MOTOR	R	RUN CONTACTOR
CPT	CONTROL POWER TRANSFORMER	N	NEUTRAL
TPI	TEST POWER INTERLOCK	TR	TIMING RELAY FOR REDUCED VOLTAGE
L1,L2,L3	INCOMING TERMINALS	2TR	TRANSITION TIMER
T1,T2,T3	OUTGOING TERMINALS		
A	AMMETER		
SB	SIPHON BREAKER		

DEVICE NUMBERS:

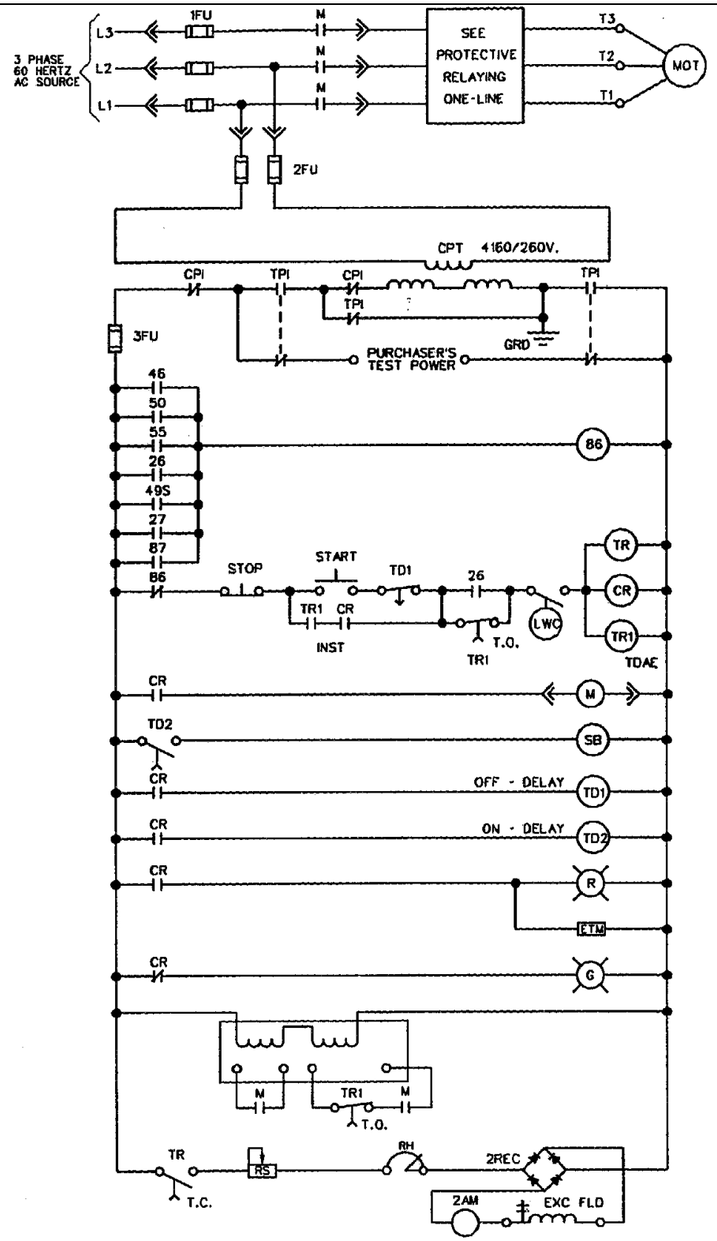
26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

NOTE:

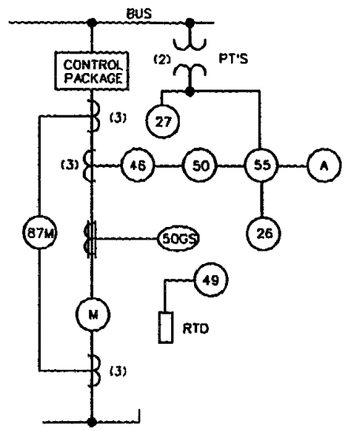
1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION

TYPICAL MEDIUM VOLTAGE REDUCED - VOLTAGE INDUCTION NON - REVERSING CONTROL SCHEMATIC RELAY LOGIC

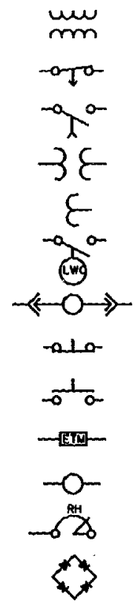


TYPICAL BRUSHLESS SYNCHRONOUS - MOTOR CONTROL
FULL VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING
FULL-VOLTAGE NON-REVERSING SYNCHRONOUS MOTOR

SYMBOLS:



TRANSFORMER
TIME DELAY TO CLOSE ON DEENERGIZATION
TIME DELAY TO CLOSE ON ENERGIZATION
POTENTIAL TRANSFORMER
CURRENT TRANSFORMER
LOW WATER CUTOFF
DRAWOUT CONTACTOR
NORMALLY CLOSED PUSHBUTTON
NORMALLY OPEN PUSHBUTTON
ELAPSED TIME METER
RELAY
RHEOSTAT
RECTIFIER

NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK	TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
1,2,3, CT	CURRENT TRANSFORMER	TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
1,2,3, FU	FUSE	ETM	ELAPSED TIME METER
GRD	GROUND	CR	CONTROL RELAY
M	LINE CONTACTOR	2AM	Dc AMMETER
MOT	MOTOR	EXC FLD	EXCITER FIELD
CPT	CONTROL POWER TRANSFORMER	TR	FIELD - APPLYING TIMER
TPI	TEST POWER INTERLOCK	RH	EXCITER FIELD RHEOSTAT
L1,L2,L3	INCOMING TERMINALS	TR1	PULLOUT PROTECTION APPLYING TIMER
T1,T2,T3	OUTGOING TERMINALS		
A	AMMETER		
SB	SIPHON BREAKER		

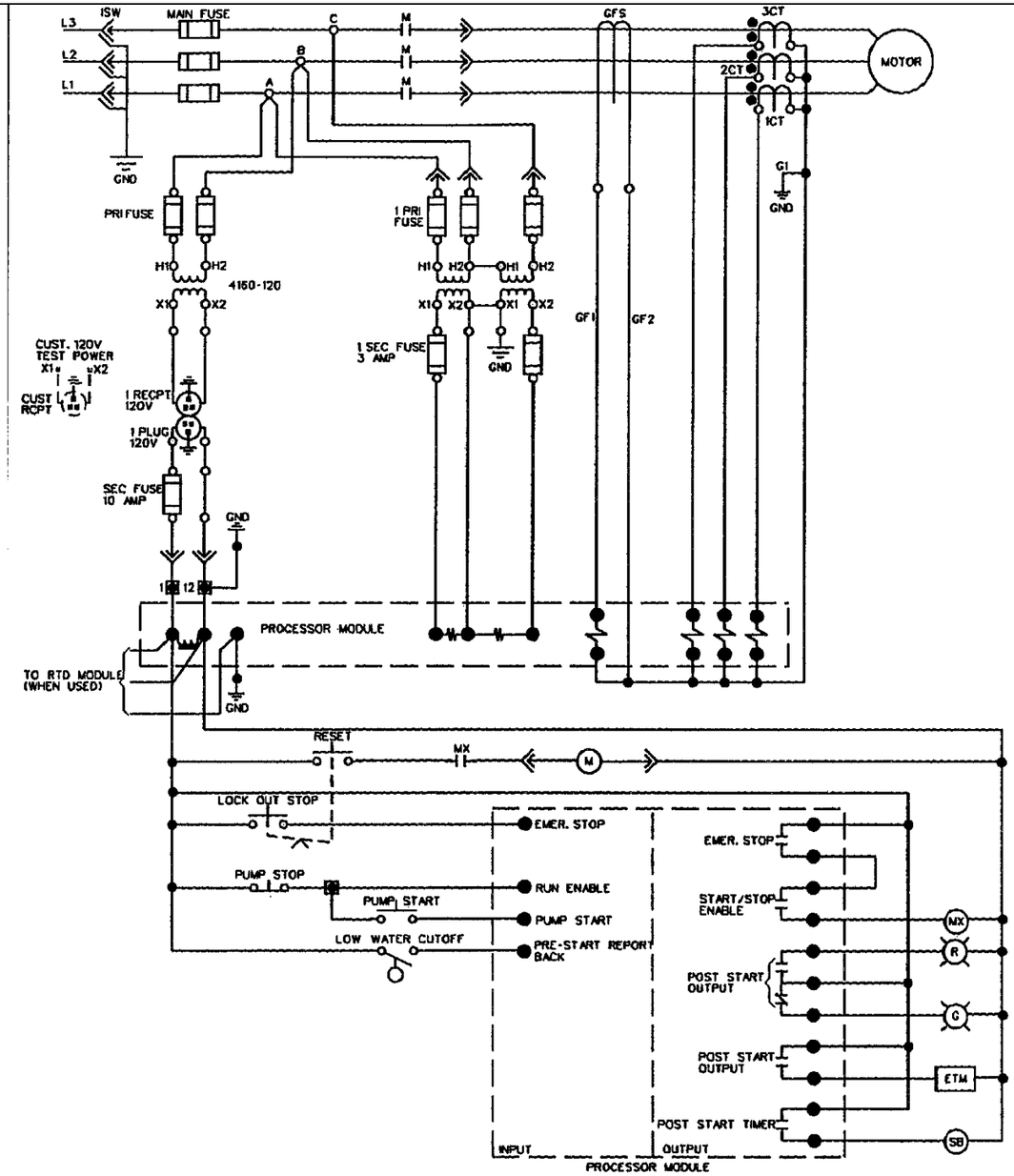
DEVICE NUMBERS:

26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB.

PUMPING STATION
TYPICAL MEDIUM VOLTAGE FULL - VOLTAGE BRUSHLESS SYNCHRONOUS NON - REVERSING CONTROL SCHEMATIC RELAY LOGIC



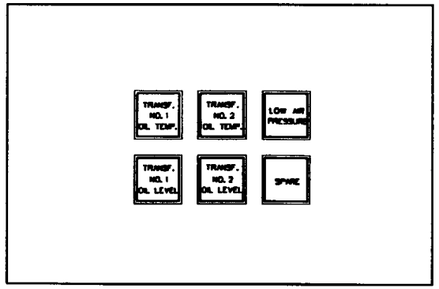
TYPICAL REVERSING MOTOR CONTROL FULL VOLTAGE NON-REVERSING MICROPROCESSOR PROTECTION PACKAGE

SYMBOLS:

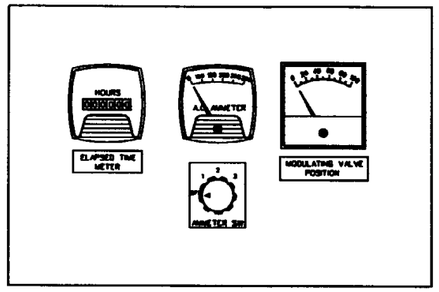
- TERMINAL BOARD POINT
- PROCESSOR TERMINAL POINT
- MX — AUXILLIARY RELAY
- TRANSFORMER
- FUSE
- GROUND
- POTENTIAL TRANSFORMER
- CURRENT TRANSFORMER
- LOW WATER CUTOFF
- DRAWOUT CONTACTOR
- NORMALLY CLOSED MOMENTARY PUSHBUTTON
- NORMALLY OPEN MOMENTARY PUSHBUTTON
- ETM — ELAPSED TIME METER
- RELAY
- NORMALLY OPEN CONTACTS
- NORMALLY CLOSED CONTACTS

PUMPING STATION

TYPICAL MEDIUM VOLTAGE FULL VOLTAGE INDUCTION NON-REVERSING CONTROL SCHEMATIC MICROPROCESSOR -BASED PROTECTIVE LOGIC



PANEL - B



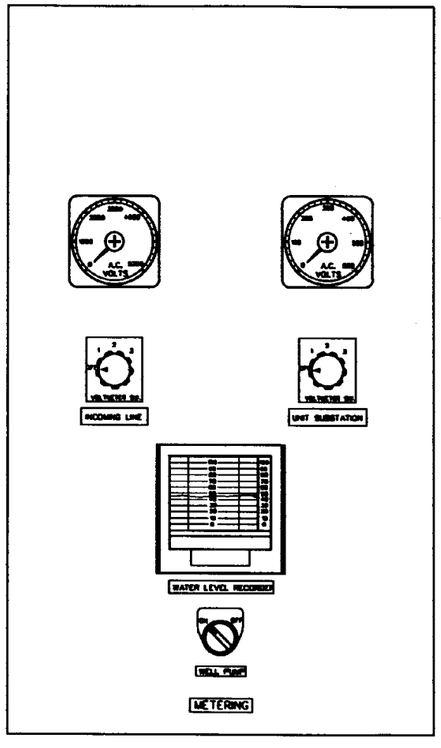
PANEL - B

METERING	PUMPING UNIT NO. 1	PUMPING UNIT NO. 2	PUMPING UNIT NO. 3	PUMPING UNIT NO. 4	PUMPING UNIT NO. 5
SECTION NO. 1	SECTION NO. 2	SECTION NO. 3	SECTION NO. 4	SECTION NO. 5	SECTION NO. 6

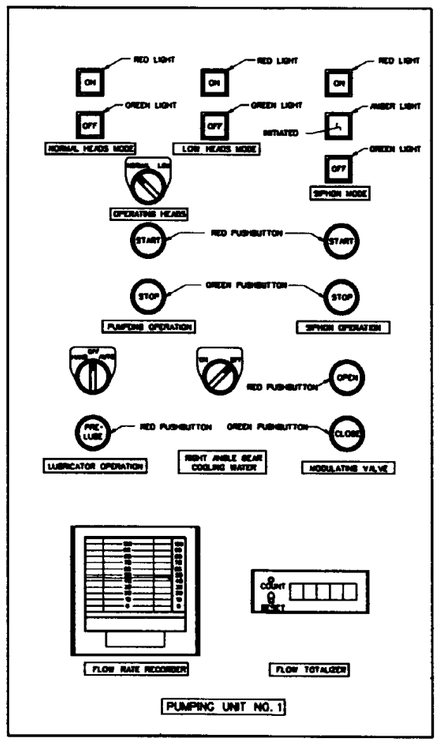
20" (TYPICAL)

10'- 0"

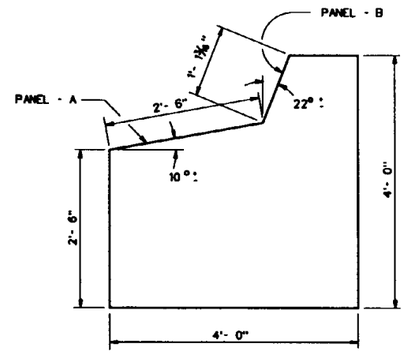
FRONT VIEW



PANEL - A



PANEL - A



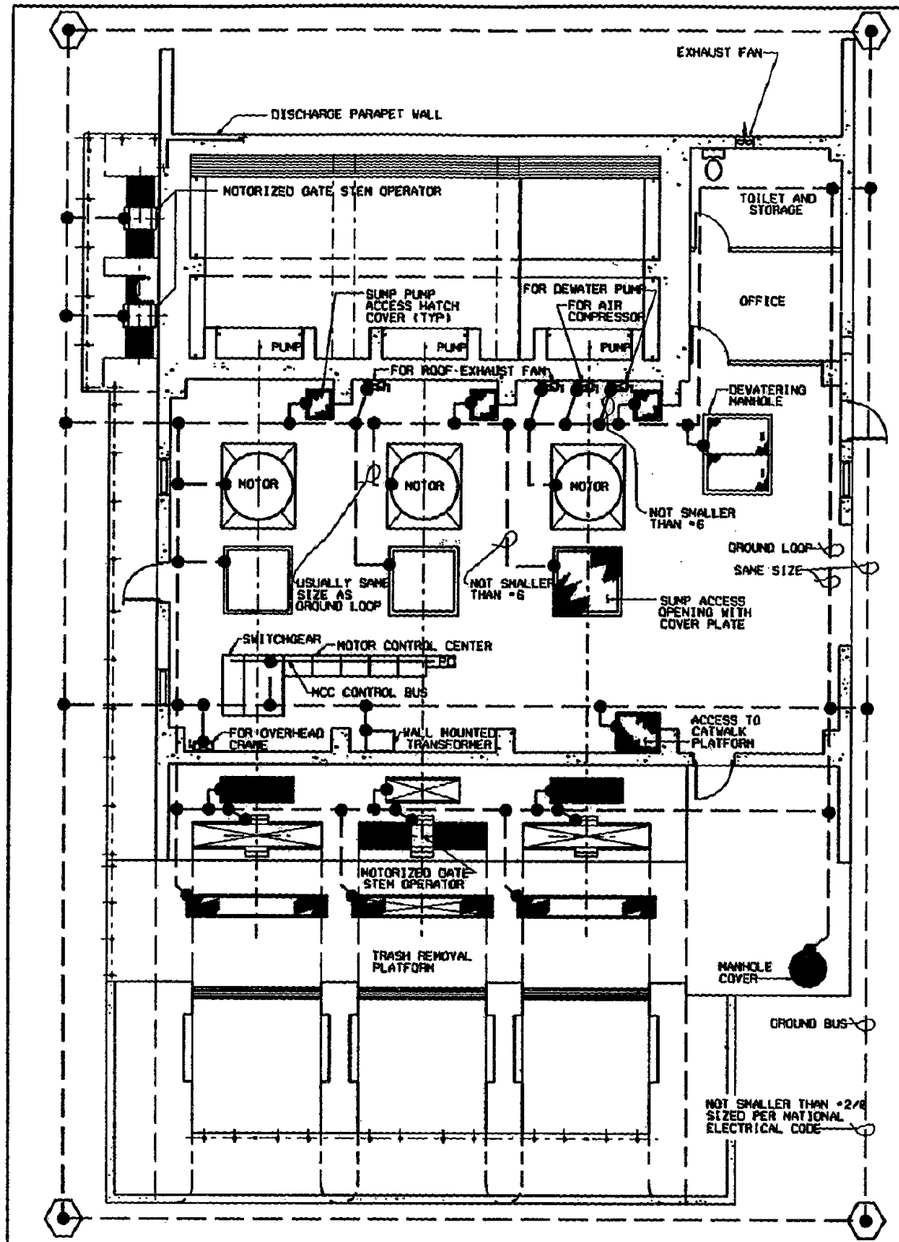
END VIEW

CONTROL CONSOLE

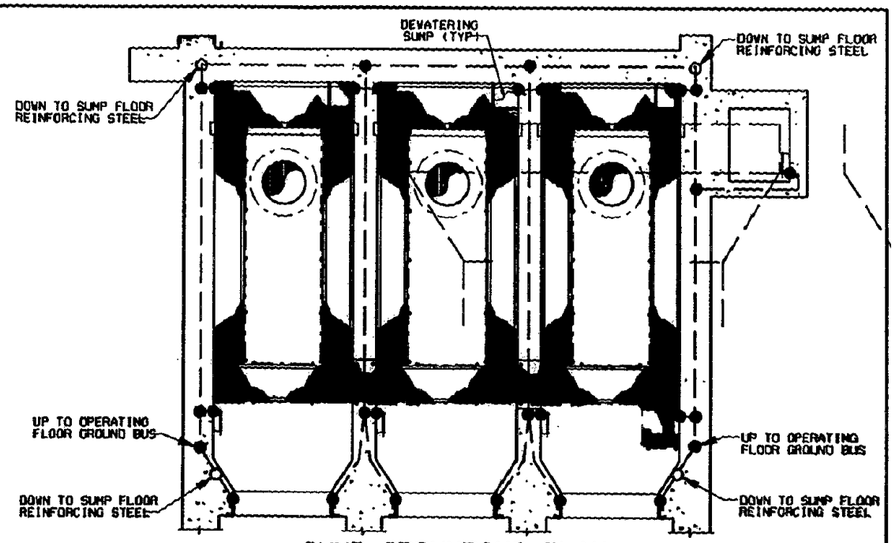
NO SCALE

PUMPING STATION

TYPICAL REMOTE CONTROL CONSOLE



OPERATING FLOOR GROUNDING PLAN



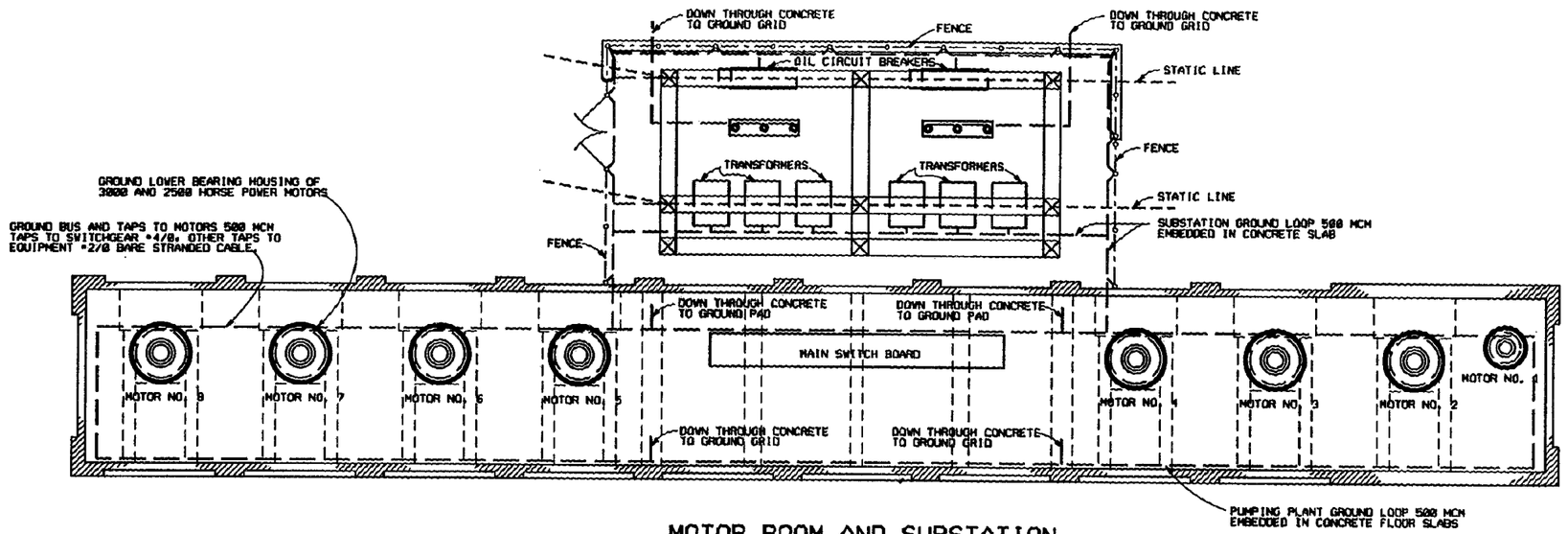
SUMP GROUNDING PLAN

TYPICAL NOTES:

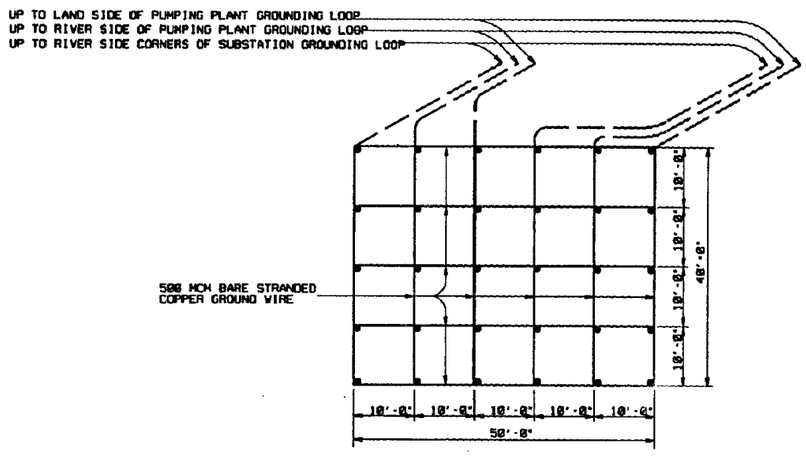
1. ADDITIONAL LENGHTS OR NUMBERS OF GROUND RODS SHALL BE ADDED AS REQUIRED TO ACHIEVE A MAXIMUM RESISTANCE TO GROUND OF 25 OHMS.
2. GROUND BUS SHALL BE EXOTHERMICALLY WELDED TO THE SUMP FLOOR REBARS, ANY METAL FRAMEWORK OF THE BUILDING AND METALLIC UNDERGROUND WATER PIPE IF PRESENT.
3. THE FRAMES OF ALL STATIONARY OR PERMANENTLY LOCATED MOTORS, STATIC EQUIPMENT OR MOTOR CONTROLLERS SHALL BE GROUNDED BY CONNECTION TO THE GROUND LOOP BY AN EQUIPMENT GROUNDING CODUCTOR EQUAL IN SIZE TO THE LARGEST CONDUCTOR IN THE LINE CONNECTED TO THE EQUIPMENT BUT NOT LESSTHAN NO. 6 AWG.

PUMPING STATION

TYPICAL GROUNDING PLAN
UTILIZING DRIVEN ELECTRODES



MOTOR ROOM AND SUBSTATION GROUND LOOPS



GROUNDING PAD

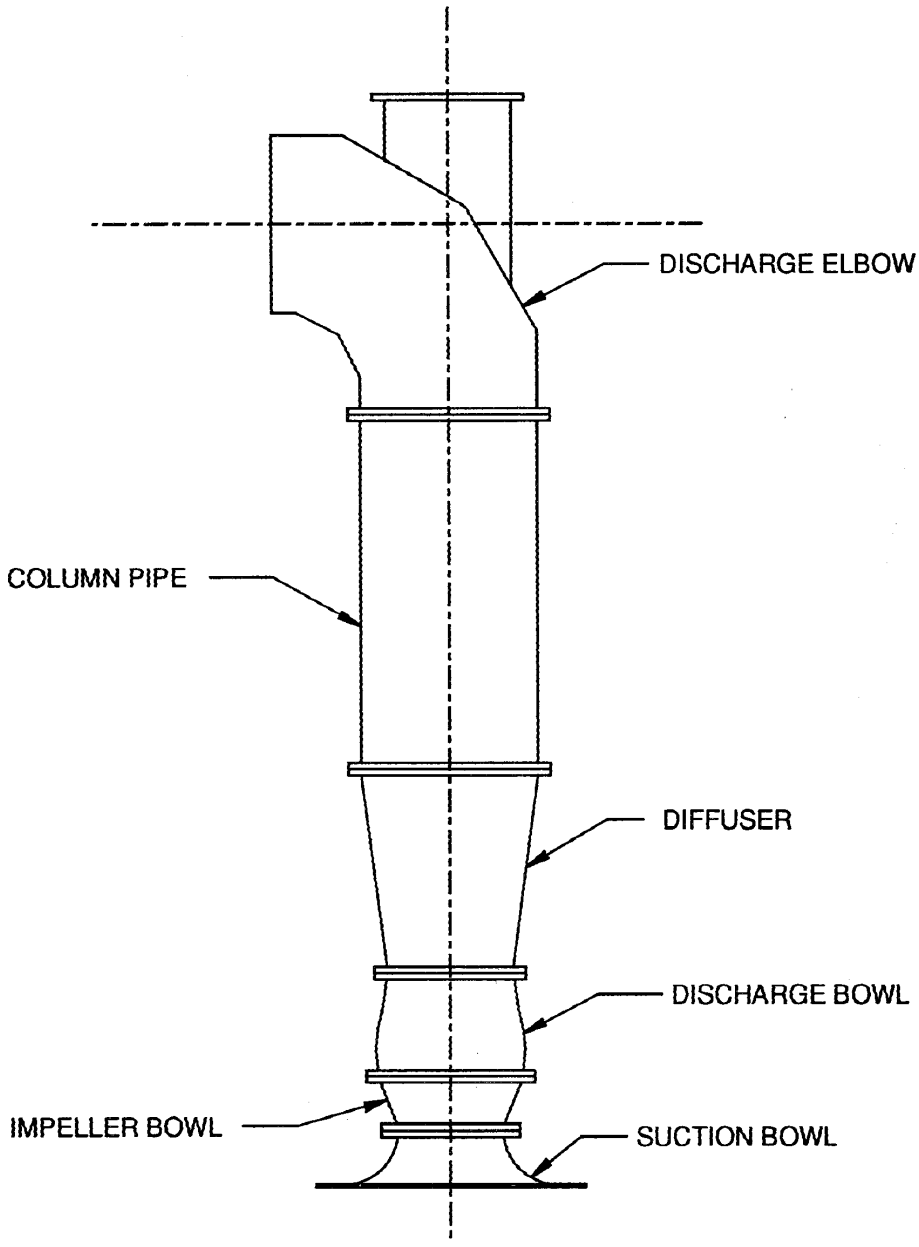
NOTE: BECAUSE OF SPACE LIMITATIONS 10'- 0" SPACING OF RODS WAS USED. A 20'- 0" SPACING WOULD GIVE MAXIMUM EFFECTIVENESS.

GENERAL NOTES:

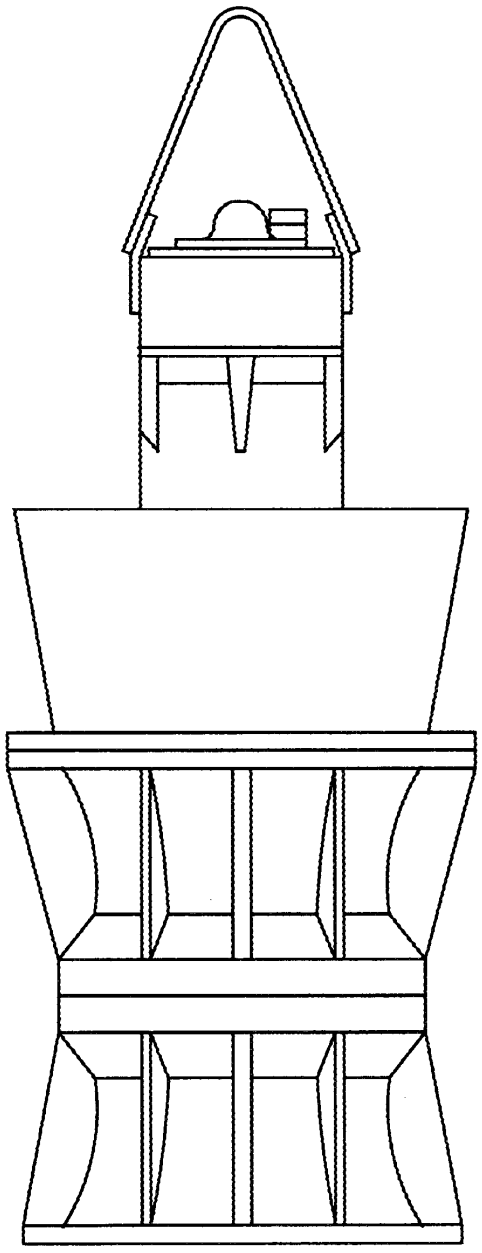
1. LOCATE GROUND GRID IN AREA OF PERMANENTLY MOIST SOIL. PADS SHOULD HAVE A MINIMUM OF 12 INCHES OF CONCRETE COVER. THE GROUND GRID BOUNDARY SHOULD BE INDICATED BY ABOVE GROUND MARKERS AND PROTECTED AGAINST WASHOUTS OR DISTURBANCES RESULTING FROM FUTURE CONSTRUCTION.
2. ALL EQUIPMENT FRAMES AND HOUSINGS, METAL CABINETS INCLOSING ELECTRICAL EQUIPMENT AND METAL CONDUITS SHOULD BE CONNECTED TO GROUNDING SYSTEM.
3. THE CONTACT AREA OF ALL JOINTS IN GROUNDING CIRCUIT SHOULD PROVIDE A CURRENT CARRYING CAPACITY AT LEAST EQUAL TO THAT OF THE CONNECTING WIRE OR CABLE. ALL TERMINAL LUGS SHOULD BE OF THE SOLDERLESS TYPE AND SECURELY CONNECTED TO THE EQUIPMENT.
4. IN ADDITION TO SOLDERLESS CONNECTORS, GROUND CONNECTIONS AND SPLICES, WHICH WILL BE CONCEALED UPON COMPLETION OF WORK, SHOULD BE EXOTHERMICALLY WELDED.
5. GROUND CABLE WHERE EMBEDDED IN CONCRETE SHOULD BE COVERED WITH WATERPROOF CORRUGATED PAPER OR SIMILAR MATERIAL TO PROTECT THE CABLE DURING PLACEMENT AND VIBRATING OF THE CONCRETE.
6. MAXIMUM RESISTANCE TO GROUND NOT TO EXCEED 25 OHMS.

PUMPING STATION

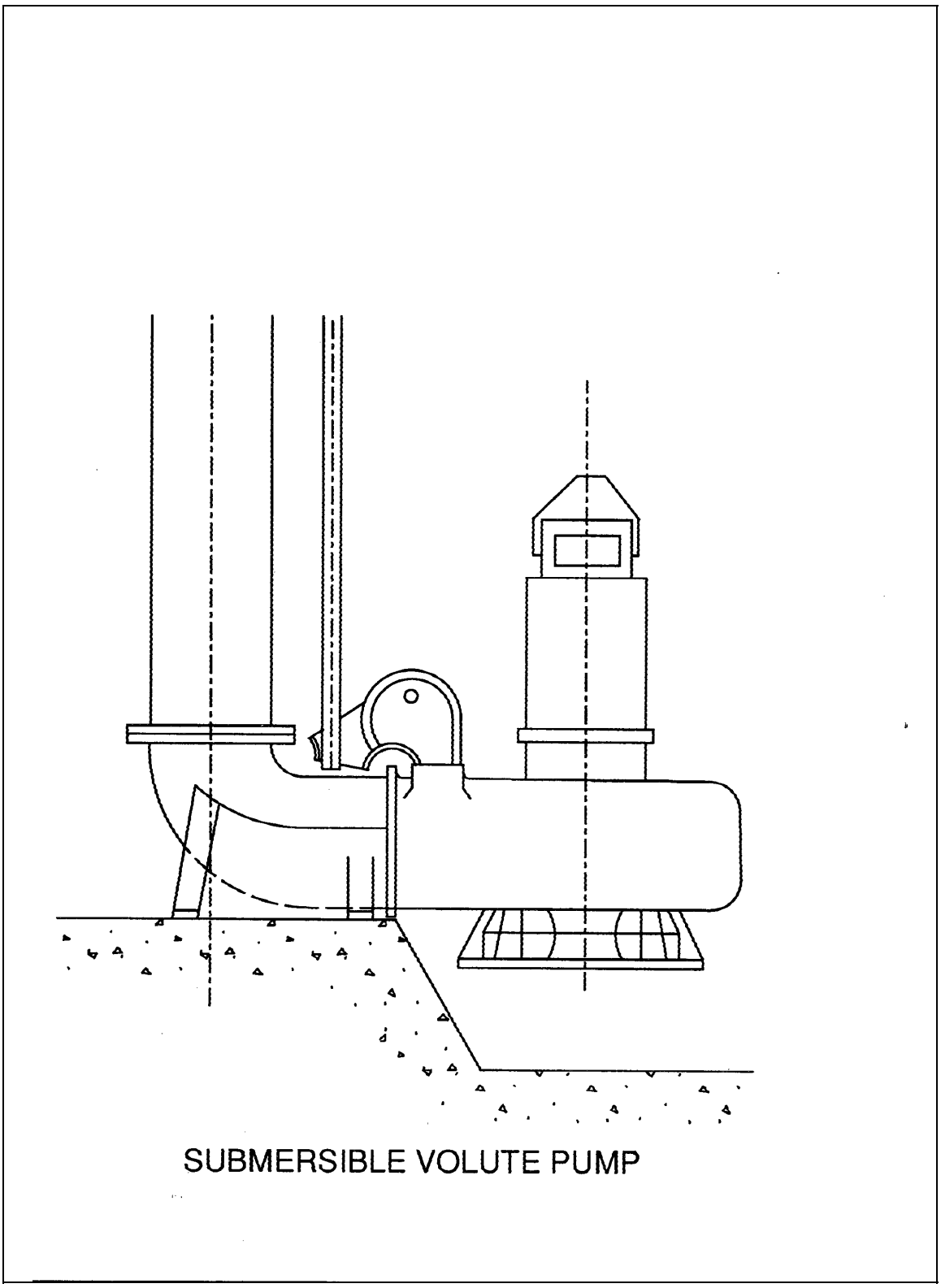
TYPICAL GROUNDING PLAN
UTILIZING GROUND GRID



VERTICAL WET PIT PUMP



SUBMERSIBLE PROPELLER PUMP



SUBMERSIBLE VOLUTE PUMP

Appendix A
References

A-l. Required Publications

Code of Federal Regulations, 29 Part 1900-1910, July 1992
Occupational Safety and Health Administration Guides

TM 5-809-10
Seismic Design for Buildings

TM 5-811-l
Electric Power Supply and Distribution

ER 25-345-l
Systems Operation and Maintenance Documentation

ER 37-2-10
Accounting and Reporting Civil Works Activities

ER 1110-2-109
Hydroelectric Design Center

ER 1110-2-1150
Engineering After Feasibility Studies

ER 1110-2-1403
Hydraulic and Hydrologic Studies by Corps Separate Field Operating Activities and Others

EM 385-l-l
Safety and Health Requirements Manual

EM 1110-2-3102
General Principles of Pumping Station Design and Layout

EM 1110-2-3104
Structural and Architectural Design of Pumping Stations

ETL 1110-2-313
Hydraulic Design Guidance for Rectangular Sumps of Small Pumping Stations with Vertical Pumps and Ponded Approaches

ETL 1110-2-327
Geometry Limitations for the Formed Suction Intake

CEGS 16415
Guide Specifications for Electric Work Interior

CW 15160
Guide Specifications for Vertical Pumps, Axial and Mixed Flow Impeller Type

CW 15170
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Appendix B
Pump Selection Method

B-1. General

a. Purpose. This appendix provides a method to determine the size of a pump to meet certain pumping requirements. It also provides dimensions for the sump and station layout once the pump is selected. Certain information must be available before the pump selection can be started. This information includes the pumping requirements as determined from hydrology data, number of pumping units, and discharge/station arrangement as determined by EM 1110-2-3101.

b. Procedure. This appendix is divided into two major sections, selection of vertical wet pit pumps and selection of vertical submersible propeller pumps (Plates 23-25). Sample calculations are used to aid in understanding the selection procedures. Chart B-1 indicates the operating range of the various type pumps used in pumping stations. This chart indicates which pumps should be investigated during the alternative study phase.

c. Selection process.

(1) Vertical wet pit pumps. The selection process uses the model and affinity laws to obtain the performance of a prototype pump from the various supplied model pump performance data. Model performance data can be obtained from pump manufacturers, existing pumping stations, or from other Districts. The following general steps are used in the selection process:

(a) Determine pump operating conditions using the furnished hydrology and station/discharge arrangement.

(b) Determine prototype pump performance from model performance.

(2) Submersible pumps. The selection process makes use of typical catalog curves of head-capacity and Net Positive Suction Head Required (NPSHR). The

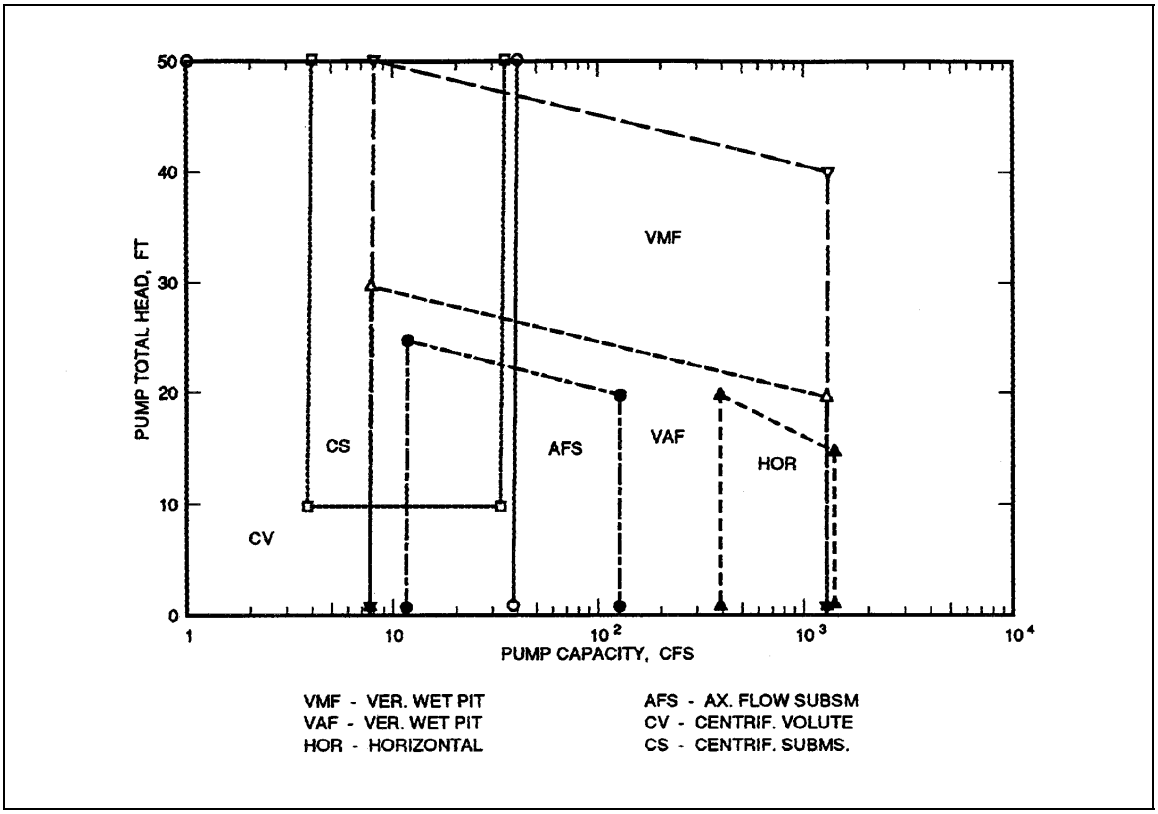


Chart B-1. Operating range of typical pumps

various curves allow direct selection of pumps after the system design conditions are known.

d. Information sources. The following is a list of information needed to perform the selection process and where it may be found:

Number of Pumps	EM 1110-2-3102
Pump Discharge Configuration	EM 1110-2-3102
Hydrology Data	Project Hydrology Report

e. Appendix results. The application of the methods illustrated in this appendix will allow the user to determine the following pump and station parameters.

(1) Maximum design head.

(2) Design heads at rated pumping station capacity.

(3) Capacity requirements other than those required by the hydrology requirements, such as capacity required for siphon priming.

(4) Type of pump.

(5) Estimated pump physical size.

(6) Power required at the design points.

(7) Pump speed.

(8) Station Net Positive Suction Head Available (NPSHA) and pump NPSHR.

(9) Sump dimensions.

B-2. Vertical Wet Pit Pump Selection Sample Problem

a. Design data and requirements.

(1) Pump conditions. The starting point for all pump selection is the hydrology requirements for the station site. The following is assumed given conditions for each pump:

Required from hydrology report:

Q_H = Flow rate at maximum differential head (design flood)

= 29,000 gpm @ river elevation (el) 339.0 and sump el 317.0

Q_L = Flow rate at minimum differential head (low head)

= 34,000 gpm @ river el 314.0 and sump el 314.0

(2) Station arrangement. Station general arrangement and discharge system are determined as presented in EM 1110-2-3102. For this example, a discharge over the protection with siphon assist was assumed (Figure B-1). A static head diagram (Figure B-2) should now be constructed. The top of the discharge pipe is obtained by sizing the pipe diameter based on an approximate maximum velocity in the pipe of 12 feet per second (fps) (using the greatest Q requirement) and adding the diameter to the invert elevation. The invert elevation is usually set equal to the top of the protection on either side of the station so that backflow will not occur with any river level to the top of the protection.

(3) Size discharge pipe.

Velocity (V_{pipe}) = Q_{max} / Pipe Area

Q_{max} = 34,000 gpm = 75 cfs

Pipe Area = $\{[(\text{Pipe Dia.})^2] / 4\} \times 3.14$

V_{pipe} = 12 fps

Pipe Area = Q_{max} / V_{pipe}

Pipe Diam. = $[(Q_{max} \times 4) / (V_{pipe} \times 3.14)]^{1/2}$

= 2.83 feet or 34 inches

Use standard sized pipe, the next larger standard size pipe = 36 inches nominal (35.25 inches inside diameter (ID))

For this first calculation, use the following wall thickness:

1/4 inch, 12- to 20-inch diameter of pipe
3/8 inch, 24- to 42- inch diameter of pipe
1/2 inch, 48 inch and over *

* (larger pipe sizes may require thickness greater than 1/2 inch for support considerations)

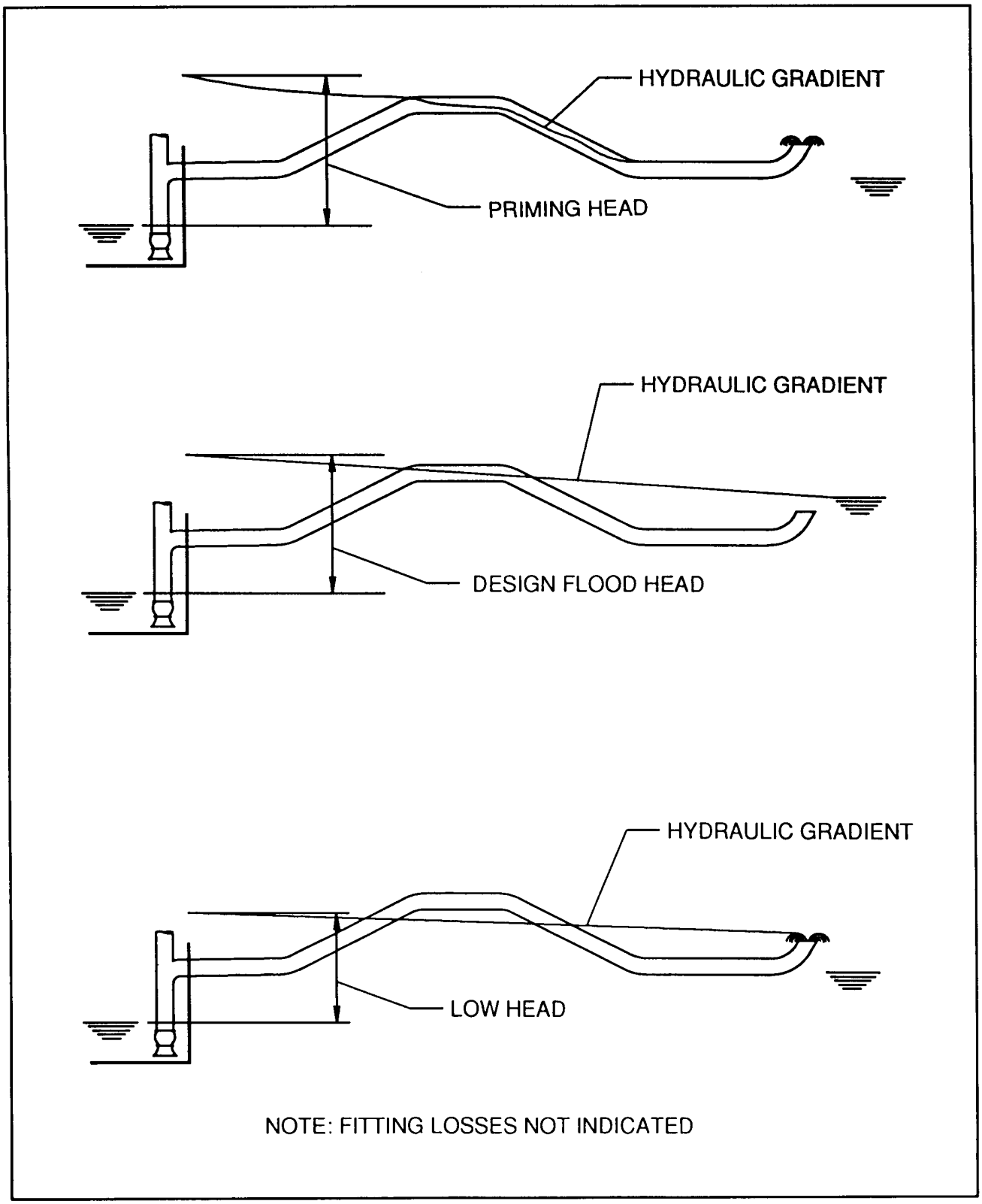


Figure B-1. Discharge pipe system

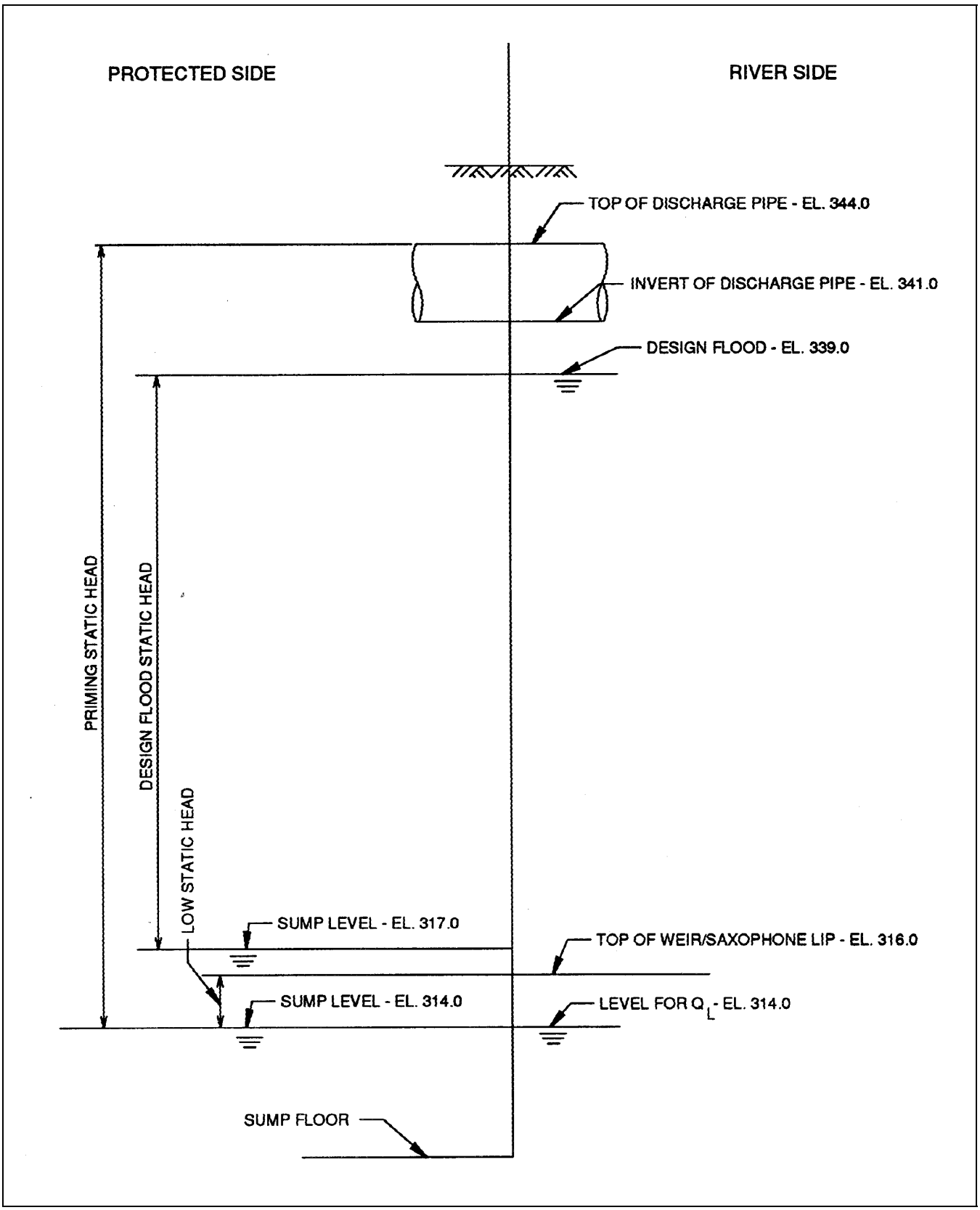


Figure B-2. Construct the static head diagram

A diagram of the typical over the levee discharge pipe system is shown in Figure B-1.

(4) Priming condition. Since the selected discharge system will use a siphon assist, another condition, priming, must be determined. The first step is to determine the required priming flow rate Q_{prime}. The computation is based on the flow required to obtain an average velocity in the discharge pipe at its highest point of 7 fps. The value of 7 fps will provide a prime for discharge pipe systems with diameters of 54 inches and less having no extra bends other than those necessary at the bottom and top of the levee. For discharge systems with larger diameters or unusual flow lines, consider using the critical depth of flow elevation occurring in the pipe instead of top of pipe. Methods used to calculate the critical depth in a circular pipe are shown in the *Handbook of Hydraulics* (King and Brater 1963).

$$Q = (\text{area})(\text{velocity})$$

$$Q_{prime} = (\text{pipe area - ft}^2)\ (7\ \text{fps})$$

$$= (6.77\ \text{ft}^2)\ (7\ \text{fps})$$

$$= 47.39\ \text{cfs or approximately 21,300 gpm}$$

The priming static head (Figure B-2) is equal to the difference between the top of the discharge pipe at its highest point and the lowest pump sump level used for starting the pumps.

Highest point in discharge pipe at top of protection = elevation of protection + diameter of pipe = 341.0 + 3.0 = 344.0.

Priming static head = 344.0 - 314.0 = 30 ft

(5) Siphon condition. With a siphon assist system, it is required that the siphon recovery is not greater than 28 feet. The value of 28 feet is used to prevent possible water vaporization and siphon priming problems. An up-turned saxophone discharge pipe or a weir is used to limit the recovery to 28 feet and seal the end of the pipe. When one of these means is used, the low head must be checked based on the saxophone or weir elevations. If, at the pumping mode, the lowest water level on the discharge side provides for a recovery less than 28 feet, then a saxophone discharge or weir is not required. The discharge end of the pipe should be submerged when a separate vacuum priming system is provided to prime the pump. The computation is as follows:

Siphon recovery = top of pipe elevation - lowest river elevation for pumping

= 344.0 - 314.0

= 30 ft (2 ft over 28 ft)

Therefore some means must be used to limit recovery to 28 feet.

El top of weir/lip = el top of pipe - 28 ft

= 344.0 - 28

= 316.0

This elevation will be used in determination of the low static head.

(6) Suction requirements. The other part of the pump conditions is the pump suction requirements. This is specified as NPSHA for the various pumping conditions. It is computed as follows:

$$NPSHA = h_{sa} - h_{vpa}$$

where

$$h_{sa} = h_p + h_{se} - h_f$$

or

for pumps with suction head:

$$NPSHA = h_p + h_{se} - h_f - h_{vpa}$$

where

h_{sa} = total suction head in absolute feet

h_{vpa} = vapor pressure of water at given temperature

h_p = absolute pressure on water surface, for open sump = atmospheric pressure in feet

h_{se} = static water level above (+) or below (-) impeller eye datum

h_f = friction and entrance (0 for pumps with bellmouths in wet sumps)

Pumping Condition	Low Hd. Cond.	Design Fl. Cond.	Priming Cond.
Sump El*	314.0	317.0	314.0
Impeller El**	311.0	311.0	311.0
h_{se} - ft +3.0	+6.0	+3.0	
h_{vpa} (80 ^{o}F) - ft	1.2	1.2	1.2
h_p - ft	33.9	33.9	33.9
NPSHA - ft	35.7	38.7	35.7

* For this condition, use the lowest water that will occur for majority of the pumping; however, all operating water levels should be examined to determine if limiting suction operation will occur. Stop pump level should generally be the lowest sump level.
** The impeller eye (entrance) is set to provide the submergence listed below, depending on the station operating hours per year.

(7) Submergence requirements. The submergence shall be for the lowest pumping level at the station where the pumps will be operating for periods of time greater than 2 hours. Operation below these submergence levels is permitted as long as the operation time is less than 2 hours. In no case will any operation occur with water levels below the impeller eye or datum. Assume for this example that the operation time will be over 300 hours per year; therefore, the impeller elevation is 3 feet below lowest sump elevation for any pumping condition to assure a flooded impeller.

Total Est. Annual Operating Hours Per Year	Min. Submergence* ft
0 to 99	1.0
100 to 299	2.0
300 and over	3.0

* Minimum submergence over impeller eye or above NPSHR level, whichever is greater.

(8) Total system head. The next step is to compute the total system head curves for each condition. The total system curves will include all the losses plus the static head for that condition. For the purposes of pump selection, the total system curves will be constructed to include the losses in the pump beyond the pump bowl. This will permit the subsequent pump selection to be done on the basis of bowl heads. Bowl head is considered the head produced by a pump if it were measured immediately after the discharge vanes. Bowl heads therefore do not include any losses in the transition piece and elbow of the pump which is supplied with the pump. The bowl heads permit the user to use any type of discharge system beyond the pump bowl. For this example, there would be three system curves: design flood, low head, and priming. It should be noted that any system total head curves used for procurement of pumping equipment would only include system losses which would be external to the pump equipment being furnished by the pump manufacturer. Generally, the pump manufacturer would subtract the column pipe and discharge elbow losses from his bowl performance, thereby producing a performance curve referenced to the discharge point of the equipment being supplied. For this design the pipe lengths are as follows:

Priming - 175 ft, operating - 250 ft

The total system head required by the pump to deliver the minimum and the maximum flow rates required should be calculated and tabulated as shown in Table B-1. The total system head should include the discharge loss, pipe and elbow losses, and static head. The next step is to use this table and develop system head (pump bowl) loss curves as shown on Figure B-3.

b. Pump selection.

(1) Formulas used. The method of pump selection consists of computing the performance of a larger prototype pump from the performance a model pump or a small prototype pump. The following relationships are used for these computations. All relationships are based on pump bowl performance.

$$d_p = d_m(Q_p/Q_m)^{1/2}(H_m/H_p)^{1/4}$$

$$Q_p = Q_m(d_p/d_m)^3(N_p/N_m)$$

$$H_p = H_m(d_p/d_m)^2(N_p/N_m)^2$$

$$H_{sp} = H_{sm}(d_p/d_m)^2(N_p/N_m)^2$$

$$BHP_p = BHP_m(d_p/d_m)^5(N_p/N_m)^3$$

Table B-1
Total System Head

Q gpm	$\frac{V^2}{2g}$ ft	$H_{F/100}$ ft	$H_{F/250}$ ft	Other Pump K = 0.4 ft	Losses Bends K = 1.2 ft	Total[1] Loss ft	Low[3] Total Head ft	Design[4] Flood Total Head ft
Low Head and Design Flood Conditions								
20,000	0.67	0.25	0.62	0.27	0.81	2.37	4.37	24.37
25,000	1.05	0.38	0.95	0.42	1.26	3.68	5.68	25.68
30,000	1.51	0.54	1.35	0.61	1.82	5.29	7.29	27.29
35,000	2.06	0.72	1.81	0.82	2.47	7.17	9.17	29.17
40,000	2.69	0.94	2.35	1.08	3.23	9.35	11.35	31.35
45,000	3.41	1.18	2.95	1.36	4.09	11.81	13.81	33.81

Q gpm	$\frac{V^2}{2g}$ ft	$H_{F/100}$ ft	$H_{F/175}$ ft	Other Pump K = 0.4 ft	Losses Bends K = 0.8 ft	Total[2] Loss ft	Priming[3] Total Head ft
Priming Head Condition							
20,000	0.67	0.25	0.43	0.27	0.54	1.91	31.91
25,000	1.05	0.38	0.66	0.42	0.84	2.97	32.97
30,000	1.51	0.54	0.95	0.61	1.21	4.28	34.28
35,000	2.06	0.72	1.27	0.82	1.65	5.80	35.8
40,000	2.69	0.94	1.65	1.08	2.15	7.57	37.57
45,000	3.41	1.18	2.07	1.36	2.72	9.56	39.56

Examples (For Q = 20,000 gpm):
[1] Total Loss(Low Head/Design Flood) = 0.62+0.4(0.67)+1.2(0.67)+0.67 = 2.37 ft.
[2] Total Loss(Priming) = 0.43+(0.4)(0.67)+(0.8)(0.67)+0.67 = 1.91 ft.
Priming Static = 344 - 314 = 30 ft. Low Static = 316 - 314 = 2.0 ft.
Design Flood Static = 339.0 - 317.0 = 22.0 ft.
[3] Low T. H. = 2.37+2.0 = 4.37 ft. Priming T. H. = 1.91+30.0 = 31.91 ft.
[4] Design Flood T. H. = 2.37 + 22.0 = 24.37 ft.

where

d_p = Impeller exit diameter of prototype pump

d_m = Impeller exit diameter of model pump

Q_p = Capacity of prototype pump

Q_m = Capacity of model pump

H_m = Head of model pump

H_p = Head of prototype pump

N_p = Rotative speed of prototype pump

N_m = Rotative speed of model pump

H_{sp} = Required suction head of prototype pump

H_{sm} = Required suction head of model pump

BHP_p = Brake horsepower of prototype pump

BHP_m = Brake horsepower of model pump

(2) General. The performance of a prototype pump can be determined by the use of the above equations applied to the model pump performance. As can be seen from the above formula, the two variables are impeller diameter and rotative speed. The selection of these two factors should be to obtain a prototype unit which has the smallest impeller diameter and the highest rotative speed, while still meeting all of the performance requirements of head, capacity, and NPSHA. The impeller diameter is

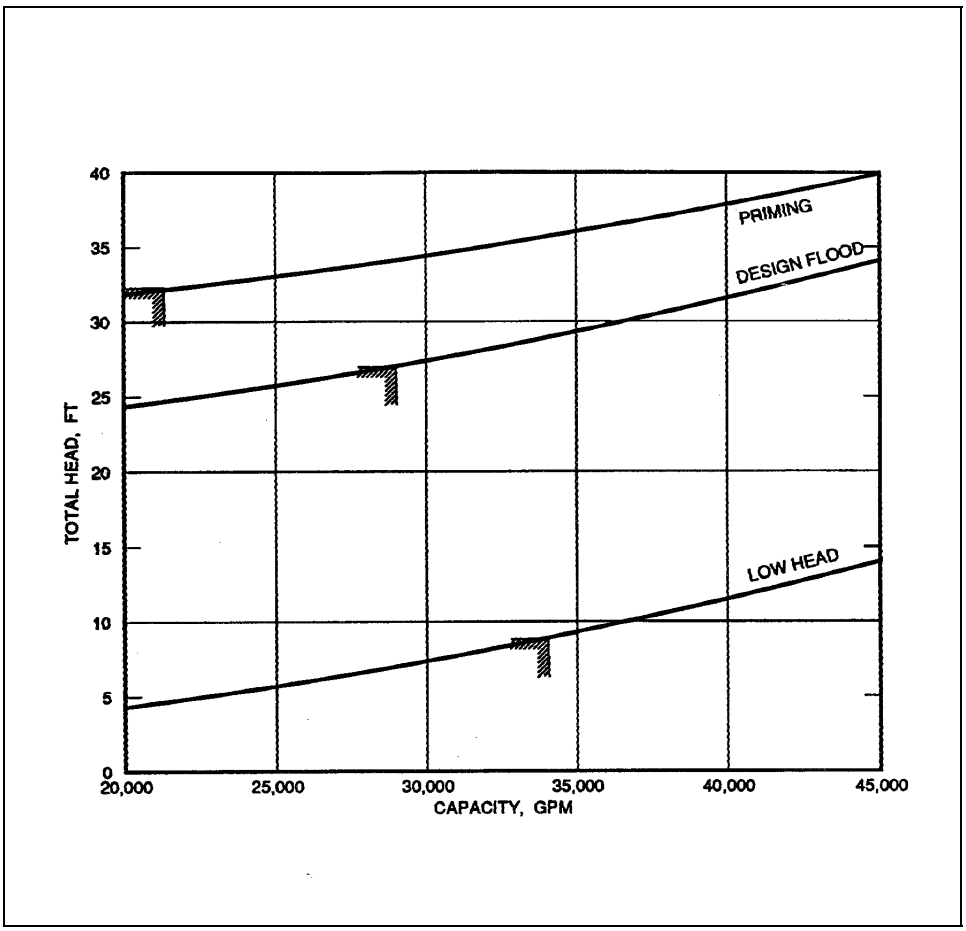


Figure B-3. System head (pump bowl) loss curves

shown on each model pump curve. For mixed-flow type pumps, the maximum impeller diameter is indicated on the curves. On mixed flow pumps, it is possible to reduce the impeller diameter by up to 5 percent, thereby changing the performance of the pump from that shown on the curves for full diameter performance. Blade pitches are taken into account and shown as different model pump curves.

(3) Calculation method. The actual calculations of the prototype pump performance is best done by trial and error. A personal computer using a spreadsheet type program simplifies and speeds these calculations and the pump selection. CECW-EE can furnish information of various Districts where different programs are available to perform these computations.

(4) Sample calculations. The following is an example of computations used to select a prototype pump. It is usually best to start with a model pump that has a head range near that of the required condition points. As a first try, use model curve MF-1 (Figure B-4) and calculate prototype performance. A mixed-flow impeller was tried because highest head requirement was over 20 feet. The selected prototype impeller is usually smaller than the discharge pipe diameter. The maximum prototype pump speed can be estimated by applying the following formula based on suction specific speed (S).

$$S = N_p \, (Q_p)^{1/2} / NPSHA_p^{3/4}$$

(a) For this sample problem, use a value of S = 8,000.

$$N_p = (8{,}000) \times (NPSHA)^{3/4} / (Q^{1/2})$$

where

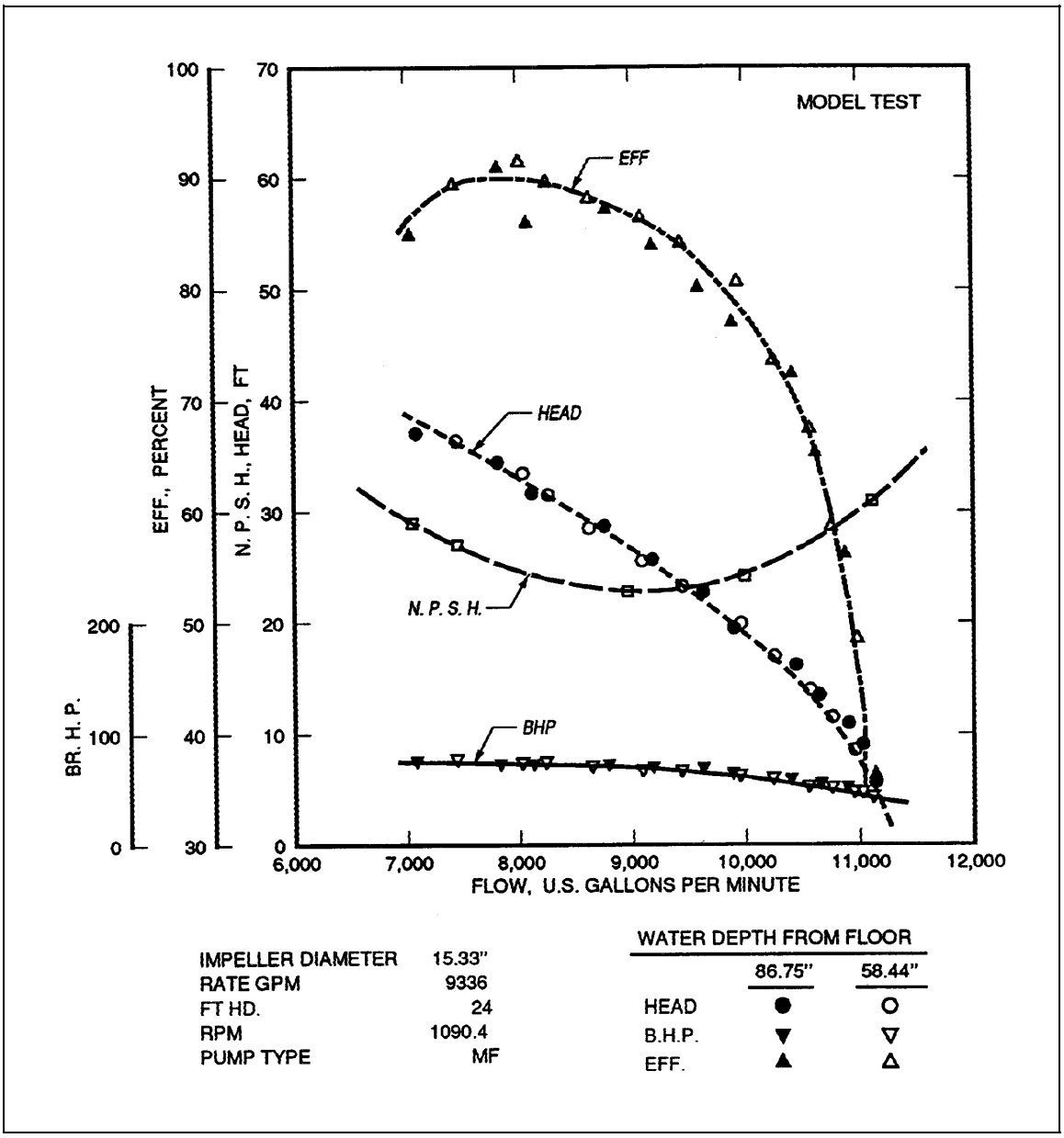


Figure B-4. Pump model curve MF-1

N_p = rotative speed of the pump, rpm

$NPSHA_p$ = calculated for the lowest head pumping condition, ft

Q_p = flow rate for lowest head pumping condition, gpm

therefore

$$N_p = (8{,}000) \times (35.7^{3/4}) / (34{,}000^{1/2})$$

N_p = 634 rpm

(b) The pump speed should not in general exceed this calculated rotative speed. The speed used must also meet the restrictions of the pump driver. If using an electric motor that is directly connected to the pump, then the synchronous speed of the motor must be considered.

When using an induction motor, the full-load speed can be estimated to be 97 percent of the synchronous speed. The synchronous speed can be calculated using the following formula for electricity with a frequency of 60 cycles.

N_p = 7,200/number of motor poles (such as 10,12,14...)

Motor speed = 7,200/12 or 7,200/10

= 600 rpm or 720 rpm

(c) Since 720 rpm is over the calculated maximum of 634 rpm, the lower synchronous speed of 600 rpm is used. Assuming an induction motor is to be used, the running speed when operating at full load is estimated to be 97 percent of 600 rpm or 582 rpm.

(d) Try Model MF-1. Based on the Pump Model Curve MF-1 (Figure B-4), calculate the diameter of the prototype impeller using the model law (constant specific speed and equal heads.

$$d_p = d_m (Q_p/Q_m)^{0.5}$$

where

d_p = 15.33 $(29{,}000/8{,}900)^{0.5}$ = 27.7 inches

d_m (from model curve MF-1) = 15.33 inches

$Q_p = Q_H$ (design flood) = 29,000 gpm at 27 feet TDH

Q_m (from model curve MF-1) = 8,900 gpm at 27 feet TDH

(e) Develop prototype performance curve based on model curve MF-1 and verify that design conditions have been met (Figure B-5).

$$Q_p = Q_m (d_p/d_m)^3 (N_p/N_m)$$

$$BHP_p = BHP_m (d_p/d_m)^5 (N_p/N_m)^3$$

where

$Q_p = Q_m (1.81)^3 (0.534) = Q_m (3.17)$

d_p/d_m = 27.7/15.33 = 1.81

N_p/N_m = 582/1,090.4 = 0.534

$BHP_p = BHP_m (1.81)^5 (0.534)^3 = BHP_m (2.96)$

From curve MF-1 model pump performance			Calculated prototype pump performance		
Q_m	H_m	BHP_m	Q_p	H_p	BHP_p
7,000	38.8	75	22,200	38.8	222
8,000	33.2	73	25,400	33.2	216
9,000	26.9	70	28,530	26.9	207
10,000	19.0	60	31,700	19.0	178
11,000	7.2	45	34,900	7.2	133

(f) The results of the first prototype pump computation are plotted on the system head loss curves. Results show that a pump with a 27.7-inch impeller rotating at 582 rpm will satisfy the design requirements. Next, other model pumps and different prototype speeds would have been tried to find other prototype pumps that will meet the requirements. An average prototype pump size could then be calculated. All station layout dimensions would be based on the corresponding standard size pump. The NPSH required by the prototype or model is then checked against the NPSH available. Cavitation curve MF-1 (Figure B-6) confirms that there is adequate submergence.

(5) Pump dimensions.

(a) General. Determine the dimensions for all the model pumps selected. Since the sump dimensions and elevations used depend on the pump dimensions, some means must be used to determine the dimensions to use for the station layout from the range of pumps selected. The selection of dimensions to allow the maximum number of pumps to meet the guidelines is given below.

(b) Bell diameter.

The bell diameter = D

Average D, (D_A) = sum of bell diameter for all selected pumps divided by number of selected pumps.

Largest bell diameter (D_{LARGE}), but not larger than 1.2 times D_A

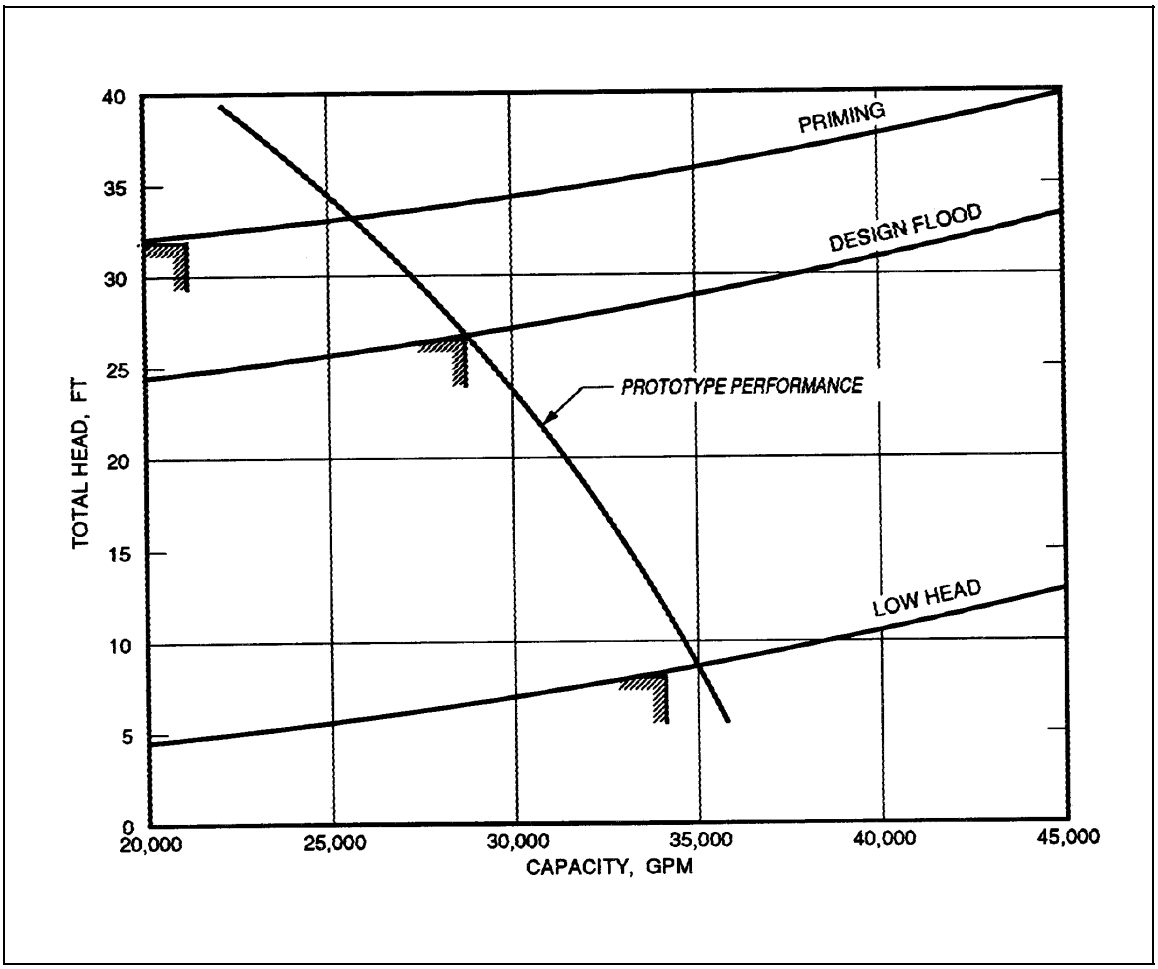


Figure B-5. Prototype performance curve superimposed on the system head curves (pump bowl) pump MF-1

Smallest bell diameter (D_{SMALL}), but not less than 0.9 times D_A

Sump $width_1$ = 2 times D_{LARGE}

Sump $width_2$ = 2.5 times D_{SMALL}

Sump width is the larger of sump $width_1$ or $width_2$

D = 1/2 of the sump width from the above step.

(c) Impeller elevation. The impeller eye (entrance) is set to provide the submergence indicated above in the paragraph on pump conditions. In this example, the impeller was set at el 311.0. The bottom of the bell and sump floor elevation are set as follows:

Bottom of pump bell = impeller eye elevation minus 1/2 D

Floor of sump = bottom of bell elevation minus 1/2 D

(d) Minimum pump height. The minimum distance from the floor of the sump to the centerline of the pump discharge must be determined to establish a minimum floor elevation. The dimension form the floor of the sump to the bell inlet is determined above. The distance between the centerline of the discharge to the suction bell inlet should be provided by pump manufacturers offering the type and size of pump indicated by the prototype. This pump dimension will vary from one manufacturer to another. The maximum distance found should be used to determine the minimum operating floor. Other

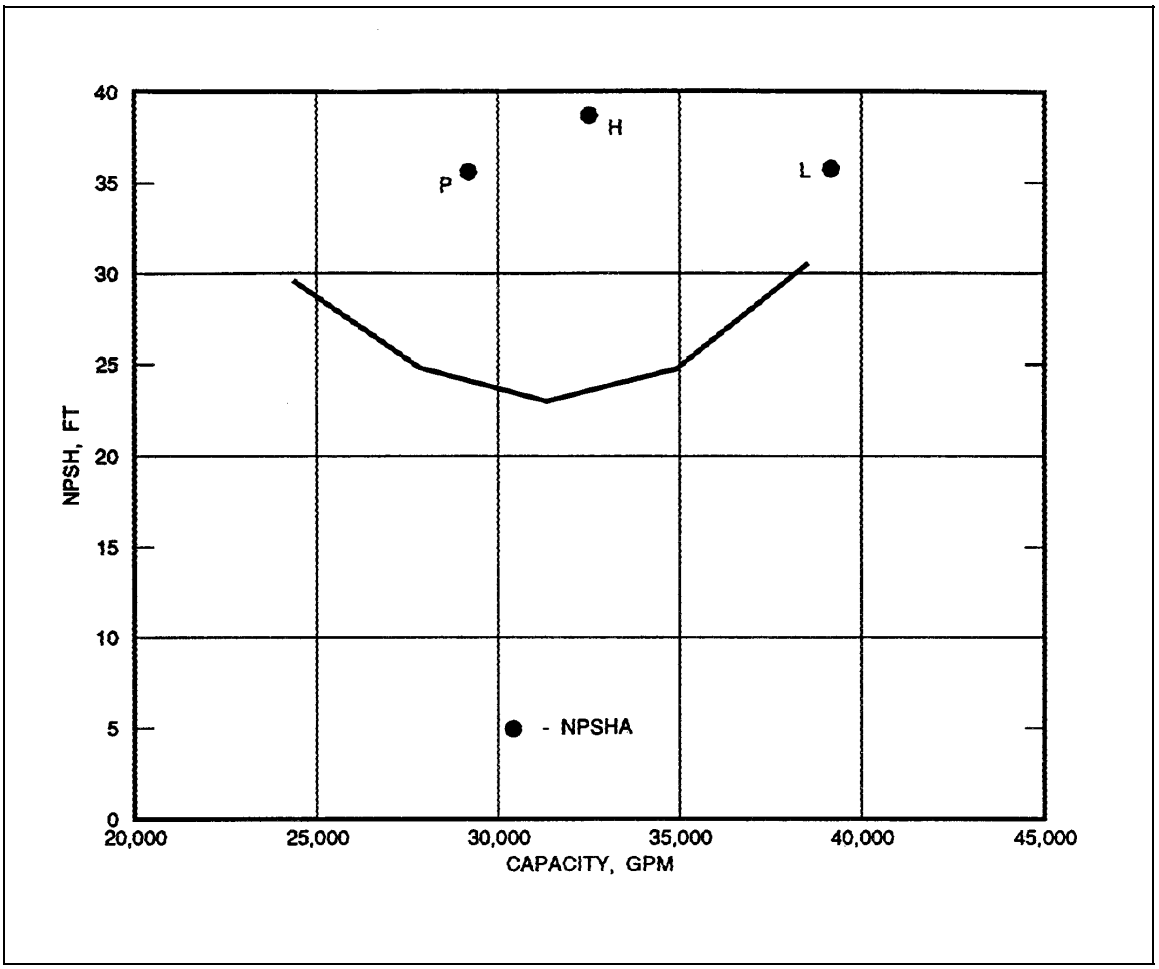


Figure B-6. Cavitation curve MF-1

considerations such as local flooding due to power outage and surrounding ground elevations may require a higher operating floor elevation.

c. Station layout.

(1) Pump dimensions. For stations with up to three equal sized pumps having capacities not greater than 5.66 m^3/s (200 cfs), and with straight inflow, in front of the station, the dimensions indicated on Chart B-2 may be used. The flow to the station should occur in a straight symmetrical channel with a length equal to or greater than five times the station width (W on Chart B-2). The invert of the channel in front of the station should not contain any slopes greater than 10^o. The submergence indicated on Chart B-2 is the depth of water suggested to prevent harmful vortexes. In most cases the water depth will be greater due to the cavitation allowance listed above. If there are any unique inflow conditions or problems the designer should contact the Waterways Experiment Station Hydraulic Laboratory to determine alternative layouts to correct or compensate for the problems.

(2) Considerations for station layout.

(a) Space inside of the station is provided to set one pump driver and disassemble one pump using the overhead crane.

(b) Space in front, side and back of electrical equipment is provided as required by the electrical code requirements.

(c) Space is provided to remove any pumping unit without disassembly of another unit or electrical gear.

(d) Space is provided for an office and sanitary facilities for any station that will be manned.

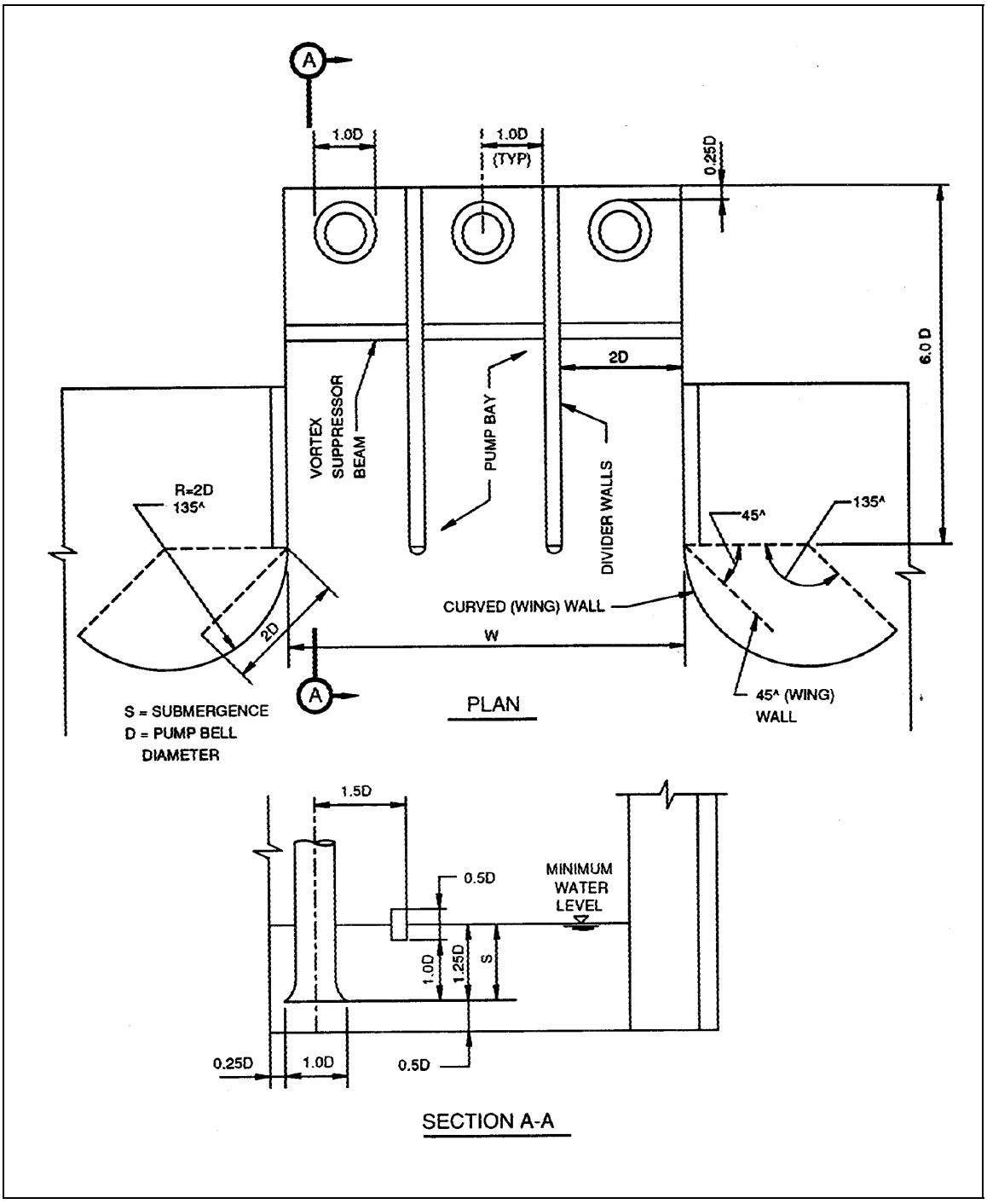


Chart B-2. Vertical pump sump dimensions

(e) Space is provided for spare parts and maintenance equipment to be stored at the station.

(f) Location of electrical gear is coordinated with service entrance.

(g) Exit and equipment door are provided and properly located.

(h) Straight approach to pump sump is provided.

(i) Any sump closure gate is neck down at least 4D from the pumps.

(j) Access is provided to trashrack platform for trash removal by truck.

(k) Sufficient room is provided to position a truck for equipment removal.

(l) Minimum slope is provided in ditch flow line beyond the front of the trashrack.

(m) Incoming overhead power lines do not present a hazard to operation and maintenance of the station.

d. Pump manufacture's selection. Using the preliminary layout, correct any system head curves such as change in low head due to different elbow elevation. Check the pump selections using the new system requirements and refine layout as necessary. It is also best at this time to request pump selections from the pump manufacturers using the requirements and sump layout above. This will confirm the pump selections. Chart B-3 is an example of the information to be furnished and requested from the pump manufacturer.

B-3. Vertical Submersible Pump Selection

a. Design data and requirements.

(1) Pump conditions. The sample calculations are based on a pumping station with a through-the-protection discharge, pumping into a discharge chamber. The following is the assumed conditions for each pump.

(a) Required from hydrology report:

Q_H = The flow rate at maximum differential head

= 27,000 gpm @ river el 339.0 and sump el 321.0

= 1,715 L/S

Q_L = The flow rate at minimum differential head

= 33,000 gpm @ river el 322.0 and sump el 319.0

= 2,095 L/S

Pump stop elevation - 315.0
Pump start elevation - 318.0
Normal pumping elevation - 316.0
(Level at which the majority of pump operation will occur)

(b) Submersible propeller pumps (Plate 24) typically are constructed in such a manner that the pitch angle of the propeller blades can be changed; therefore, the selection method used is different from that used with fixed blade pumps. The selection procedure used for submersible pumps will be to compute the system requirements, and then select a pump from available performance curves. After the initial selection is made, then the system requirements can be corrected if necessary due to a more accurate discharge tube sizing and the pump selection confirmed or changed. In addition to the selection based on pump head and capacity requirements, the pump selected must also be checked to ensure that its suction requirements are satisfied by those provided by the station layout.

(c) The pumping system is composed of a discharge/support tube in which the submersible pumping unit is located. In this example, the tube would be fitted with an elbow section and a horizontal pipe terminating with a flap gate. For submersible pump installations of this type, the discharge line invert should be well above the motor to hold the elbow losses to a minimum but low enough to keep reasonable the static head reasonable.

(d) The first estimate of the tube diameter can be based on the size required using a 6.5-fps velocity and the greatest required capacity. After calculating a diameter based on these conditions, the nearest size tube diameter as shown on Table B-2 shall be used for the preliminary calculations. For the example problem, the calculated discharge is 45.4 inches. The nearest standard tube diameter of 48 inches is used. The bottom of the tube can be set using the minimum tube submergence required. These submergence requirements are provided by the submersible pump manufacturer and are based on annual operating hours and pump tube design. For this example, 3.0-ft minimum submergence is required.

Elevation bottom of the tube = 315.0 - 3.0 = 312.0

PUMP MANUFACTURER'S DATA SHEET

Information furnished:

Name of station
Type of driver and operating voltage if electric
Type of pump
System head curves, using losses external to the pump, showing required condition points
Pump setting elevation
Sump layout
Number of pumping units to be installed

Information requested from the pump manufacturer:

Pump model/type number
Pump size - discharge, bell and impeller diameter
Pump diameter below impeller where a formed suction intake would attach
Pump operating speed
Pump setting elevation including;
- Elevation of bell
- Elevation of impeller
- Height of the motor above baseplate elevation
- Length of pump elbow of discharge flange dimensions
- Minimum distance from impeller elevation to centerline of elbow
- Elevation of attachment of a formed suction intake

Estimated pump weight
Estimated motor weight
Estimated pump cost
Estimated motor cost
Pump performance curve showing head, horsepower, efficiency, and NPSHR plotted against capacity

For large pumps over 54-inch size, additional information such as the WR^2 of both the pump and motor along with starting torque curves would also be requested.

Chart B-3. Pump manufacturer's data sheet

Table B-2
Submersible Pump Dimensions

Pump No.	Discharge Tube Diameter inches	Pump Speed rpm	Height of Pump/Mot. inches	Max. Wt. Pump.Mot. pounds	Motor kW rating
AF-S-1	40	705	97	7,350	236
AF-S-2	48	590	135	12,200	355

(e) The bottom of the tube elevation may need to be lowered later to satisfy the sump velocity criteria as indicated in Figure B-7; however, this will not affect the pump selection.

(f) The minimum invert elevation must be above the top of the motor. With the bottom of the tube set at el 312.0, the minimum elevation of the elbow invert can be determined by adding the pump/motor height indicated on Table B-2 to the bottom tube elevation.

Minimum invert elevation of elbow = 312.0 + 135 inches = 323.25

(g) This elevation will be used since it is above the river elevation for the low head condition. The horizontal discharge pipe connected to the tube is sized based on the flow velocity of 12 fps at maximum capacity. The calculated horizontal discharge pipe size is approximately 33.5 inches; use nominal 36-inch pipe.

(h) A static head diagram is constructed (Figure B-8) using the given hydrology information and preliminary information determined above on the pump tube and the discharge piping. The floor elevation is set 1/2 tube diameter below the bottom of the tube. This first static head diagram will be used to make a preliminary pump selection. In most cases, at least one or more static head diagrams will need to be prepared after the preliminary pump selection is made to allow the pumping unit dimensions to agree with the static head diagram. The pump selection process would follow the steps below:

1		2		3		4		5
Prepare Static Head Diagram	---->	Prepare System Head Curves	---->	Make Prel. Pump Select.	---->	Check Pump NPSHR	---->	Repeat Steps 1, 2,3 & 4 If Nec.

(2) System head. The next step is to compute the system head curves (Table B-3). The system head curves include all of the losses plus the static head for that condition (Figure B-9). The system loss curves include all the losses beyond the pump motor, since losses below this point are included in the given pump curves. A loss of K = 0.7 is used for the losses in the pump column and elbow. The other losses in this example are considered to be equal to the velocity head. Next, calculate the net positive suction head available (NPSHA) for the various pumping conditions. Refer back to the previous example problem for the definition of terms.

Pumping Condition	Low Hd. Cond.	High Hd. Cond.
Sump Water El*	316.0	316.0
Bottom of Tube**	312.0	312.0
h_{se}*** - ft	+4.0	+4.0
h_{vpa} (80 °F) - ft	1.2	1.2
h_p - ft	33.9	33.9
NPSHA - ft	36.7	36.7
NPSHA - m	11.2	11.2

* For this condition, use the lowest water level that will occur for majority of the pumping; however, all operating water levels should be examined to determine if potential damaging operation will occur. For this example, it has been assumed this elevation to be 1 foot above the pump stop elevation.

** The NPSHR curves are referenced to the bottom of the tube location rather than the impeller entrance or eye.

*** 4 feet is the submergence above the bottom of the tube.

$$NPSHA = h_p + h_{se} - h_f - h_{vpa}$$

b. Pump selection.

(1) General. Using the pump curves AS-F-1 and AS-F-2 (Figures B-10 and B-11) and the required condition points from the system head loss curves, a preliminary pump selection can be made. The pump performance head-capacity curves are shown for the various blade angles that are available for that pump. A single blade angle that satisfies all design conditions should be used. Changing blade angles during flood events should not be considered because of the need to remove the pumping unit and thereby taking it out of operation. These pumps have the motors directly attached to the pumping unit. The motors' ratings are

For the example pump conditions the selected pump would have the following sump dimensions:

D = 48 in., a = 36 in., b = 96 in., c = 24 in., L = 16 ft.

S = submergence over bottom of tube

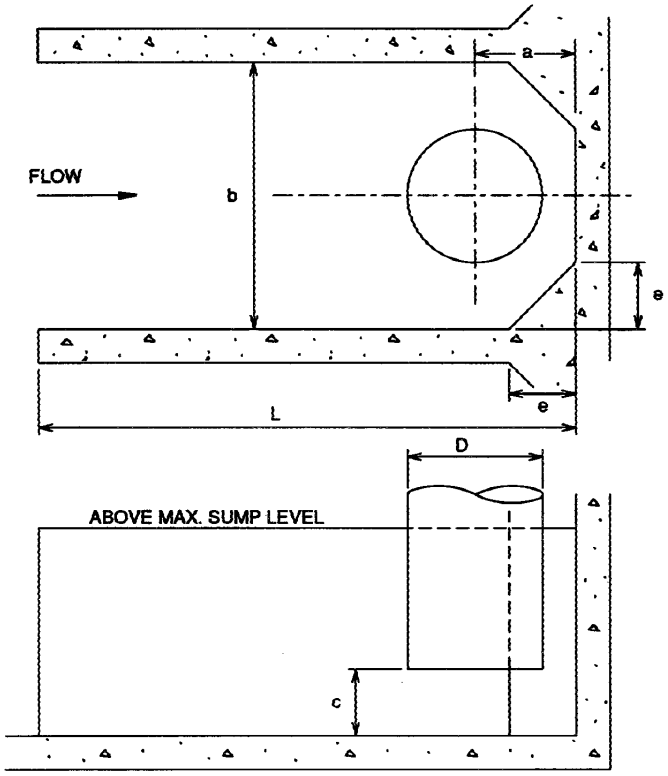
V = Q/A and if V = 1.2 fps, then A = Q/1.2 also A = 2D x (S+.5D)

then $S = (Q_{cfs} / 2.4D_{ft}) - .5D_{ft}$ and $S = 5.66$ ft. ft

Bottom of tube = Pump stop level minus submergence

= 315.0 - 5.66 ft. = El. 309.34 instead of El. 312.0

Submersible Pump Sump Layout



TUBE DIA.	DIM.
a	0.75D
b	2.0D
c	0.5D
e	0.5D
L	4D Min.

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Figure B-7. Typical submersible pump sump layout

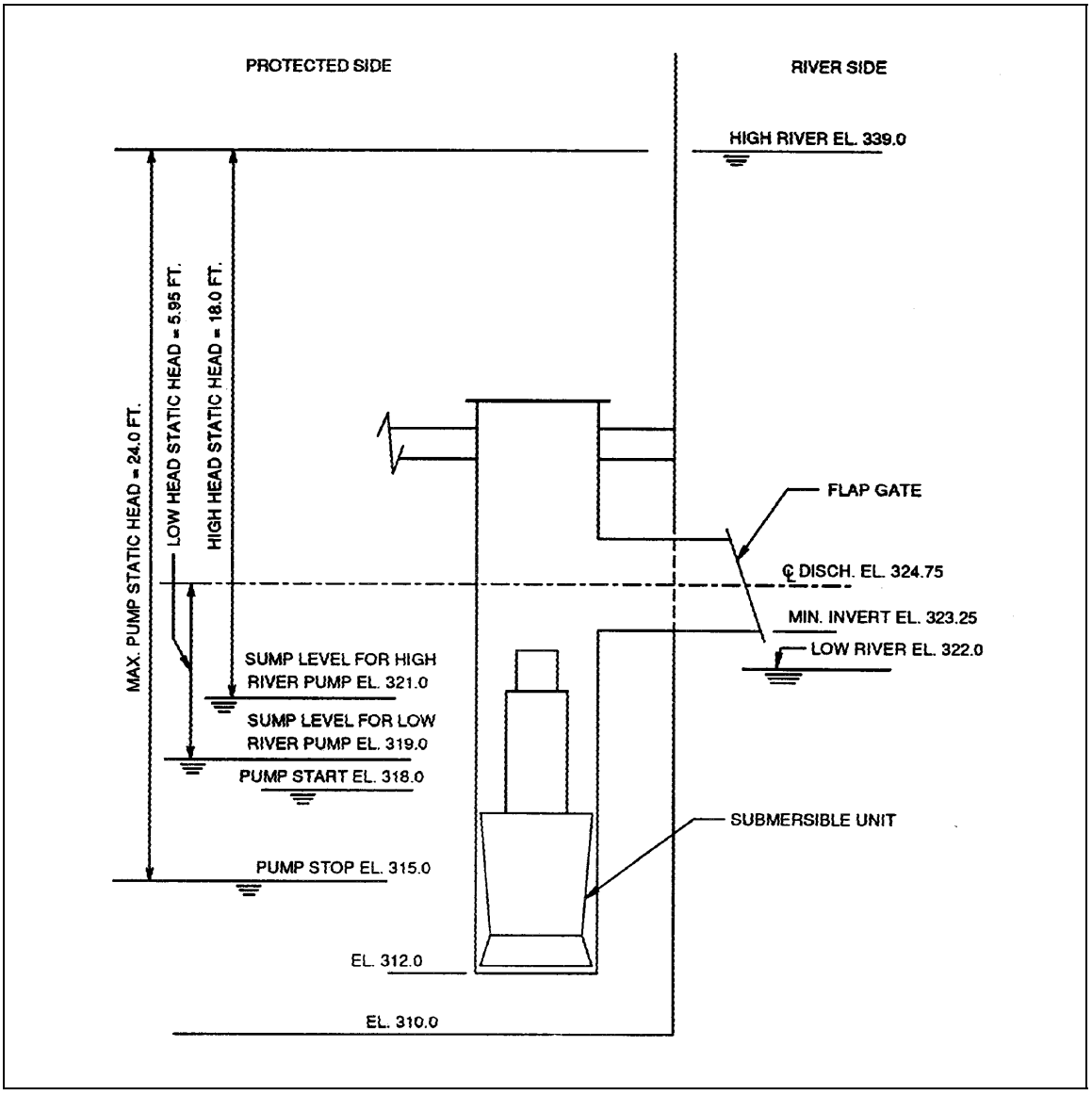


Figure B-8. Static head diagram

Table B-3
Low and High Head Conditions

Q gpm	$\frac{V^2}{2g}$ ft	Pump & Elbow K = 0.7 ft	Total Losses ft	Total Head Low Hd/ ft	m	Total Head High Hd. ft	m	Max. Head ft
20,000	0.22	0.15	0.37	6.3	1.93	18.4	5.61	24.4
25,000	0.28	0.19	0.47	6.4	1.96	18.5	5.63	24.5
30,000	0.33	0.23	0.56	6.5	1.98	18.6	5.66	24.6
35,000	0.39	0.27	0.66	6.6	2.02	18.7	5.69	24.7
40,000	0.44	0.31	0.75	6.7	2.04	18.8	5.72	24.8
45,000	0.50	0.35	0.85	6.8	2.07	18.9	5.75	24.9
50,000	0.55	0.38	0.95	6.9	2.10	19.0	5.78	25.0

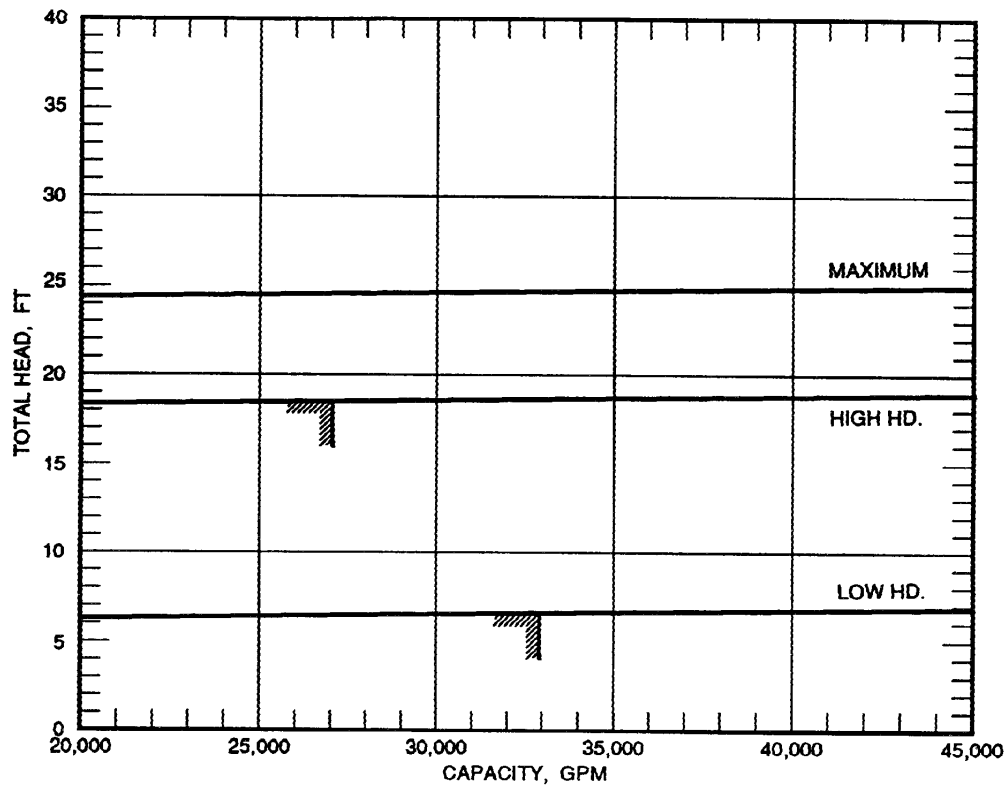


Figure B-9. System head loss curves

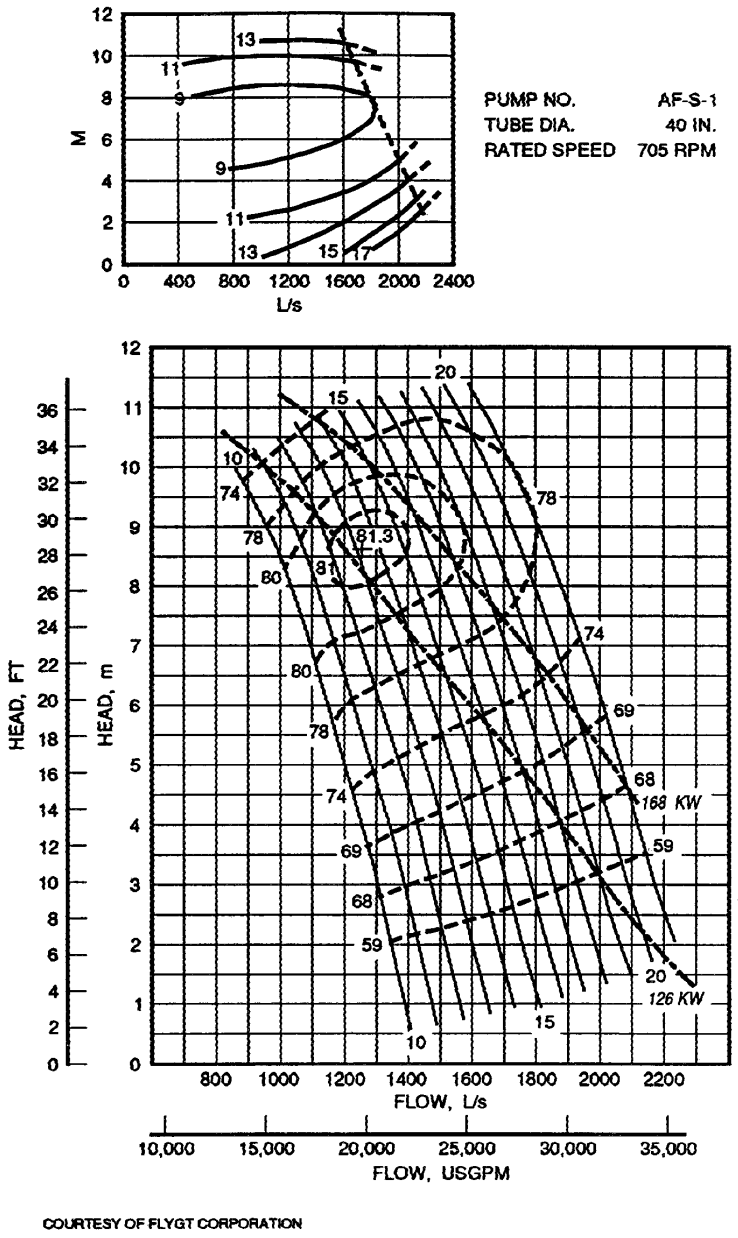


Figure B-10. Submersible pump curve AF-S-1

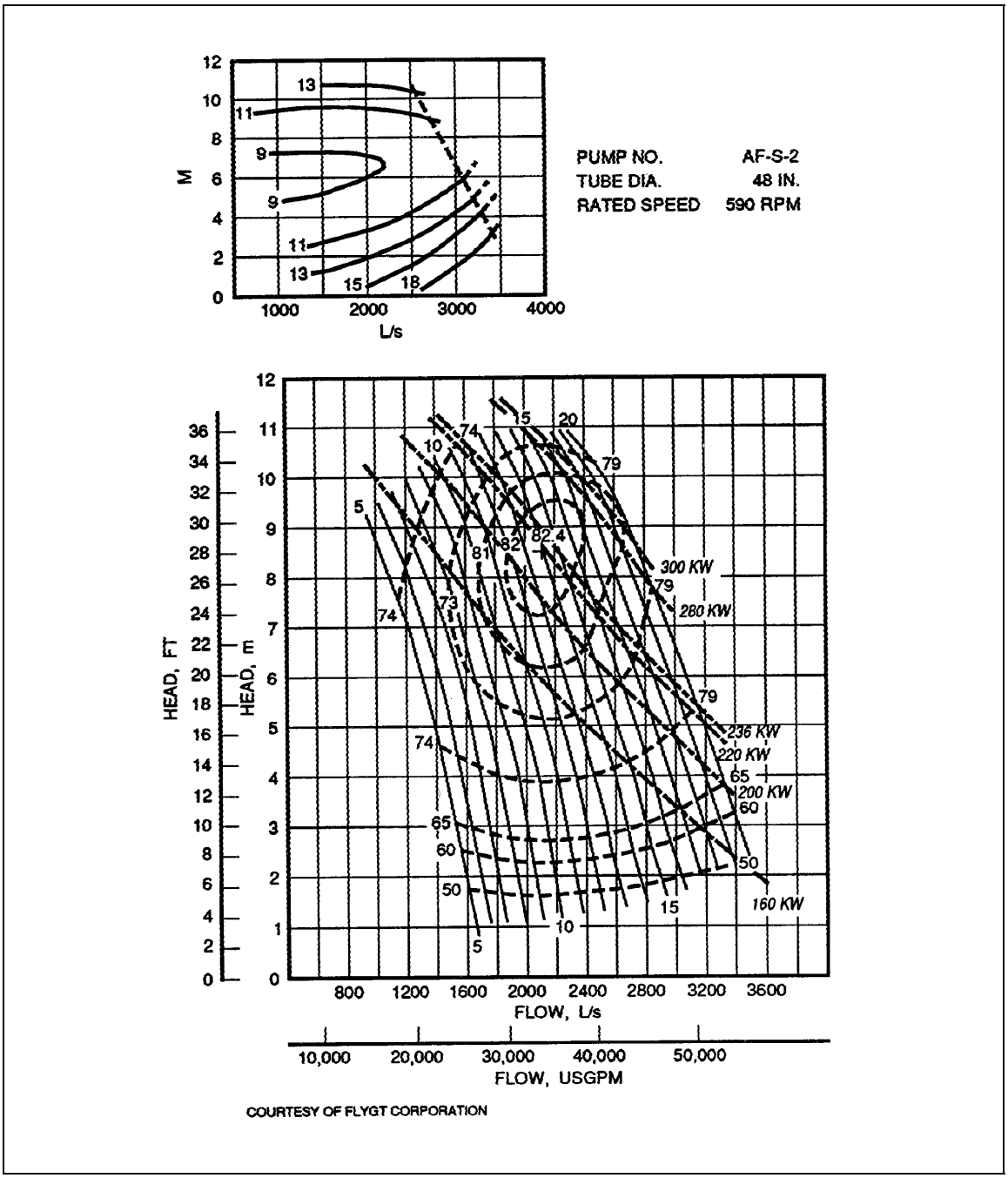


Figure B-11. Submersible pump curve AF-S-2

shown in kilowatts, which is the input power to the pump shaft. The dashed lines running diagonally from upper left to the lower right show the motor sizes available. Any design condition below these dashed lines may use the motor rating indicated for that line. The information furnished in this manual can be used for the preliminary layout of submersible type pumping stations; however, information should be requested from all manufacturers for the design memorandum.

(2) Selection procedure. Review of the pump curves indicates that an AF-S-1 size pump operating at a speed of 705 rpm and set at a blade angle of 20 degrees will satisfy the head-capacity design conditions.

(a) The next step is to check the suction requirements of the pump. This is done by plotting the head-capacity curve for the blade angle chosen above on the NPSHR curve for that pump. The plotted head-capacity curve crosses the various NPSHR curves for that pump indicating the required suction head for different pumping requirements. The curve shown below indicates that the preliminary AF-S-1 pump selection requires a greater submergence than is available; therefore, another pump must be tried or greater submergence provided. Unless the additional submergence required is less then 1 or 2 feet, it is usually less expensive to provide a larger, slower speed pump than provide a deeper station. A cost comparison can be made to more accurately compare a deeper sump station with that station requiring a larger area because of increased pump size.

(b) The next choice would then be the next larger size pump operating at its the highest available speed and meeting all the required design conditions. This would be the AF-S-2 size pumping unit operating at 590 rpm. The 10-degree blade angle satisfies the design conditions and the suction requirements.

(c) Since the selected size pump of AF-S-2 has the same size tube as that first selected, the static head diagram and system head curves are correct.

(d) The net positive suction head requirements for the pump are determined by plotting the selected blade angle head-capacity curve on the cavitation curve. Where this head-capacity curve crosses the NPSHR lines indicates the NPSHR values for the pump.

(3) Station layout. Using the listed discharge tube diameter (Table B-2), the sump can be sized according to Figure B-7. Check the pump selections using the new system requirements and refine the layout as necessary. The sump layout is now complete, and the remainder of the station layout can now be done. It is also best at this time to request pump selections from the pump manufacturers using the requirements and sump layout above. This will confirm the pump selections and permits adequate bidding competition. The following are considerations for station layout:

(a) Sump velocities. The average velocity in each pump sump in front of the pump for continuous operation should not be greater than 0.37 meter per second (1.2 feet per second). For intermittent operation (less than 200 hours per year), the average velocity may be increased to 0.49 meter per second (1.6 feet per second). To obtain these velocities, the sump depth is varied while the sump width is kept equal to two tube diameters. These maximum velocities are maintained to diminish the formation of vortices in the sump. The water levels obtained by application of these velocities may not be high enough to satisfy the pump's NPSHR. The NPSHR takes precedent, and the resultant submergence will be greater than that necessary to prevent vortices.

(b) Superstructure. A structure should be provided to house the motor starters, switchgear, and engine generator, if provided, and office space for operating personnel. Unless dictated by climatic conditions or needed to satisfy some other specific purpose, the structure need not cover the pump locations.

(c) Hoist. A method for removing the pumping units should be provided. Any inspection or repair work to the pumping unit is done with the unit removed from the tube. Inspection which requires the removal of the pumping unit are required at least annually to check the integrity of the pump/motor seal system. A monorail hoist capable of lifting the entire pumping unit should be provided. If the maintenance organization has a truck crane of sufficient capacity to raise the pumping unit or such a crane would be readily available on an emergency basis, then a permanent hoist would not be required.

B-4. Formed Suction Intakes

a. General. The formed suction intake (FSI) is used on pumps to improve flow to the impeller of vertical pumps. The FSI can be used on almost any pumping application. It is, however, recommended when adverse flow conditions occur upstream. Figure B-12 shows a typical FSI. ETL 1110-2-327, Geometry Limitations for the Forced Suction Intake, provides additional information. The FSI can be used on small pumps; however, the

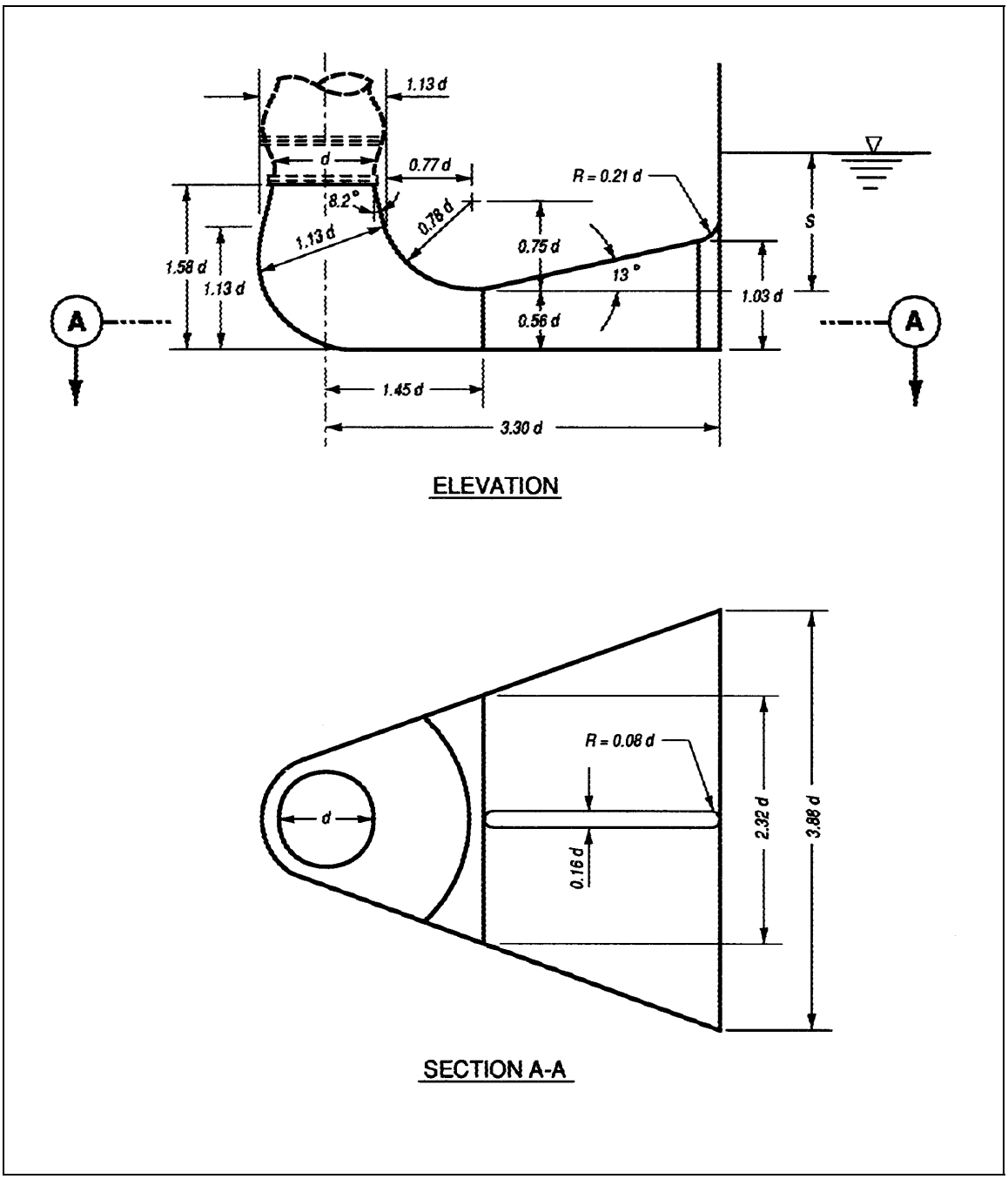


Figure B-12. Typical formed suction intake

small openings could clog or silt in during nonoperational periods.

b. FSI size determination. FSI is connected directly to the suction flange below the impeller. This diameter, d, will determine the size of the FSI. The selection of the pump will be the same as that used for the vertical wet pit pump except for the additional suction loss. Whereas the conventional vertical pump with a bell uses a suction loss of zero, the pump equipped with an FSI should use a loss of K = 0.15. After the pump has been selected, it is necessary to determine the suction flange connection inside diameter, d. For axial flow pumps, d will be the same diameter as that determined for the impeller. For mixed flow impellers, d can be estimated to be 0.85 of the impeller diameter d. After d has been determined, the rest of the dimensions of the FSI can be found by applying the ratios indicated in Figure B-12. In a typical pump selection, the suction diameter will vary with different pump manufacturers. To permit maximum biddability, the FSI must be sized to allow sufficient manufacturers to bid.

c. FSI connection. For vertical wet pit pumps which are suspended from the operating floor, the connection between the FSI and the pump is determined by the pump manufacturer after the pump manufacturer performs a dynamic analysis of the pumping unit to determine the critical speeds of the pump. It is recommended that the FSI be formed or cast integral with the sump concrete.

Appendix C
Trashraking Equipment

C-1. Description

Trashraking equipment is classified in three general categories. These categories are cable hoist, mechanical, and catenary. Figure C-1 shows the various types of rakes by classification. The types of trash to be handled are classified in Table C-1.

a. Cable hoists.

(1) General. Cable hoist trashrakes use wire rope hoists to move the rake up and down to clean the trashrack. The rake portion can be the guided or unguided type.

(2) Guide cable hoist trashrakes. Guided cable trashrakes cover the full width of a set of trashracks. Fixed channels at each side of the rack section or pump bay guide the rake up and down in front of the trashrack. The trashrake is raised and lowered along the front face of the trashrack by a cable hoisting system. The rake is lowered by gravity and raised by the hoist machinery. The teeth of the rake are designed to pull away from the rack during lowering and are engaged into the rack when the rake is raised. The width of the rake is usually limited to 4.57 meters (15 feet) with the vertical travel limited to about 12 meters (40 feet). The rake can discharge into a removable cart for transporting to a location for trash removal by a truck. The entire trashrake can be power driven to run on rails for use in multiple pump bays or can be fixed at one location. The electrical power is supplied to the rake by means of a cable on a pull out reel or from a fixed bus bar with a trolley collector. Electrical controls consist of lower and upper limit switches and hoist overload protection. A typical arrangement of the guided cable hoist trashrake is shown on Figure C-2. The trash removal capability of the guided cable hoist trashrake would include material classes 1, 2, 3, and 4. The handling ability of class 4 debris depends on the size of the rake and how far the teeth of the rake clear the rack when the rake is being lowered.

(3) Unguided cable hoist trash guides. Unguided cable hoist trashrakes are similar to the guided types except that the rake is not restrained by guides on the sides (Figure C-3). The rake moves up and down the trashrack on wheels. Except for the guided provisions, the unguided mechanism is very similar to the guided cable hoist trashrake. The width of these rakes are limited to approximately 10 feet, and the vertical travel ranges up to 40 feet. The trash removal capability of the unguided cable hoist trashrake would include material classes 1, 2, 3, and 4. This type of rake tends to lose trash when being raised and has had overall poor performance in some Corps-designed structures when compared with the guided type of rake.

b. Mechanical trashrakes.

(1) General. Mechanical trashrakes use chains, levers or arms, hydraulic cylinders and gears to move the rake up and down to remove the trash from the trashrack. Four types of mechanical trashrakes are described below. The types are climber, elbow arm, sliding arm, and chain driven.

(2) Climber trashrakes. The climber-type mechanical trashrake consists of a rake that covers a full bay width and is raised and lowered along guides and driven by sprockets on the rake assembly that mesh with a fixed roller chain or rack attached to the side guides. The rake assembly rotates around a pivot which permits the rake to rise from the trashrack when lowered and mesh with the trashrack when raised. The rake is driven positively during both the up and down movements. The rake is supported by a superstructure above the operating level. The side guide bars, motor drive mechanism, and other moving parts are located above the operating floor level. A climber trashrake would be required for each pump bay since they are fixed at one location. A climber trashrake can be obtained to rake trashracks that are up to 9 meters (30 feet) wide and 12 meters (40 feet) deep. The rack needs to be inclined for this type of rake. The electric controls consist of lower and upper limit switches along with motor overload provisions. The controls can permit a complete operation cycle of the rake with one activation. A typical arrangement of the climber type mechanical trashrake is shown on Figure C-4. The trash removal capability of the climber type mechanical trashrake would include trash material classes 1, 2, 3, and 4. The handling ability of classes 3 and 4 depend on the length of the trash item and its effective diameter. The width of the rake and the distance the teeth retract from the face of the trashrack determine the rakes capacity to remove large trash.

(3) Elbow arm-type trashrakes. The elbow-type unit consists of a rake on the end of a two-piece arm similar to that used on a backhoe. The arm is moved by means of a hydraulic cylinder. In addition to the up and down movement of the rake, it also can be made to pivot

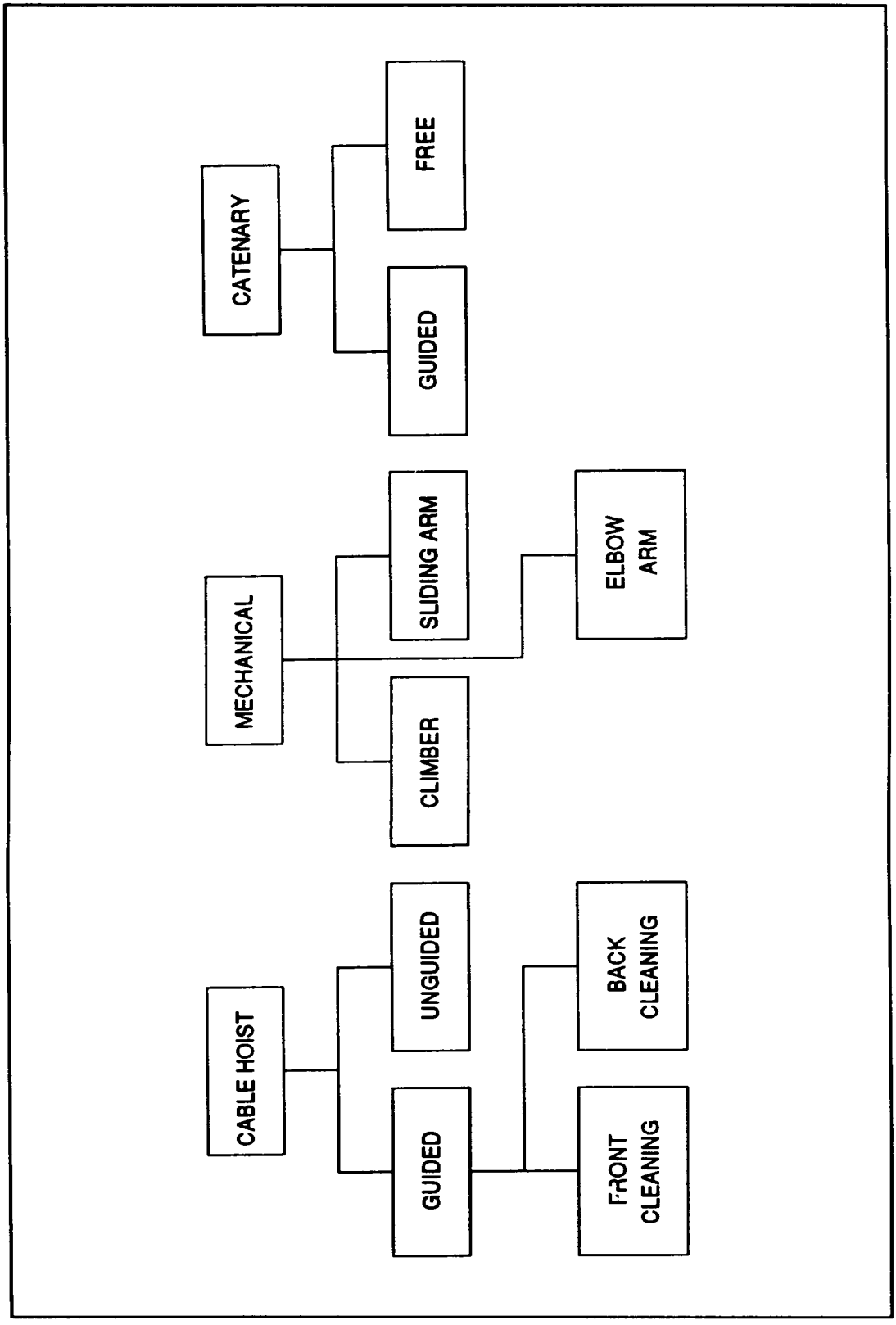


Figure C-1. Trashrake categories

Table C-1
Trash Material Classification

Class	Description
1	Very light weight debris or no debris
2	Light weight floating debris - small limbs or sticks, agricultural waste, orchard prunings, corn stalks, hay and leaves.
3	Medium weight floating debris - limbs or large sticks and small logs (up to 76.2-millimeter (3-inch) diameter)
4	Flowing debris - water grass, water-logged debris and refuse such as tires, rugs, and mattresses
5	Heavy weight floating debris - large logs or trees

where attached to the operating platform, thus allowing it to sweep a greater width and provide unloading capability adjacent to the rake unit. For a station with multiple pumps, the rake unit is mounted on a traveling platform allowing its operation in front of any pump. The rake is limited to a width of 3.0 meters (10 feet), and the raking depth can vary to 8.7 meters (25 feet). Manual control of the rake is performed by an operator from a cab located on the platform. This rake also has the advantage of power down movement rather then depending on gravity forces to lower the rake. A typical arrangement of the elbow type trashrake is shown on Figure C-5. The trash removal capability of the elbow-type rake would include material classes 1, 2, 3, 4, and 5.

(4) Sliding arm trashrakes. Sliding arm or telescoping arm rakes consist of a pivoting boom assembly supported from a frame. The boom assembly supports a sliding rake arm that allows the rake to be lowered and raised. Pivoting of the boom assembly also allows the rake arm to be moved away from or to the trashrack. The frame supporting the rake can be permanently fixed at one location for raking only one trashrack or can be mounted on a rail-supported platform which would permit one unit to rake multiple trashracks. The rake can empty into a cart onto the operating platform. This rake can be obtained in widths up to 4.6 meters (15 feet) and rake racks to 8.7 meters (25 feet) deep. The controls can permit a complete operation cycle of the rake with one activation. A typical arrangement of the sliding arm trashrake is shown on Figure C-6. The trash removal capability of the sliding arm trashrake would include material classes 1, 2, 3, and 4. The ability to handle classes 3 and 4 depends on the rake arm being able to clear the trash on the downward movement of the rake arm.

c. Catenary trashrakes.

(1) General. Two types of catenary trashrakes are unguided (free hanging) and guided. Both types consist of a chain on each side, supported by two sprockets that hang down the front of the trashrack. Several beams with teeth attached (rakes) have each end connected to each chain. The continuous movement of the chain drags the beams across the rack. The beams are held into the rack by gravity. This type of rake can be used for racks up to 12.2 meters (40 feet) wide with depths up to 12.2 meters (40 feet). The chains are motor driven utilizing gearing and drive shafts similar to dam tainter gate machinery. Since the beams rub along the trashrack, care must be given to the alignment of the racks so that it provides a smooth surface without any projections for the rake beams to catch on.

(2) Unguided catenary trashrakes. The unguided catenary trashrake consists of a free-hanging chain with rake beams spaced approximately every 3.0 to 4.6 meters (10 to 15 feet) along the chain. The chains are supported by an idler sprocket at the top of the trashrack and a driven sprocket located at the same elevation as the idler sprocket and a sufficient distance from the trashrack so that the free hanging chain makes contact with the bottom of the rack. A typical unguided catenary trashrake is shown on Figure C-7. The trash removal capability of the unguided catenary trashrake would include material classes 1 and 2 with some limited capability of classes 3 and 4. Items of size greater than the depth of the rake beams are usually not removed by the rakes.

(3) Guided catenary trashrakes. The guided catenary trashrake is the same as the unguided catenary trashrake except that the down leg of the chain from the driven sprocket is guided to ensure that the chain reaches the bottom of the rack. A typical guided catenary trashrake is shown on Figure C-8. The trash removal capability of the guided trashrake would include material classes 1 and 2. As with the unguided type, this rake can on a limited basis handle some class 3 and 4 material depending on its size.

C-2. Selection Criteria

a. General. Table C-2 indicates some of the comparison factors that can be used to judge the trashrakes and their application. Intangible factors may also need to be considered such as local operating agencies' requests. In most cases it will be necessary to make a comparison for a minimum of two different type rakes and obtain

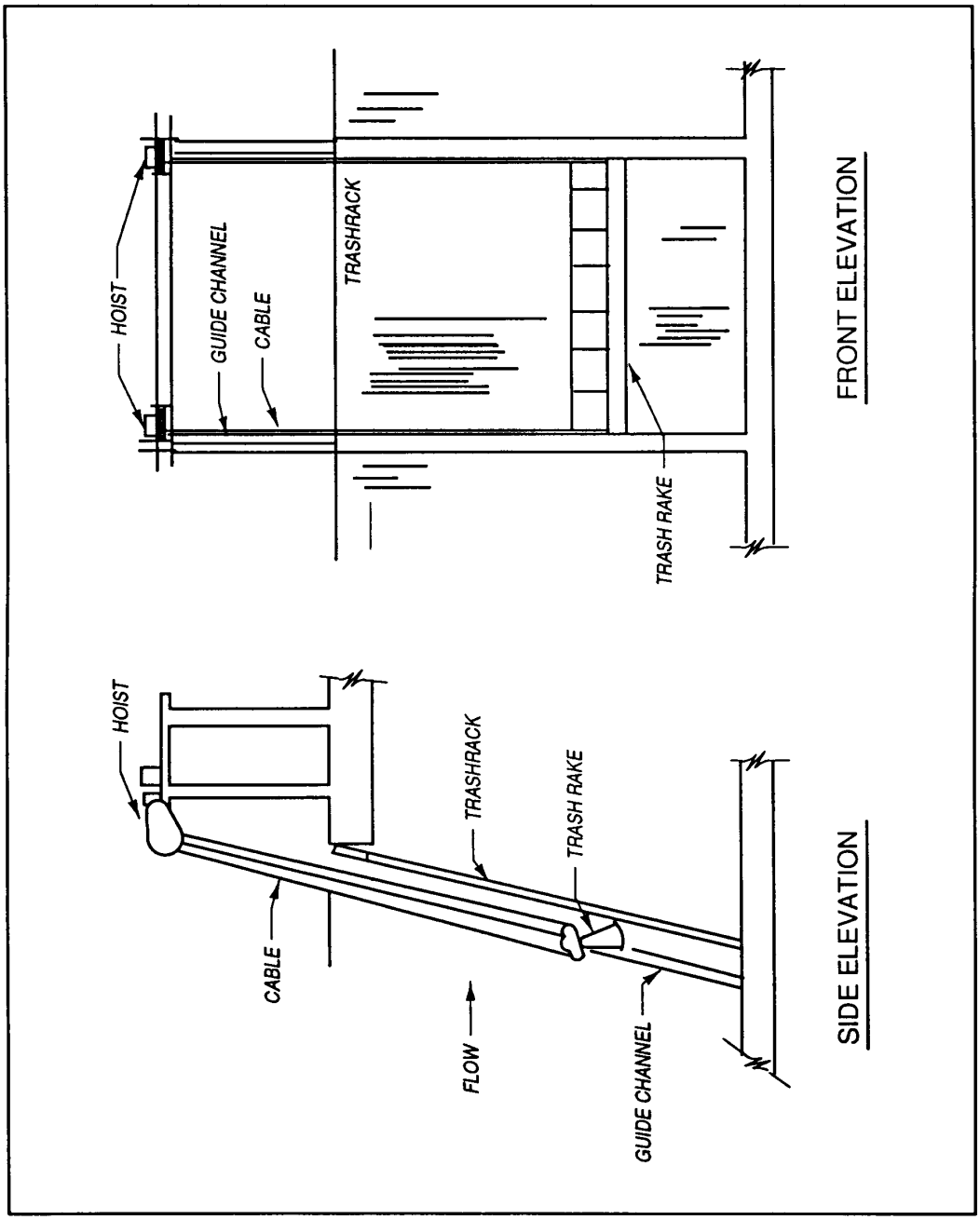


Figure C-2. Guided cable hoist trashrake arrangement

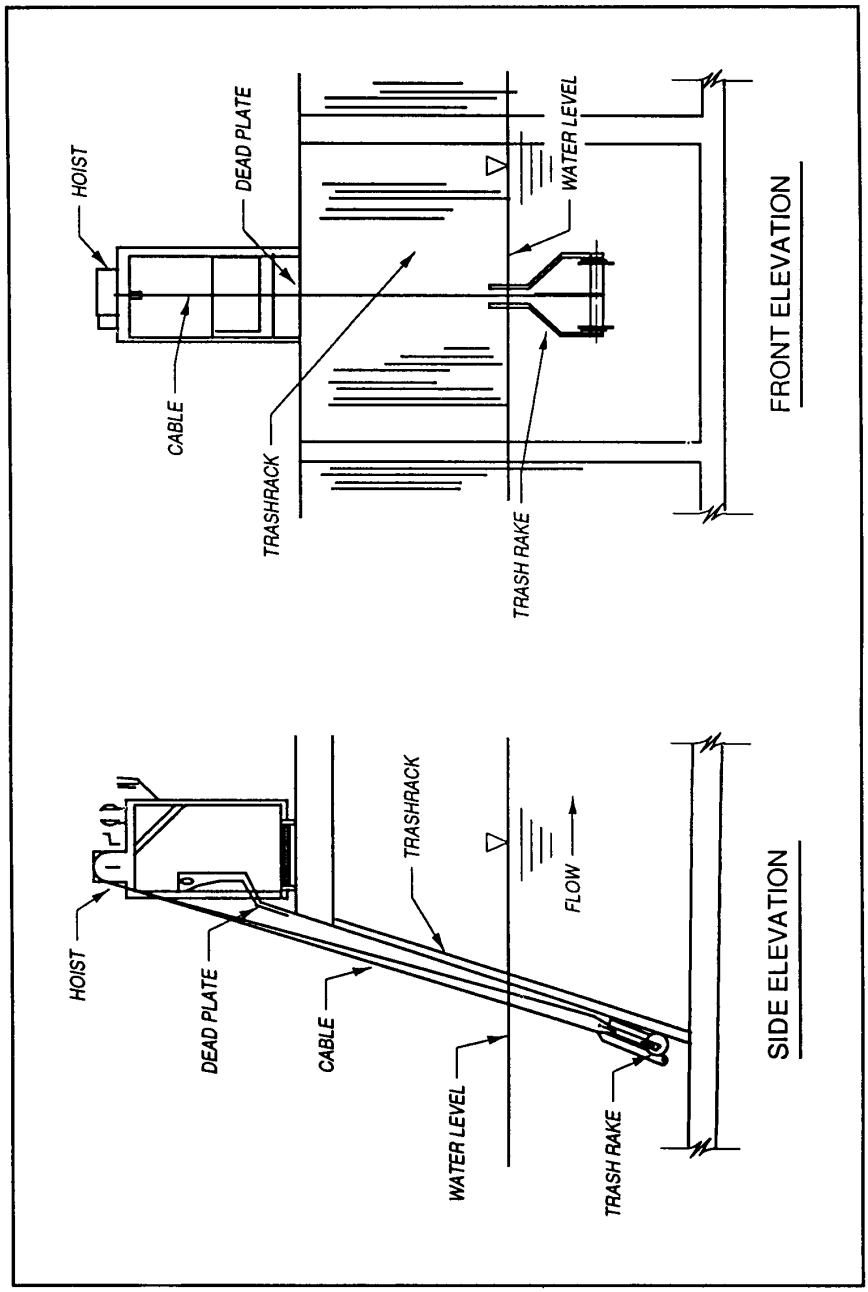


Figure C-3. Unguided cable hoist trashrake arrangement

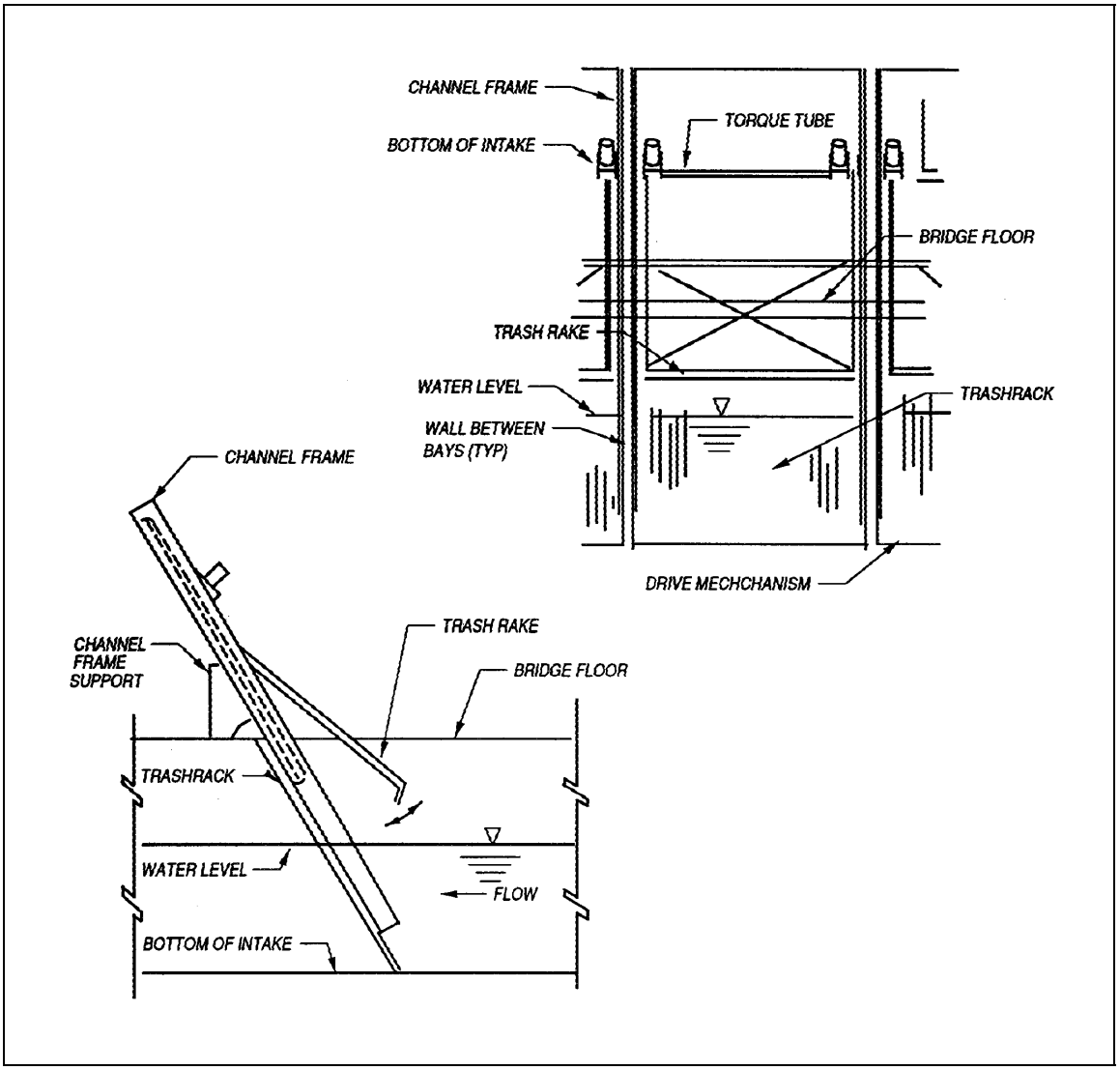


Figure C-4. Mechanical climber screen arrangement

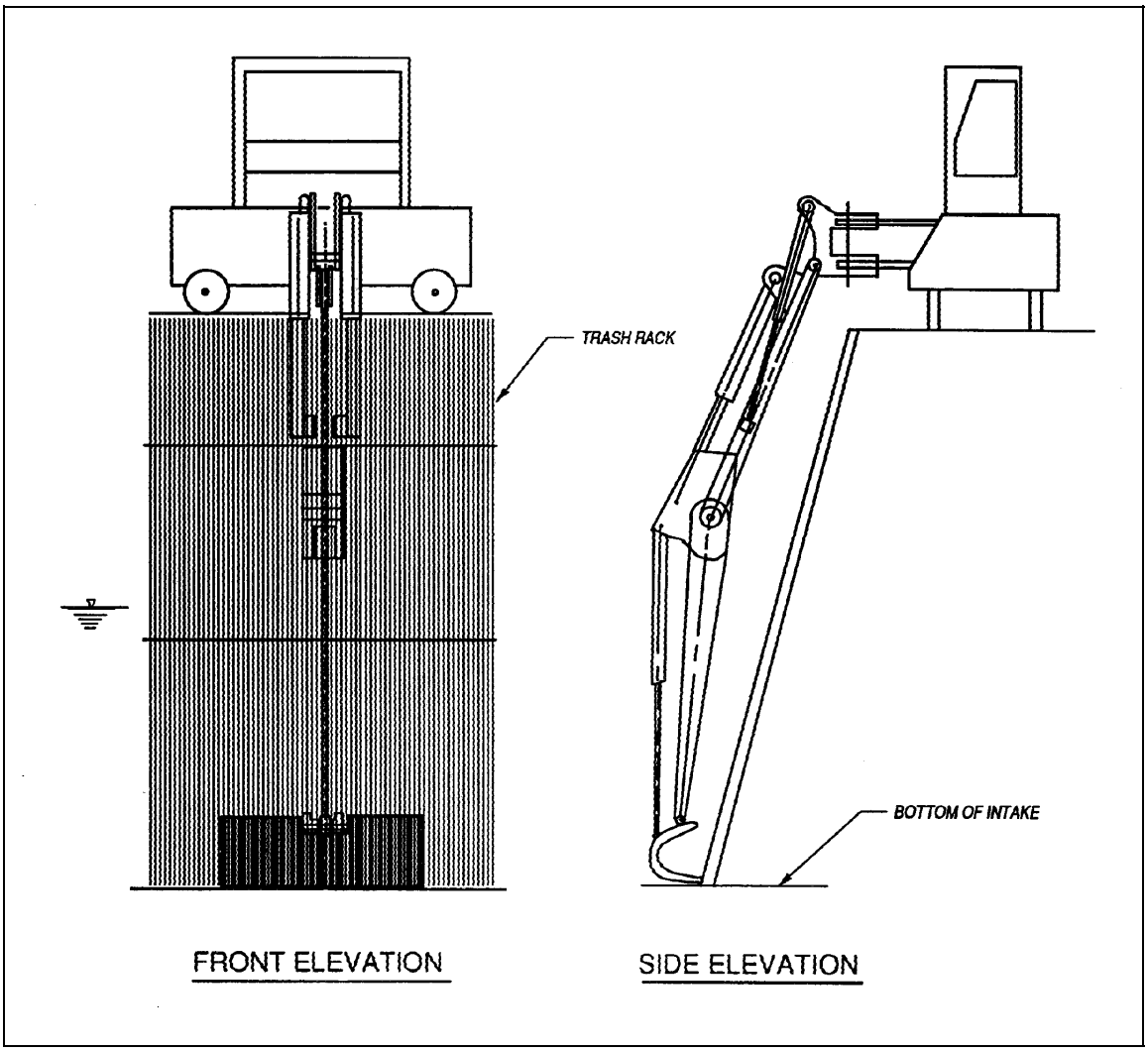


Figure C-5. Mechanical elbow arm arrangement

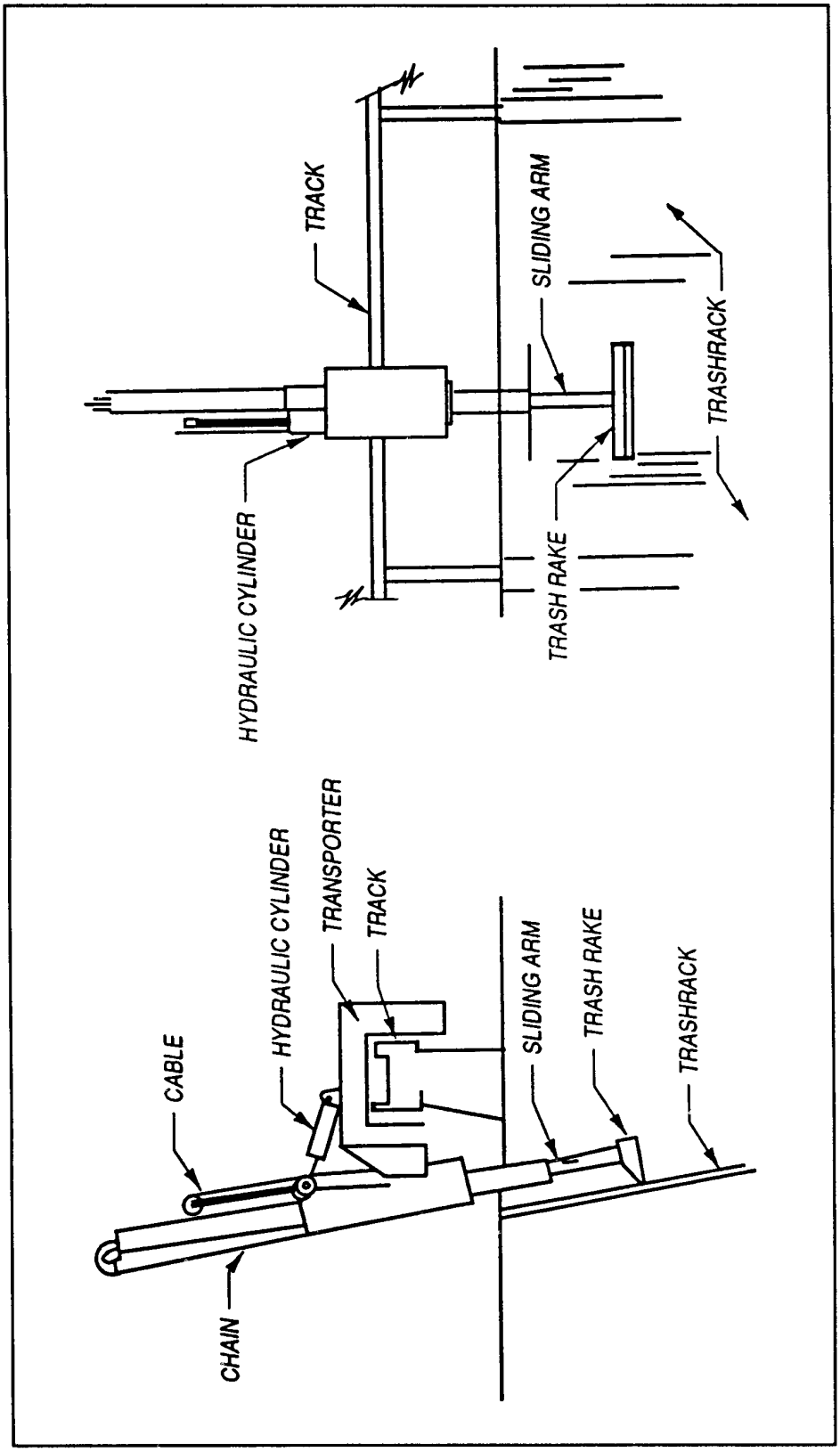


Figure C-6. Sliding arm trashrake arrangement

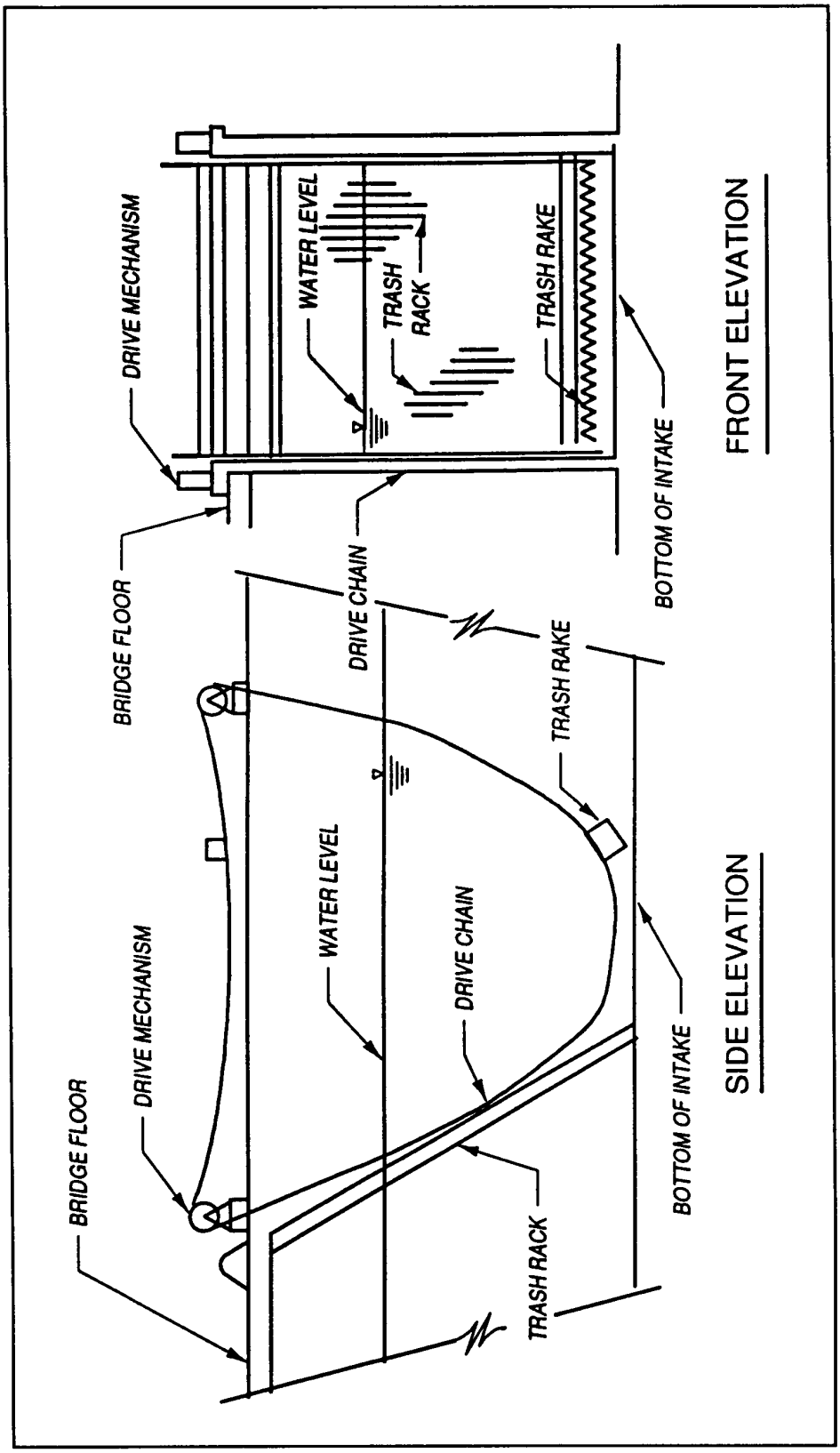


Figure C-7. Unguided catenary arrangement

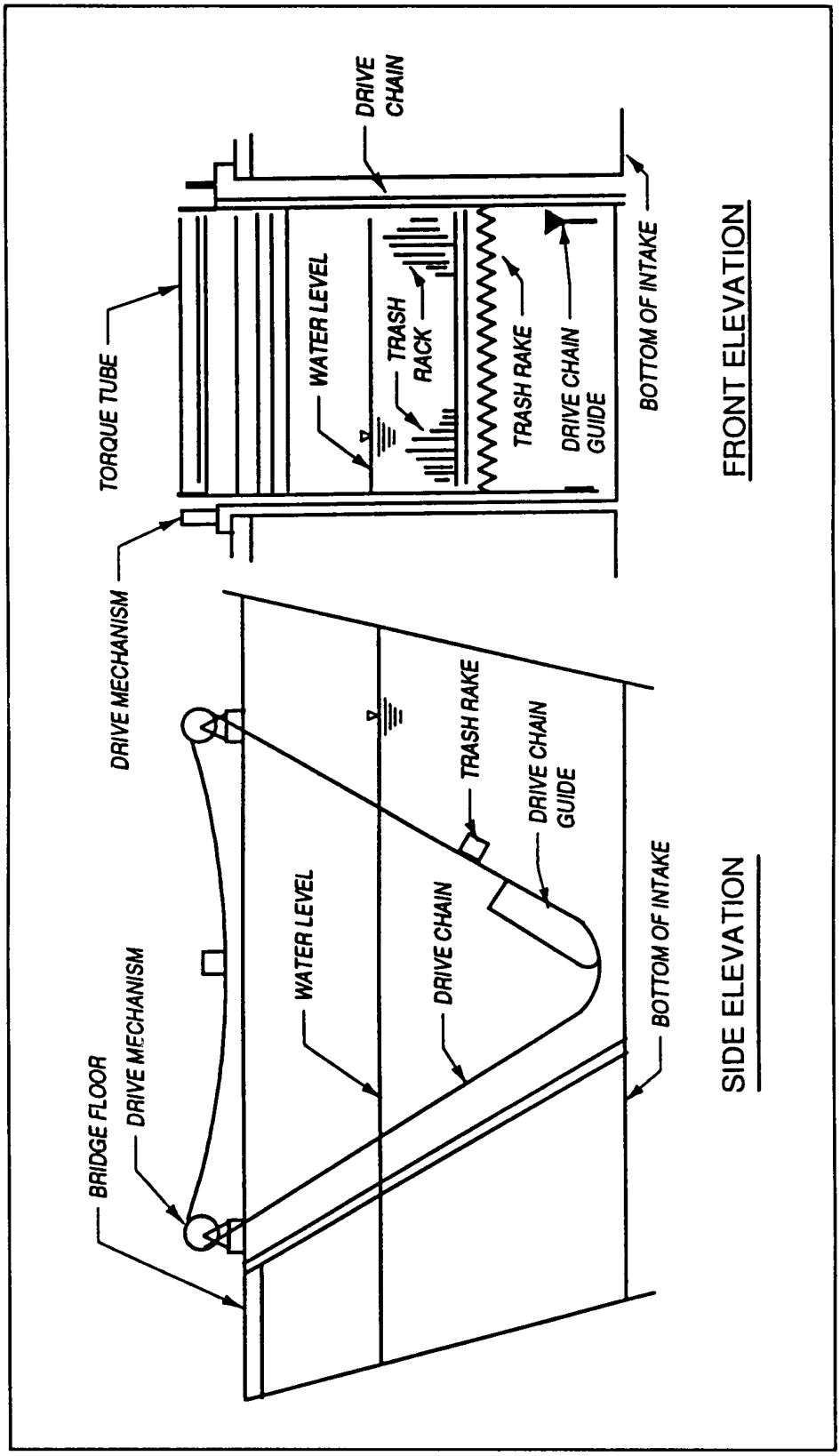


Figure C-8. Guided catenary arrangement

Table C-2
Selection Factors

Type of Rake	Guided Cable	Unguided Cable	Mech. Climber	Mech. Elbow Arm	Mech. Sliding Arm	Catenary Guided	Catenary Unguided
Handles all types of trash	A	P	A	G	A	A	A
Quantity of trash handled	A	A	G	A	G	A	A
First costs	L	L	H	L	L	M	M
Operating costs	M	M	M	M	M	M	M
Maintenance costs	M	M	M	M	M	M	M
Rack can be manually raked upon breakdown	G	G	P	G	G	PP	
Large trash can be removed from in front of the rake	G	G	A	G	G	P	P
Speed of operation	L	L	H	L	L	M	M

Abbreviations used:

G - Good
A - Average
P - Poor
H - High
M - Medium
L - Low

estimated costs from the manufacturers. The results of this study and reasons for selection should be presented in the design memorandum.

b. Design considerations. Many items must be considered in the selection of the type of trashrake and whether the rake should be manually or power operated. Some of these items are the type of trash expected, the quantity of trash and how quickly it occurs, the number and size of the pump bays to be raked, the hazard created with a trashrake failure, and the first costs and operating and maintenance costs.

(1) Type and quantity of trash. A physical survey of the contributory area and consultation with the local interests and operators at nearby pumping stations should be conducted to determine the type and quantity of trash expected. If information concerning the quantity of trash is not available, the following can be assumed.

(a) Pumping stations located on open ditches will have the trash arrive at an even rate, and the trash can be handled with a minimum number of raking units.

(b) Pumping stations located on sewers in urban areas will have most of the trash arrive during the first flush of the runoff, and the raking system should be designed to remove this first flush quickly in order to prevent a buildup that may damage the trashrack.

(c) It is usually best to plan for a greater amount of trash than current conditions may indicate since it is very costly to make changes to the raking system after the pumping station has been constructed.

(2) Other considerations. The rated lifting capacity of the rake should be large enough to lift the majority of the trash expected. In most cases, a capacity of 454 kilograms (1,000 pounds) is sufficient. The speed of operation is also a consideration. Some rakes, due to their design, do not permit fast raking of the entire trashrack. The maximum time for the rake system to be able to rake the entire pumping station trashrack should be less than 1 hour. The hazards that may be created with a trashrake failure should be considered when deciding on the number and type of rake to use. Where the entire pumping station capacity is expected to be used on a regular basis and trash may occur which would clog the trashrack limiting pump operation, multiple units or units with good raking capability should be used. If trash is larger than capable of being handled by normal raking, such as large parts of trees, an auxiliary crane in front of the raking area should be considered.

Appendix D
Closure Gates

D-1. Purpose

The purpose of this appendix is to explain the procedure used in determining the size of gate closure, the stem size, the operator size, and loads to be carried by the structure at the gate location (Figures D-1, D-2, and D-3).

D-2. Gate Size

The size of gate required is determined using the maximum pumping capacity of the station and the number of pumps. The velocity through the gates at the maximum capacity should be limited to 2.0 feet per second (fps) to achieve the best flow conditions to the pump when used for sump closure. The maximum capacity of the station can be estimated at 33 percent above the design capacity.

Example: Station Capacity = 180 cfs
No. of Pumps = 3

$V = Q/A$

where

V = Velocity through gate = 2.0 fps

Q = Flow through a gate = Max. Cap./3
Max. Cap. = 180 × 1.33 = 240 cfs
therefore Q = 240/3 = 80 cfs

A = Gate area in ft^2

$2.0 = 80/A \quad => \quad A = 40\ ft^2$

$A = W \times H$

where

W = Gate opening width in feet.

H = Gate opening height in feet.

Note: The gate opening height and width are then determined using the area calculated, the sump floor elevation, sump width, and the minimum pumping elevation. The top of the gate opening should not be higher than the minimum pumping elevation. If this is not possible at a particular site, then the top of the gate opening should not be higher than the elevation at which all pumps are operating. For this example use:

$40 = H \times W \quad => \quad H = 5$ ft and $W = 8$ ft

D-3. Type of Gate Operation

Slide gates can be used for seating and unseating operating head conditions. Seating head occurs when the level of the water is greater on the gate side of the wall. This type of head condition results in the best seal against leakage. Unseating head occurs when the level of the water inside the gate is greater than the water outside the gate. This type of head condition results in a lesser seal when compared with that achieved with the seating head condition.

D-4. Gate Operator Size

a. Required force. The size of the gate operator is determined by first calculating the force needed to open the gate with the maximum differential head acting on the gate. This will normally occur when the sump is dry and the maximum expected forebay water elevation is present.

(1) There are three terms used during the selection of a motorized gate operator: run torque, pullout torque, and stall torque. The definition of each of these terms is as follows:

(a) Pullout torque. This is the torque the operator develops to initially break the seal caused by the wedges on the sluice gate; operators are designed to develop this torque for only a short period of time.

(b) Run torque. This is the torque the operator develops to move the gate after the wedge seal is broken; operators should be designed to develop this torque continuously.

(c) Stall torque. This is the torque that is developed by the operator just as the motor stalls out; this is the maximum torque which will be exerted on the gate stem.

(2) Example: See Figure D-1:

Gate centerline - el 50.0

Maximum expected forebay water elev. - el 54.0

Gate height - 5.0 ft. Gate width - 8.0 ft.

Operating floor elevation - el. 65.0

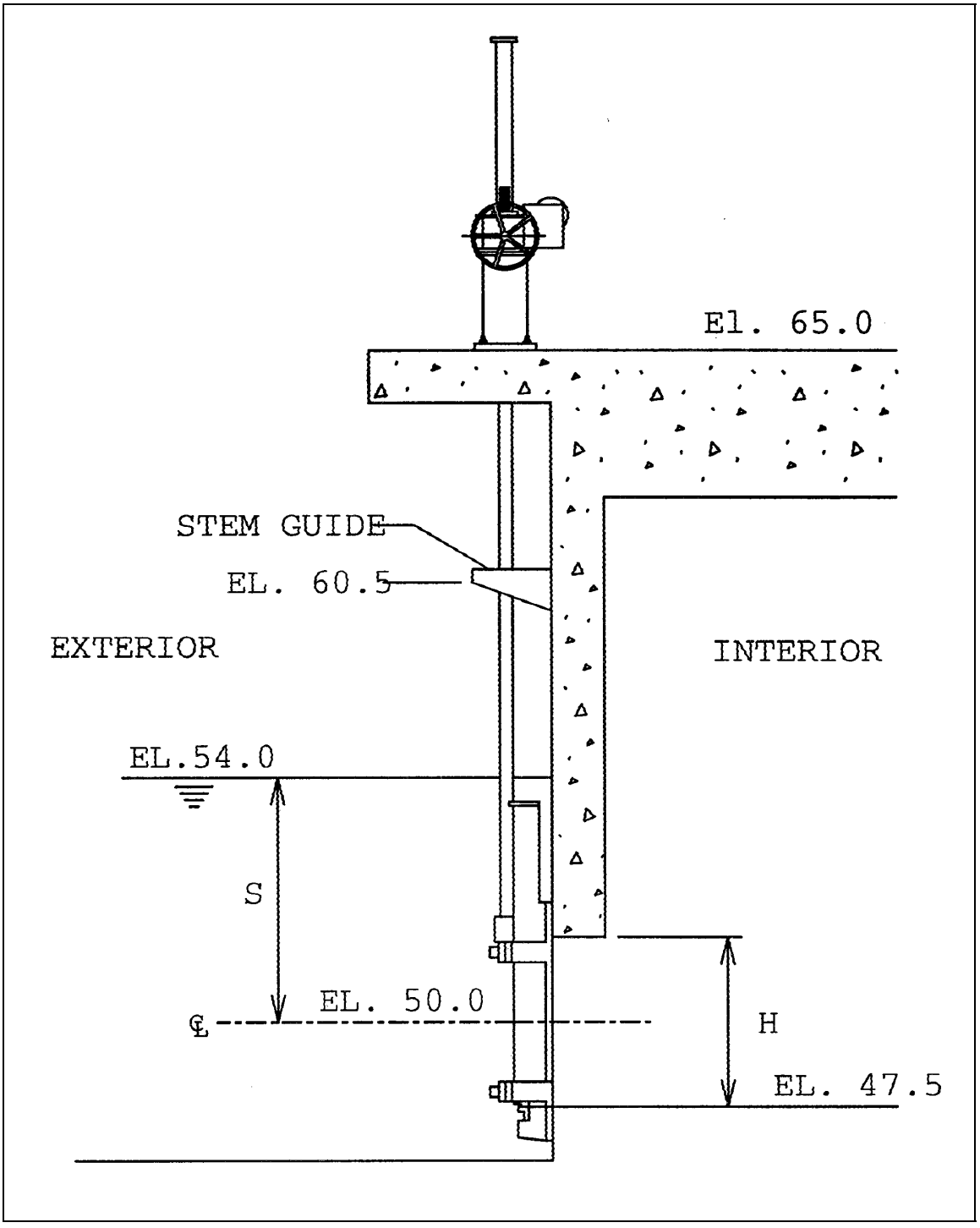


Figure D-1. Sluice gate and operator

$$F_u = 62.4 \times S \times A \times f_u + W_G + W_S \quad \text{(D-1)}$$

where

F_u = Maximum required gate unseating force, lbf

S = The distance from gate centerline to maximum forebay water elevation, ft

A = Gate opening area, ft^2

f_u = Friction factor for unseating (bronze seals)

W_G = Weight of the movable disk, lb (standard sluice gate catalog information)

W_S = Weight of stem, lb. Assume a 3-inch diameter stem that extends from the top of the disc to 4 feet above the operating platform elevation (standard sluice gate catalog information)

For this example:

S = el 54.0 - el 50.0 = 4 ft

A = $5 \times 8 = 40$ ft^2

f_u = 0.6

W_G = 4900 lb

W_S => Stem length - (el 65.0 + 4.0) - (el 50.0 + 5.0/2) = 16.5 ft

Weight = 16.5 ft × 24.03 lb/ft = 396.5 lb

Therefore,

$F_u = 62.4 \times 4.0 \times 40.0 \times 0.6 + 4{,}900 + 396.5$
$= 11{,}287$ lbf

(b) Preliminary hoist and stem size. This force or thrust to unseat the gate is then compared with manufacturers of motorized gate operators' catalog information to determine a preliminary hoist and stem size.

b. Required torque. The required torque (ft-lb) is determined by multiplying the calculated thrust with the stem factor (provided by manufacturer). For this example the stem factor is 0.0204 with 3 threads per inch.

The resultant torque = 11,287 × 0.0204 = 230.3 ft-lb

c. Output rotation speed. The required output rotation speed of the operator (in rpm) is then determined. For this example, the desired gate travel speed is approximately 1 foot per minute.

Stem Nut Rotation Speed = (1 ft/min)(12 in/ft)(3 thrd/in) = 36 rpm

(1) The torque required of 230.3 ft-lb and speed of 36 rpm is used to select an operator.

(2) The electric data for this operator are then obtained from either the catalog or directly from the manufacturers. These data are used for preparing the electrical design of the station.

D-5. Maximum Loads on Stem

a. Calculation of maximum loads. The maximum loads which can be transferred to the stem and the structure are calculated. The design shall be such that the stem would fail before any supporting structural failure would occur. The maximum loads are based on 125 percent of the stall torque (taken from published catalog information) of the operator selected.

(1) For this example, the stall torque of the selected operator is 481 ft-lb (this figure should always be verified by the gate operator manufacturer).

Max. Thrust = (Stall Torque × 1.25)/Stem Factor

$= (481 \times 1.25)/0.0204 = 29{,}473$ lbf

(2) The maximum thrust is an upward thrust of 30 kips and a downward thrust of 35 kips (this includes the dead weight of the gate itself).

(3) The required spacing of the stem guides is then determined. The Euler Column Formula is used:

$$F_{CR} = C\ ^2EA/(L/r)^2 \quad \text{(D-2)}$$

where

F_{CR} = Maximum thrust, lbf

C = End condition factor

E = Modulus of elasticity, psi

A = Cross-sectional area of the stem, in^2

L = Maximum unsupported length of stem, in.

r = Radius of gyration, in.

(4) The L/r ratio shall not exceed 200.

(5) For this example:

C = 2 (for all slide gate computations)

E = 28,000,000 psi (for stainless steel)

A = for threaded portion = 2.14 in^2
for plain portion = 3.14 in^2

r = for threaded portion = 0.41 in.
for plain portion = 0.50 in.

(6) Using these numbers, the maximum unsupported lengths of the stems can be calculated:

$$L = r\ [(C \times E \times A)/F_{CR}]^{1/2} \qquad \text{(D-3)}$$

Maximum length of threaded stem (L_{MT}) = 82.2 in.

Maximum length of plain stem (L_{MS}) = 121.5 in.

(7) However, at an L/r ratio of 200

$L_{MT} = 200 \times 0.41 = 82$ in.

$L_{MS} = 200 \times 0.50 = 100$ in.

(8) Since both the L/r ratio < 200 and the Euler's Column Formula criteria have to be met, the criterion resulting in the shortest lengths is used. For this example, the L/r ratio < 200 criterion has resulted in the shortest lengths. Two stem guides are located to meet these calculated lengths. Figure D-1 shows that one stem guide was placed at el 60.5 or 96 inches (8.0 feet) above the top of the gate (this length of stem is solid; therefore the previously calculated 100-in. maximum length is applied). The other stem guide would be located at the bottom of the gate operator base. This location would result in a length between guides of 54 inches, which is less than the minimum for threaded stem (82 in.).

b. Position limit switches. All motorized gate operators shall be equipped with position limit switches in the open and closed positions. In addition, mechanical torque limit switches should be provided. These would provide backup in case the position limit switches fail or if debris jams the gate while opening or closing.

c. Roller gates. The same computations are done for roller gates to size the operators and structural design loads. The force required to open this type of gate is the sum of gate weight, stem weight, seal friction, and roller friction. The seal friction is a result of the deflection of the rubber J-seal attached to the top and sides of the gate. The roller friction is a result of the bearing friction in the roller and the roller-to-rail friction. The amount of seal and roller friction will vary depending on the types of materials used for the roller wheels, roller bearings, rails and seal plates.

(1) If the roller gate is extra wide or if the ratio of the width to the height is equal to or greater than 2:1, the gates are normally raised and lowered through the use of two stems placed near each side of the gate. Each stem passes through a geared operator. The geared operators are both connected to an electric or hydraulic operator located between the two stems. The loads incurred by raising the gate are equally distributed between the two stems.

(2) During the early design phases of a pump station, a roller gate manufacturer should be consulted to assist in determining the design loads, forces, and lifting arrangement.

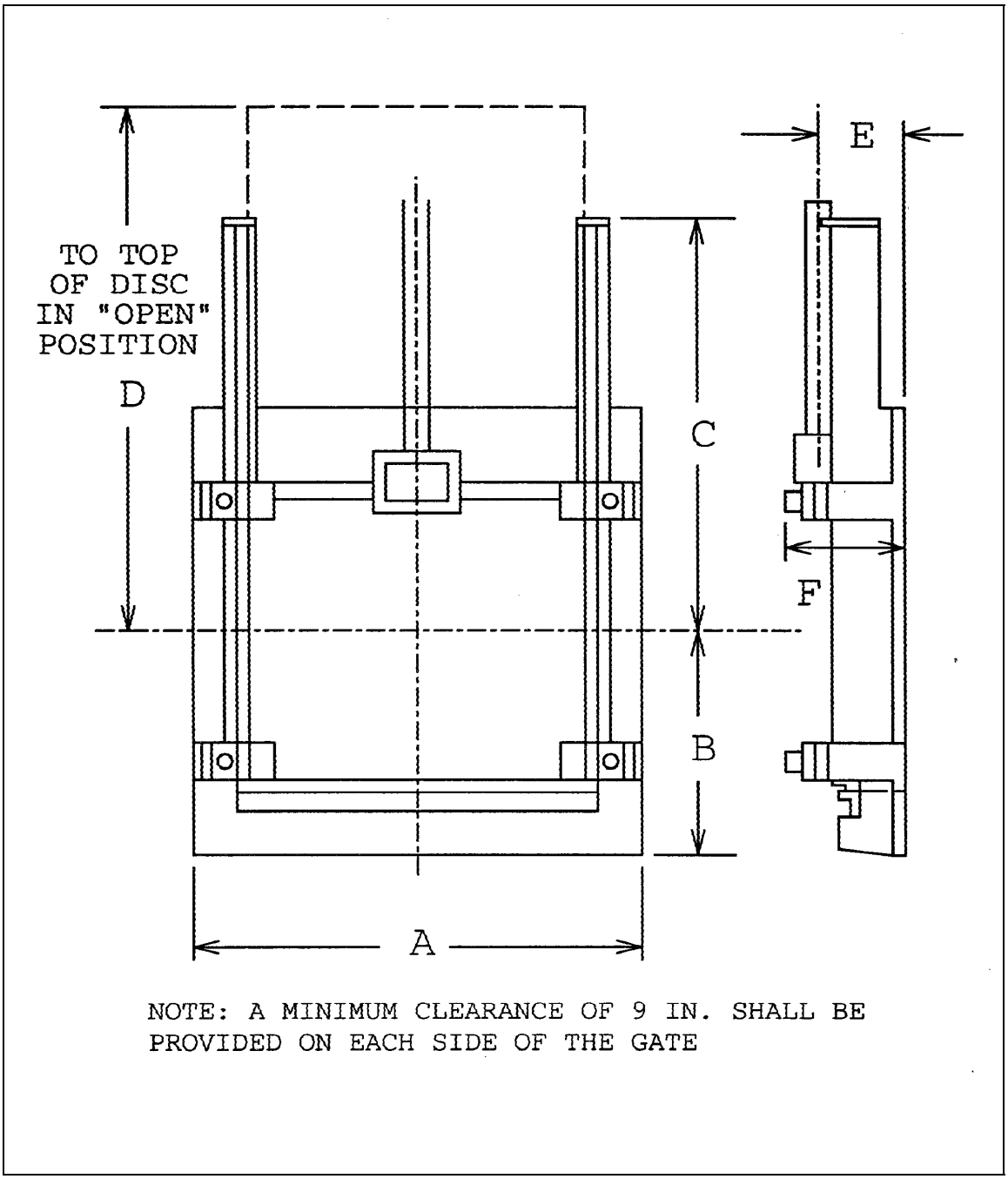


Figure D-2. Sluice gate layout

Typical Slide Gate Dimensions

Size Width × Height Inches	Design Head Ft. Seat	Unseat	Dimensions Inches A	B	C	D	E	F
36 × 18	88	40	46	14	20	33	6	8-1/2
36 × 24	88	30	46	17	26	42	6-1/4	8-1/2
36 × 30	60	36	46	20	32	51	6-1/2	9-1/2
36 × 36	60	30	46	23	38	60	6-1/4	9-1/2
36 × 42	76	43	47-1/2	26	44	69	6-1/4	9-1/2
36 × 48	65	30	47-1/2	29	50	78	6-1/2	10
42 × 24	90	21	53-1/2	17	26	42	6	8-1/2
42 × 30	88	25	53-1/2	20	32	51	6-1/4	9-1/4
42 × 36	88	24	53-1/2	23	38	60	6-1/4	9-1/2
42 × 42	87	23	53-1/2	26	44	69	6-1/4	9-1/2
42 × 48	80	23	53-1/2	29	50	78	6-1/4	10
48 × 24	58	21	59-1/2	17	26	42	6-1/4	8-1/2
48 × 30	60	32	59-1/2	20	32	51	6-1/4	9-1/4
48 × 36	62	27	59-1/2	23	38	60	6-1/4	9-1/2
48 × 42	65	32	59-1/2	26	44	69	6-1/4	9-1/2
48 × 48	69	16	59-1/2	29	50	78	6-1/4	10
54 × 48	130	45	67-1/2	30-3/4	51-1/2	81-1/2	9-1/2	15-1/4
54 × 54	130	45	67-1/2	33-3/4	57-1/2	90-1/2	9-1/2	15-1/4
54 × 60	130	45	67-1/2	36-3/4	63-1/2	99-1/2	9-1/2	16-1/2
54 × 72	130	45	67-1/2	42-3/4	75-1/2	117-1/2	9-1/2	16-1/2
54 × 84	130	45	67-1/2	48-3/4	87-1/2	135-1/2	9-1/2	17-3/4
54 × 96	130	45	67-1/2	54-3/4	99-1/2	153-1/2	9-1/2	17-3/4
60 × 36	80	25	71-1/2	23-3/4	39-1/4	61-1/2	8-3/4	13-1/4
60 × 48	80	25	71-1/2	29-3/4	51-1/4	79-1/2	8-3/4	13-1/4
60 × 54	80	25	71-1/2	32-3/4	57-1/4	88-1/2	8-3/4	13-1/4
60 × 60	80	25	71-1/2	35-3/4	63-1/4	97-1/2	8-3/4	14
60 × 72	80	25	71-1/2	41-3/4	75-1/4	115-1/2	8-3/4	14
60 × 84	80	25	71-1/2	47-3/4	87-1/4	133-1/2	8-3/4	14-3/4
60 × 96	80	25	71-1/2	53-3/4	99-1/4	151-1/2	8-3/4	14-3/4
72 × 36	60	20	83-1/2	23-3/4	39-1/4	61-1/2	8-3/4	13-1/4
72 × 48	60	20	83-1/2	29-3/4	51-1/4	79-1/2	8-3/4	13-1/4
72 × 54	60	20	83-1/2	32-3/4	57-1/4	88-1/2	8-3/4	13-1/4
72 × 60	60	20	83-1/2	35-3/4	63-1/4	97-1/2	8-3/4	14
72 × 72	60	20	83-1/2	41-3/4	75-1/4	115-1/2	8-3/4	14
72 × 84	60	20	83-1/2	47-3/4	87-1/4	133-1/2	8-3/4	14-3/4
72 × 96	60	20	83-1/2	53-3/4	99-1/4	151-1/2	8-3/4	14-3/4
72 × 108	108	36	85-1/2	60-3/4	114	171-1/2	9-1/2	19

Figure D-3. Typical slide gate dimensions **(Continued)**

Typical Slide Gate Dimensions

Size Width × Height Inches	Design Head Ft. Seat	Unseat	Dimensions Inches A	B	C	D	E	F
84 × 36	54	17	95-1/2	23-3/4	39-1/4	61-1/2	8-3/4	13-1/4
84 × 48	54	17	95-1/2	29-3/4	51-1/4	79-1/2	8-3/4	13-1/4
84 × 54	54	17	95-1/2	32-3/4	57-1/4	88-1/2	8-3/4	13-1/4
84 × 60	54	17	95-1/2	35-3/4	63-1/4	97-1/2	8-3/4	14
84 × 72	54	17	95-1/2	41-3/4	75-1/4	115-1/2	8-3/4	14
84 × 84	54	17	95-1/2	47-3/4	87-1/4	133-1/2	8-3/4	14-3/4
84 × 96	54	17	95-1/2	53-3/4	99-1/4	151-1/2	8-3/4	14-3/4
84 × 108	80	30	97-1/2	60-3/4	114	171-1/2	9-1/2	19
84 × 120	80	30	97-1/2	66-3/4	126	189-1/2	9-1/2	19
96 × 36	52	14	107-1/2	23-3/4	39-1/4	61-1/2	8-3/4	13-1/4
96 × 48	52	14	107-1/2	29-3/4	51-1/4	79-1/2	8-3/4	13-1/4
96 × 54	52	14	107-1/2	32-3/4	57-1/4	88-1/2	8-3/4	13-1/4
96 × 60	52	14	107-1/2	35-3/4	63-1/4	97-1/2	8-3/4	14
96 × 72	52	14	107-1/2	41-3/4	75-1/4	115-1/2	8-3/4	14
96 × 84	52	14	107-1/2	47-3/4	87-1/4	133-1/2	8-3/4	14-3/4
96 × 96	52	14	107-1/2	53-3/4	99-1/4	155-1/2	8-3/4	14-3/4
96 × 108	65	25	109-1/2	60-3/4	114	171-1/2	9-1/2	19
96 × 120	65	25	109-1/2	66-3/4	126	189-1/2	9-1/2	19
108 × 48	55	23	121-1/2	30-3/4	51-1/2	81-1/2	9-1/2	15-1/4
108 × 54	55	23	121-1/2	33-3/4	57-1/2	90-1/2	9-1/2	15-1/4
108 × 60	55	23	121-1/2	36-3/4	63-1/2	99-1/2	9-1/2	16-1/2
108 × 72	55	23	121-1/2	42-3/4	75-1/2	117-1/2	9-1/2	16-1/2
108 × 84	55	23	121-1/2	48-3/4	87-1/2	135-1/2	9-1/2	17-3/4
108 × 96	55	23	121-1/2	54-3/4	99-1/2	153-1/2	9-1/2	17-3/4
108 × 108	55	23	121-1/2	60-3/4	114-1/2	171-1/2	9-1/2	19
108 × 120	55	23	121-1/2	66-3/4	126-1/2	189-1/2	9-1/2	19
120 × 48	50	20	133-1/2	30-3/4	81-1/2	81-1/2	9-1/2	15-1/4
120 × 54	50	20	133-1/2	33-3/4	90-1/2	90-1/2	9-1/2	15-1/4
120 × 60	50	20	133-1/2	36-3/4	99-1/2	99-1/2	9-1/2	16-1/2
120 × 72	50	20	133-1/2	42-3/4	117-1/2	117-1/2	9-1/2	16-1/2
120 × 84	50	20	133-1/2	48-3/4	135-1/2	135-1/2	9-1/2	17-3/4
120 × 96	50	20	133-1/2	54-3/4	153-1/2	153-1/2	9-1/2	17-3/4
120 × 108	50	20	133-1/2	60-3/4	171-1/2	171-1/2	9-1/2	19
120 × 120	50	20	133-1/2	66-3/4	189-1/2	189-1/2	9-1/2	19

Figure D-3. (Concluded)

Appendix E
Head Loss Methods and Formulas

E-l. General

This appendix shows the different methods and formulas used to determine the head losses occurring in a pumping station. For stations with complex discharge configurations and which are over 2,000-cfs total capacity, consideration should be given to performing a model test to confirm the losses. This is particularly important when the low head determines the size of the pump driver and the losses are greater than 15 percent of the total head. All losses should be determined for the maximum flow rate expected to occur for that pumping condition.

E-2. Internal Pipe Losses

a. Friction losses. The Darcy-Weisbach formula can be used to determine friction losses in circular pipes. This formula is preferable to other formulas since it takes into consideration all the variable conditions. For water temperatures above 60°F. and using the friction factors found in typical Corps of Engineers discharge pipe * systems, the following formula (in the form of Hazen and Williams) applies:

$$h_f = 0.0366\ V^{1.83} / D_{pipe}^{1.17} \qquad \text{(E-1)}$$

where

h_f = frictional resistance, ft of fluid per 100-ft length

V = velocity, fps

D_{pipe} = inside diameter of the pipe, ft

b. Bend losses. Bends are usually constructed either by fabrication of mitered cut straight pieces welded together or of cast or forged construction. Friction factor "K" can usually be obtained from various charts and tables. The inside diameter of the pipe in used to locate the correct friction factor "K." The loss for the bend is found by multiplying the "K" value by the velocity head occurring in that section of pipe.

c. Entrance, exit, and other losses. Other losses occur when a section of piping changes in diameter. These changes in size can be from something less than one pipe diameter to an infinitely greater diameter, such as a discharge into a pool or lake where the velocity downstream of the pipe is zero. Various charts and tables are available for determining the appropriate friction factor "K" for the various fittings, increasers, and reducers. Chart E-l shows the various water surfaces for open discharges from vertical tubes such as used with submersible pump installations. When using this chart, the velocity head would not be added into the system losses since this loss is expended in obtaining the height of water above the vertical pipe exit. It is also seen from the chart that the elevation of the water is also dependent on the discharge bay dimensions.

E-3. External Losses

a. General. The capacity used to determine the external head losses is usually calculated on the basis of total station capacity. An exception to this would be the loss through a single gate opening on an individual pump sump.

b. Discharge chamber losses. ***The*** head loss in a discharge chamber usually is caused by a constriction in area at its exit. This restriction is usually the stop log slots used for dewatering the chamber for repair of a flap gate during high discharge stages. A critical depth condition (Figure E-l) can occur at this location if the water level downstream of this point is at a lower elevation. The discharge chamber critical depth is determined using the formula shown on Chart E-2. This formula applies * when a free discharge exists beyond the stop log slot at the exit of the discharge chamber. In order to obtain flow in the discharge chamber, a head of water is required at the opposite end of the chamber. This head of water is added to the water elevation caused by either the critical depth condition at the stop log slots, or the downstream water elevation, whichever is greater. The head of water is equal to the velocity head occurring with the depth of water at the stop log slots. An example of calculation of the critical depth and the resulting discharge chamber depth is shown below. It can be seen that the real head on a pump may be greater because of the artificial head created by the losses in the discharge chamber. It is required to determine which is greatest, the water level in the discharge chamber created by the restriction or the center-line elevation of the flap gates. The center-line elevation of the flap gate is used to determine the low static head whenever it is higher than the water level, in the discharge chamber, occurring for that pumped flow rate. The slope of the water surface in the chamber will be greatest at the opposite end from the constriction, and usually not at the exact location of all

the discharge flap gates. For purposes of head determination, it is assumed that the greatest water level occurring in the discharge chamber will be effective for all the pump discharges.

c. Trashrack losses. Head loss through the trashracks should be less then 6 inches for a properly designed rack that is raked regularly. A head loss value of 6 inches will be used when determining the trashrack portion of the total external losses. It is possible to exceed this value when the rack becomes partially clogged with debris; therefore the structure design of the rack should be in accordance with EM 1110-2-3104. In unusual cases where the design of the rack is such that for a clean rack the losses would be greater than 6 inches, the calculated loss plus a 6-inch margin should be used for the head loss.

d. Gate opening losses. The head loss through gate openings is assumed to be equal to the velocity head that occurs for the gate opening. If multiple gate openings occur in the water path to the pumps, then a loss would occur at each gate opening and be additive.

$HD_{ft} = 0.0001(m)(Q) + b$

Where m = Value from table

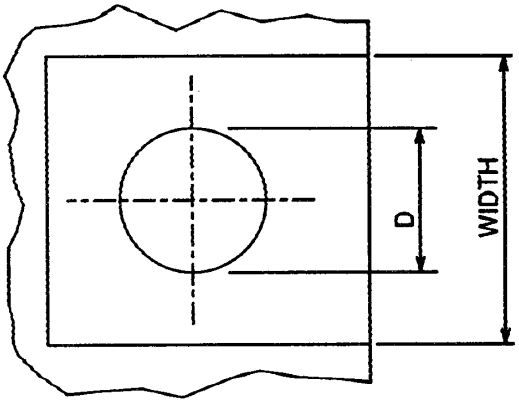
Q = Pump capacity in GPM

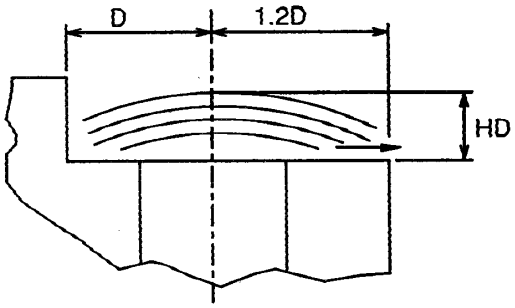
b = Value from table

HD = Water height above floor in feet

WIDTHS = 1.5D, 2.0D, 2.5D & 3.0D

D = TUBE DIAMETER





TUBE DIA. in. nom.	DISCHARGE WIDTH - VALUES OF m AND b								TUBE DIA. mm.
	1.5 D		2.0 D		2.5 D		3.0 D		
	m	b	m	b	m	b	m	b	
28	1.65	0.33	1.24	0.25	1.36	0.13	1.24	0.07	700
32	1.36	0.33	1.24	0.23	1.03	0.13	1.03	0.07	800
40	0.83	0.39	0.89	0.30	0.91	0.16	0.78	0.07	1000
48	0.68	0.62	0.68	0.43	0.52	0.26	0.52	0.07	1200
56	0.52	0.72	0.52	0.82	0.52	0.30	0.39	0.16	1400
64	0.41	0.82	0.41	0.66	0.41	0.33	0.41	0.16	1600

Chart E-1. Open tube losses

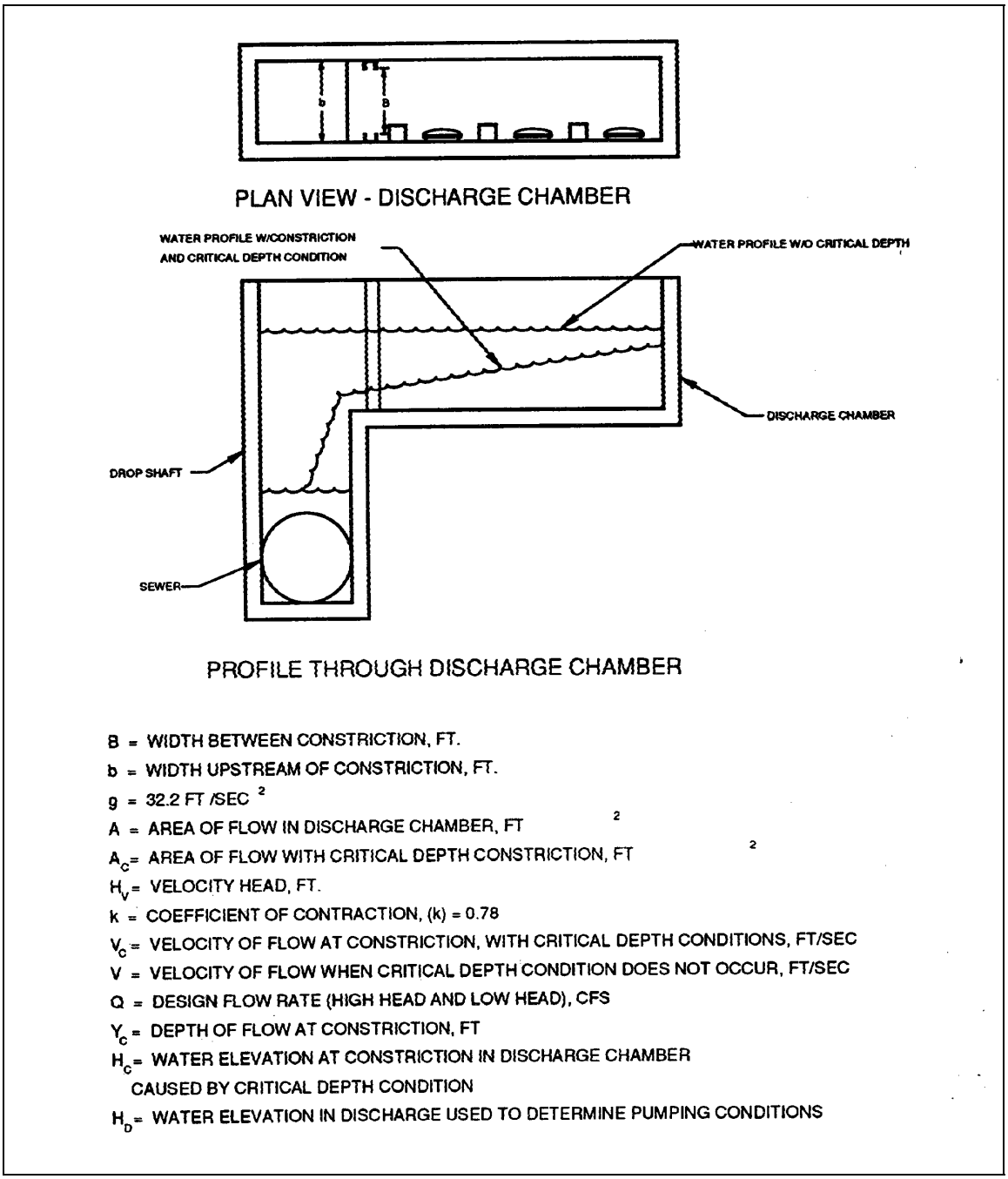


Figure E-1. Discharge chamber critical depth

DISCHARGE CHAMBER CRITICAL DEPTH

The determination of total head on the pump requires determination of water elevation in the discharge chamber. Three different head conditions are considered.

1. During pump operation back-up water does not exceed the center of the flap gate.

2. Water elevation in drop shaft next to discharge chamber is below elevation of the critical depth water level. Elevation of water back-up is above the center of the flap gate.

3. Water elevation in drop shaft is higher than water elevation due to critical depth condition.

The total head is then based on the greatest depth at the constriction plus the velocity head required to maintain flow.

The following is a typical computation to determine total head for discharge chamber type pump station. The computations are based on the layout shown on Figure E-1.

Given Conditions:

B = 4.5 ft.	Discharge chamber floor elevation at constriction = 413.0
b = 5.0 ft.	
Q_L = 177 cfs	Drop shaft water elevation due to sewer losses beyond drop shaft with 177 cfs flowing = 417.0
Q_H = 93.4 cfs	
k = 0.78	Drop shaft water elevation with 93.4 cfs flowing = 431.0
	Elevation of flap gate centerline = 416.75

Computations for water levels as result of critical depth -

STEP 1. Determine ratio of width at constriction to channel width upstream.

$$\text{Ratio} = B/b = 4.0 \text{ ft.}/5.0 \text{ ft.} = 0.9$$

STEP 2. Determine Y_c.

$$Y_c = (Q^2/(k^2 \times b^2 \times g))^{1/3}$$

$$= (177^2/(0.78)^2(5.0)^2(32.2))^{1/3} = 3.9 \text{ ft.}$$

STEP 3. Determine velocity of flow at the constriction.

$$V_c = [(Y_c)(g)]^{1/2} = 11.2 \text{ ft/sec}$$

Chart E-2. Critical depth condition (Sheet 1 of 3)

STEP 4. Determine critical area of flow at the constriction.

$A_c = Q_L/V_c$ = 177 cfs/11.2 ft/sec = 15.8 ft/sec

STEP 5. Determine the velocity head based on the velocity occurring at the constriction.

$H_V = Y_c/2$ = 3.9 ft/2 = 1.95 ft.

STEP 6. Determine the maximum elevation of water in the discharge chamber at constriction with critical depth condition.

H_c = Elev. of discharge chamber floor + $1.5Y_c$

= 413.0 + 1.5(3.9 ft.) = 418.8

STEP 7. Water elevation in drop shaft with low river elevation and flow rate of 177 cfs is 417.0.

STEP 8. Determine water elevation in discharge chamber with constriction of flow.

H_c = Floor elev. at constriction + depth of flow at constriction + velocity head based on flow at constriction

= 413.0 + Y_c + $Y_c/2$

= 413.0 + 3.9 + 1.95

= 418.8

STEP 9. This elevation (418.8) is greater than the water level in the drop shaft (417.0), therefore it is used to determine head loss if it is higher than the centerline of the flap gate.

STEP 10. When the elevation of water in the drop shaft is greater then the water elevation as result of a critical depth condition at the constriction, the water level in the discharge chamber is only dependent on the drop shaft water elevation and the resultant velocity head.

The discharge chamber water elevation would equal the drop shaft water elevation + the velocity head.

Water elevation in drop shaft = 431.0

Velocity at constriction, V_c

V_c = Flow rate (cfs)/(Drop shaft elev. - Floor elev.)(B ft)

= 93.4/(431.0 - 413.0)(4.5)

= 1.15 ft/sec

Velocity Head = $(V_c)^2/2g$

= $(1.15)^2/(2)(32.2)$

= 0.02 ft. => Negligible

Therefore, Elevation 431.0 would be used for head computations.

Chart E-2. (Sheet 3 of 3)

Appendix F
Sample Operation and Maintenance Manual

F-1. General

a. Purpose. This appendix provides the format for an Operation and Maintenance (O&M) manual for a typical stormwater pump station. The O&M manual is prepared for a pump station at the time the station has been completed including all pump testing.

b. Procedure. This appendix is divided into two major sections. The first is the example presentation of the table of contents for a pump station O&M manual. This indicates the topics which are normally covered by a manual of this type. The second is a presentation of the charts and instructions usually provided in a manual of this type. These include an operating log, annual inspection report, maintenance chart, operating sequence diagram, and operating instructions.

OPERATION AND MAINTENANCE MANUAL

BLUE WATERS DITCH PUMPING STATION

Table of Contents

Paragraph		Page No.
	Section 1 - Pumps	
1.01	Description of Pumps	
1.02	Stormwater Pump Discharge Piping	
1.03	Operation of Pumps	
1.04	Pump Operating Sequence	
1.05	Operation of Sump Pump	
1.06	Maintenance of Stormwater Pumps	
1.07	Maintenance of Sump Pump	
1.08	Lubrication of Stormwater Pumps	
	Section 2 - Pump Motors	
2.01	General	
2.02	Operation	
2.03	Overcurrent Condition, Stormwater Pumps	
2.04	Maintenance	
2.05	Lubrication	
2.06	Motor Winding Insulation Resistance	
	Section 3 - Compressed Air System	
3.01	General	
3.02	Air Compressor	

3.03 Air Receiver

3.04 Filter - Dryer

3.05 Air Lubricator

3.06 Pressure Regulator

3.07 Operation

3.08 Maintenance

Section 4 - Gates

4.01 Roller Gate Description

4.02 Operation

4.03 Maintenance

Section 5 - Trash and Silt Removal

5.01 Inlet Channel and Upstream Creek Trash Removal

5.02 Trashrack Description

5.03 Catenary Bar Type Trashrake, Description

5.04 Basket Type Hand Rake

5.05 Operation of Trashrakes

5.06 Maintenance

5.07 Sump Silt Removal

Section 6 - Cranes

6.01 Bridge Crane

Section 7 - Building and Additional Equipment

7.01 Building Grounds and Appurtenant Structures

7.02 Potable Water and Sanitary Sewer Systems

7.03 Fire Extinguishing Equipment

7.04 Ventilators

7.05 Subdrainage System

7.06 Relief Wells

7.07 Unit Heaters

Section 8 - Switchgear

8.01 Switchgear - 4160V

8.02 Maintenance

Section 9 - Lighting Panel and Controls

9.01 General

9.02 Lighting Transformer

9.03 Lighting Panel

9.04 Grounding

9.05 Float Control

9.06 Lubricator Control Panel

9.07 Sump Pump Control

9.08 Electrically Operated Crane Control

9.09 Gate Operator Control

9.10 Catenary Trashrake Operations

9.11 Exhaust Ventilator Control

9.12 Electric Air Compressor

9.13 Maintenance

Section 10 - Stormwater Pump Unit Failure Diagnosis

10.01 General
10.02 Very Little or No Water Being Discharged
10.03 Not Enough Water Being Discharged
10.04 Pump Requires Too Much Power
10.05 Pump Vibrates
10.06 Excessive Wear
10.07 Reverse Flow Through Pump-Power Off
10.08 Motor Will Not Start
10.09 Motor Noisy
10.10 Motor Temperatures Too High

Section 11 - SumpPump Unit Failure Diagnosis

11.01 General
11.02 Very Little or No Water Being Discharged
11.03 Not Enough Water Being Discharged
11.04 Pump Requires Too Much Power
11.05 Pump Vibrates
11.06 Excessive Wear
11.07 Reverse Flow Through Pump-Power Off
11.08 Motor Will Not Start
11.09 Motor Noisy
11.10 Motor Temperatures Too High

APPENDICES

Maintenance Page No.

Maintenance Responsibilities

Title 33 - Navigation and Navigable Waters

Pump Station Operating Log

Annual Report

Testing Main Pump Motor Starters Without Starting The Motors

Maintenance Chart

Operation

Operating Sequence Diagram

Operating Instructions

Staff Gages

Motor Data

Motor Data Table

Insulation Resistance Test Record

Winding Temperature Correction

Arrangement Drawings

Siphon Breaker Assembly and Compressed Air Control Panel Operation

BLUE WATERS DITCH PUMPING STATION

PUMP STATION OPERATING LOG

River Stage Reading: _____ Date: _____

Operator: _____

Storm Water Pump Unit No.	No. 1	No. 2	No. 3	Remarks
Float Dial Reading or Staff Gage Reading				
Motor Start Time				
Motor Stop Time				
Time of Reading				
Air Receiver Pressure				
Discharge Staff Gage Reading				
Motor Readings				
Voltage				
Amps				
Elapsed Hours				

BLUE WATERS DITCH PUMPING STATION
ANNUAL INSPECTION REPORT

DATE: _____

MECHANICAL:	GENERAL CONDITION OF EQUIPMENT				
	STORM WATER PUMPS			SUMP	
	No.1	No. 2	No. 3	PUMP	REMARKS
1. Pump					
Bearings					
2. Farval Lubricators					
3. Roller Gates					
Gate Operator (Manual)					
Gate Operator (Motor)					
Stems					
4. Crane and Hoist					
5. Siphon Breakers					
6. Trashracks					
7. Trash Rakes					
Drive Chain					
Bearings					
Gear Reducers					
ELECTRICAL:					
1. Motors					
2. Motor Bearings					
3. Switchgear Controls					
4. Control Panels					
GENERAL:					

1. Water Levels	Elevation	Remarks
Forebay		
Sumps		

Building and Grounds: DATE: _____

1. Sump	
2. Forebay	
3. Discharge Chamber	
4. Gatewell to River Outlet	
5. Structure	
6. Fire Extinguishers	
7. Tools and Cabinets	
8. Painting	
9. Caulking	
10. Grating, Rails and Ladders	
11. Water System and Plumbing	
12. Louvers and Ventilators	
13. Windows	
14. Doors	

Remarks: _____

Mechanical Vibration Levels:		STORM WATER PUMPS			SUMP PUMP	REMARKS
		No.1	No. 2	No. 3		
North-South	Upr					
	Lwr					
East-West	Upr					
	Lwr					
Axial:						
Motor						
Floor						
Coast Down Time						

Electrical Insulation Resistance Readings:					ROLLER GATES	REMARKS
T1						
T2						
T3						

Temp. in Degrees C

SIGNATURE: _____

BLUE WATERS DITCH PUMPING STATION MAINTENANCE CHART

	START-UP	MONTHLY	3-MO	6-MO	1 YR	5 YR	OPR HRS
FARVAL SYSTEM					GI		
RESERVOIR	GI, AL						
PUMP OIL					AO (2)	CH (2)	
CLEAN SCREEN						CL	
MOTOR		0	GI				
HEATERS	GI	GI					
THRUST BEARING		GI	TO		CH (3)		
GUIDE BEARING					PG(4)(1)		PG-3000
INSULATION					MR		
INTERIOR & VENTS		CL					
CURRENT READINGS	GI						
STORMWATER PUMP			GI				
STUFFING BOX							GI-8
VIBRATION	GI						
RELIEF PASSAGE	GI						
SUMP PUMP					GI (1)		GI-2000

BLUE WATERS DITCH PUMPING STATION MAINTENANCE CHART (CONTINUED)

	START-UP	MONTHLY	3-MO	6-MO	18-MO	1 YR	OPR HRS
COMPRESSED AIR		GI, 0					
COMPRESSOR CRANKCASE	GI					CH (5)	
COMPRESSOR INTAKE FILTER				CL			
BELT TENSION		GI					
AIRLINE FILTER/DRYER		CL					
MOTOR BEARINGS						PG	
RECEIVERS	RC					GI	
BRIDGE CRANE		0				GI (6)	
PILLOW BLOCKS, WHEELS AND WHEEL BEARINGS				PG GI			
GEAR REDUCERS		AL (7)				CH (7)	
COUPLINGS AND KEYWAYS			GI				
BRAKES			GI				
CONTROLS AND CONTACTS				GI,CL			
MOTORS						GI,CL	
BOLTED CONNECTIONS						GI	
ROLLER GATES				CL,0,GI			
STEM	GI			CL,SG			
THRUST NUT	GI			CL,SG			
MANUAL OPERATORS					PG		
MOTOR OPERATORS					GI,CL		

NOTE: FOR LEGEND AND NOTES SEE SHEET A-12

Blue Waters Ditch Pumping Station
Appendix A

	START-UP	MONTHLY	3-MO	6-MO	1 YR	5 YR	OPR HRS
TRASH RAKE		GI,O,CL			GI (6)		
MOTORS				AL (8)	PG (9)	CL	
HEATERS	GI						
GEAR REDUCER		GI		CH (10)			
DRIVE CHAIN	PG-8						PG-8
PILLOW BLOCKS				PG (9)			
TORQUE LIMIT COUPLING					PG (9)		
SHEAR PIN & SPROCKET		GI					
TRIP CAM		GI					
CONTROL PANEL					GI,CL		
SUBSTATION DRAINAGE					GI		
BUILDING STRUCTURE			GI				
TRASHRACK				GI			
TOILET FACILITY				GI			
DOMESTIC WATER				GI			
HOLDING TANK			GI		PO		
SIPHON BREAKERS			GI				
UNIT HEATERS					GI		
FIRE EXTINGUISHERS		GI		GI			
SWITCHGEAR	GI						
BUS AND CONNECTIONS					GI,CL		
INSTRUMENTS AND LAMPS	GI				GI,CL		
HEATERS					GI		
LIGHTING PANEL	GI				GI		
CONTROL PANELS	GI				GI		
GROUNDING					GRT		
FLOAT CONTROL	GI				GI		
MAIN PUMP MOTOR STARTS		TS					
ENTRANCE CHANNEL						GI,RS	
SUMP					GI,RS		

NOTES:

1. TIME PERIOD OR HOURS, WHICHEVER COMES FIRST
2. 5 TO 10 % ACIDLESS TALLOW WITH VISCOSITY OF 150 SSU @ 210 F
3. TURBINE OIL ISO VG68 (APPROX. 30 GAL.)
4. SCRAPE OUT OLD GREASE AND ADD 19.5 OZ. LITHIUM BASE GREASE (NLGI #2)
5. 150 SSU NON-DETERGENT NAPHTHENIC-BASE OIL WITH RUST AND OXIDATION INHIBITORS
6. ANSI B30.16
7. SEE HOIST O&M MANUAL FOR LUBRCATION TYPE
8. SAE 10
9. NLGI #2
10. AMGA #4

LEGEND:

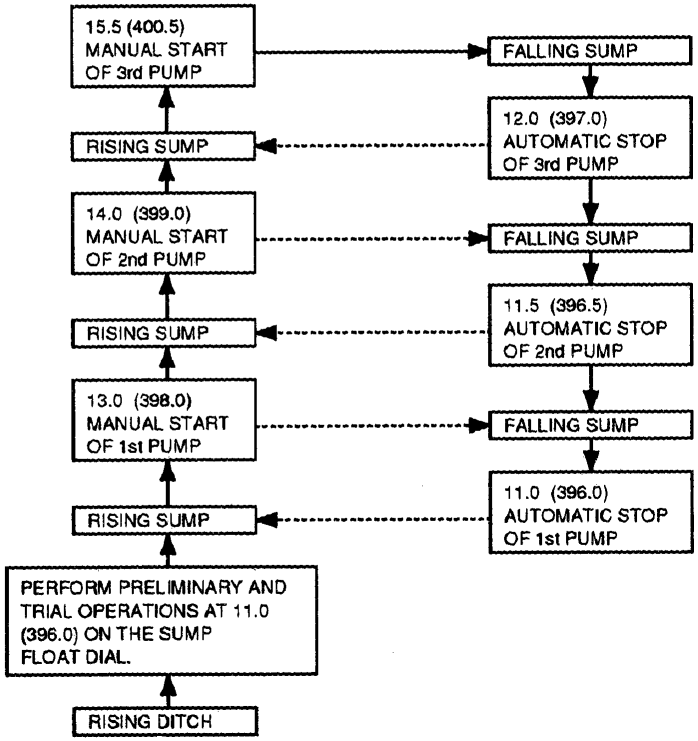
O	OPERATE
CH	CHANGE
CL	CLEAN
MR	MEGGER AND RECORD
PG	PRESSURE GREASE
SG	SURFACE GREASE
RC	REMOVE CONDENSATE
GI	GENERAL INSPECTION
GRT	GROUND RESISTANCE TEST
TO	TEST OIL
AL	ADD LUBRICANT
PO	PUMP OUT
TS	TEST (SEE A-13 FOR PROCEDURE)
RS	REMOVE SILT

Blue Waters Ditch Pumping Station
Appendix A

BLUE WATERS DITCH PUMPING STATION

GENERAL

The Pump Station shall be made ready for operation by performing the preliminary and trial operations described by a competent operator when there is a rising sump and an interior water level of 396.0 The pump station shall be put into flood stage operation at a water elevation of 398.0 on the interior water level gage.



NOTES:

1. The Zero on the float dial is Elev. 385.0 feet N.G.V.D. which is sump floor elevation.

2. The float dial switch contacts are set the same for all pumps for permissive start and as shown on the chart for Elev. 396.0.

3. The operation of the Blue Waters Ditch Gravity Drain is by the Metro-East-Sanitary District. The pump station operator should coordinate with the sanitary district before operating the pumping station to insure the drain is closed.

BLUE WATERS DITCH PUMPING STATION

INTERIM OPERATING INSTRUCTION

GENERAL

THE PUMP STATION SHALL BE MADE READY FOR OPERATION BY PERFORMING THE PRELIMINARY AND TRIAL OPERATIONS SHOWN BELOW WITH A COMPETENT OPERATOR WHEN THE INTERIOR WATER LEVEL REACHES 398.0 FEET OR 11.0 FEET ON THE FLOAT DIAL. THE PUMP STATION SHALL BE PUT INTO FLOOD STAGE OPERATION AT 398.0 FEET ON THE LANDSIDE GAGE OR 13.0 FEET ON THE FLOAT DIAL.

PRELIMINARY

1. OPENING STATION
   A. TURN ON LIGHT INSIDE THE STATION.
   B. TURN MAIN CIRCUIT BREAKER CONTROL TO "CLOSE" POSITION. (RED "BREAKER CLOSED" INDICATING LIGHT ON)
   C. MAKE CHECK OF THE PHASE-TO PHASE USING THE "VOLTMETER" SWITCH TO SELECT PAIRS OF PHASE.

NOTE: THE VOLTAGE MUST BE BETWEEN 3700 AND 4500 VOLTS FOR EACH PHASE WITH NOT GREATER THAN 200V DIFFERENCE PHASE TO PHASE. IF THE VOLTAGE IS OUTSIDE THIS RANGE, THE UNION ELECTRIC COMPANY MUST BE NOTIFIED IMMEDIATELY. NO PUMP OPERATION WILL BE ALLOWED WITH THE VOLTAGE OUTSIDE THIS RANGE

   D. TURN ON ALL POWER PANEL BOARD CIRCUITS. (NO. 1-17 ON SWITCH GEAR)
   E. REMOVE THE THREE INTAKE LOUVER COVERS.
   F. START THE TWO POWER ROOF VENTILATORS BY TURNING THE SWITCHES TO THE "HAND" POSITION.
   G. CHECK THAT THE THREE MOTOR OPERATED INTAKE LOUVERS ARE OPEN.

2. AIR SYSTEM
   A. START ELECTRIC DRIVEN AIR COMPRESSOR SYSTEM.
      (1) SET DISCONNECT SWITCH TO "ON" POSITION.
      (2) PRESS "RESET" PUSH-BUTTON.
      (3) TURN SELECTOR SWITCH TO "AUTO". (RED INDICATING LIGHT ON.)
   B. CHECK THAT THE AIR COMPRESSOR STARTS IF THE AIR RECEIVER PRESSURE IS LESS THAN 120 PSI AND THAT IT STOPS WHEN THE PRESSURE REACHES 150 PSI.
   C. OPEN AND CLOSE THE DRAIN VALVES ON THE BOTTOM OF THE AIR RECEIVER, STRAINER, AND FILTER TO DRAIN ANY CONDENSATION.

3. CONDITION OF DITCH APPROACH AND TRASHRACK.
   A. CHECK FOR ICE OR OTHER DEBRIS.
   B. LUBRICATE THE THE LINKS OF TRASH RAKE DRIVE CHAIN USING THE AIR OPERATED PORTABLE GREASE PUMP.
   C. REMOVE TRASH FROM THE TRASH RACK.
      (1) SET DISCONNECT SWITCH TO "ON" POSITION.

NOTE: ALARM SIREN WILL SOUND.

      (2) PRESS THE "RESET" PUSH-BUTTON.
      (3) PLACE SELECTOR SWITCH TO "FWD" POSITION.
      (4) PRESS THE "FORWARD START" PUSH-BUTTON.
      (5) REMOVE DEBRIS.
      (6) PRESS THE "STOP" PUSH-BUTTON.

NOTE: ABOVE PROCEDURE SHALL BE REPEATED FOR ALL THREE TRASH RACKS.

4. OPEN ALL OF THE SUMP ROLLER GATES.
   A. SET DISCONNECT SWITCH TO "ON" POSITION.
   B. USE ELECTRIC OPERATOR TO FULLY OPEN THE GATE BY PRESSING THE "OPEN" BUTTON (GREEN INDICATOR LIGHTS ON AT FULL OPEN POSITION)
   C. IF GATE DOES NOT OPEN ENGAGE MANUAL LEVER AND OPERATE HANDWHEEL IN THE "OPEN" DIRECTION.

NOTE: ABOVE PROCEDURE SHALL BE REPEATED FOR ALL THREE ROLLER GATES.

5. PUMP LUBRICATION
   A. CHECK THAT THE LEVEL OF GREASE IN THE FARVAL LUBRICATOR RESERVOIR IS ADEQUATE
   B. TURN LUBRICATOR CONTROL SWITCH (LOCATED ON THE OUTSIDE OF THE FARVAL CONTROL ENCLOSURE) TO "MANUAL" POSITION AND PRESS THE "MANUAL" PUSH-BUTTON TWO TIMES, FOR PRE-GREASING CYCLE.
   C. TURN FARVAL LUBRICATOR CONTROL SWITCH TO THE "AUTO" POSITION.

6. ELECTRIC MOTOR LUBRICATION
   A. CHECK THAT THE LUBRICATING OIL IN THE UPPER CHAMBER IS AT THE PROPER LEVEL BY CHECKING THE SIGHT GLASS TO SEE THAT THE OIL LEVEL IS BETWEEN THE MINIMUM AND THE MAXIMUM.
   B. CHECK THAT LUBRICANT IS PRESENT IN THE LOWER MOTOR BEARING BY OPENING THE "GREASE OUTLET" PLATE ON THE SIDE OF THE MOTOR.

7. ROTATE PUMPS MANUALLY ONE FULL REVOLUTION TO ASSURE FREE ROTATION.
8. CHECK FLOAT SWITCH SETTINGS ACCORDING TO OPERATING SEQUENCE DIAGRAM.
9. SIPHON BREAKER VAULT (LOCATED AT TOP OF LEVEE).
   A. CHECK THAT WIRE CLOTH PIPE COVER IS UNBROKEN.
   B. CHECK THAT AIR-OPERATED BUTTERFLY VALVE IS IN "OPEN" POSITION.
   C. CHECK THAT EACH OF THE THREE MANUAL ACTUATED BUTTERFLY VALVES IS IN THE "CLOSED" POSITION.

THE PUMP STATION SHALL BE MADE READY FOR OPERATION BY PERFORMING THE PRELIMINARY

TRIAL OPERATION

1. PUMP START (WATER LEVEL IN SUMP MUST BE ELEV. 396.0 OR HIGHER - 11.0 ON THE FLOAT DIAL)

A. LIGHTING PANEL.

(1) TURN 'OFF' YASKAWA MOTOR WINDING HEATERS (*17, *19, *21) CIRCUIT BREAKERS BEFORE STARTING MOTORS.

B. ELECTRIC MOTORS

(1) TO TEST MOTOR STARTER WITHOUT ENERGIZING MOTORS:

A) BE SURE THAT THE PUMP MOTOR CONTACTOR BEING TESTED IS DRAWN OUT BY CHECKING THAT THE MOTOR LOAD BREAK SWITCH OPERATING HANDLE IS IN THE FULLY DOWN POSITION. TURN THE "TEST - NORMAL" TWO-POSITION SELECTOR SWITCH TO THE "TEST" POSITION. THE GREEN "OFF" PILOT LIGHT WILL ILLUMINATE, INDICATING THAT CONTROL POWER IS ON.

B) TEST THE 3 - PHASE 4160 VAC CONTACTOR BY DEPRESSING THE "TEST" PUSHBUTTON.

C) WITH THE "TEST" PUSHBUTTON DEPRESSED, DEPRESS THE BLACK "START" PUSHBUTTON. THE 3- PHASE 4160 VAC CONTACTOR SHALL BE HEARD TO BANG SHUT, SIMULTANEOUSLY ILLUMINATING THE RED "RUN" PILOT LIGHT AND EXTINGUISHING THE GREEN "OFF" PILOT LIGHT.

D) IF THIS DOES NOT HAPPEN, CALL A CERTIFIED ELECTRICIAN TO CHECK THE SWITCHGEAR.

E) IF THE TEST IS SUCCESSFUL, DEPRESS THE RED "STOP" PUSHBUTTON. THE CONTACTOR SHOULD BANG OPEN. SIMULTANEOUSLY THE GREEN "OFF" PILOT LIGHT SHOULD ILLUMINATE AND THE RED "RUN" PILOT LIGHT SHOULD EXTINGUISH

F) RETURN THE "TEST - NORMAL" TWO-POSITION SELECTOR SWITCH TO THE "NORMAL" POSITION.

(2) RAISE MOTOR LOAD BREAK SWITCH TO "ON" POSITION FOR PUMP NO. 1 AND THREAD THE CAPTIVE THUMB SCREW INTO PLACE USING FINGER PRESSURE ONLY TO TIGHTEN. (GREEN "OFF" INDICATING LIGHT ON) NOTE TIME.

WARNING: DO NOT OPERATE PUMPS WHEN WATER LEVEL IN SUMP IS BETWEEN ELEV. 396.0 AND ONE FOOT BELOW THE PUMP SUCTION.

(3) AFTER WAITING FIVE MINUTES PLACE THE "SIPHON MODE" SWITCH IN THE "OFF" POSITION.

(4) TURN THE START SELECTOR SWITCH TO THE "ON" POSITION.

(5) DEPRESS AND HOLD DOWN THE "TEST" PUSH-BUTTON AND THEN PRESS THE "START" PUSH-BUTTON ("RUN" LIGHT ON).

(6) AFTER MOTOR HAS OPERATED FOR APPROXIMATELY 10 SECONDS RELEASE THE THE "TEST" PUSH-BUTTON ("OFF" LIGHT ON). IF THE FLOAT DIAL IS BELOW THE CUTOFF ELEVATION FOR THE PUMP THE UNIT WILL SHUTDOWN. IF THE UNIT DOES NOT STOP THEN DEPRESS THE "STOP" PUSH-BUTTON.

(7) TURN FARVAL LUBRICATOR SWITCH TO "OFF" POSITION.

NOTE: REPEAT ABOVE PROCEDURE FOR PUMPS NO 2 AND 3.

PUMPING OPERATION DURING FLOOD STAGE

1. WET TEST PUMPING SYSTEM IF SUMP WATER LEVEL IS AT FLOAT DIAL READING 11.0 FT. (ELEV. 396.0 N.G.V.D.). PERFORM IDENTICAL OPERATIONS AS DONE IN DRY TEST.
2. TURN THE FARVAL LUBRICATOR SELECTOR SWITCH TO THE "AUTO" POSITION.
3. REPEAT "TRIAL OPERATION" NO 1B.
4. PUMPING OPERATION.

A. OPEN SIPHON BREAKER AIR SUPPLY VALVE LOCATED IN THE SOUTHWEST CORNER OF BUILDING.

B. PLACE THE FARVAL LUBRICATOR CONTROL SWITCHES IN THE "AUTO" POSITION.

C. FOLLOW THE OPERATING SEQUENCE DIAGRAM.

D. MANUALLY START PUMPS AT SPECIFIED LEVELS.

(1) START PUMP FOLLOWING THE SAME PROCEDURE USED IN WET TEST EXCEPT PLACE THE "SIPHON MODE" SELECTOR SWITCH IN THE "AUTO" POSITION AND PRESS THE "START" PUSH-BUTTON ONLY (RED "RUN" INDICATING LIGHT ON) TO START EACH PUMPING UNIT.

NOTE: A TIMER IN THE SWITCHGEAR WILL PREVENT THE RESTART OF ANY UNIT UNTIL 5 MINUTES AFTER SHUTDOWN (TO PREVENT RESTART OF MOTOR WITH THE PUMP BACK SPINNING).

E. DURING PUMPING OPERATIONS, AT 15 MINUTE MAXIMUM INTERVALS OBSERVE THE RUNNING CONDITION OF THE EQUIPMENT.

(1) CHECK THE VOLTMETER ON THE SWITCHGEAR AND THE AMMETERS ON THE CONTROL PANELS OF EACH MOTOR STARTER.

(2) IF THE CURRENT EXCEEDS 150 AMPS THE MOTOR SHALL BE STOPPED AND THE CAUSE OF THE EXCESSIVE CURRENT CORRECTED.

(3) RECORD OPERATING DATA AT 30 MINUTE INTERVALS.

(CONTINUED ON B-4)

(Continued from B-3)

5. Lubrication During Pumping Operation.
   a. Check that the Farval unit lubricates the pump automatically every 20 minutes of operation by observing the counter every two hours. (Red indicating light on through grease cycle).
6. Keep Trash Rack Clear of Debris.
   a. follow step 3b of the preliminary section as needed.
7. Keep log of All Operations.
   a. Record start and stop times.
   b. Record all abnormal noise, vibration and overheating.
8. As float control automatically shuts down pumping units, check that siphon breaker valve has opened. If it does not open, the operator must open it by manually operating the valves in the compressed air control panel as shown in appendix E of the O&M manual or must manually operate the lever actuated butterfly valve located in siphon breaker vault must be opened.
NOTE: Ear protection must be used when opening this valve.

CLOSING DOWN STATION

1. Loosen the captive thumb screw and lower motor load breaker switch to the "OFF" position. Padlock the switches.
2. Lubrication.
   a. Fill Farval lubricator reservoir with grease.
   b. Turn heater switch on Farval lubricator control panel to 50-watt position.
   c. Check that the lubricating oil in the electric motors is at the proper level by checking the sight glass to see that the oil level is between the minimum and the maximum.
   e. For cold weather:
      (1) Turn off water
      (2) Drain all pipes by opening drain valves in the sump
      (3) Add anti-freeze to sink trap, toilettrap and toilet flush tank and bowl.
   d. Check that lubricant is present in the lower motor bearing by opening the "GREASE OUTLET" plate on the side of the motor.
3. Check Supplies and Clean Station.
   a. Inspect and clean all equipment.
   b. Restore tools to tool chests.
   c. Replenish supplies (oil, grease, ie...)
   d. Remove all fire hazards (oily rags, ie...)
4. De-energize Air System.
   a. Turn electric driven air compressor switch to "OFF"
   b. Drain air receiver.
   c. Set disconnect switch to the "OFF" position.
5. Turn off power roof ventilators and check that all motor operated dampers close.
   a. Replace the three intake louver covers.
6. Insure that all strip heater circuits in the lighting panel are turned on. Leave the three lubricator circuits on.
7. Dewater Sump..
   a. Close all the sump roller gates.
      (1) Press the "CLOSE" push-button and wait until gate is completely closed.
      (2) Set disconnect switch to the "OFF" position. Padlock the switches.
   b. Turn on the sump pump and wait until the float switch in the dewatering man hole shuts off the pump. Clean the sump as required.
8. Set the disconnect switches on each trash rake to the "OFF" position. Padlock the switches.
9. Turn Main Circuit breaker to "TRIP" position. (Green "BREAKER OPEN" light on)
10. Turn off all power panel board circuits except #15.
11. Transfer to 240V 3 Phase auxiliary power circuit from Union Electric.
12. Turn off all lights.
13. Close station and lock doors.

REFER TO SHEET B1 FOR OPERATING SEQUENCE DIAGRAM.

NOTE: In case of a loss in the 240 volt service the following procedure will allow continued operation of the station.
   a. Depress the "CLOSE" push-button on the "Transformer FEEDER". (Red indicating light on).
   b. Transfer switch must be moved from the down position to the up position

Appendix G
Electrical Data Request

ELECTRIC POWER SYSTEM DATA SHEET

PROJECT: _____
LOCATION: _____

POWER COMPANY: _____
MAIL ADDRESS: _____
STREET: _____
CITY/ST/ZIP: _____

ATTN: _____
TITLE: _____
PHONE: _____

POWER COMPANY SOURCE DATA

1. NEAREST SUBSTATION FROM WHICH THE PROJECT WILL BE SUPPLIED:

a. SUBSTATION NAME AND LOCATION: _____

b. PRIMARY AND SECONDARY VOLTAGES: _____

c. POSITIVE SEQUENCE SOURCE RESISTANCE: _____

d. POSITIVE SEQUENCE SOURCE REACTANCE: _____

or

c. THREE-PHASE FAULT MVA AND X/R: _____

d. IF IN PER UNIT, BASE MVA AND KV: _____

e. EXPECTED VOLTAGE SPREAD AT SUBSTATION: _____

2. POWERLINE FROM NEAREST SUBSTATION TO PROJECT MAIN TRANSFORMER:

a. LINE VOLTAGE/PHASES/WIRES: _____

b. POSITIVE SEQUENCE RESISTANCE: _____

c. POSITIVE SEQUENCE REACTANCE: _____

d. IF IN PER UNIT, BASE MVA AND KV: _____

3. PROJECT MAIN TRANSFORMER:

a. POSITIVE SEQUENCE RESISTANCE: _____

b. POSITIVE SEQUENCE REACTANCE: _____

c. RATED KVA AND SECONDARY VOLTAGE/PHASES/WIRES: _____

d. TAP VOLTAGES: _____

e. PRIMARY CONNECTION: DELTA, UNGROUNDED or _____

f. SECONDARY CONNECTION: WYE, SOLIDLY GROUNDED or _____

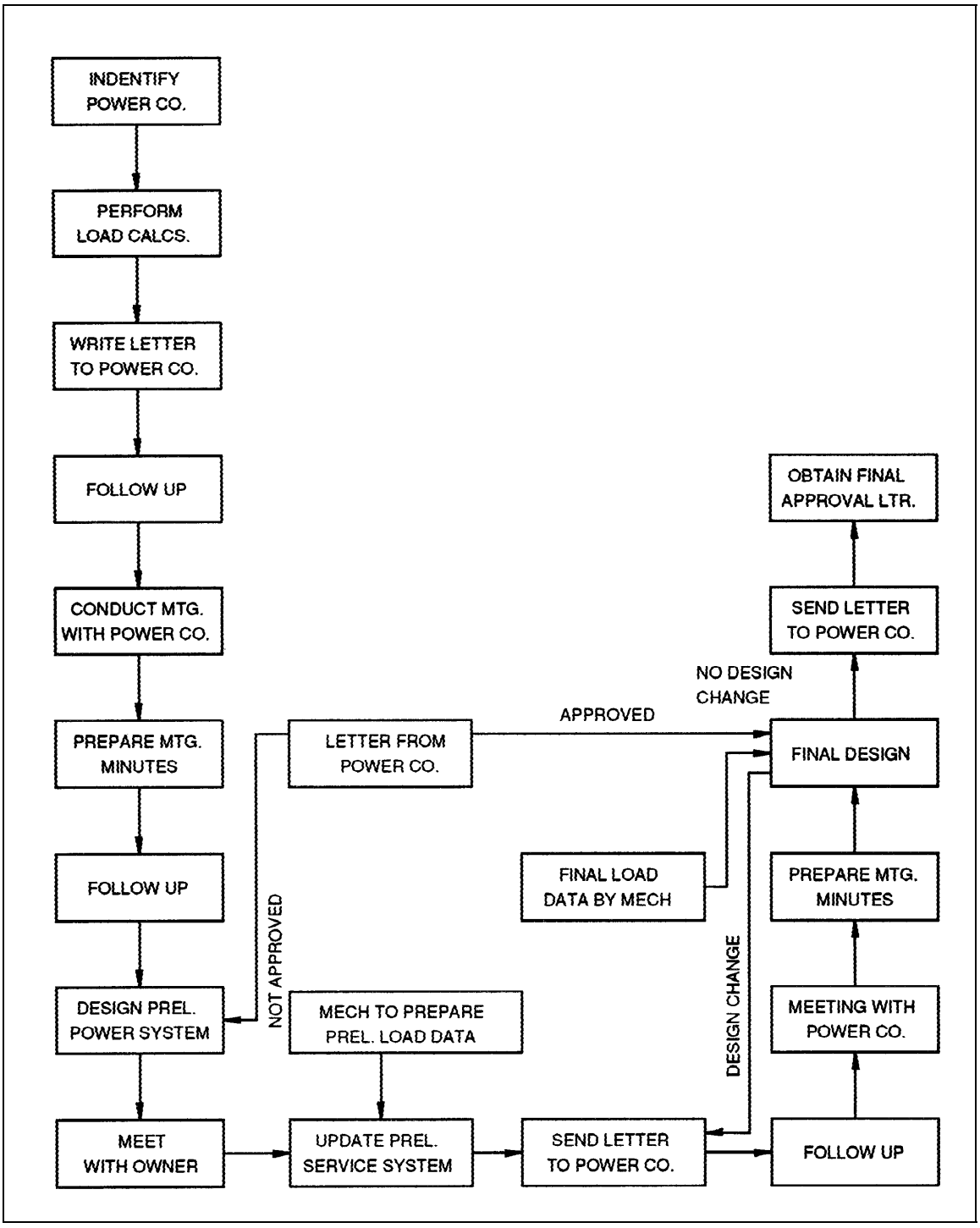


Chart G-1. Electric power company interfacing flowchart

Appendix H
Glossary

Antireverse (Backstop) Device - A device mounted on the pump driver, either on the motor shaft or the gear reducer shaft, that will prevent reverse rotation of the pump. This device protects the pump driver from damage. It is especially important for engine drives. When installed on a gear reducer unit, it is recommended, for ease of maintenance, that it be installed on the output shaft.

Axial Flow Pump - Sometimes called a propeller pump. Flow enters impeller axially and discharges nearly axially. It develops most of its head by a lifting action of the vanes of the impeller on the liquid. Specific speed is typically above 9000. Large capacity at low head. Total head is less than 20 feet.

Cavitation - The formation of vapor bubbles caused when the local absolute pressure falls to or attempts to fall below the vapor pressure of the liquid moving through the pump. Damage occurs when the bubbles collapse against the surfaces of the impeller or casing causing a loss of metal.

Centrifugal Pump - A general classification of pumps in which pumping of liquids or generation of pressure is effected by the rotary motion of the impeller. This classification does include axial flow pumps, but for our purposes, we will define it as a pump in which impeller discharge flow is in the radial direction and pressure is developed principally by the action of centrifugal force. Pumps with single inlet impellers have a specific speed below 4000, and with double suction impellers below 6000.

Critical Speed - Critical speed occurs when the pump rotates at its natural frequency. At this speed or speeds, minor unbalances are magnified.

Energy Gradient - The plot of total head at various locations along a pumping system with respect to a datum.

Friction Head - The pressure required to overcome the frictional resistance of a piping system to liquid flow.

Hydraulic Gradient - Shows the static pressures at various locations along a pumping system. The difference between the energy gradient line and the hydraulic gradient line is the velocity head in the pipe at that point.

Mixed Flow Pump - Flow enters axially and discharges in an axial and radial direction. The head developed is partly by centrifugal force and partly by the lift of the vanes on the liquid. Specific speed is typically from 4000 to 9000. Large capacity at moderate head. Total head can be as high as 50 feet.

Net Positive Suction Head (NPSH) - The minimum suction conditions required to prevent cavitation in a pump. It is defined as the total suction head in feet of liquid absolute determined at the suction nozzle and referred to datum less the vapor pressure of the liquid in feet absolute. The pumps required NPSH (NPSHR) is determined by test and will be stated by the manufacturer. The available NPSH (NPSHA) is calculated based on the installation and must be at least equal to the NPSHR.

Siphon - A pipe or closed conduit that rises and falls. When there is no net change in elevation, no pumping head is required to sustain flow except to overcome friction and minor losses. The siphon must flow full and free of liquid vapor and air. The limiting height of the siphon for complete recovery is dependent upon the conditions that will cause vaporization of the liquid.

Specific Speed - A dimensionless quantity used to classify pump impellers with respect to their geometric similarity. It is a correlation of pump capacity, head, and speed at optimum efficiency.

Static Head - A fixed system head that does not vary with the rate of flow. It is the difference of the discharge elevation or pressure and the suction elevation or pressure.

Submergence - The distance from the impeller eye to the minimum free water surface in the sump. Some manufacturers defined it from the bottom of the suction bell to the minimum water surface elevation in the sump.

Submersible Pumps - Submersible motor-driven wet pit pumps have an electric submersible motor close coupled to the impeller of the pump. Both the motor and pump are submerged. This arrangement is typically more compact and simplified than a conventional pump. The need for a long shaft to couple motor to pump is eliminated.

Suction Specific Speed - A dimensionless quantity used to classify pump impellers based on suction characteristics. The formula is similar to specific speed except that instead of using total head, the net positive suction head required is used.

Appendix I
Formed Suction Intake - Geometry Limitations

I-1. Purpose

This appendix provides guidance necessary to properly select the best, most cost-effective formed suction intake (FSI) design.

I-2. Background

The U.S. Army Engineer Waterways Experiment Station (WES) conducted research to determine by how much the height of the FSI could be reduced without adversely affecting its performance. ETL 1110-2-327 presents, in detail, the results of the research. Results of prior research conducted at WES about the basic FSI design are presented in Technical Report HL-90-l. Formed Suction Intake Approach Appurtenance Geometry (Fletcher 1990). The 1990 report provided guidance for the design of FSI external appurtenance geometry (pump bay width and/or length) relative to the direction of approaching flow, discharge, and submergence. The type 1 design (Figure I-l) provided the optimum design at that time. The research presented here was initiated by requests from field personnel involved in pumping station design. The field wanted to know how to reduce the height of the type 1 FSI. Reducing the height of the FSI impacts favorably on the design of a pumping station. It raises the sump floor and reduces the elevation of the impeller. This in turn reduces excavation and increases the available static suction head on the pump impeller.

I-3. Test Results and Recommendations

Site-specific model tests conducted at WES demonstrated that changing one or more of the FSI's internal dimensions adversely affected the flow distribution inside the FSI. The minimum permissible height of an FSI was determined by conducting tests to evaluate independently and compositely the limiting values for the radius of the roof curve, the cone height, and the height of the roof curve above the floor of the FSI. The type 10 FSI (Figure I-2) represents the optimum design, i.e., a design with the minimum permissible height. By reducing the cone height from *0.45d* to 0.22d and the height of, the roof curve above the floor from *0.56d* to *0.49d,* the type 10 design changed the overall height of the type 1 design from *1.58d* to *1.28d.* This provided a 19-percent reduction in the overall height. Based on the test results, it is recommended that the height of the FSI not be less than *1.28d* and that the cone height and the height of the roof curve above the floor not be less than *0.22d* and *0.49d* respectively. The dimensions of the FSI are provided in terms of the throat diameter *d.* Various views of the FSI are shown in Figure 1-3. The isometric view shown in Figure I-3 clarifies the isometric view shown in ETL 1110-2-327. The ETL shows horizontal lines in the roof portion of the FSI. These were intended to be a drafting technique, not a method of construction. The roof should be constructed in a manner similar to that shown in Figure I-3.

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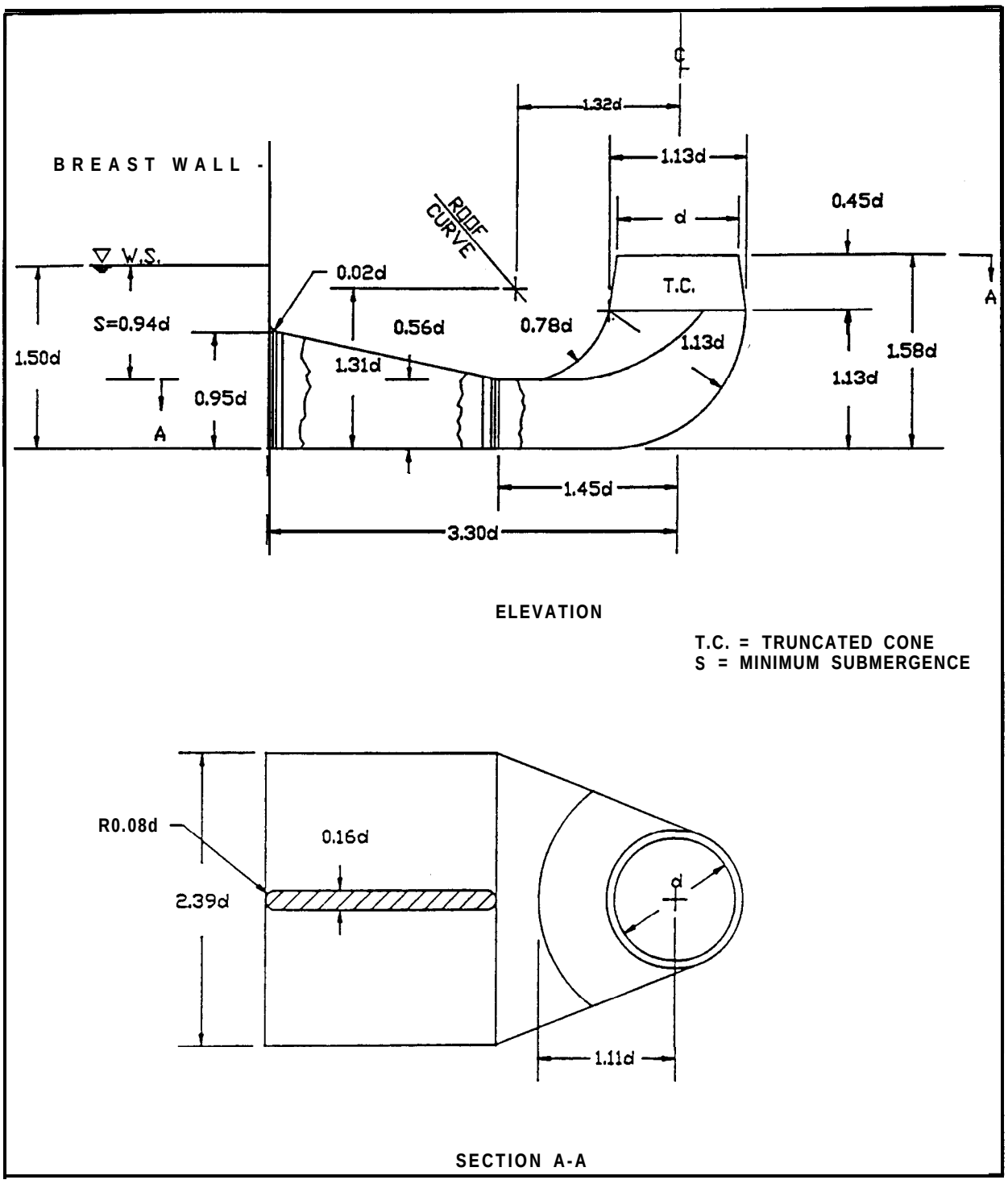


Figure I-1. FSI type 1 design

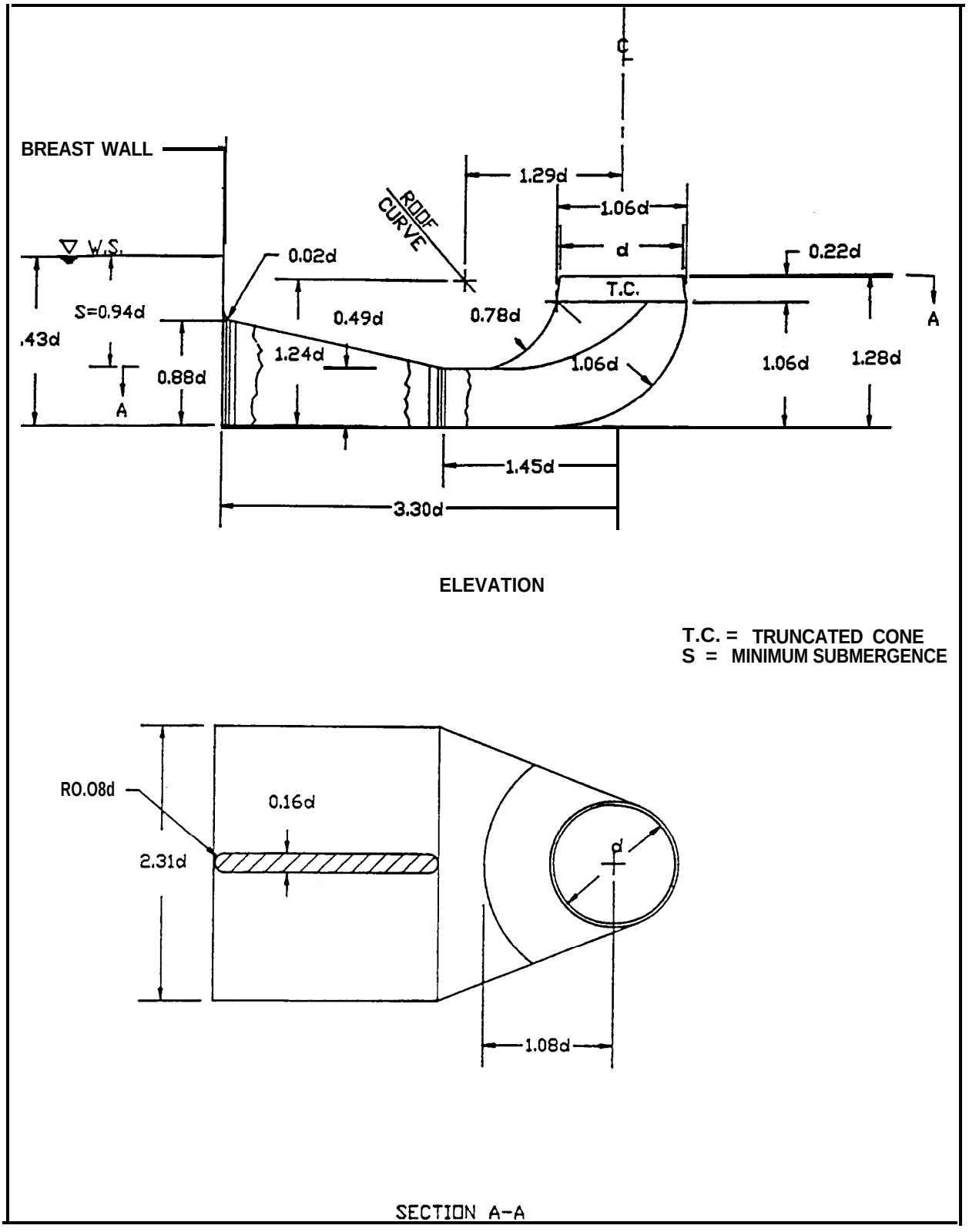
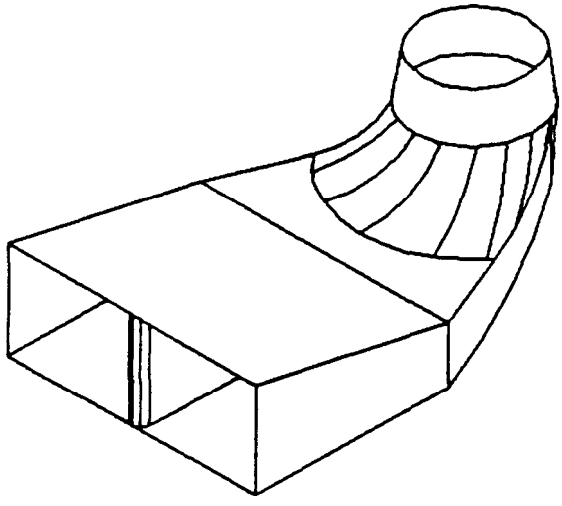
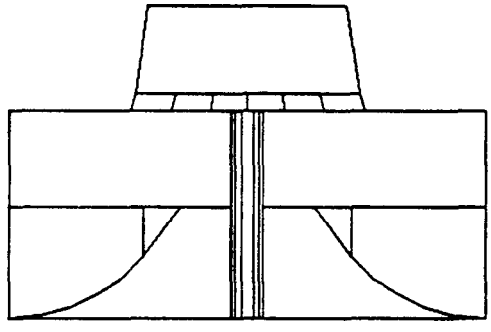


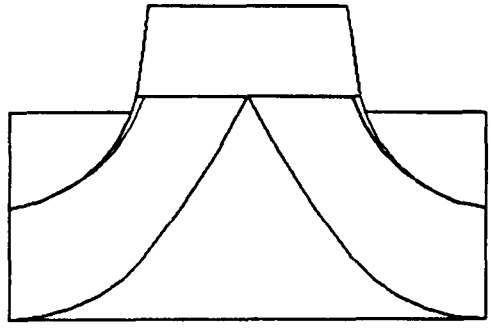
Figure I-2. FSI type 10 design



ISOMETRIC VIEW



FRONT VIEW



REAR VIEW

Figure I-3. Typical FSI

Total Dynamic Head - (Total Head) - The measure of the work increase per pound of liquid, imparted to the liquid by the pump. From the general energy equation, the total dynamic head (total head) is the difference of the discharge head, as measured at the discharge nozzle and referred to the pump shaft centerline, and inlet or suction head, as measured at the suction nozzle and referred to the same datum and the difference in velocity heads at the discharge and suction nozzles.

Total Suction Head - The height of water from the centerline or eye of the impeller to the water surface in the sump. The term "total suction lift" is used when the water surface elevation is below the eye of the impeller and is defined as the height from the water surface to the centerline or eye of the impeller.

Velocity Head - The kinetic energy in a mass of flowing liquid per unit weight of the liquid.